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The Forested Wetlands of the Southern United States

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Twenty-five papers are presented in five categories: Nonpoint Sources of Pollution and the Functions and Values; Best Management Practices for Forested Wetlands; Streamside Management Strategies; Sensitive Areas Management; and Balancing Best Management Practices and Water Quality Standards for Feasibility, Economic, and Functional Effectiveness.

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symposium

The Forested Wetlands of the Southern United States

Editors
Donal D. Hook
Russ Lea

Orlando, Florida
July 12-14, 1988

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PREFACE

This volume contains 25 papers presented at the symposium on The Forested Wetlands of the Southern United States at Orlando, Florida, July 12-14, 1988. Each paper was reviewed by one or more outside reviewers and the editors. We gratefully appreciate those who helped with this important task. The papers are organized into five general subject matter areas on forested wetland protection and management.

The purpose of the symposium was to bring together into one volume the state-of-the-art of what is known about nonpoint source pollution, protection, and management of forested wetlands. Such readily available information should:

a) provide guidance to managers of forested wetlands on the role of forestry in nonpoint source pollution,
b) provide guidance to managers and regulatory personnel on Best Management Practices for forested wetlands lands,
c) help regulatory personnel determine what is normal silvicultural practices,
d) help managers and regulatory personnel achieve the goals of the Clean Water Act, especially Section 308,
e) provide a foundation and reference point for identifying research needs.

STEERING COMMITTEE

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CONTENTS

AN OVERVIEW OF NONPOINT SOURCE POLLUTION IN THE SOUTHERN UNITED STATES

D.G. Neary, W.T. Swank, and H. Riekerk[1]

Abstract.-This paper examines nonpoint source pollution (NPSP) in the thirteen states of the Southern Region. The definitions, sources, types, and trends of NPSP are discussed. NPSP is of particular concern to wetlands because it is difficult to manage and most states have little knowledge of the effects on wetlands. Information is very limited on the cumulative effects of different NPSP sources on wetlands. Where water quality is deteriorating, NPSP is frequently the major cause. Best management practices implemented by local and state agencies provide the best means of controlling NPSP.

INTRODUCTION

During the past 15 years the definitions, attitudes towards, and philosophical approaches to nonpoint source pollution (NPSP) have changed substantially. The original focus of water pollution research and control in the late 1960's and early 1970's was on point sources because they were the major cause of deterioration in the quality of surface waters in the United States. At that time, NPSP was considered to be a small part of the water pollution problem. Research was started on the sources, effects, and control of NPSP in response to-passage of the Water Pollution Control Act Amendments of 19'72, Public Law 92-500. By the time the Clean Water Act was enacted in 1978, hundreds of projects on NPSP were in progress (Chesters and Schierow 1985).

Research quickly determined that the magnitude of NPSP was much larger than originally believed and that over half of all the water pollution was nonpoint in nature. The magnitude of NPSP was originally underestimated because some of it is due to natural causes, it is often difficult to separate from point source pollution, and baseline information was lacking. Ultimately, NPSP was found to play a major role in the remaining water quality problems in this country. Where water quality showed deteriorating trends, NPSP was identified as the main source (Smith et al. 1987; EPA 1984).

Water quality researchers and managers have difficulty in coming to grips with NPSP. Unlike point source NPSP is a landscape-scale phenomenon and thus the land area involved is enormous. Some NPSP (i.e., sediment) is due to natural conditions as identified by some long-term NPSP records. But some of these NPSP problems may be aggravated by control of NPSP elsewhere on the landscape (i.e., stream bed and bank sediment transport subsequent to reductions in upstream erosion). There is also a considerable problem with establishing cause and effect relationships between NPSP and water quality problems. In-stream NPSP, released years ago and stored in sediments, wetlands, and water bodies, may provide continuous water quality problems long after the NPSP source has been controlled.

NPSP has proved to be a management problem since it frequently is intractable to economical, legal, and institutional management efforts. Site-specific prescriptions to control NPSP are often made difficult by political relations between governmental bodies, and, frequently, workable prescriptions will not work everywhere.

NPSP is a major environmental concern in the South because of the region's abundant water resources (Table 1; EPA 1984). Surface waters have been the prime focus of NPSP research and management because they provide much of the region's domestic water supply and recreational opportunities. In some states, wetlands are more abundant than perennial surface waters. As development has encroached upon these wetlands, and our understanding of the importance of wetlands in regulating surface hydrology and providing wildlife habitat has improved, the need to better understand the impacts of NPSP on wetlands has become very urgent.

Table l.-Wetlands, rivers, and lake resources by state, Southern Region

	Wetlands		Surface water	
State	Inland	Tidal	Rivers	Lakes #
	ha	ha	km	ha
AL	1,052,168	161,872	65,338	281,469
AR	364,212	0	18,027	249,112
FL	4,300,094	604,960	18,861	929,943
GA	1,941,655	202,340	32,186	277,069
KY	59,638	0	64,372	284,087
LA	1,214,093	1,043,518	479,224	502,589
MS	259,805	*	16,534	307,351
NC	1,507,028	1,492,055	59,866	229,777
OK	21,448	0	37,014	542,822
SC	1,681,850	203,959	15,576	356,173
TN	318,483	0	30,956	423,760
TX	121,404	64,749	128,744	1,198,029
VA	U	86,197	43,837	86.162

Includes lakes, ponds, and reservoirs; * = data included in figures reported for estuaries.

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Forested wetlands entered into the NPSP picture from two different directions. Traditionally, wetlands were considered to be a filter for mitigating point source and NPSP fluxes into aquatic ecosystems (Todd et al. 1983; Lowrance et al. 1985). Forested wetlands often occur between upland sources of NPSP and the aquatic systems prized for their wildlife, recreational, and aesthetic values. But then, it was recognized that NPSP has a major impact on the intrinsic values of wetland ecosystems. For forested wetlands in particular, forestry practices represent a major source of NPSP. The real difficulty in dealing with NPSP in relation to wetlands lies in defining NPSP and determining its impacts.

DEFINITIONS AND TERMINOLOGY

To define NPSP, such basic terminology as "water quality," "water contamination," and "water pollution" must be defined. Often these terms are not clearly defined and are confused with each other.

Water quality.-This is a neutral term relating to the condition or composition of water as affected by natural processes and cultural activities. It is classified as "good," "fair," "poor," etc., relative to its intended use. For example, most people have an intuitive sense of what constitutes good water quality, but there can be disagreement over this term. Water quality and water pollution are determined by comparison to sets of standards, objectives, criteria, etc. While some water quality standards are universally accepted, others are not.

Water pollution.-This term relates to some objective, usually undesirable change in the condition of water relative to standards and criteria. Often, subjective criteria are interjected into the determination of water pollution. This occurs because of misunderstandings of what constitutes the "natural" condition of water resources.

Water contamination.-This term **refers** to the presence of non-water materials in water such as elements, minerals, organic and inorganic chemicals, biological debris, and living organisms. All water is contaminated to some extent, but not all water is polluted.

NPSP Definition

According to the classical definition, there are three characteristics which distinguish NPSP from point sources of pollution (Vignon 1985). The first characteristic of NPSP is that of a dominant overland and/or subsurface flow component which must occur to transport pollutants. These modes of transport are not amenable to analysis by traditional open-channel hydraulic techniques and, thus, are difficult to relate to processes generating sources of pollutants (in contrast to the end of a pipe discharging wastes into a stream). A second characteristic of NPSP is that it is intermittent in both time and space. The variability associated with intermittent behavior makes NPSP difficult to quantify and manage. The third basic attribute of NPSP is that the pollution originates in a diffuse manner from a large and broad landscape. Thus, it is difficult to couple causal relationships the substantial volumes of water and associated pollutants that are generated across entire watersheds.

Vignon (1985) suggested expanding the distinguishing characteristics of NPSP to include factors other than physical-chemical considerations. The jurisdictionally descriptive complexity of NPSP is more uncertain than for point source pollution because few NPSP problems are the responsibility of a single jurisdictional entity. Furthermore, NPSP involves a broader array of agencies and individuals than is concerned with point source pollutant generation and water quality management. Finally, NPSP is distinguished from point source pollution in that it is resistant to regulatory-based control.

NPSP SOURCES

There are six main source activities of NPSP. The first five are the traditional sources: agriculture, silviculture, mining, construction, and urban activities. The sixth, atmospheric deposition, has only been recognized in recent years, but is a major contributor of some types of NPSP in certain regions. Agriculture is by far the most pervasive NPSP in the thirteen-state Southern Region (Table 2). Silviculture is primarily a localized problem but can affect high quality waters used for human consumption and fisheries habitat. Urban and construction sources are also localized problems, but in some states they affect a major portion of the water resources. Mining occurs in localized areas, but can produce some severe NPSP problems.

Table 2.-NPSP problems by state and source (EPA 1984; Myers et al. 1985)

State	Agr	Sil	Min	Con	Urb
AL	xxx[1]	**[2]	**	**	**
AR	xxx	**	**	--[3]	**
FL	xxx	**	**	**	xxx
GA	xxx	**	**	**	**
KY	xxx	**	**	**	**
LA	xxx	**	**	**	**
MS	**	**	**	**	**
NC	xxx	xxx	**	**	**
OK	**	**	**	**	**
SC	xxx	**	**	**	**
TN	xxx	**	**	**	**
TX	0[4]	0	0	0	0
VA	xxx	**	**	xxx	xxx

[1] XXX = Major NPSP problem affecting >50% of a state's waters.
[2] ** = Localized NPSP problem.
[3] -- = Minor problem or does not occur in the state.
[4] 0 = Not reported.

Agriculture

Since agriculture constitutes the most extensive and intensive land use activity it is not surprising that it accounts for much of the NPSP in the Southern Region. Activities such as field tillage, pesticide and fertilizer applications, drainage, irrigation, grazing, and feed-lot operations contribute to NPSP. In addition, agricultural operations occur annually (or monthly during the growing season) on the same landscape.

Silviculture

Forestry operations may be as intensive as agriculture, but occur far less frequently and are less extensive in nature. The types of activities which affect NPSP include road construction, vegetation removal, fertilizer and pesticide applications, burning, and mechanical equipment operations. The hydrologic functions of forested watersheds are much different than agricultural ones, thus the magnitudes and routing of NPSP are often different.

Mining

Surface and underground mines can produce large quantities of NPSP. Activities which contribute to NPSP include access road construction, vegetation clearing, overburden removal, rock extraction, and backfilling operations.-Ore processing waters and acidic mine and tailing leachates also contribute to NPSP.

Construction

Construction of physical facilities including homes, businesses, manufacturing plants, roads, and utility corridors result in land disturbances which generate NPSP. While this source of NPSP is usually localized, States such as Florida that are undergoing major population expansions can have significant problems with construction-generated NPSP. The major population growths in this and other major wetland states are expected to occur within 80 km of the coast where most wetlands are located.

Urban

Storm water drainages from urban areas can be a major source of NPSP for wetland areas. This is particularly true in states with large, expanding urban areas. Runoff during storm events can rapidly transport heavy metals, sewage, fertilizers, pesticides, sediment, petroleum products etc., and other manufacturing products into wetlands.

Atmospheric

This source of NPSP is still undergoing extensive research and evaluation. Atmospheric inputs are a form of natural NPSP utilized by plants (Swank 1984). Emissions from power plants, industrial facilities, vehicles, and domestic heating are certainly the most important sources of the major pollutants (sulfur and nitrogen oxides).

NPSPTYPES

The types of NPSP consist of erosional products (sediments), biologically active elements or ions (heavy metals and nutrients), synthetic organic chemicals (pesticides), and biological material. All of these materials interact with or affect the functioning of aquatic ecosystems, or affect the quality of natural waters. These NPSP types can be generated by some or all of the NPSP source activities. The NPSP types either occur naturally in terrestrial and aquatic ecosystems or are introduced. The classification of these types as pollutants is due to the quantity of flux into wetlands and aquatic ecosystems as well as adverse changes in the functioning of each system.

Sediment.-The largest contributor to NPSP by volume and the single most important water quality problem in the United States is sediment. It consists of sand, silt, clay particles, and organic matter dislodged from exposed soil, stream channel banks, and channel beds. The enormity of sediment contributions is reflected in the topsoil loss from agriculture in the thirteen-state Southern Region. Some 16.1 million hectares of cropland is 8 metric tons/ha/yr, with substantial portions being deposited in waterways or adjacent wetlands (Larsen et al. 1983). The cost of this sediment loading is estimated to be $6 billion per year nationally (Clark 1985).

As a NPSP source, sediment is complex since many other pollutants are transported with sediment. These sediment-bound pollutants (i.e., nitrogen, phosphorus, potassium, pesticides, heavy metals. etc.) are less available biologically can be buried with deposited sediment. However, sediment-bound pollutants that do not degrade can be reintroduced into aquatic systems, and can hasten the eutrophication of slow-flushing bodies of water such as lakes, ponds, and wetlands.

Heavy metals.-A variety of these metals may occur in toxic concentrations, they do not degrade, and can bioaccumulate in aquatic ecosystems. Heavy metals originate from sources such as sewage sludge, urban runoff from industrial areas, transportation activities, building materials. mining leachates, and tailing sediments. Most heavy metals are either sediment-adsorbed or complexed and are transported with these materials.

Anions/cations or nutrients.-Anions and cations that serve as plant and animal nutrients are generated naturally across landscapes. However, human activities usually magnify the levels at which nutrients are introduced into natural waters and wetlands. Land use activities such as fertilizer application, animal grazing, vegetation removal, land clearing, and storm runoff channeling are major sources of nutrients. Nationally, cropland, rangeland, and pastures contribute almost 7 million metric tons of nitrogen and 3 million metric tons of phosphorus to surface waters. In the thirteen states of the Southern Region, eroded sediments alone carry 1.2 million metric tons of nitrogen (Larsen et al. 1983). Additional nitrogen is transported in solution. Loehr (1974) compared the different concentrations and area1 loadings of nitrogen and phosphorus produced by various land uses (Figures **1** and 2). Intensive agricultural practices clearly produce both higher concentrations and loadings of N and P compared with other sources. It is also important to note that precipitation ranks high in N loading.

Biological.—Biological NPSP consists mainly of fecal organisms associated with feedlots and sewage. This type of NPSP is usually rather localized, but shock loadings and localized problems from livestock farming areas and urban runoff can occur.

Pesticides and organic chemicals.-NPSP of this type originates from use of Herbicide, and insecticide NPSP originates in agriculture, in forestry, lawn care practices, and from the manufacture, transportation, and use of synthetic organic chemicals. Storm runoff and urban storm water are the main mechanisms for moving these materials into surface waters and wetlands.

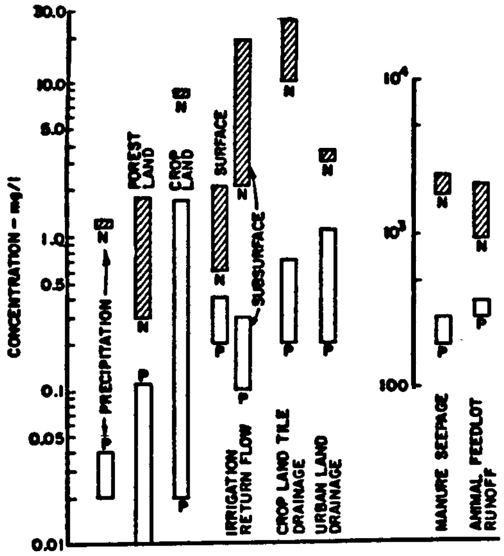

Figure 1.-Comparison of nonpoint sources, giving range of total N and P concentrations (Loehr 1974).

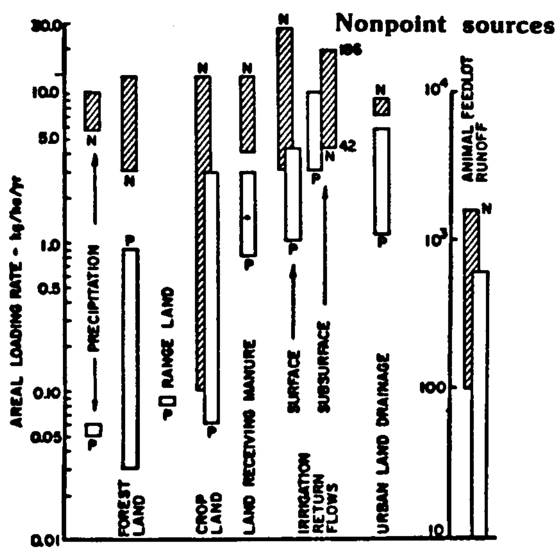

Figure 2.-Contributions of total N and P by various nonpoint sources (Loehr 1974).

Pesticide use alone amounts to about 1.2 million metric tons per year, with 75% of that being in agriculture (EPA 1984). While concentrations of pesticides are relatively low in surface waters, chronic toxicity problems with aquatic and wetlands biota can occur in certain situations (Wauchope 1978).

CUMULATIVE AND OFF-SITE EFFECTS

The off-site water quality effects of NPSP have been well documented for surface waters (Tables 3a and 3b). Many of the same qualitative effects can be found in wetlands. However, few of these effects have been quantified for wetlands, particularly for NPSP originating from forested lands. For most forested wetlands, baseline information on NPSP effects is lacking and natural inputs of NPSP are not well documented.

Cumulative effects of NPSP are not well documented or understood. Much of the NPSP research in the past has concentrated on outputs from specific practices on small portions of large watersheds. For wetlands, rigorous analyses of cumulative effects are needed to understand the inputs and impacts of NPSP.

NPSP TRENDS

There is considerable variation across the thirteen states of the Southern Region in the extent of NPSP assessment for rivers and lakes (Table 4; adapted from EPA 1984). Because of differences in rating NPSP or awareness of NPSP, it is difficult to make straight comparisons of NPSP impacts reported by individual states. However, some trends can be delineated. Rivers and lakes have had the first priority in terms of NPSP assessment (EPA 1984). Only five states have assessed more than 50% of their rivers, while just about half have assessed more than 50% of their lakes for NPSP effects. Of the known NPSP impacted waters, most states reported NPSP for rivers and lakes at moderate to threatened levels. In most states, agriculture is responsible for the predominant NPSP impacts. Except for two states (Arkansas and Louisiana), silviculture was responsible for $< 8\%$ of the impacts on surface waters. Urban and construction sources account for high levels of NPSP in Georgia, South Carolina, and Texas. In Kentucky, mining is an important NPSP generator. Two states, North Carolina and Oklahoma, either did not report NPSP data or were uncertain about the amount of NPSP impacts. Virginia and Texas were also uncertain of the scope of NPSP, but did report data on some of their surface waters.

In regards to wetlands, most states do not know the magnitude and sources of NPSP effects on wetlands (Table 5; adapted from EPA 1984). Kentucky, North Carolina, South Carolina, and Oklahoma reported data on percent of wetlands currently impaired by NPSP or potentially threatened. However, the data from these three states indicate that there is still great uncertainty about NPSP impacts on wetlands. Thus, much work remains to be accomplished in terms of both determining NPSP impacts and assessing the extent of NPSP to wetlands in the region.

Table 3a.—NPSP effects on aquatic systems and wetlands

Type	Source		Effects (* = pertains to wetlands)
Sediment	A,S,M[1] U,C	* 1.	Decrease in light transmission through water
		* 2.	Direct effects on respiration and digestion of aquatic spp.
		* 3.	Decrease in viability of aquatic life
		* 4.	Increased temperature of surface water
		* 5.	Decreased recreational and commercial value
		6.	Increase in drinking water costs
Salts	A,M,U	* 1.	Favors salt-tolerant aquatic spp., and affects the types and populations of fish and aquatic wildlife
		2.	Reduce crop yields
		* 3.	Destruction of fish habitat and food sources
		* 4.	Reduced suitability for recreation
		5.	Drinking water quality affected
Pesticides	A,S,U C	* 1.	Hinders photosynthesis in aquatic plants
		* 2.	Lowers organism resistance and increases susceptibility to other environmental stress
		* 3.	Affects reproduction, respiration, growth, and development of aquatic spp., and reduces food supply and habitat
		* 4.	Lethal effects on nontarget spp.
		* 5.	Bioaccumulation in tissue of fish and other-aquatic spp.
		* 6.	Carcinogenic, teratogenic, and mutagenic effects
		* 7.	Reduces fishing and other recreational values
		* 8.	Health hazard from consumption of contaminated fish and water

[1] #A = agriculture; S = silviculture; U = urban, M = mining; C = construction sources of NPSP.

Table 3b.—NPSP effects on aquatic systems and wetlands

Type	Source		Effects (* = wetlands)
Nutrients	A,S,U[1] C	* 1.	Promote premature eutrophication of lakes, and estuaries
		* 2.	Algal blooms
		* 3.	Favor less desirable fish spp.
		* 4.	Interfere with boating and fishing
		5.	Reduce the quality of water supplies
		* 6.	Reduce 02 levels in water
		7.	Reduction of waterfront property values
		8.	Health problems
Metals	U,M	* 1.	Affect bottom-feeding aquatic organisms and predators
		* 2.	Bioaccumulate in animal tissue
		* 3.	Affect reproduction and lifespan of aquatic spp.
		* 4.	Disrupt food chain in aquatic environments
		* 5.	Affect recreational and commercial fishing
		6.	Affect water supplies
Biological	A,U	* 1.	Introduce pathogens into waters
		* 2.	Reduced recreational usage
		3.	Increased treatment cost of drinking water
		4.	Human health hazard
Anions	M	* 1.	Significant change in stream acidity
		* 2.	Leaching of toxic metals
		* 3.	Elimination of aquatic communities
		4.	Severely limited domestic and industrial use of water

[1] A = agriculture; S = silviculture; U = urban, M = mining; C = construction sources of NPSP.

Table 4.—NPSP assessment by state, intensity, and source for rivers and lakes in the thirteen-state Southern Region; EPA 1984

			Proportion of known NPSP-impacted waters								
		Waters	Intensity #			Source @					
State	Type	assessed	Sev	Mod	Thr	A	S	C	U	M	0
			%								
AL	R	30	9	73	18	71	1	1	1	42	2
	L	0	U	u	u	u	u	u	u	u	u
AR	R	100	17	13	70	51	34	8	U	7	U
	L	3	U	u	100	63	37	u	u	u	u
FL	R	40	10	45	45	60	Cl	2	2	14	25
	L	44	4	6	90	93	0	<1	3	1	11
GA	R	85	27	5	68	10	4	72	26	0	0
	L	57	91	9	0	99	4	0	92	0	0
KY	R	25	16	84	0	53	u	u	0	47	u
	L	51	0	100	0	0	0	0	0	100	0
LA	R	1	4	75	21	86	4	7	13	19	6
	L	37	1	8	91	43	47	7	8	11	16
MS	R	100	0	45	55	100	0	0	0	0	0
	L	65	0	100	0	100	0	0	0	0	0
NC	R	100	7	36	57	+	+	+	+	+	+
	L	56	0	0	100	+	+	+	+	+	+
OK	R	52	0	0	100	u	u	u	u	u	u
	L	41	0	0	100	u	u	u	u	u	u
SC	R	29	2	42	56	100	0	36	90	0	31
	L	51	0	8	92	74	0	0	12	0	<1
TN	R	31	16	49	35	61	8	1	3	29	0
	L	51	14	42	44	98	<1	<1	<1	1	0
TX	R	18	0	0	100	0	0	100	100	0	0
	L	45	+	+	+	+	+	+	+	+	+
VA	R	7	u	u	u	u	u	u	u	u	u
	L	53	0	2	98	56	6	36	2	U	U

U = Unknown; + = not reported; # = Intensity columns sum to 100%; @ = Source columns not additive.

Table 5.-NPSP assessment for inland (I) and tidal (T) wetlands in the thirteen-state Southern Region; EPA 1984

					NPSP impaired		
	Wetlands		Current use		No current use		NPSP-PSP
State	Type	Total	Sev	Mod	Threat	Minor	Mixed
		ha x 10^3	%				
AL	I	1,052	U	U	U	U	U
	T	162	u	u	U	U	U
AR	I	364	LJ	u	U	U	U
	T	0	•	•			
FL	I	4,300	u	u	U	U	U
	T	605	u	u	U	U	U
GA	I	1,942	u	u	U	U	U
	T	202	u	u	U	U	U
KY	I	59	9	3	0	1	<1
	T	0	•	•			
LA	I	1,214	u	u	U	U	U
	T	1,044	u	U	U	U	LJ
MS	I	260	u	u	U	U	U
	T	*	•	•			
NC	I	1,507	0	0	26	0	0
	T	1,492	0	0	U	U	0
OK	I	21	0	0	0	0	0
	T	0	•	•			
SC	I	1,682	0	0	0	100	0
	T	204	0	0	0	100	0
TN	I	318	u	u	U	U	U
	T	0	•	•			
TX	I	121	u	u	U	U	U
	T	65	U	u	U	U	U
VA	I	U	u	u	U	U	U
	T	86	0	0	8	U	U

U = Unknown; * = included with estuaries; • = does not apply.

CONTROL OF NPSP

The basic elements for effective control of NPSP in surface waters as well as wetlands consist of the following:

1. Rank high-priority water bodies;
2. Identify those water quality problems in high-priority waters that are caused by NPSP;
3. Identify key NPSP sources and activities;
4. Choose appropriate best management practices (BMP's).

The key to reducing NPSP impacts is effective state management of water quality and implementation of BMP's. Decisions must be made at the local level on site-specific, high-priority problems.

While many states have implemented BMP's to control NPSP inputs into rivers and lakes from sources like agriculture and silviculture, few have developed BMP's specifically for wetlands (Florida Division of Forestry 1988; South Carolina Forestry Association Environmental Committee 1987). For most areas of the South, the information on the magnitude of NPSP inputs into forested wetlands, the effects within wetlands, and the effectiveness of BMP's is highly variable. The following paper by Riekerk, Neary, and Swank (this volume) will specifically examine these topics, and will address specific NPSP types and research needs. But, in general, there is a large need for specific process-oriented research on NPSP impact and on wetland ecosystem functions. This is one reason why, as has been illustrated, states are having difficulty with assessing the effects of NPSP on wetlands.

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THE MAGNITUDE OF UPLAND SILVICULTURAL NONPOINT SOURCE POLLUTION IN THE SOUTH

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Abstract.-Streamflow water quality data from intensive silvicultural practices in the southern United States are summarized and discussed with respect to regional differences of nonpoint source pollution, and Best Management Practices. Suspended sediment production by silviculture was low in the mountains and lower coastal plain, but high in the Piedmont and upper coastal plain regions. This reflected an interaction between site preparation intensity and topographic relief. Cation nutrient export after harvesting in the mountains was increased by higher nitrate carrier-ion production and by more runoff. Nutrient exports in the Piedmont and upper coastal plain regions were controlled by the degree of soil disturbance and by the recovery rate of vegetation. Nutrient exports in the lower coastal plain were not much affected by intensive silviculture. Information gaps and research needs for upland nonpoint source pollution effects on wetlands are identified.

INTRODUCTION

Wetlands are dependent on the water quantity and quality from upland source areas for their functioning. Thus, landuse practices on adjacent uplands have a distinct influence on wetlands. Neary and others (this volume) outline the major anthropogenic activities generating nonpoint source pollution (NPSP) and identified silvicultural activities as having a relatively low impact. They also discuss the major effects of sediments, heavy metals, nutrients, pathogens, and pesticides on physical, chemical, and biological properties, on ecosystem function, and on human valuation of water. This paper focuses on the magnitude of silvicultural NPSP that could enter wetlands and will identify land/water interface research needs in the South.

Conceptual Framework

The watershed concept integrates the hydrologically-driven interactions between various interconnected terrestrial and aquatic ecosystems within a drainage basin (figure 1). Precipitation input is differentiated into evapotranspiration, runoff, deep seepage, and retention storage. Evapotranspiration includes canopy and litter interception, transpiration, and evaporation from open water. Runoff comprises steady baseflow and rapid stormflow, while deep seepage represents the percolation of soil water out of the watershed. Retention storage is that amount remaining in the soil, groundwater, and in ponds and lakes. The water, carbon, sediment, and mineral fluxes usually are summarized in annual balances to evaluate normal rates of erosion and weathering. However, critical stormflow and pollution events of catastophic pulses are based on short time periods.

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The development of the concept of variable source areas for stormflow from forest lands has been summarized recently by Hibbert and Troendle (1988). Litter-covered forest soils are very porous because of their relatively undisturbed nature. Rainfall infiltrates and part of it moves rapidly as subsurface quickflow through macro-pores, while percolation through the deeper soil emanates later as baseflow. Downslope water movement saturates streamside discharge areas which expand as rainfall continues. These streamflow source areas contract again upon cessation of rainfall because of progressive soil drainage. Most silvicultural activities within or near the source areas have the potential to generate more water pollution.

Silvicultural Practices

Forest roads provide access for management, protection, and recreation. Their location, preferably, should be outside wetlands or on highest ground. Construction disrupts the soil and should minimize cut and fill, with careful stabilization of exposed areas. Crushed-rock surfacing reduces periodic grading needed for maintenance. Sufficient culverts should be present to minimize disruption of flow patterns. Skid trail locations should be in narrow corridors on the most stable ground conditions.

Logging entails cutting and skidding of trees. Cutting is done with power saws or by mechanical shearing with a feller-buncher. The latter operation exposes and compacts soil, allowing more overland flow with its attendant erosion. Tree removal with rubber-tired or tracked skidders is most common and tends to disturb the soil most. Cable systems commonly used in the mountains have less impact, and helicopter or balloon logging produce the least soil disturbance.

Forest regeneration methods are described elsewhere in this volume. Site preparation for some of these methods may severely disturb the site. Felling of residual trees and slash burning are the least-disruptive operations. Slash chopping and soil disking are more disturbing, especially on steep slopes. Slash piling with a tractor-mounted rake or blade exposes much more soil, and shearinglwindrowing with a

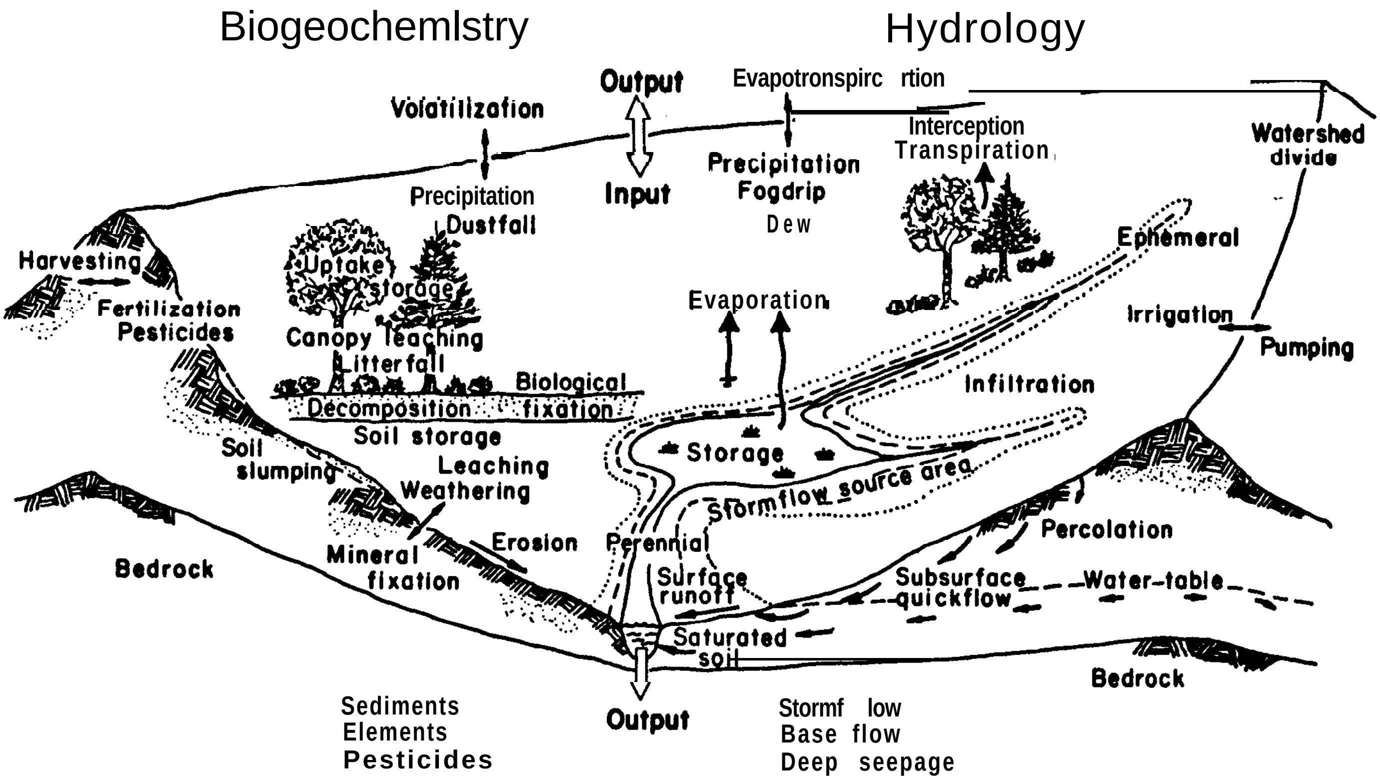

Figure l.-Conceptual model of biogeochemistry, hydrology and stormflow source area interactions.

KG-blade causes the most disturbance. Poorly-drained sites require planting beds to start the seedlings above saturated soil conditions. Vegetation control during stand development usually is achieved with prescribed burning or with herbicides.

MAGNITUDE OF NPSP

Silvicultural NPSP has two major components-water quantity and water quality. The combination of these two components represents the downstream output flux. Additional effects are due to the seasons and to hysteresis caused by early flushing of accumulated decomposition products during a storm event (Hirsch 1988). The effects of silviculture on water quantity will be covered first to help elucidate some effects on water quality later. Sources of data are primarily from small experimental watersheds with a single cover type. While the number of data sources is limited, all physiographic regions in the South are represented.

Hydrologic Responses to Silviculture

Tree removal reduces evapotranspiration, which in turn makes more water available for soil moisture, seepage, and runoff. Higher soil moisture reduces the strength of the surface soil and promotes puddling, rutting, and compaction by heavy equipment. This increases the hazard of streamflow pollution. The first-year increase in streamflow was found to be proportional to the amount of forest vegetation removed. Additional factors were climate, geology, and topography as indexed by the site aridity or runoff-rainfall ratio (figure 2). The increase for humid regions was about 2.5 mm per percent of forest cover removed (Neary and others 1982). More specific equations incorporating potential solar radiation have been developed for watersheds of the Appalachian Mountains (Swank and others 1988). The rate of streamflow recovery to baseline level was related to the density and vigor of forest regrowth.

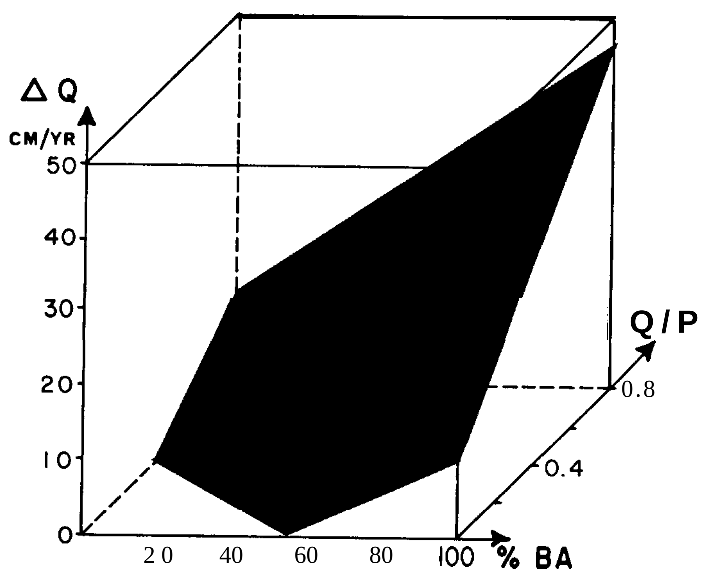

Figure 2.-Relationship between first-year runoff increase (dQ), percent vegetation removed (%BA) and site aridity (Q/P), based on data summarized by Troendle and others (1980).

Water Quality Responses to Silviculture

Sediments

The major pollutant from silvicultural activities is sediment. As described by Neary and others (this volume), sediments have a physical effect on downstream biota and may transport significant amounts of carbon, nutrients, and pesticides. Logging roads are primary nonpoint sources of sediment pollution (Pope 1977). Roadside ditch turnouts into adjacent forest land significantly reduce sediment pollution of streamflow. The initial construction phase of a mountain road was shown to generate erosion up to 600 ton/ha of roadway area (Swift 1988). Rapid stabilization of fill by mulch-grassing and placement of brush barriers at the toe of fills reduced soil movement significantly. Heavy use during logging operations generated about 100 ton/ha of roadway area. This was reduced by one-half by grassing, and practically eliminated entirely by fully gravelling the roadbed. Basin-wide roadbed erosion rates in another study (Miller and others 1985) averaged 0.2 ton/ha/yr, one percent of which was estimated to reach streams as sediment.

Ursic (1986) summarized and discussed sediment data from silvicultural activities in the South. In general, prescribed burning and harvesting did not significantly increase sediment levels in runoff in any of the physiographic regions. Slash burning and chopping usually had no statistically significant effect, but mechanical site preparation with shearing and windrowing of debris generated significant sediment pollution. In most cases the effect became non-significant after the first year, except for loess soils in Mississippi where effects lasted over two years. Complete vegetation removal by mechanical site preparation caused more runoff which generated relatively high export values in the upper coastal plain. This was due in part to increased channel bank scouring.

First-year treatment effects of harvesting and/or mechanical site preparation practices on suspended sediments in the physiographic regions of interest are presented in figure 3. The information generally shows an interaction of increasing soil disturbance by site preparation and decreasing topographic gradients from the mountain regions to the lower coastal plains. Customarily low site disturbance in the mountain regions generated less sediment. Most sediment

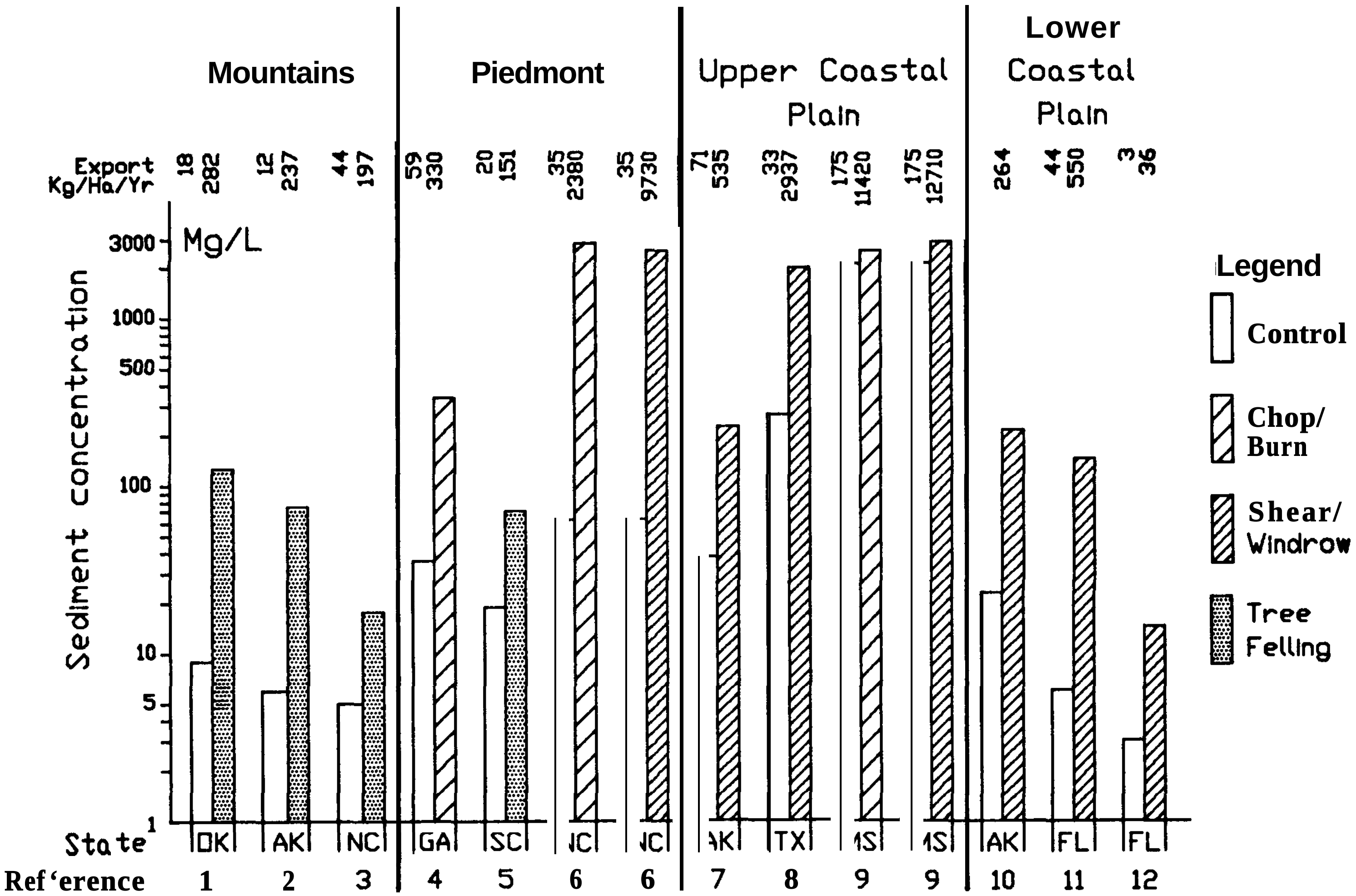

Figure 3.-First-year sediment concentration in runoff and export after harvesting and/or site preparation operations in the South. References: 1. Miller 1984, 2. Miller and others 1988, 3. Swank unpublished data, 4. Burns and Hewlett 1983, 5. Van Lear and others 1985, 6. Douglass and Goodwin 1980, 7. Beasley and others 1986, 8. Blackburn and others 1986, 9. Beasley 1979, 10. Beasley and Granillo 1988, 11. Hollis and others 1978, 12. Riekerk 1983.

production was from unstable road fills. Slumping after saturation of the soil by harvesting, heavy storms, or snowmelt contributed occasional pulses of sediments (Grant 1988; Swanston and others 1980). The Piedmont showed higher sediment production rates. These high losses were due to the practice of mechanical site preparation on steep slopes. Stormflow increases due to forest harvesting accelerated erosion of minor channels by cutting headward into earlier sediment deposits of anthropogenic origin. The more intensive silvicultural practices on the sloping and sedimentary soils of upper coastal plain watersheds, especially on loess soils of Mississippi and Tennessee, generated most sediments. Lower sediment levels from runoff plots (McClurkin and others 1985; McClurkin and others 1987) suggested significant sediment contributions from scouring and headward cutting of minor channels in watersheds. Silvicultural sediment pollution of streamflow was generally less in the lower coastal plain region because of the low topographic gradients.

Export of particulate organic matter from upland watersheds was found to be proportional to annual runoff (Mulholland and Kuenzler 1979). This proportionality combined with the first-year runoff increase after harvesting could export about 6 kg/ha/yr more particulate organic matter per percent basal area removed in the humid South.

Nutrients

Watershed nutrient balances of atmospheric input and runoff **output** of undisturbed systems generally show net gains of nitrogen (N) and phosphorus (P) as well as net losses of cations depending on the geologic substrate (Likens and Bormann 1975; Swank and Waide 1988). Now we will turn our attention to changes in watershed outputs due to silvicultural practices, assuming that adjacent downstream wetlands receive similar rates of atmospheric input.

Removal of the forest canopy allows more moisture and solar radiation to reach the forest floor and soil. Changes in these physical factors accelerate mineral cycling processes such as decomposition, mineralization, and weathering. Higher production of mobile bicarbonate, nitrate, and phosphate carrier anions (Johnson and others 1986) coupled with more available water causes increased cation movement in the soil and more nutrient release into runoff (Neary and others 1986). However, increased denitrification of nitrate in the wetter and more anaerobic soil, phosphate fixation in soil, and rapid nutrient uptake by sprouting vegetation and pioneer plant species counteract this mobility to some extent. The net effect usually is a higher level of nutrients in runoff followed by a decline which is dependent on the rate of vegetation recovery. However, when the supply of mobile nutrients in the soil remains constant, a higher water yield will dilute the concentration in runoff. Nutrient export fluxes provide an integrated measure for establishing resistance and resilience indices of ecosystem stability (Waide 1988).

Few long-term watershed studies of silvicultural effects on nutrient dynamics have been published for all the physiographic regions of interest. The available nutrient flux and runoff concentration data from several silvicultural practices have been summarized in figures 4 and 5, respectively. Our discussion will focus on the export fluxes documented in figure 4, but will draw on the concentration data documented in figure 5 for speculation on the underlying watershed and mineral cycling processes. Site preparation on the mountain sites and on the South Carolina Piedmont site was accomplished by simply felling all residual trees. Both coastal plain studies experienced a drought in the middle period, as exemplified by low flux rates, which makes it difficult to discern trends (figure 4). Organic bottom sediments of a wetland in the control watershed of the lower coastal plain study were exposed during the drought year, causing extremely high nitrate-nitrogen (NO3-N) levels in the little stormflow that did occur (figure 5, part A).

Fluxes of NO3-N from the harvesting treatment in the mountain region site were relatively high and lasted for the duration of the study (figure 4, part A). Somewhat higher export levels with a similar response pattern were reported for a study in the West Virginia mountains (Patric 1980). The relatively high export levels were mainly due to the high rainfall regime of the mountains combined with higher water yields and NO3-N levels after cutting. The major increase of NO3-N was delayed (figure 5, part A) and appeared to be coupled with the dynamics of soil microbial activity. A complete vegetation kill with hexazinone in the Piedmont generated a very high NO3-N export of 4.9 kg/ha during the first year and carried large amounts of potassium (K) and calcium (Ca) out of the watershed (Neary and others 1986). Harvesting had little effect on NO3-N outputs from four watersheds in the South Carolina Piedmont site, probably because of immobilization by microorganisms and uptake by rapid plant regrowth (Van Lear and others 1985). Harvesting and chopping on the Georgia site significantly increased NO3-N export levels, presumably because of less rapid plant regrowth. The high-disturbance treatment in the upper coastal plain site generated a significant increase in NO3-N export, while that for the lower coastal plain was half as much. The difference occurred despite the fact that more runoff was generated by silviculture in the lower coastal plain as evidenced from the concentration levels. The low-disturbance site preparation treatment of the upper coastal plain also generated a relatively high NO3-N level, suggesting that this site is more sensitive to disturbance. The response to high-disturbance treatment of the lower coastal plain site may have been due to significant denitrification in the poorly-drained soils. Somewhat lower NO3-N concentrations were reported by Ewel (1985) in swamps after cypress harvesting. Export patterns in both coastal plain regions dropped rapidly to baseline levels, which was mostly due to the distorting drought conditions and partly due to rapid vegetative recovery in the warm climatic conditions.

Mineralization of organic matter yields ammonium-nitrogen (NH4-N) cations which, if not absorbed or immobilized, are quickly converted to mobile NO3-N anions in well-drained upland soils. This conversion process appears to become more prominent after harvesting. The NH4-N export fluxes from the mountain study site best reflected the inverse relationship with NO3-N exports after harvesting (figure 4, part B). Export patterns of NH4-N after silvicultural treatments in the other regions were complicated by rapid plant uptake and by drought conditions. Only the high-disturbance treatment in the upper coastal plain site showed more export during the first and last (wet) years. First-year NH4-N concentration in runoff from the high-disturbance treatment in the lower coastal plain site was reduced more than NO3-N was generated, suggesting a significant loss due to denitrification (figure 5, part B). Fisher

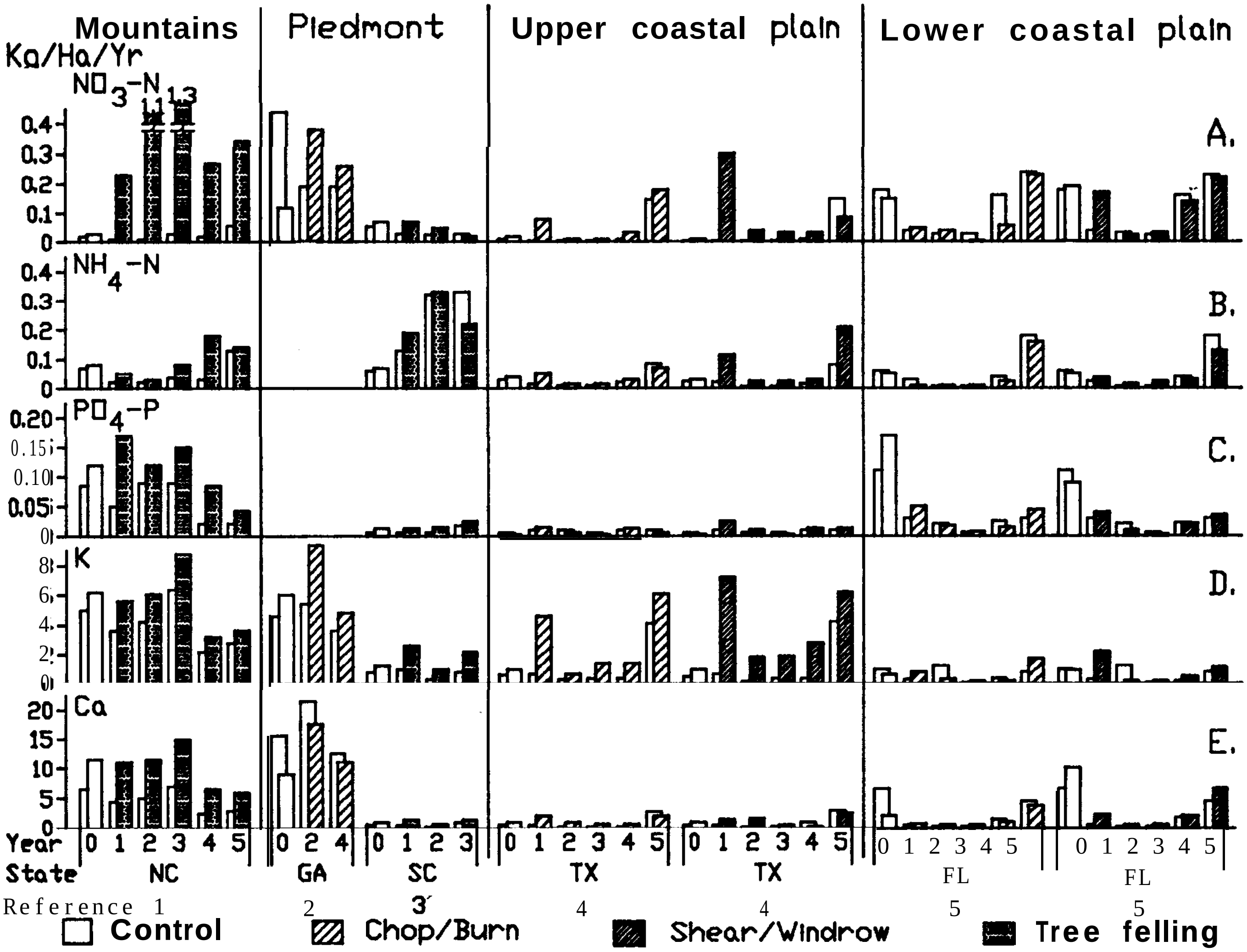

Figure 4.-Annual nutrient export before and after harvesting and/or site preparation operations in the South. References: 1. Swank 1988 and unpublished data, 2. Hewlett and others 1984, 3. Van Lear and others 1985, 4. Blackburn and Wood 1988, 5. Riekerk 1983 and unpublished data.

(1981) reported little increase in NO3–N but much higher NH4–N exports after intensive site preparation in a wet lower coastal plain site. Average NH4–N concentrations in runoff increased from the mountains to the lower coastal plain, while that of NO3–N remained somewhat the same. This NH4–N trend may reflect an increase of reactive soil depth and of nitrogen mineralization rates with growing season length and temperature in the transect.

The mountain site showed increased phosphate–phosphorus (PO4–P) export persisting after the silvicultural treatment which was mostly due to increased water yields (figure 4, part C). Of the other regions, only the high-disturbance treatment of the upper coastal plain site showed a first-year treatment response suggesting somewhat higher sensitivity (figure 5, part C). Return to baseline after disturbance was confounded by the drought conditions, but part of the recovery may have been caused by P fixation in the soils developed in this region (Johnson and others 1986). Fisher (1981) reported much more PO4–P export from a wet lower coastal plain site after intensive site preparation, which suggests higher solubility in more often saturated and acid soil conditions.

Potassium is a biologically mobile element as was evidenced by a very high export of 13 kg/ha during the first year after complete vegetation kill with hexazinone (Neary and others 1986). All of the harvesting and site preparation treatments listed in figure 4, part D, caused increased K exports with runoff lasting over the study period, including data reported for the West Virginia mountains (Patric 1980). The export responses diminished from the mountains to the lower coastal plain, except for the high-disturbance treatment in the upper coastal plain site. Comparison with concentration data of figure 5, part D, showed that increased runoff was the major factor. Therefore, the reduction during the drought period in both coastal plain sites probably masked a relatively low rate of recovery.

Calcium is immobilized in structural components of organic matter, so the concentrations in runoff waters mostly reflect the processes in soils and geochemical abundance in parent materials. The mountain study site showed an increase due to the harvesting treatment which lasted for the duration of the study. The export data amplified this effect significantly suggesting an association with NO3–N export. Calcium export data from the West Virginia mountain site showed only a first-year response (Patric 1980). The concentration

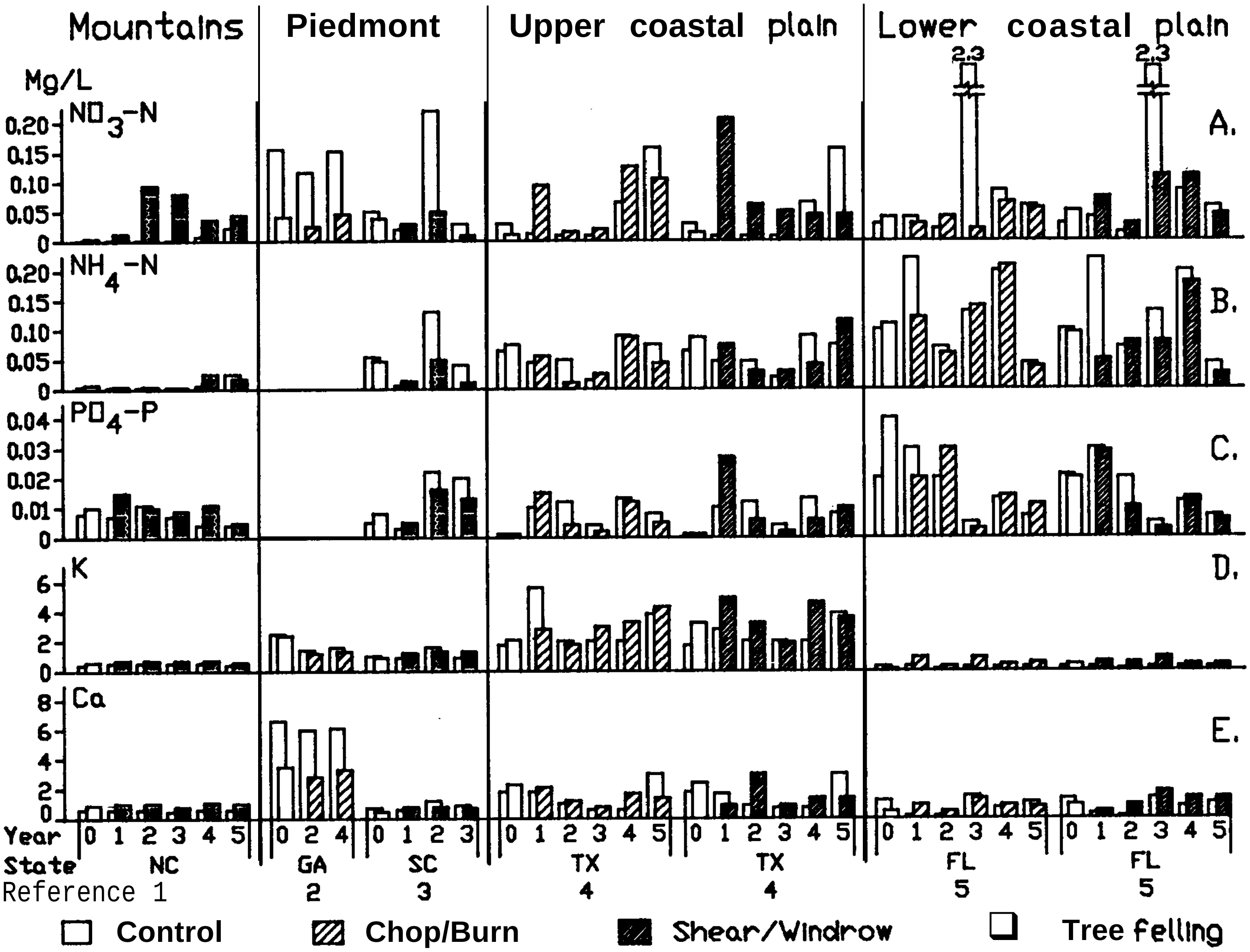

Figure 5.-Annual concentration of runoff before and after harvesting and/or site preparation operations in the South. References: 1. Swank 1988 and unpublished data, 2. Hewlett and others 1984, 3. Van Lear and others 1985, 4. Blackburn and Wood 1988, 5. Riekerk 1983 and unpublished data.

data of figure 5, part E, showed very high levels in runoff from the Georgia Piedmont with little effect from the site preparation treatment. These high Ca levels were representative of the area, mostly consisting of abandoned cropland, in contrast to the levels reported for the South Carolina site. The next highest concentration levels were in the upper coastal plain site, also showing little effect due to treatments. The Ca export showed a low but long-term response to the high-disturbance treatment. The high-disturbance treatment of the lower coastal plain study increased Ca export somewhat, but the intervening drought period made it difficult to evaluate the recovery rate. Pretreatment export and concentration data were somewhat higher because of ditching for watershed construction during a wet year. A significant increase of sediment and Ca levels in runoff due to disturbance of the soil and parent materials by ditching was also reported for the lower coastal plain by Williams and Askew (1988).

Sediment increases due to intensive silvicultural practices were significant, specifically in the upper coastal plain study sites. Some increases of dissolved nutrient elements were significant, but the absolute levels remained low. Moreover, total nutrient exports relative to the amounts in storage and recycling within the watersheds were small, suggesting the ecosystems to be rather resistant to the silvicultural treatments discussed. Similar conclusions also have been reached for more extreme treatments after whole-tree harvesting (Mann and others 1988). The rather rapid recovery relative to the long time interval to the next treatment cycle suggests good resilience of the soil-vegetation types. Altogether, the ecosystems seem to be relatively stable.

Figure 2 describes first-year water yields after harvest in worldwide regions of different aridity, as determined by climate, geology, and forest type. Similarly, the sediment data of figure 3 and the nutrient data of figure 5 describe some interactions of the topographic and anthropogenic factors in the South. Jenny (1964) has suggested that the interactions of the major factors of climate, topography, parent material, genetic pool, and time develop the properties of soils. The driving force is dissipation of free energy. Our data suggests that we could modify the concept by adding an intelligence factor and by integrating all factors over time to describe an ecosystem or watershed property, such as drainage. Anthropogenic activities in the landscape free embodied energy (Odum and Odum 1981), which becomes dissipated by accelerated runoff, erosion, and carbon and nutrient turnover. The acceleration of these processes on forested uplands could result in NPSP of downstream wetlands.

Pesticides

Pesticides are chemicals used to control pests such as insects (insecticides) and weeds (herbicides). These organic substances are introduced into forest ecosystems, but their presence does not necessarily result in the pollution of streamflow or groundwater. Pesticides represent a direct effect of the anthropogenic intelligence factor on ecosystem development. Properties of ionic state, water solubility, volatility, and degradation affect the environmental fate of pesticides. Pathways of pesticide movement include aerial drift, decomposition, leaching and adsorption in the soil, uptake by microbes and vegetation, and release into runoff in solution or in association with sediments. Persistence of pesticides is advantageous for control of target organisms, but it increases the risk of water pollution. Table 1 presents the solubility in water, half-life in soil, and the 1986 use rate of the major silvicultural pesticides.

Table l.-Pesticide properties, and 1986 use rates in the South (Neary and Michael 1988)

Pesticide	Water solubility mg/1	Soil half-life days	Annual use rate ac/yr
DDT	< 1	3837	0
Carbofuran	700	60	5,000
Atrazine	33	70	
2,4-D	3,000,000	28	10,100
Hexazinone	33,000	30	48,700
Imazapyr	15,000	30	1,600
Picloram	430,000	63	8,100
Sulfometuron	300	10	2,400
Triclopyr	430	46	

Pesticides are applied in liquid (solution, suspension, dispersible powder), or solid (granular, pellet) formulations. Application is directly on foliage and soil, or by injection into stems and soil. Aerial foliar applications have the highest hazard for water pollution because of drift, wash off, and erosion processes. Application to the soil surface has a lower hazard, but retention and dilution by the soil mass reduces toxic effectiveness. Tree injection methods are least hazardous for water pollution but are labor intensive.

Few data are available on water pollution effects by silvicultural applications of insecticides in the South. Grzenda and others (1964) reported maximum DDT levels of 346 parts per billion (ppb) in streamwater after aerial application to control elm spanworm in two mountain watersheds. These levels dropped to 5 ppb two months later. A second application respecting buffer zones showed no detectable DDT levels in runoff. Peak levels of carbofuran in runoff after annual soil injections in a seed orchard in the Piedmont reached 7,100 ppb during a wet year, but showed rapid degradation between applications (Bush and others 1986). No long-term accumulations of silvicultural insecticides were detected in fish of adjacent lakes. However, more persistent insecticides such as DDT, toxaphene, lindane, and dieldrin were prevalent.

Herbicides are commonly employed to control undesirable vegetation as a supplement or substitute to mechanical site preparation. Water yield increases and sediment pollution are less than from conventional methods, but the incidence of chemical water pollution is higher (Neary 1985). Table 2 lists peak concentrations reported for herbicides in streamflow after applications to forested watersheds in the South.

Atrazine and paraquat in mountain streamflow reduced to trace levels within two months. Reapplication including 2, 4-D outside a buffer zone resulted in nondetectable levels. Hexazinone residues were nondetectable in stormflow after liquid spot applications in a small mountain watershed, but baseflow showed levels up to 14 ppb during the year. Broadcast application of hexazinone in the Piedmont resulted in a peak concentration of 442 ppb in the first stormflow event followed by a steep decline, with a pulse of 24 ppb two months later. An aerial application of hexazinone pellets to 18 percent of a large watershed in the Appalachian Mountains did not produce detectable levels in runoff. However, in an instance of direct stream contamination by an aerial application in the lower coastal plain, levels peaked at 2,400 ppb, dropped to 110 ppb in two days, and were <10 ppb after ten days. Aerial imazapyr application to an upper coastal plain watershed with buffer zones resulted in a short-duration peak of 130 ppb followed by an average level of <30 ppb. Only occasional trace levels were detected six months later. Picloram pellets were manually broadcast in early spring outside a wide buffer zone in a small mountain watershed. Trace levels of picloram were found in springs with six samples of <5 ppb and two samples of 10 ppb in runoff over five seasons. An aerial picloram application in the upper coastal plain hit some stream water because of a poor buffer-zone marker. Residue levels at the overflight site rose to a maximum of 240 ppb, but was diluted downstream at the weir to 77 ppb and remained at 20–30 ppb over five seasons. Sulfometuron methyl suspensions applied to a large watershed in the lower coastal plain outside a streamside management zone resulted in peak levels of 44 ppb in the first few storms, with intermittent occurrences of residue traces three months later because of low temperatures. A similar treatment of a small watershed in the lower coastal plain during the summer resulted in a peak level of 7 ppb and nondetectable levels after seven days. Triclopyr was nondetectable during five months after application to small watersheds in the coastal plain with buffer zones extending along ephemeral channels.

NPSPCONTROL

Nonpoint source pollution resulting from the silvicultural practices described above cannot be controlled in an absolute sense except by refraining from any significant activity. Control is normally achieved by implementing Best Management Practices (BMP's) to reduce extreme pollution problems and to promote rapid recovery. The BMP's are focused on the sensitive stormflow source areas and use accepted road construction and soil conservation practices. Specific guidelines are usually based on available erosion and

Table 2.— Peak concentrations in streamflow from herbicide applications to forested lands in the South (Neary and Michael 1988)

Herbicide	Moun-tains	Pied-mont	Upper Coastal Plain	Lower Coastal Plain	Reference
	ppb				
Atrazine;					Douglass and
spray	35				others 1969.
Paraquat;					"
spray	35				
2,4-D;					
spray	0				"
injection		0	0		Neary and Michael 1988.
Hexazinone;					
spot	14	36			Bouchard and others 1985.
broadcast		442			Neary and others 1983.
aerial			0		Neary 1983.
aerial*				2,400	Miller and Bace 1980.
Imazapyr;					
aerial			130		Michael 1986.
Picloram;					
broadcast	10				Neary and others 1985.
aerial*			240		Michael and others 1988.
Sulfometuron;					
spray				44	Michael and Neary 1987.
spray				7	
Triclopyr;					
spray	80				McKellar and others 1982.
spray			3		Neary and others 1987.

* Direct contamination of stream water.

water quality information. However, few data is available on the actual effectiveness of BMP's implemented in the South. Silvicultural BMP's may be divided into those designed for roads and those for lands (Riekerk 1988).

Road BMP's

Permanent roads should avoid wetlands and be provided with broad-based drainage dips, ditches with turnouts into the forest, and sufficient culverts with protected outfalls. Runoff from logging decks and firelines also should be diverted into the forest. Ditches and culverts should be kept clear at all times to prevent blowouts. Roadfills should be at rest slope and grassed, and with vegetative or brush barriers at the toe. No fill is allowed below the ordinary high-water line in wetlands. Fords should only be on a solid streambed. Culverts or bridges should not change the high-water channel, and be placed to pass fish at normal low water. Approaches to culverts and bridges need to be erosion protected. Temporary roads should avoid fragile areas, and be constructed and used with minimum impact on drainage.

Land BMP's

Most states in the South require removal of trees and slash from channels [2]. Leaving a protective buffer zone next to open water is a standard guideline for maintaining hydrologic integrity of a watershed. The width of adjacent streamside management zones with limited practices is proportional to slope and to erosion hazard. Skidding should be toward uphill logging decks to form a runoff-dispersing trail pattern, cross over temporary culverts, log bundles, or portable bridges, and avoid changing natural drainages. Wet-weather harvesting should be limited to well-drained upland soils. Soil disturbance should be kept to a minimum, leave a protective soil cover, and follow contour lines. Fuel, oil, and chemical spills should be avoided.

RESEARCH NEEDS

This review of available information on NPSP produced by upland silvicultural practices as input for wetlands suggests several areas of future research focus. Foremost is the scarcity of long-term upland/wetland interface studies of an interdisciplinary nature in the regions of interest (Hasler 1975). These studies should concentrate on assessing the conservation-release mechanisms and couplings of pollutants within and between both upland and wetland forests. The information is needed to understand and model scenarios of silvicultural practices and upland/wetland interactions at different scales of space and time. Research and analyses of cumulative effects are also needed to determine the impacts of multiple silvicultural practices on downstream wetlands.

Furthermore, little information is available on the effects of silvicultural practices within wetlands. Data are needed on such environmental variables as hydroperiod, flow-through rate, biogeochemical cycling, and storage and release of pollutants by bottom sediments. LaBaugh (1986) also identified the scarcity of hydrological information about wetlands as crucial to an adequate understanding of input-output relationships. The groundwater pathway was singled out as being the most problematic. Internal biogeochemical process studies in conjunction with input-output studies of turnover rates were found to be lacking for wetlands.

Lastly, assessment of the actual effectiveness of BMP's, implemented to control silvicultural NPSP, is rather inadequate. Some small-scale information suggests that pollutants may bypass buffer zones (designed for filter action) by incipient channel flow of runoff, but few data are available on the effectiveness of silvicultural BMP's at the watershed level.

SUMMARY AND CONCLUSIONS

Suspended-sediment data show little effect from conservative silvicultural practices in the mountain region. However, the Piedmont and upper coastal plain regions are sensitive to soil disturbance by high-intensity site preparation practices. These systems recover relatively rapidly. Numerous studies of the sensitive but small loess area in the upper coastal plain put a bias in regional comparisons. Sediment production from site preparation practices in the lower coastal plain is low because of low topographic gradients.

Data for all nutrient export patterns demonstrate that the mountain region has substantially elevated losses after harvesting, mostly due to increased water yields. Temporary disruption of forest water use and mineral cycling processes generates large pools of mobile nutrients. Export rates return to baseline levels within five years after harvest. Nutrient exports from treatment watersheds in the Piedmont region generally are not changed except for some increase of Ca, which recovers quickly. Except for Ca, all nutrient export patterns in the upper coastal plain region are rather sensitive to shearing and windrowing practices for site preparation. The low level of Ca export recovers only slowly after treatment. Nutrient export patterns in the lower coastal plain show relatively low sensitivity to disturbance by intense site preparation treatments. For NO_3-N this is probably due to increased denitrification rates in the poorly-drained soils. The drought periods in the coastal plain mask recovery patterns for K and Ca, but increased export of both nutrients appears to persist over the study periods.

Potassium and Ca cation fluxes are facilitated by the output of mobile carrier anions, such as nitrate. Potassium is sensitive to all silvicultural treatments across all regions. The main reason is the disruption of the mineral cycling mechanisms normally conserving this biologically controlled element. General NH_4-N levels increase from the mountain region to the lower coastal plain. This increase was possibly because of higher mineralization rates in deepening soils of the geologic, and increasing temperatures of the climatic gradients.

Herbicide formulations, application methods, and mitigation measures are available to reduce the potential for significant sediment and nutrient pollution. Some questions remain regarding the effects of documented small amounts of these herbicides on aquatic ecosystems. The review of herbicide data generally shows that residue levels in surface runoff were <36 ppb for ground, and <130 ppb for aerial applications, if well outside buffer zones. Peak residues (up to 500 ppb) may occur in the first few stormflows, but degradation and dilution rapidly reduces levels more than tenfold, followed by a slower drop in concentrations of the more persistent herbicides. Accidental direct contamination of streamwater by careless handling or application errors increases the residue level and persistence significantly. Some wetlands, as hydrologic endpoints, could accumulate relatively persistent pesticides, such as insecticides.

Future research should be focused in a few interdiciplinary efforts within each region to assess and model the interactions of upland/wetland interfaces. Evaluation of the environmental effects of silvicultural practices within wetlands is severely limited by incomplete information about wetland hydrology and internal biogeochemical processes. The effectiveness of BMP's implemented for NPSP control is unknown for different scales of resolution.

[2] Aquatic biologists argue that established log dams are beneficial to stream ecology, but not fresh debris.

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FORESTED WETLANDS IN URBANIZING LANDSCAPES

Mark T. Brown[1]

Abstract.-While the direct conversion of wetlands to urban and agricultural uses in Florida has been reduced in the past decade, there has been a noticeable decline in quality of wetlands throughout areas of rapid urbanization. This is attributed to changes in environmental conditions like hydrologic and nutrient regimes resulting from development of the surrounding landscape. A classification of wetlands using landscape position, nutrient access, and hydrologic regime is introduced and related to sensitivity to change. Successional phasing and timing may be modified as the result of changes in hydrologic and nutrient regimes. Suggestions are given for landscape scale management that might reverse current trends of wetland loss resulting from cumulative alteration of the landscape.

INTRODUCTION

There is no question that wetlands are an important component of the landscape mosaic. Their habitat value, their role in nutrient dynamics, and their value as water detention systems have been alluded to by many individuals in a variety of publications. As a result, there has been increasing attention paid to protecting wetland ecosystems and preserving their important functions.

The State of Florida, through its “Wetlands Protection Act of 1984” (17.12 Florida Statutes) and the rules that were promulgated as a result, have all but stopped the conversion of wetlands into urban land uses and have greatly reduced their conversion into agricultural uses. The five regional water management districts and numerous local governments throughout Florida have developed policy and regulations protecting isolated wetlands that were not under State jurisdiction and have all but eliminated the conversion of these important wetlands. Estimates using U.S. Fish and Wildlife Service data suggest that between 1900 and the end of the 1970’s nearly 1.5 million hectares of wetland ecosystems in Florida were directly converted to other land uses. The score card for the last year (1987), as a result of Florida’s aggressive legislation and rule making, is quite different:

Category:	Acres
Permanently lost	2,366
Created	2,480
Enhanced	3,026
Permanently Protected	20,299

Source: Florida Department of Environmental Regulation, 1987. With Proper education and continued attention given to the importance of wetland ecosystems, the successes of Florida can easily be duplicated in other States and regions throughout the United States.

However, the protection of wetlands is not simply a matter of eliminating direct conversion to other land uses. The question of wetland loss has become one of degree and timing and no longer one of direct conversion. Increasingly, we have begun to witness the continued deterioration of the quality of wetlands that have been “saved” from conversion and have been incorporated into the urban fabric of rapid growth areas of Florida. Our recent experiences suggest that loss of wetland function and “slow” conversion through changes in surface water and groundwater hydrology and regional nutrient dynamics may be having as severe a consequence as simple direct conversion, only much less noticeable. The implications are serious. The quality of wetlands in rapidly urbanizing landscapes has been greatly compromised and while they still exist after the wave of development has passed them by, their very existence in the long run is questionable.

In this paper the impacts and consequences of urbanization on wetlands are explored, and several long term solutions to the serious implications of recent trends observed and measured throughout rapidly urbanizing areas of Florida are given.

CUMULATIVE IMPACTS OF URBANIZATION

Wetland Community Types

The impacts of development on wetland ecosystems have different consequences and magnitudes depending on the type of community, its position in the landscape, and the development action. Illustrated in Figure 1 are various wetland community types arranged according to nutrient regime and hydroperiod. Since wetlands represent a point of convergence in the landscape, the size of the watershed governs the amount of water and nutrients that are concentrated within the wetland.

Bayheads and bogs, with little or no watershed rely almost exclusively on inputs of rain water or, in some cases, groundwater seepage. Cypress ponds and flatwood marshes have some drainage from the surrounding landscape with increased nutrient concentrations and hydroperiods. Where watershed area is equal to or slightly greater than the area of the wetland, still larger nutrient concentrations and longer hydroperiods are characteristic. Sloughs or strands develop in low relief landscapes where surface waters from a larger

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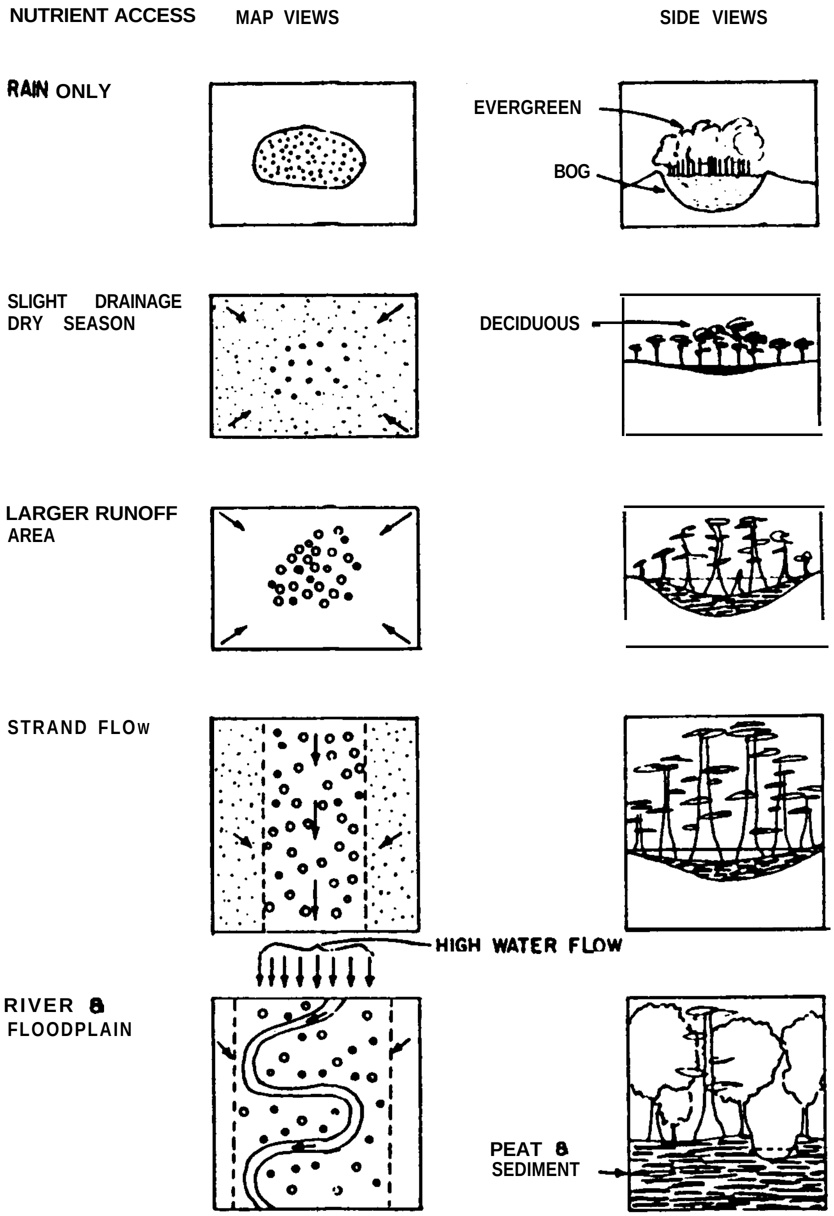

Figure 1.-Landscape position related to nutrient access and water flows. Wetlands are arranged according to nutrients and water from lowest (top) to highest (bottom). In effect, the ranking also suggest sensitivity to modifications to nutrient and hydrological regimes, where most sensitive wetlands are at the top of the diagram. (from Odum 1984)

watershed converge in broad sluggish flows in ill-defined channels. River floodplain forests result where watershed areas are quite large and where highest water flows and nutrient access are characteristic.

Productivity and structural properties of wetlands are related to nutrient loads and hydroperiods. Bogs and bayheads, at the low end of the spectrum, tend to have low species diversity and lower overall biomass, while river floodplain forests have much greater biomass and diversity of species. Thus landscape position, in general, directs availability of nutrients and water and, more or less, the type of wetland community that may develop. Certainly other factors like frequency of drought and fire have an organizing influence and may alter community type and species composition.

Figure 1 can also be thought of as a diagram of wetland sensitivity. Wetlands near the top of the figure have driving energies of lower magnitude and flux than those toward the bottom and are more apt to show signs of community reorganization under a given impact. Low nutrient wetlands with relatively small hydrologic variation are easily disrupted with minor alteration in hydrologic regimes in the surrounding landscape. Whereas minor modification of hydroperiod and depths of inundation of floodplain wetlands usually has relatively inconsequential effect on community structure.

Table 1 lists wetland community types found in central Florida and several of their most important characteristics. The communities span a wide range of environmental conditions; probably the single most important of which are hydroperiod and depth of inundation. Water depths and the duration of flooding within wetlands seems to have a greater organizing influence on community structure than other factors. Changes in hydrologic regime, then, can shift community structure toward an assemblage of species that are better adapted to the new conditions. In some regions where introduced (exotic) species are prevalent, the new hydrologic regime often increases the invasion of introduced species that are better adapted to the new conditions.

In landscapes dominated by humanity, hydrologic regimes are often altered to accommodate changes in land use. In low lying areas and landscapes of low relief, drainage works are often constructed to lower groundwater tables and as a means of managing the increased volumes of storm water that result from increased impervious surface. In higher relief landscapes, storm water systems route increased volumes of runoff to downstream areas increasing magnitude and shortening duration of hydroperiods. These changes usually are accompanied by changes in nutrient availability. In all, urbanization changes hydrologic and nutrient regimes in the local landscape; in some instances decreasing depths and duration of flooding and nutrient availability and in others, increasing water levels and nutrient concentrations.

Modification of the landscape to accommodate development, while not directly infringing on wetland communities, often has long term impacts as the hydrologic regime shifts in response to the characteristics and requirements of urban land uses. In recent studies of created wetlands in central Florida (Brown et al. 1988), a series of undisturbed wetlands were needed as controls. After surveying wetlands within the study area, it was quite obvious that disturbance' increased with proximity to urbanizing landscapes. The more urbanized the surrounding area, the lower the "quality" of the reference wetland.

A Landscape Perspective of Wetland Succession

The classic view of wetland succession starts with open water and proceeds through marshes, shrub swamps, forested swamps, and finally mixed hardwood forests. While this may seem to make intuitive sense, the actual process may be quite different.

Table 1.—Characteristics of wetlands in north central Florida (from Brown and Starnes 1983)

	Hydric hammock	Mixed hardwood swamp	Cypress dome	Bayhead	Wet prairie	Shallow marsh	Deep marsh
Water quality enhancement, % removal							
Phosphorus	40	90	98	85	40	98	30
Nitrogen	40	98	92	85	60	97	30
Evapotranspiration (mm/day)	4.8	5.8	3.8	3.0	5.4	5.6	5.6
Hydroperiod (days)	loo-150	200-250	250-300	200-250	150-200	365	365
High water (m)	0.10	0.60	0.50	0.30	0.50	0.70	1.00
Low water (m)	0	0	0	0	0	0	0.20
Maximum level (m)	0.30	1.50	1.50	1.00	1.50	2.00	2.00
Recharge potential ($m^3/m^2/yr$)	0.1	0.1	0.84	0.6	0.37	0.68	0.1
Peat depth (m)	o-o.2	o-o.5	o-o.5	0.5-0.3	o-1.5	0.5-3.0	0-1.0
Life form richness	3	4-5	4-5	4-5	2	3	3
Wildlife utilization	86	71	56	32	74	84	84
Gross primary productivity (g organic matter/m^2/day) during growing season	60	52.1	25.3	20.0	23.9	19.6	54.5

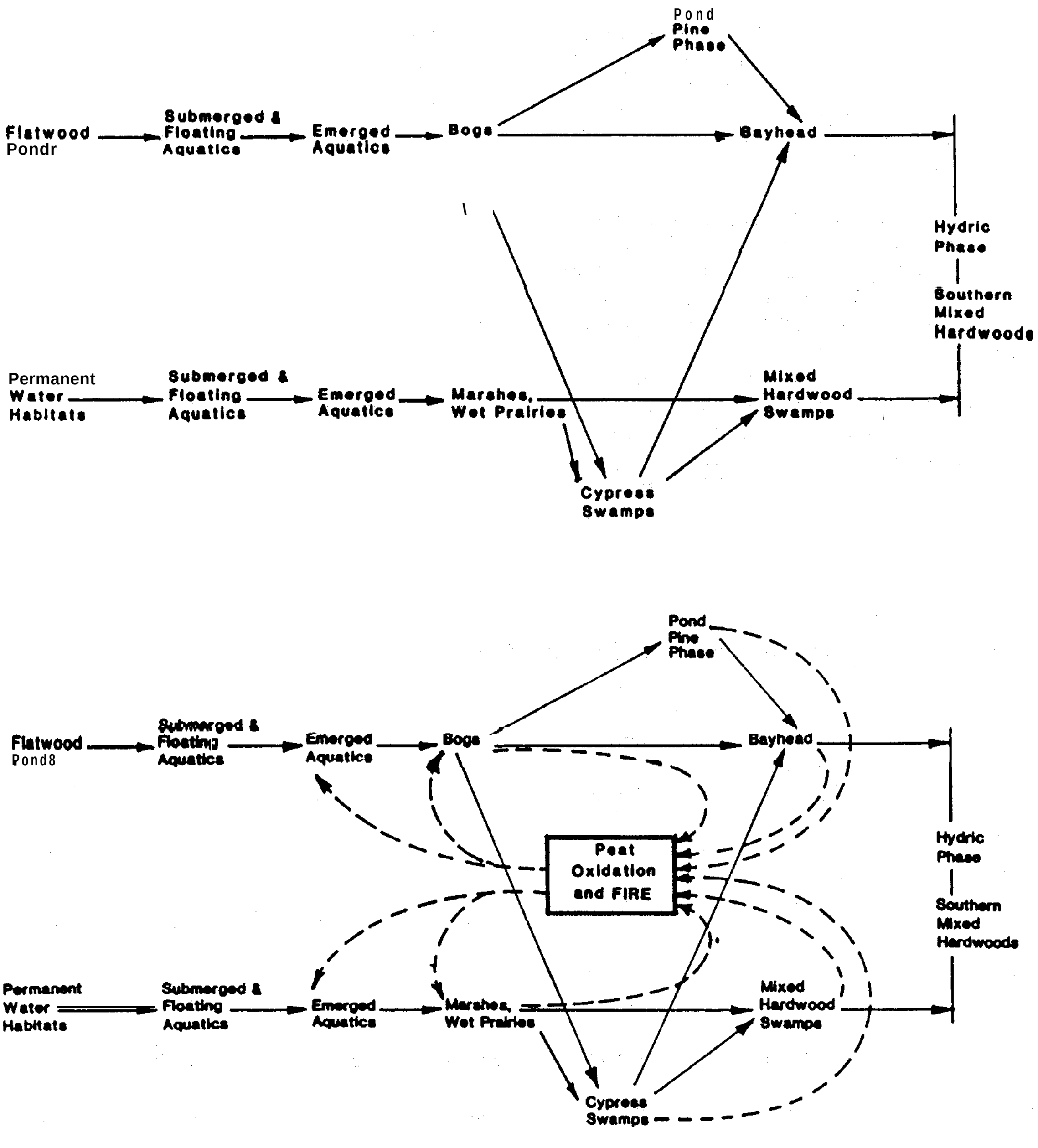

Figure Z.-Diagram (top) showing primary stages in plant succession in north-central Florida suggested by Monk (1968). The bottom diagram has additional pathways of succession toward the left resulting from drought oxidation of peat accumulations and from fire.

Figure 2 illustrates two concepts of wetlands succession in north central Florida. In the classical sense, wetland succession is said to be driven by accumulation of organic matter and a resulting slow change in depth and duration of flooding. As organic matter accumulates, the volume of water detention decreases and hydroperiod is shortened. All other things being equal, these trends would suggest environmental change that favors a shift in species composition to species better adapted to drier conditions. However, all other things are not equal. Imbedded in a dynamic landscape driven by cyclic pulses of drought and flood and occasional fire, wetlands have little chance of attaining textbook succession. In the real landscape where drought increases oxidation and the potential for fire, accumulation of organic matter to levels that would push successional trends toward drier conditions is the exception. Most probably, in the long run, accumulation of organic matter is balanced with oxidation as wetlands dry out from time to time and fire occasionally burns hot enough to kill vegetation and lower ground surface elevations in its wake.

The landscape then, is a dynamic system of driving energies and interrelated components that produces an ever changing mosaic of ecosystems in a continuum of successional stages. Add to this mosaic, human influences, and the net result is still further complexity, fragmentation, and increased cycling between successional stages.

An important consequence of fragmentation and increased urbanization of surrounding lands has been to shift wetland successional patterns. Drier conditions brought on by lowered water tables and the berming effects of roadways coupled with changes in frequency of fire occurrence, have sped up wetland succession in some cases and in others caused the system to revert to earlier successional stages. The exact consequences depends on type of wetland and combination of exogenous impacts. Where groundwaters have been lowered and the wetland protected from burning, succession tends toward the right in Figure 2. If the wetland burns, because of the drier conditions, often the fiie burns deep through underlying peat, and succession is toward the left; how far left is controlled by the depth of the burn. Impoundments are less common than drainage, but where waters are impounded within a forested wetland, open water and emergent wetlands are created as the deeper water kills most trees, thus succession is toward the left.

The process of urbanization and agricultural conversion of lands seems to speed up the time constants of the landscape. Clear cutting seems to mimic disastrous fire in its ability to reverse forest succession. General drainage of the landscape seems to push wetland succession toward drier conditions. Fragmentation resulting from sprawling urbanization quickly produces island refuges of wildlife and vegetation. The mosaic of ecological communities, agricultural lands and urban places becomes increasingly fine grained with increased human use. Figure 3 illustrates this point showing changing community structure and landscape organization with increased fragmentation in a portion of central Florida over a time frame of about 40 years. What was once a landscape of sandhills dominated by a large heterogeneous wetland of cypress and marshes, has become over the years a fragmented landscape of shrub swamps and remnant swamp forests dominated by human uses. The imports shown here are less the result of direct conversion than they are of secondary impacts of ditching, draining, and roadway construction. The general pattern throughout developing landscapes is first alteration of environmental conditions through fragmentation and drainage, and then development for urban uses later when wetlands are less viable or completely gone.

IMPLICATIONS FOR MANAGING THE URBANIZING LANDSCAPE

The environmental conditions of the urbanizing landscape are quite different from those of the nonurbanized landscape. The processes of urbanization converts wildlands to urban uses leaving behind pockets of forested lands, old agricultural fields, and wetlands. Drainage works and impervious surfaces alter hydrologic regimes and in turn affect downstream and isolated wetlands. Left untouched, these remnant islands of the former landscape reorganize in response to the new conditions. The extent of reorganization depends on the magnitude of the impacts and the size of the remnant island. Larger islands have greater "buffering' capacity while small isolated systems tend to exhibit less resiliency. Managing the urbanizing landscape to insure the continued productivity and biological functions of forested patches (whether wetland or upland) may be an impossible task if the goal is to maintain these systems in some static unchanging state. Successional changes brought on by changing environmental conditions may force today's wetland toward tomorrow's upland. The loss of wetland function in itself may not be of critical concern, especially in heavily

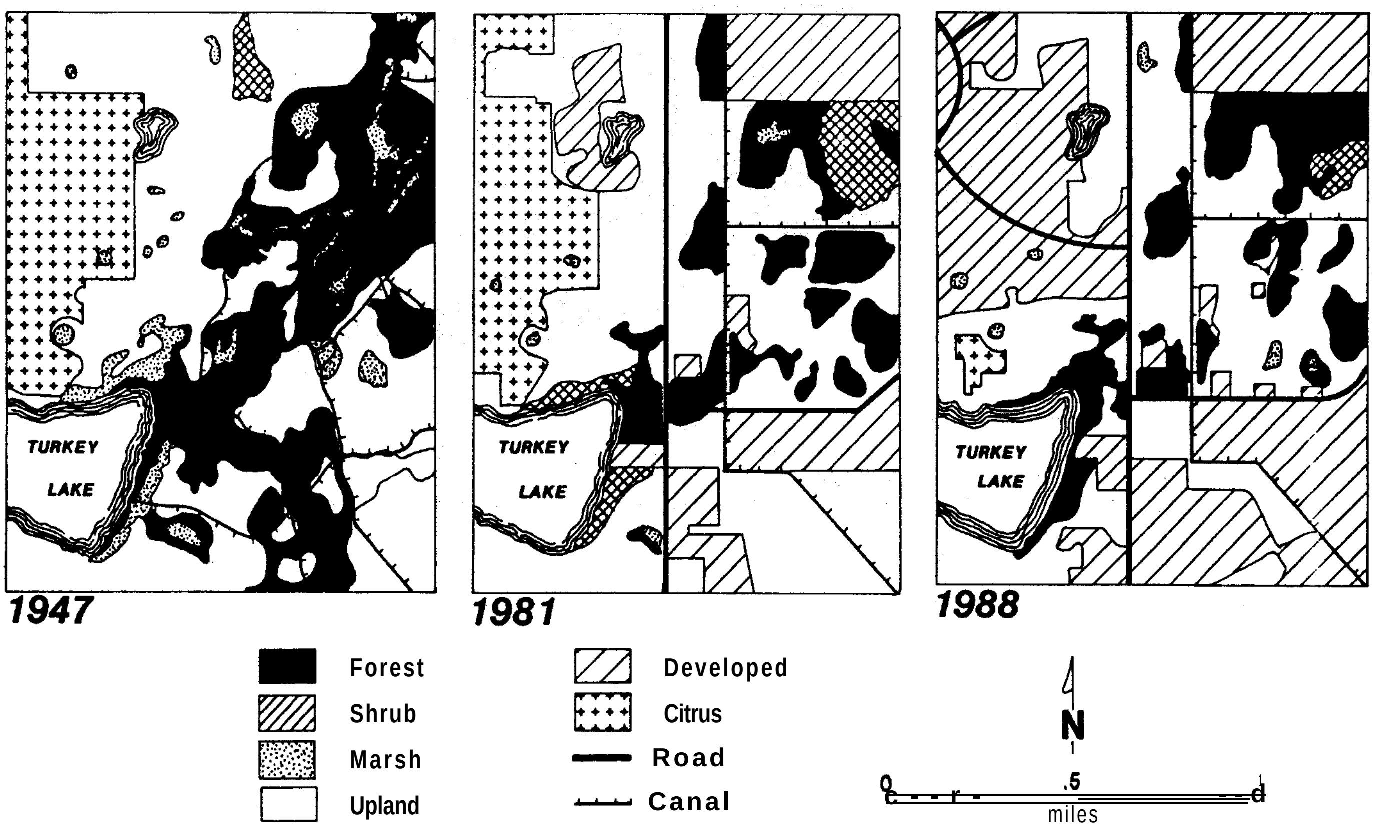

Figure 3.-Map showing the effects of development in and around an extensive wetland system near Orlando, Florida. Aerial photographs were taken from Palmer and Tighe (1988), interpretation and compilation for 1946 and 1931 by the author, wetland interpretation in 1988 by Palmer and Tighe.

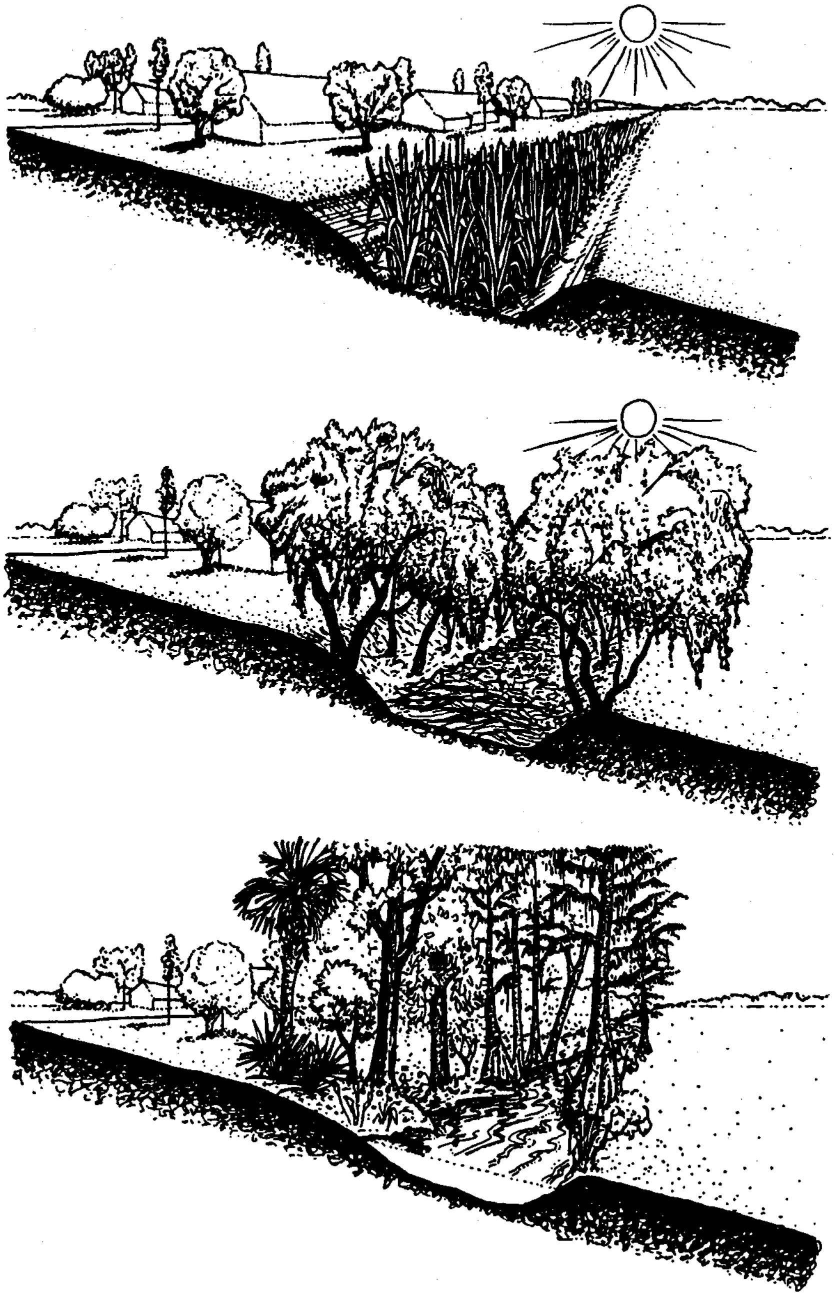

Figure 4.—Time series sequence of succession in urban drainage ditches if vegetation is allowed to colonize. Vegetation acts to retard flow through friction, yet during storm events the system can still function effectively. Once canopy is established, herbaceous vegetation is shaded out and the stream channel resembles a first order **stream** system.

urbanized areas, if it were not for the fact that a good bit of our regulatory effort now-a-days is concerned with sparing these systems from conversion.

The general trend throughout Florida in the past several decades has been a progressive drying out of the landscape and a consequent shift in wetland ecosystems toward drier and drier community types. While wetlands have generally been "spared" from conversion to other uses, they have not been left unchanged. The cumulative effects of a changing landscape have slowly but surely caused serious erosion in the quality and quantity of wetlands within and adjacent to rapidly urbanizing regions of the state. Public policy has long recognized the value of wetlands, and has been successful in minimizing their conversion to urban uses; however, their continued decline in quality as a result of **overdrainage is** little recognized. Might it be better policy to discourage overdrainage and seek ways of **"rehydrating"** the landscape?

To more effectively manage the landscape in the face of increasing development pressure it is imperative that the cumulative, secondary impacts of urbanization be given considerable attention and regulatory initiatives be directed at reversing current trends. To this end, the following management guidelines for urbanizing landscapes are given as a means of establishing a regulatory framework.

Educate the Public

As in most environmental programs, a sound approach to educating the public is extremely important. Public perception has long been that swamps are ok if seen on TV, but not in the backyard. Couple this with the perception that wetlands produce mosquitos and mosquitos carry disease and it is relatively impossible to convince the general public that wetlands are an important part of the urban fabric. Programs need be developed that increase public awareness of the importance of wetlands within the urban fabric.

A second area needing increased public awareness is especially important. The public has come to expect that their cities and neighborhoods will remain dry during any and all rainfall events. Storm waters are expected to drain quickly after any event, and if they do not it is cause for great displeasure. The public must be made aware of the benefits of a wet landscape, and learn to accept some standing water during the wetter times of the year.

Discourage Overdrainage

The lowering of groundwater tables to accommodate housing and roads has a wider influence than just the developed portion of the landscape. A better method of development is to elevate housing and roads and expect some flooding during extreme rainfall events. Encourage the use of vegetated and forested drainage structures (Figure 4) that act to impede surface water discharge, but allow for storm waters to discharge through meandering channels that mimic natural first order streams.

Rehydrate the Landscape

Where overdrainage has occurred, it may be possible to reverse these trends by recycling treated wastewaters back on the land instead of depositing them in surface water bodies, the ocean, or deep well injection. By encouraging landscape recycle through natural wetlands, constructed wetlands, overland flow systems, and spray irrigation systems, area groundwater tables are replenished.

Encourage the use of vegetated wetland retention systems for storm water management. Instead of grassed detention basins that require continual maintenance, wetland retention basins (Figure 5) require no maintenance, add to landscape diversity, increase wildlife habitat values, and act to hold and conserve storm waters on site replenishing local groundwater tables.

Manage Resources at the Landscape Scale

Increasingly, it has become obvious that a piecemeal approach to landscape management can only lead to an ever increasing fragmentation of the landscape. This revelation has recently lead the author to propose a concept for landscape management that incorporates the best of physical land use planning related to growth management and landscape ecology, as well as results of research related to the Florida landscape that suggest a continuing trend of environmental deterioration. The concept has been termed "Wildlands Management" and has as its fundamental objective the identification and preservation of a landscape mosaic of wildlands that are large enough to provide

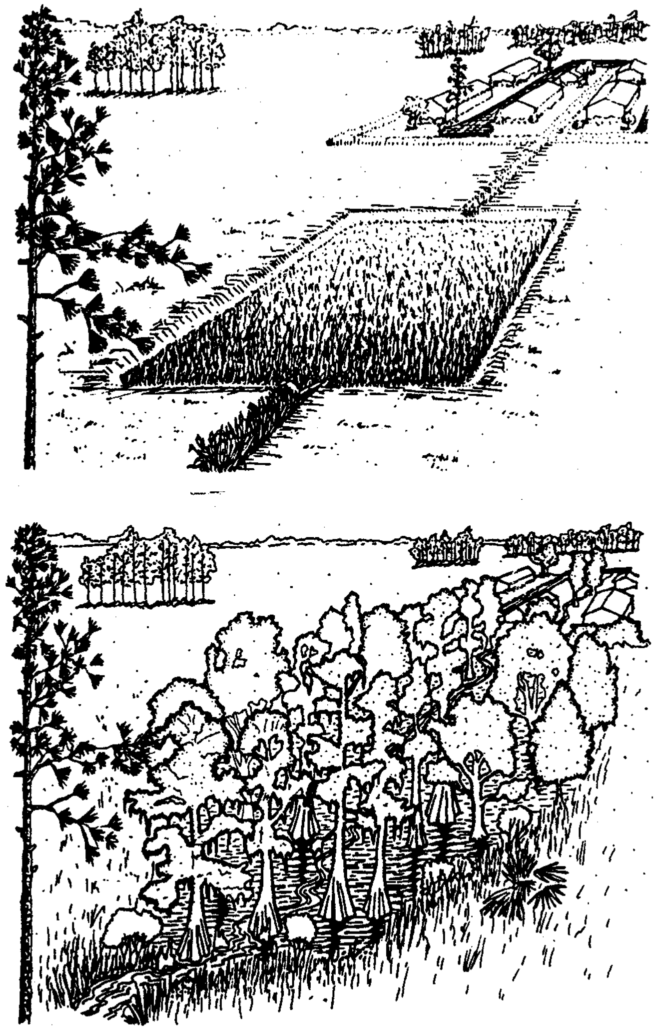

Figure 5.—An illustration of the potential of wetland stormwater retention systems. In the top diagram the retention basin is clogged with herbaceous vegetation and requires continuous maintenance, while if allowed and encouraged to develop forested canopy would be more self-maintaining.

significant wildlife habitat, are capable of suffering development impacts from adjacent lands, can contain urban sprawl and give definition to urban areas, and are ecologically diverse and relatively intact.

The motivation for Wildlands Management has developed as a result of observations of the rapid urbanization of the Florida landscape. As regions experience urbanization, small pieces of the landscape are left undeveloped either because they are "protected" or because they have been purchased for their potentials as preserves. These fragments become islands in a sea of developed land. Often resented by their neighbors, because they contain unwanted vestiges of the former landscape, these patches suffer from either neglect or overexposure. Most often they slowly deteriorate to the point that one must question if they could survive without massive doses of human management.

As long as there is development pressure, urban areas will continue to sprawl ever outward in wider and wider circles of urbanization, leaving in their wake remnants of the former wild landscape mosaic. Soon, if urbanization is complete urban centers begin to merge and the landscape becomes one dominated by developed lands with a smattering of "protected" wetlands, parks, and wildlife management areas. Not only do urban centers spread, but intensity of uses increase as urbanization continues. The greater the intensity, the less likely a remnant forested island can be maintained without significant human management.

Presumably, without a wider perspective, that is, without a landscape perspective, effective landscape planning and management that might preserve portions of the landscape mosaic as wildlands is not possible. The first stage in developing a landscape perspective is to identify mosaics of ecological communities that are relatively intact and that might serve as the beginnings of a statewide wildlands system.

The initial premise upon which wildlands management was based was grounded in the belief that a landscape perspective is absolutely necessary to achieve meaningful regulation and management of our natural resources. Past efforts to develop a landscape perspective in the face of a rapidly growing population and all its attendant infrastructural requirements have been continually frustrated by the lack of a "macroscopic," systematic approach. Resources and authority over them are compartmentalized to such a degree that it is impossible to manage the landscape and regulate its use. We manage and regulate the parts. It has long been known that the sum is greater than the parts, yet our approach to achieving some measure of control over the perceived impacts of human use of the landscape is to delegate the management of water to one agency, air to another, soil to another, wildlife to another, minerals to another, and planning of the whole thing to yet another. The wildlands management approach is an attempt to thwart these impediments to a landscape perspective and achieve consensus between the public and all agencies that the landscape must be planned and managed as a mosaic of contiguous blocks of developed lands and wildlands and not a continuous sprawl of development having remnant patches of recreational amenities. The approach can work if all regulatory agencies, developmental agencies, and the public work in tandem to develop a regulatory environment that recognizes its absolute necessity and implements a wide diversity of mechanisms to achieve it. Every mechanism of "growth management" must be utilized. Transfer of development rights, purchase of development rights, overlay zoning, green belts, transfer of mitigation requirements, impact fees, and performance zoning to name a few, can be used to implement the wildland program. There are other mechanisms, we are only limited by a lack of commitment.

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FUNCTIONS AND VALUES OF BOTTOMLAND HARDWOOD FORESTS ALONG THE CACHE RIVER, ARKANSAS: IMPLICATIONS FOR MANAGEMENT

Ellis J. Clairain, Jr., and Barbara A. Kleiss[1]

Abstract.-Forested wetland areas in the southeastern United States have declined dramatically in recent years, primarily due to conversion to agricultural crops. This decline has occurred despite claims that these areas provide many important functions and values. However, few comprehensive, multiyear research studies have been conducted to provide definitive information to support these claims. This paper provides an overview of one such comprehensive study initiated in 1986 and scheduled for completion in 1991. Research underway in bottomland hardwood wetlands along the Cache River in Arkansas has examined hydrology, water quality, and fish and wildlife habitat functions. Research objectives are to obtain quantitative data to determine functions and values of bottomland hardwood areas and improve techniques to assess these functions. These evaluation techniques will provide managers with information necessary to accurately assess functions and values of bottomland hardwood forests and examine impacts of land use changes.

INTRODUCTION

Wetlands have long been recognized as important habitats for fish and wildlife species. However, within the last two decades benefits such as floodflow alteration, sediment trapping, and nutrient retention and removal have also been identified. In spite of this growing awareness of additional wetland benefits, there has been a dramatic decline in the extent of wetland. Between the 1950s and 1970s, there has been an average annual decline of 380,000 acres (Frayer and others 1983). Palustrine forested wetlands in the conterminous United States experienced a net annual loss of 300,000 acres during this 20-year period with the vast majority occurring in Louisiana, Mississippi, and Arkansas (Frayer and others 1983).

Federal laws such as the Clean Water Act of 1977 and executive mandates such as Executive Order 11990 recognize many wetland functions and values but provide little guidance on how to assess these functions and values. Therefore, in 1981 the Wetlands Research Program was initiated at the Waterways Experiment Station (WES) to address this and other wetland-related issues. This paper presents an overview of an ongoing study to assess the functions and values of a bottomland hardwood wetland in eastern Arkansas. Since the study has been underway for approximately one year and will proceed for several more, only preliminary results can be presented here. However, results from this study will ultimately be used to refine the Wetland Evaluation Technique (WET) developed at WES (Adamus and others 1987) to assess multiple wetland functions and values.

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APPROACH

A survey of U.S. Army Corps of Engineers district and division personnel was conducted in 1982 (Forsythe and others 1983) to determine which wetland types should receive the highest priority for research funding. Bottomland hardwood wetlands in the lower Mississippi River Valley were assigned the highest priority for research (Clairain 1985). Subsequently, approximately 25 candidate sites were examined and the Cache River site was selected for comprehensive study of physical, chemical, and biological functions and values. The field study was initiated in 1986 and will continue through 1991. Research efforts during 1987 and 1988 were directed toward characterizing the site and developing a data base. This data base includes information on the physical features of the site (e.g., roads and streams), land use, elevations, soils, hydrology, and vegetation types. A description of the study design and preliminary results of the characterization studies follow.

SITE DESCRIPTION

The Cache River Basin floodplain supports one of the largest remaining tracts of bottomland hardwood and alluvial swamp forests in the Lower Mississippi River Alluvial Plain (Cache River Basin Task Force 1978). The study site is located along the Cache River in eastern Arkansas (Figure 1). It is bounded on the north and south by highway bridges approximately 27 kilometres apart. Much of the wetland is located within the Rex Hancock/Black Swamp Wildlife Management Area (BSWMA), which is owned and operated by the Arkansas Game and Fish Commission and the Arkansas Natural Heritage Commission. The BSWMA is reportedly one of the most ecologically significant areas in the Cache River system (U.S. Army Corps of Engineers 1974).

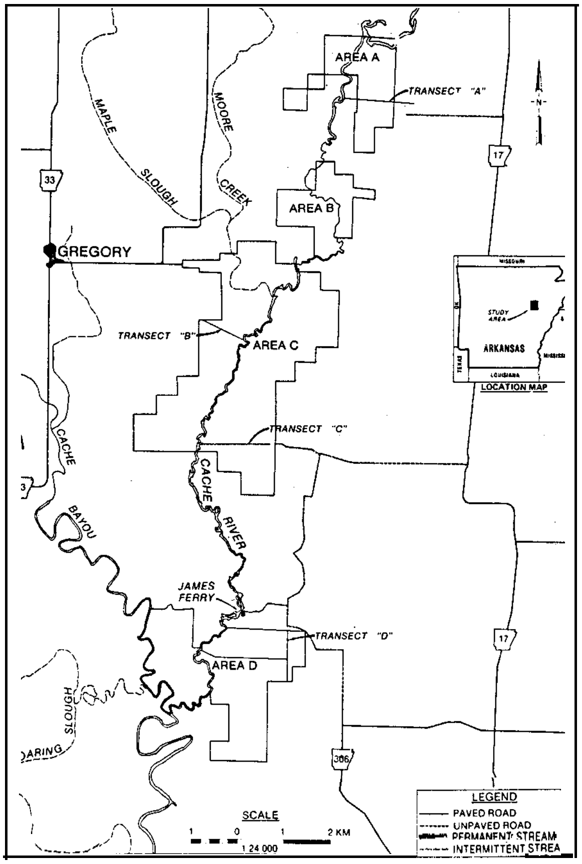


Figure 1. --Cache River bottomland hardwood site and sample transect locations.

Drainage area for the project is about 30,000 hectares. About 6,000 hectares is bottomland hardwood forest, which typifies the wooded wetland and bottomland hardwood systems located in the lower Mississippi River Valley. Lands bordering the forested areas are primarily in private ownership. Agriculture is the dominant land use in the area, and agricultural chemicals probably enter the project area. Harvesting of row crops such as cotton and soybeans results in exposed soils subject to erosion and sediment transport into the wetland via overland flows and several small channels. Preliminary water quality information indicates that the Cache River is highly turbid. No point-source contribution of wastewater is known.

Average annual rainfall for the area exceeds 120 centimetres, with heavy rainfall occurring during winter and spring. Water levels in the Cache River frequently vary as much as 3 metres over an annual cycle. Groundwater is used heavily for crop irrigation and preliminary review of information suggests that the groundwater table in the area has declined.

Soils in the project area are dominated by Typic Fluvaquents, Typic Ochraqualfs, Albic Glossic Natraqualfs, and Vertic Haplaquepts (U.S. Department of Agriculture (USDA), Soil Conservation Service 1968). These soils are considered hydric (USDA, Soil Conservation Service 1985).

Plant communities in bottomland hardwoods have been divided into six different zones, based on species composition, soils, and hydrology (Clark and Benforado 1981). Plant zonation is evident at the study area. Zone 2, dominated by cypress-tupelo (Taxodium **. Nyssa aquatica),** is most prevalent in the study area. Plant communities in this zone are fairly homogeneous with very little understory diversity. Zones 3 and above tend to exhibit greater diversity. Water hickory (*Carya* ***aquatica)*** and overcup oak ***(Quercus lyrata)*** are prevalent in the overstory of Zone 3 and common buttonbush ***(Cephalanthus occidentalis)*** and English dogwood (*Cornus* foemina) are common in the understory. Evidence of logging within the last 25 to 30 years (primarily high graded timber) can be seen in some areas but, overall, little disturbance is observed on the site.

STUDY DESIGN

The Cache River project consists of three separate but closely related subprojects: (1) hydrology studies, (2) water chemistry and sedimentation studies, and (3) biological studies. Each subproject is discussed below.

Hgdrologg

The hydrology component of the Cache River project has been designed to address principal flow components in a wetland water budget. These components are expressed in thefollowingequation:P + SWI + GWI = ET + SWO + GWO + S, in which P is precipitation, SWI is surface-water inflow (including overland runoff), GWI is groundwater inflow (discharge into the wetland), ET is evapotranspiration, SWO is surface water outflow, GWO is groundwater outflow (recharge to the aquifer, seepage), and S is change in storage (Carter 1986).

Information for the precipitation portion of the hydrologic budget is being collected by extrapolating data from five National Oceanic and Atmospheric Administration (NOAA) weather stations surrounding the site and refining it with an automated meteorological station positioned at about the north-south center of the project area. Temperature, humidity, barometric pressure, wind velocity and direction, solar radiation, and photosynthetically active radiation are also being measured. This information will also be used to calculate evapotranspiration.

Over 50 years of surface water records exist from a gaging station maintained by the U.S. Army Engineer District, Memphis at Patterson, AR (Station 1 in Figure 2). To supplement this information, a second full-scale gaging station has been established at station 2, and four secondary stage stations with water-level recorders have been installed at stations 4, 5, 8, and 9 (Figure 2). Discharge relationships are being developed at the primary stations.

Groundwater of eastern Arkansas is presently being studied because of recent heavy use of aquifers for irrigation. Potentiometric surface of the alluvial aquifer has been recently mapped (Plafcan and Fugitt 1987). The measurement and construction of groundwater wells clustered in the Cache River vicinity and in the Rex Hancock/Black Swamp area will further refine this information. The alluvial aquifer is now being seasonally measured at twenty existing irrigation wells, and ten shallow wells have been installed to help define groundwater flow patterns.

Water Chemistry and Sedimentation Studies

Water Chemistry

Water chemistry parameters being examined at the Cache River site include temperature, pH, dissolved oxygen, specific conductance, selected nutrients, total organic carbon, organic and inorganic suspended sediments, turbidity, color, alkalinity, base cations, iron, manganese, and selected pesticides and metallic contaminants. Surface water chemistry is being conducted in a two-part study. The first part addresses inputs and outputs to the system and uses a mass-balance approach. The second part of the study addresses specific factors influencing water chemistry within the bottomland hardwood forest adjacent to the Cache. River.

Input-output information is being collected at nine stations in the project area (Figure 2). Stations 1 and 2 are located on the main stem of the Cache River and are the major inflow and outflow points within the project area. Stations 4, 5, 8, and 9 account for significant tributary discharge into the study area. Stations 6 and 7 occur along small agricultural ditches typical of the project area. Water chemistry conditions are being monitored weekly at the nine input-output sites between November and May, and once every two weeks during the remainder of the year. Selected storm events are also being monitored.

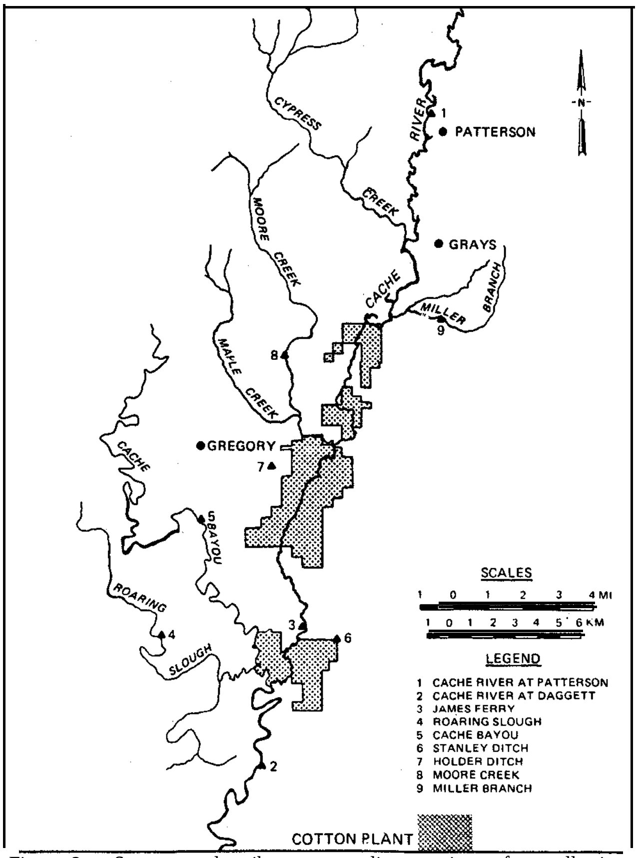
Thirty-one stations (Figure 3), representing a wide variety of wetland characteristics including vegetation type, elevation, hydrologic regime, soil type, and upstream-downstream orientation, are being intensively studied. At the 31 forest sites, water samples are being collected for chemical analysis at monthly intervals during high-water periods.

Sedimentation Studies

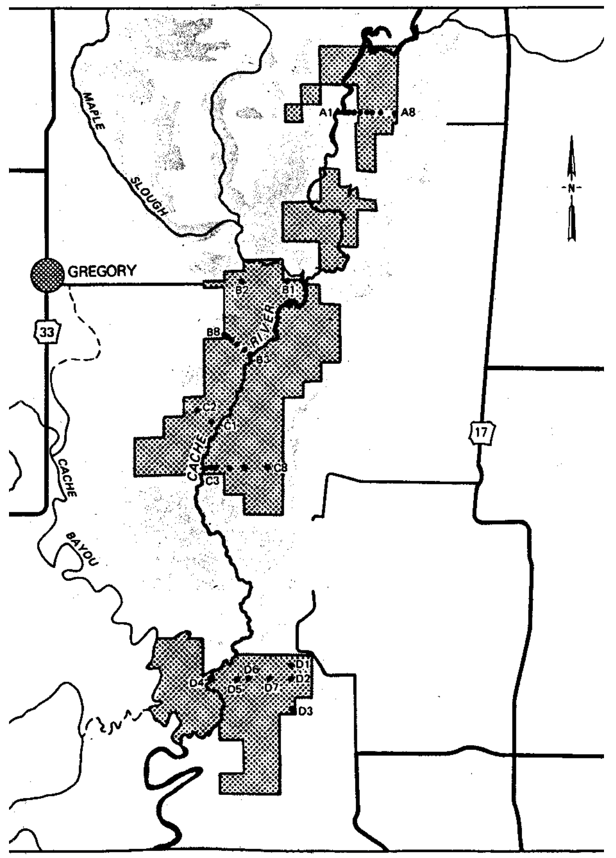
A suspended sediment budget for the project area, based on mass-balance estimates of retention, is being developed in cooperation with the U.S. Geological Survey (USGS) in Little Rock. Flow-weighted sediment samples are being taken daily at stations 1 and 2 (Figure 2). In addition, suspended sediment concentrations in cross sections of the stream channel are being measured monthly. Effects of storm events on sediment loadings at different times of the year are also being evaluated.

Two methods are being used to examine short-term sedimentation rates. With the first method, Plexiglass disks, 15 centimetres in diameter, have been anchored to the soil surface at each of the 31 forest stations. The disks will remain in the field for one year, from one fall low-water period until the next. Short-term sedimentation will also be measured using feldspar clay marker horizons (Baumann and others 1984). Vertical depth of the accreted sediments will be measured. Materials collected using both methods will be physically and chemically characterized and contrasted with soils and suspended sediments collected in contiguous areas.

Long-term sedimentation rates will be determined by examination of soil profiles collected at each of the forest stations. These profiles have been described, in cooperation with the Soil Conservation Service. Information from the profiles will also be useful in determining the age of particular soils, location of areas of rapid deposition, and the project area's general geomorphology.



Fiyre 2. -Stream and tributary sampling stations for collection of hydrology data.



Fiyre 3. -Water quality stations within the forested wetlands.

Biological Studies

The biological studies are divided into three interrelated components: (1) vegetation, (2) fish, and (3) wildlife. Each component is discussed below.

Vegetation

Vegetation studies are being conducted to provide baseline information needed to assess fish and wildlife habitat. Information will also be used to aid in refinement of several hydrology and water-quality models in WET.

In the spring of 1986, 1:12,000-scale color infrared aerial photography was taken of the site to aid in establishing vegetation transect locations, type mapping vegetation communities (Society of American Foresters 1980), and determining adjacent land use. Based on preliminary type mapping and field reconnaissance, four areas along the Cache River were examined for potential intensive vegetation sampling (Figure 1). Four sample transects were established within three of the four areas identified.

During the fall of 1986, temporary benchmarks were established at the highest point along each transect. A total of 171 0.04-hectare sample plots were located along the transects at 60-metre intervals. Transect directions and locations were established to traverse the hydrologic gradient from the Cache River upslope to the highest vegetated ground. Plot elevations were subsequently determined to assess flood duration at each vegetation plot.

Vegetation sampling is being conducted during the summer and fall along the four transects. Initial sampling occurred in 1987. Within each 0.04-ha plot, trees greater than 6.6 centimetres diameter breast height (dbh) are identified by species and dbh measured. Saplings (2.5-6.6 centimetres dbh), shrubs, and woody vines are also identified by species and tallied in two 0.004-hectare circular subplots randomly located within the larger 0.04-hectare plot. Woody seedlings (<2.5 centimetres dbh) are identified and tallied in two 0.0004hectare subplots nested within the 0.004-hectare subplots. Absolute and relative density of seedlings, saplings, woody vines, and trees will be calculated for each plot and subplot. Absolute and relative basal area of trees will also be calculated for each plot. The Importance Value (IV) 200 (relative density + relative basal area) (Curtis 1959) will be calculated for trees at each plot. These data will be placed into separate matrices for tree basal area, density, and IV 200 as well as matrices for sapling, seedling, and woody vine relative densities. Matrices will be used as input to the Two-Way Indicator Species Analysis (TWINSPAN), a classification algorithm that objectively classifies plots into community types (Hill 1979). The original forest cover types will be evaluated and revised using the community types identified by TWINSPAN. Forest cover types will be characterized in terms of species composition, dominance and density of trees, density of saplings, woody seedlings, shrubs, woody vines, and soil characteristics.

Fish

The purpose of the fish habitat study is to test and refine fish habitat models in WET. Specifically, fisheries studies will: (1) assess use of bottomland hardwood forests by fish found within nearby watercourses; (2) relate the abundance and distribution of fish to variations in measured physical, chemical, and biological attributes (such as vegetation composition and distribution) of the wetland; (3) construct a testable model to evaluate use of bottomland hardwoods by fish; and (4) incorporate the findings of this field study into bottomland hardwood evaluation models.

Only transects B and C (Figure 1) of the four study areas are being sampled for fish since these areas represent all the physical features characteristic of the BSWMA. Within each area, three habitats are sampled. Zone 2 is sampled as a homogeneous unit. Zone 3 consists of two distinctly different types of microhabitats: areas with little understory vegetation and areas with dense understory growth.

Because of the diversity of habitat conditions and sample gear constraints, several different collection methods are being used. Adult fish were collected in 1987 using hoop nets, electroshocking equipment, and gill nets throughout the study area. Small seines were also used in fairly open habitat. Gill nets were excluded from the 1988 sampling efforts. Larval fish collecting began in 1988 using plankton nets and a Ventura-type diaphragm pump to provide quantitative measures of abundance within the river and open water areas of the floodplain during high water stages. Small light traps were also set adjacent to the channel and within the forested floodplain. Larval fish were collected during both day and night.

During fish sample collections, several physico-chemical parameters are also being measured. Current velocity, depth, and amount and general type of vegetation are recorded at each fish sampling station. In addition, water temperature, dissolved oxygen, turbidity, pH, and conductivity are collected at selected stations within each habitat type.

Wildlife

Wildlife habitat has been examined more thoroughly and has a broader literature base upon which to develop evaluation models than most other wetland functions. Therefore, early emphasis of the wildlife studies has been and will continue to be directed toward detailed reviews and revision of WET models. Many wildlife models have also been developed for use in the Habitat Evaluation Procedures (U.S. Fish and Wildlife Service 1980) and will be reviewed to determine applicability to WET.

General objectives of the wildlife habitat studies are to expand the scope of the wildlife component of WET to include other vertebrate groups in addition to birds, improve the structure and flow of the method, and develop and incorporate modifications to improve the accuracy of results.

Information on mammals, reptiles, and amphibians was collected from the study area during the spring and summer of 1988. Fifty-two sampling arrays were installed on the vegetation plots along transects A and C (Figure 1) in May

1988. Each complete array included three drift fences, four pitfall traps, one tree platform including a trap set, and two ground sets. The sets consisted of a Sherman and a Museum Special trap. These traps were baited with a mixture of horse feed and peanut butter rolled in oatmeal to maintain its shape. Observations were also recorded of individuals that were on the plot but not in a trap. A November trip is planned to take advantage of low water conditions.

Mammals captured in Sherman traps were identified, toe clipped, weighed, measured, and then released at the trap site. Those caught in Museum Special traps and in the pitfalls were donated to the Department of Biological Sciences, Arkansas State University, where they were cataloged, weighed and measured to be used in their museum collection.

Bird census studies are conducted to correlate bird observations with habitat characteristics to improve models in WET. A survey was conducted during a 3-week period in late April to early May 1988 to assess use by migrating species. Sampling was conducted twice, along transects A and C and along parallel transects (A' and C') located 80m to the side. Sample plots 60m apart along the transects and 80m wide were established along each of the 4 transects resulting in 25 plots along transect A, 2'7 along transect A', and 29 plots along each of transects C and C'. The center of each bird census plot coincided with the center of a vegetation plot. During the spring sampling, observations began about sunrise and continued until bird activity ceased (usually about 1030 am). Approximately 20 minutes were spent within each plot noting abundance and presence of birds by species. Detection relied primarily on sounds although many species were observed directly. Position of the birds relative to the vegetative strata was also noted. The observer also noted other animal species when observed during sampling.

Another bii sampling trip is planned during January 1989 following similar observation procedures. This sampling effort should detect many winter migrants, including waterfowl.

Characteristics of the sample area, such as canopy cover of the overstory, species composition and density of shrubs, herbaceous cover, and abundance of downfall and litter, were measured on the 0.04-hectare plots used'in the vegetation studies. These data, along with information on flooding regime, juxtaposition of cover types, and other topographic features, will be used to define species/habitat relationships.

PRELIMINARY RESULTS

Hydrology

Early evidence from the USGS suggests that surface-water inflow and outflow on the Cache River during the spring and summer of 198'7 were approximately equal. This implies a minimal contribution from tributaries and nonpoint source runoff, significant evapotranspiration, or substantial groundwater recharge. Calculations using Thornwaithe's equation (American Society of Civil Engineers (ASCE) 19'73) show that a volume of water equal to between 15 and 20 percent of the surface water discharge may be lost to the atmosphere through evapotranspiration. USGS measurements suggest that during low-water periods, groundwater may enter the river at the northern end of the site, while the river may be recharging the groundwater at the southern end.

Water Chemistry

Water chemistry sampling for the first year has recently been completed. Chemical concentrations have been coupled with hydrologic discharges to give loading rates. Declines in the chemical loads between the upstream station 1 and downstream station 2 are evident for many of the suspended sediment and nutrient parameters, indicating at least seasonal retention of several parameters. Retention and export in this system seem to be closely correlated with the hydrologic stage of the river.

Biological Components

Fish Habitat

Adult fishes of the Cache River system, and the BSWMA in particular, have not historically been adequately sampled. A preliminary list of species potentially occurring in the study area was compiled by reviewing existing published fish lists from the region, and by contacting state Game and Fish Commission personnel. Adult fish were sampled intensively in June and July 198'7 to refine the preliminary list. Using this list, and published information on spawning requirements and seasons, a table of species occurrence and potential spawning times in the BSWMA was compiled. Based on this table, and an analysis of hydrology data for the study area, sampling in 1988 was initially scheduled for early March through June, at approximately three-week intervals. Such a schedule would insure that the typical high-water season in the BSWMA would be adequately covered and that all species expected to spawn in the area would be sampled.

Emphasis in 1988 was on sampling larval fish; adult fish sampling continued, although less intensively than in 1987. Due to an extremely dry spring throughout the region, water levels in the Cache River and the floodplain did not attain expected heights or duration. Following the mid-May sample, water levels in the channel and on the floodplain were insufficient to permit further sampling.

Thirty-six species of fish have been collected from the project area. Predominant larger species have been buffaloes (*Ictiobus bubalus, I. cyprinellus,* and *I. niger*), freshwater drum (*Aplodinotus grunniens*), gars (*Lepisosteus oculatus* and *L. platostomus*), and common carp (*Cyprinus carpio*), channel and flathead catfish (*Ictalurus punctatus, Pylodictus olivaris*), and several small sunfishes (*Lepomis spp.*), spotted bass (*Micropterus punctulatus*). The buffaloes, carp, catfishes, and drum represent important commercial species within the Cache River system; spotted bass is an important sport species. Abundant smaller species include blacktail shiner (*Notropis venustus*), ribbon shiner (*Pimenphales vigilax*), and pirate perch (*Aphredoderus sayanus*). Preliminary results suggest no difference in adult abundance or diversity between 198'7 and 1988 collections. However, collection results indicated a dramatic difference in larval fish catch between day and night samples, with many more larval fish fish were caught at night.

Only approximately one-third of the 450 larval fish samples collected in 1988 have been processed but preliminary results indicate that larval fish were much more diverse and abundant within the floodplain, regardless of sampling gear, than within the main channel. However, adults, particularly spawning buffaloes, were more prevalent within the channel. This distribution probably was a result of the unusually low spring water levels, which prevented many of these species from moving onto the floodplain during their usual spawning season.

Fish sampling to date has permitted an evaluation of gear use and effectiveness. For sampling adult fish, electroshocking, hoop netting and seining will continue to be used regularly, with the primary reliance being on electroshocking and seining. The number of hoop net sets will be reduced, but coverage will be extended to include a relatively deep "drainage channel" area of the floodplain. Gill net use will be discontinued, because they required excessive time and effort, and because they provided no information that could not be obtained from the other gears. Although larval fish data acquisition is not complete, indications are that all three gear types will be used in 1989.

Wildlife Habitat

There were 362 animals captured in May and 197 captured in August (Table 1). An additional 100 individuals were observed during the two trips. Most of the pitfall captures consisted of frogs, toads, skinks, and salamanders. Ground and tree platform traps caught mice. Thirty different species were either captured in the trap sets or observed in the array area. The most common organisms were the deer mouse (*Peromyscus maniculatus*) and juveniles of the marbled salamander (*Ambystoma opacum*).

Sixty-five bird species were detected during the spring observations. Many species were observed throughout the study area particularly canopy-dwelling species. Generally, more diversity and greater abundance of birds was observed in the higher elevations. Ground-dwelling species were notably limited in the lower plots where understory cover was limited. Prothonotary warblers (*Prothonotaria citrea*) were most prevalent in cypress-tupelo areas as expected. Chimney swifts (*Choetura pelagica*) were also prevalent in this plant community, apparently feeding on an abundant insect population. The prevalence of morning doves (*Zenaidura macroura*) within this plant community was surprising because these birds are primarily grain feeders. As additional vegetative data are gathered and analyzed and bird information is more thoroughly examined, more definitive bird habitat correlations should be developed.

SUMMARY

A comprehensive, multiyear study is underway on a bottomland hardwood wetland in east-central Arkansas. Hydrology, water quality, and biological studies have been conducted for approximately one year and preliminary results are presented. Research will continue through 1991 with results used to revise and refine the Wetland Evaluation Technique.

Table l.-Number of mammal and herpetofauna captures by trap type

Capture technique	May	August	Total
Pitfall	325	156	481
Ground Traps	28	25	53
Tree Platforms	9	16	25
TOTALS	362	197	559

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RESPONSE OF COASTAL WETLAND FORESTS TO HUMAN AND NATURAL CHANGES IN THE ENVIRONMENT WITH EMPHASIS ON HYDROLOGY

William H. Conner and John W. Day, Jr.[1]

Abstract.-Forested wetlands in the southern United States are subject to many human and natural changes that have altered hydrological and regeneration patterns. Human impacts include impoundments and drainage; dam construction, thermal water additions, and nutria introduction. Natural impacts include sea level rise, salinity intrusion, and tropical storms. Unfortunately, we still have a poor understanding of the overall impact of these changes on the functioning of these systems. Studies from around the southern U.S. are reviewed to describe how these factors are impacting forested wetlands.

INTRODUCTION

Forested wetlands are one of the most extensive forest types in the southern United States and can be found along many coastal streams, rivers, lakes, and bays. These forests have been recognized as being important ecosystems because they provide wildlife and fish habitat, improve water quality, attenuate flood peaks, produce timber products, and provide recreational sites (Brinson and others 1981; Mitsch and Gosselink 1986). Much attention has been focused recently on these forests because of rapid clearing and conversion to other uses (Harris and others 1984; Abernethy and Turner 1987). The acreage of forested wetlands has declined steadily, and in Louisiana alone, only 45 percent of original forested wetlands remain (Turner and others 1980).

Although there have been a number of studies of these forests, there is still a poor understanding of the overall functioning of these systems (Mitseh 1988). We do know that the productivity of these forests is dependent upon both hydrologic conditions and nutrient dynamics, but only now, Mitsch (1988) reports, are we beginning to develop quantitative approaches to understanding the relationships among hydrology, nutrients, and productivity.

Research in Virginia (Dabel and Day 19'77; Day 1979, 1982; Montague and Day 1980; Gomez and Day 1982), North Carolina (Brinson 1977; Mulholland and Kuenzler 19'79; Brinson and others 1980; Mulholland 1981), South Carolina (Scott and others 1985; Shure and Gottschalk 1985; Shure and others 1986), Georgia (Schlesinger 1978; Benner and others 1985), Florida (Carter and others 1973, Mitsch and Ewel 1979; Brown 1981; Elder and Cairns 1982; Mattraw and Elder 1982; Marois and Ewel 1983), Mississippi (de la Cruz and Post 1977; Post and de la Cruz 1977), and Louisiana (Conner and Day 1976, 1988; Conner and others 1981; Kemp and others 1985), has shown that hydrology is an important factor in determining levels of productivity, decomposition, and nutrient cycling. However, human activity and natural processes have altered hydrological patterns in many of the coastal regions of the southern United States. It is the purpose of this paper to review the impacts these changes in hydrology have had on forests. Conversion of forests to agriculture will not be covered in this paper since it has been so well discussed in the literature.

HUMAN IMPACTS

Impoundments and Drainage

In many coastal areas, such activities as dredging, impoundment, and channelization have altered hydrology. In Louisiana, highways, canals, and pipelines crisscross swamplands. Streams have been dredged for navigation, flood control, and drainage. In many cases, canals with associated spoilbanks represent major modifications in hydrology (Walker and others 1987) and result in partial or complete impoundment of large sections of forest. Because these areas are continuously flooded, little recruitment of the major timber species is occurring. Instead, there is the proliferation of shrubby, flood-tolerate species like red maple (*Acer rubrum*) and buttonbush (*Cephalanthus occidentalis*) that germinate on fallen logs, stumps, or any raised area. Conner and others (1981) found that net aboveground productivity of trees in these impounded areas is less than adjacent natural swamps, and productivity decreases over time (Table 1). Tree species other than baldcypress (Taxodium *distichum*) and water tupelo (Nyssa *aquatica)* are dying because of constant flooding.

Table l.-Aboveground net production in natural and impounded wetland forests of southern Louisiana (1978 data from Conner and others 1981)

Flooding regime	Litterfall ($g/m^2/yr$)	Stem production ($g/m^2/yr$)
Impounded		
1978	328	566
1987	189	103
Natural flooding		
1978	417	749
1987	486	464

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Impoundments are also sites of lowered timber productivity in Florida. Productivity in an impounded cypress dome was only 192 $g/m^2/yr$ as compared to 960 $g/m^2/yr$ for a natural cypress dome (Mitsch and Ewel 1979; Brown 1981). The impoundment of the Ocklawaha River in Florida flooded approximately 1620 ha of mixed hardwood swamp with up to 3 m of water. In the deep flooded sites, 100 percent mortality occurred in less than 4 yrs (Fig. 1) (Harms and others 1980; Lugo and Brown 1984). Ash (*Fraxinus* sp.) and red maple (*Acer rubrum*) trees were the most sensitive to water depth changes, while baldcypress was least sensitive and swamp tupelo was intermediate (Harms and others 1980).

In addition to causing flooding problems, canals and spoil banks also disrupt natural overland flow in wetlands. Nutrient-laden waters from agricultural fields adjacent to wetlands are often carried past the swamps and directly into streams and lakes. The result is highly eutrophic conditions (Day and others 1977; Seaton 1979). If these swamps are adjacent to estuaries, eutrophication of estuarine waters can result (Cramer 1978; Hopkinson and Day 1979; Seaton 1979). Gael and Hopkinson (1979) found that canal density is significantly correlated with the trophic state index in the Barataria Basin of Louisiana. Kuenzler and others (1977) reported that channelized streams carry waters with higher levels of nitrate and total phosphorus than do natural streams. Kuenzler and others also found that organic export was higher in forested wetland streams, but this decreased if the streams were channelized. Research has shown that the nutrient filtering capacity of streamside forests can be maintained if the hydrologic regime is not disrupted (Lowrance and others 1983, 1984).

Dam Construction

Along the Atlantic Coastal Plain, discharges of many major rivers are managed by dams or other water control structures. In floodplains of these rivers, water flow changes may exceed normal river stages or completely change the timing of hydrologic events (Sharitz and Lee 1985b). As an example, major discharges along the Savannah River are kept high during the growing season which may be affecting seed availability and subsequent community regeneration (Schneider and Sharitz, in press). In one study on the Savannah River, 99 percent of the seedlings in a baldcypress water tupelo forest were killed by flooding during the growing season (Sharitz and Lee 1985a).

Flow regimes below dams are such that many forests are continuously flooded causing widespread mortality to seedlings, saplings, and undergrowth in baldcypress-water tupelo swamps. Even with continuous flooding, however, recovery is possible in such areas. Baldcypress-water tupelo forests along the Savannah River maintain the potential to regenerate after 30 years of river flow regulation (Sharitz and Lee 1985b).

In addition to changing the hydroperiod of forested wetland areas, dams can also influence downstream salinity patterns. With the completion of the Santee-Cooper Project in South Carolina, salinity regimes changed dramatically in the lower reaches of the Santee River. Salinities of 1 ppt could be measured as far upstream as 13-18 km (Kjerfve 1979). One of the results of this project was the conversion of coastal forests to salt marsh.

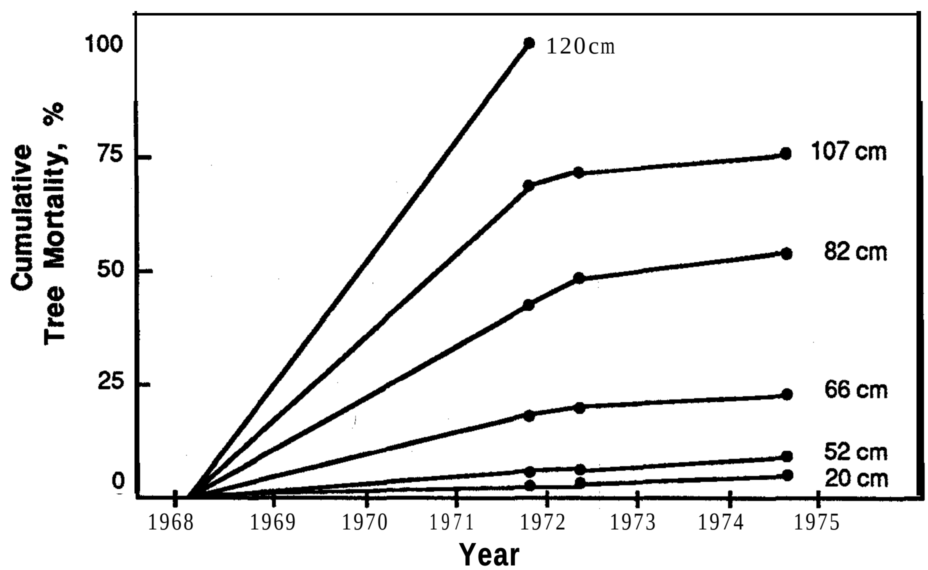

Figure 1.-Tree mortality through time of trees in the impounded Oklawaha, Florida floodplain (adapted from Lugo and Brown 1984).

There have been limited studies addressing the ecological impact of water level management on forested wetlands (Conner and others 1981), but the relationship between watershed processes and the condition of floodplain forests needs more study (Sharitz and Lee 1985a). Although watershed management is not aimed towards maintenance of forests, long-term changes in forest structure, productivity, and wildlife habitat values are occurring as the result of increasing water resource development on southeastern U.S. streams (Sharitz and Lee 1985a).

Thermal Water

Probably the most studied man-made impact, although relatively limited in area of impact, is the effect of thermal waters on forested wetlands in the South Carolina coastal plain. Since the 1950's, the Savannah River Plant on the Savannah River has discharged water with temperatures as high as 50°C into natural streams (Gibbons and Sharitz 1974). The Savannah River Ecology Laboratory (SREL) has been studying the impacts of this discharge since the 1970's, and there are numerous publications on the subject (for information on these publications, please contact Librarian, SREL, Drawer E, Aiken, SC 29801).

Gibbons and Sharitz (1974) reported that large volumes of thermal waters killed 226 ha of the 3,035 ha forest (mainly baldcypress-water tupelo) in and adjacent to the floodplains of the reactor streams. The death rate was slight to moderate in another 1,885 ha. Recent studies have shown that portions of the forest continue to decline even after 30 years of thermal effluent discharge (Scott and others 1985). Downstream forests are affected when floods during the growing season bring plumes of hot water into relatively unaffected areas. Interestingly, trees that have survived exhibit increased growth rates (Scott and others 1985), similar to the findings in Louisiana impounded areas (Conner and others 1981).

The physical environment along thermal stressed streams was significantly altered. With no trees to hold the soil, erosion increased and large deltas have been created on former baldcypress-water tupelo forest sites. Continuous discharges of thermal effluents in some streams prevents wetland recovery. Root stocks have been killed by heat and sedimentation (Muzika and others 1987). In addition, very few viable seeds of baldcypress have been found in these areas (McLeod and Sherrod 1981). Where thermal discharge has ceased, the recovering vegetative community is unlike the predisturbance community (Dunn and Sharitz 1987).

Nutria

The nutria   is a native of South America commonly found in low marshy places. In Louisiana, nutria were first imported and released near Covington in 1933, but a population of animals failed to develop (Kays 1956). Thirteen nutria were released in Iberia Parish in 1937 and several animals were released into the St. Bernard and Orleans Parish marshes several times prior to this without establishing a breeding population (O'Neil 1949). Twelve nutria were imported by McIlhenny at Avery Island in 1937 for experiments in pen raising nutria for fur (Kays 1956; Lowery 1974). In 1939 approximately 12 pair of the McIlhenny animals escaped into the marshes surrounding Avery Island. A hurricane in 1940 released another 150 animals. After this occurrence, landowners began releasing breeding stock into their marshes for fur and weed control. Two hundred and fifty nutria were transplanted to the Mississippi River delta in 1951 and the population increased so rapidly that the marsh in the delta area was almost destroyed by 1957. By 1955-59, the nutria population in Louisiana was over 20 million animals (Lowery 1974). Nutria were firmly established in the freshwater area between the Atchafalaya River and the Texas state line by 1950 (Atwood 1950) and north to the Red River by 1960 (Blair and Langlinais 1960). Substantial populations today occur from Texas to Alabama and from North Carolina to Maryland. Feral populations occur in 15-18 states (Adams 1956; Willner 1982).

Nutria are known to cause damage to newly planted baldcypress seedlings. During 1956-57 personnel from the Louisiana Soil Conservation Service attempted to plant baldcypress seedlings in a cut-over swamp area. After four months, 90 percent of the seedlings had been destroyed, and nutria were suspected as the cause. The Soil Conservation Service subsequently recommended that the planting of baldcypress be suspended until some means of nutria control were perfected (Blair and Langlinais 1960).

Recent studies in Louisiana (Conner 1988; Conner and Toliver 1988) have shown that nutria still are a problem in regenerating swamp areas. In three different projects, nutria caused heavy mortality in baldcypress plantings by clipping and/or pulling the seedlings out of the ground. Even with "Vexar" plastic guards that have worked well in the Pacific northwest in preventing rodent herbivory, nutria damage to seedlings was quick and severe in most cases (Conner and Toliver 1987). Rarely was anything except the bark of the tap root and root collar eaten. Baldcypress seedlings were unharmed in four plots (out of 18). The only observed difference among the sites was the fewer number of nutria resting and feeding mounds in the relatively untouched plots (only 1 in the four plots versus 8/plot in the heavily damaged sites). Assuming that mounds are an indication of the nutria population in a given area, it appears that adequate seedling survival is dependent on the number of nutria in close proximity to the planted areas. The surviving seedlings are growing well, averaging over 24-40 cm of height growth in year 1 and 29-47 cm in height growth the second year. The average height of the seedlings after two'growing seasons was 130 cm (Conner 1988).

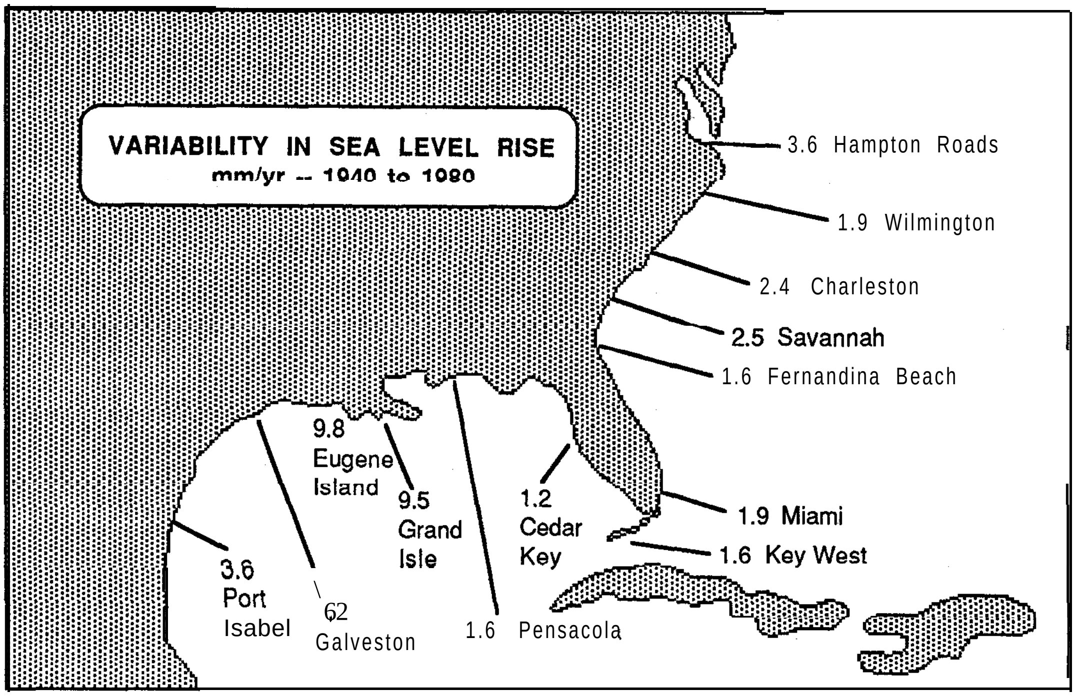

Figure Z.-Relative sea level rise for coastal areas of the southern United States (adapted from Stevenson and others 1979).

NATURAL IMPACTS

Rising Sea Level

One of the most important current issues is sea level rise and its potential impact on coastal land loss. The rate of apparent sea level rise varies tremendously around the southern United States (Fig. 2), with Louisiana experiencing the greatest increase in water levels. Ninety per cent of the increase in water level in Louisiana is attributed to subsidence (DeLaune and others 1987). The Mississippi River and its distributaries once supplied enough sediment to coastal Louisiana so that land building occurred (Walker and others 1987). Today, levees direct sediment out of the mouth of the rivers and little overbank flooding occurs, and there is insufficient sedimentation on the marsh surface to allow vertical accretion to keep up with apparent sea level rise (Baumann and others 1984).

Although there is considerable discussion of the impact of water level rise on the coastal marshes, there is very little concerning the impact this rise might have on coastal wetland forests. The authors have been conducting a study during the past 3 yrs of the impact of water level rise on the baldcypress-water tupelo and bottomland hardwood forests of southcentral Louisiana. Some of the results are summarized here.

Analysis of the yearly average water level in the Barataria and Lake Verret Basins of Louisiana showed that there was a significant apparent increase in water levels (Fig. 3). Water level rise was estimated to be 8.5 and 13.7 mm/yr for the Barataria and Lake Verret Basin, respectively (Conner and Day in press). Sedimentation averaged 2.7 (±1.2) mm in the bottomland hardwood forest of the Lake Verret Basin as compared to 8.8 mm (Lake Verret) and 6 mm (Barataria) in the more flooded baldcypress-water tupelo forests. This difference is undoubtedly due to the frequency and height of flooding experienced by each area. Overall, there are about ten flooding events each year in Louisiana coastal forests varying in duration depending on elevation (Conner and Day in press). This comparison of apparent water level rise and sedimentation rates clearly indicates that sedimentation is less than apparent water level rise in these forests. Vertical accretion deficits range from 2.5 to 10.8 mm/yr, meaning that flood duration is increasing. Even during dry periods such as 1981 and 1985-86, these forests were rarely free of standing water.

Tree growth in these areas generally starts between the middle of March and the middle of April and is completed by the end of September (growth patterns of the 6 major species are illustrated in Fig.4). Across an elevation/flood gradient there were differences in growth rates among species. Sugarberry (*Celtis laevigata*), American elm (*Ulmus americana*), green ash (*Fraxinus pennsylvanica*), and water hickory (*Carya* ***aquatica)*** grew best in the driest area. Nuttall oak, baldcypress, red maple, and sweetgum ***(Liquidambar*** *styraciflua*) grew best in the intermediately flooded site. With all species except baldcypress, poorest growth occurred in the permanently flooded site. Baldcypress grew the least on the ridge where intense competition with other bottomland hardwood species probably limits its growth (Conner and Day 1988).

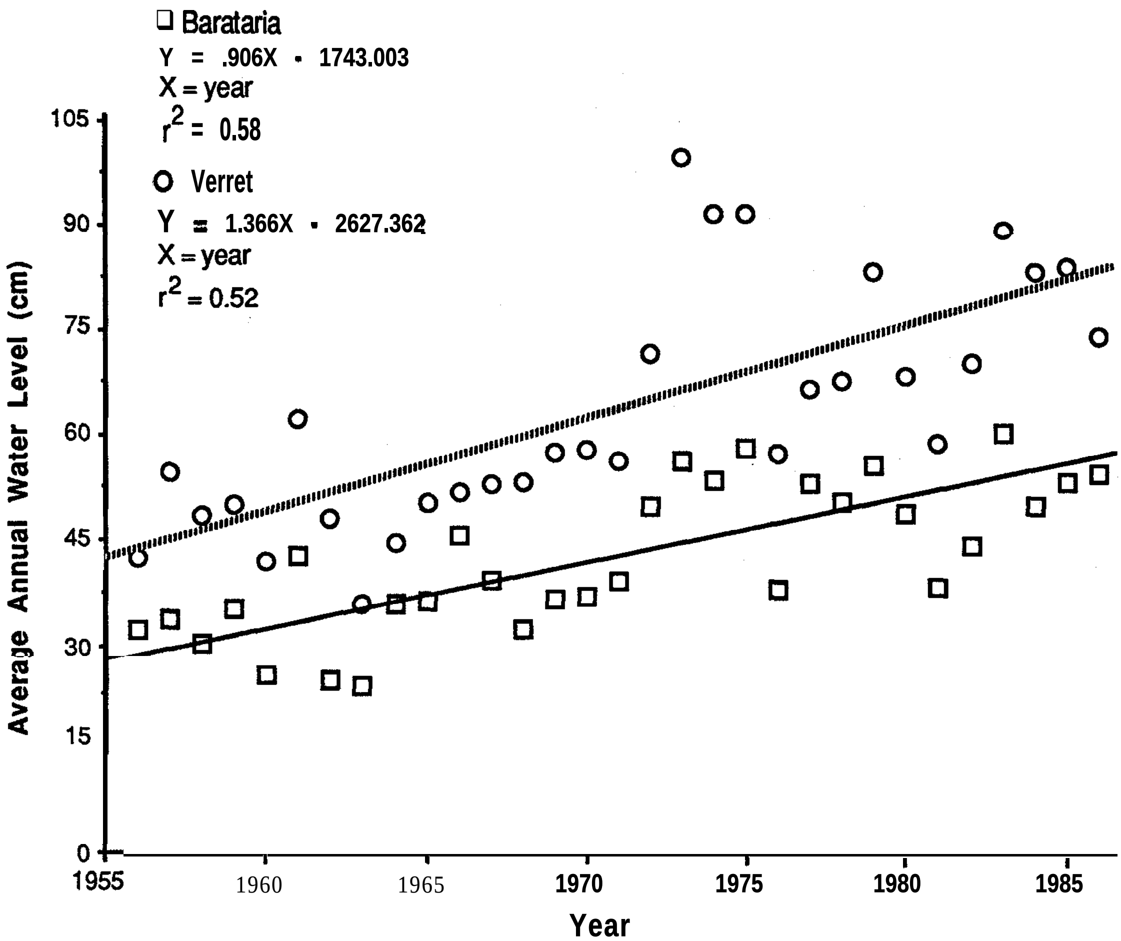

Figure 3.-Average yearly water level change for two watersheds in southern Louisiana (Conner and Day, in press).

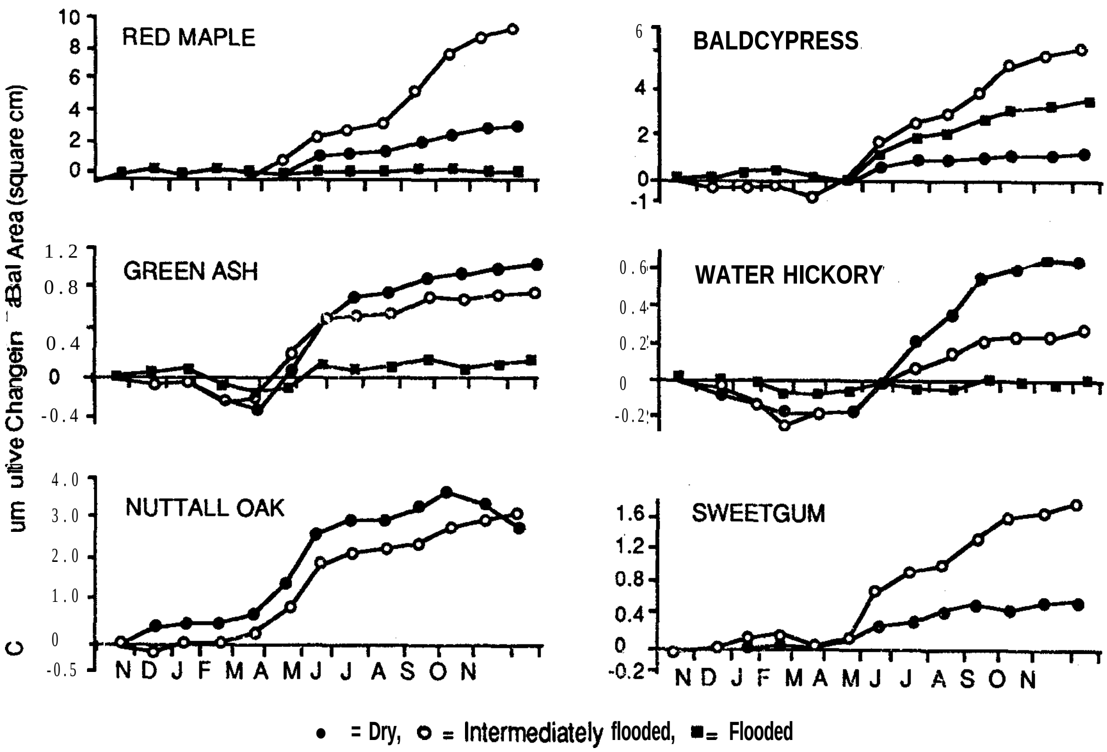

Figure I.-Growth rates of six canopy tree species in a bottomland forest experiencing rising water levels (Conner and Day 1988).

Water hickory, water elm (*Planera aquatica*), persimmon ***(Diospyros virginiana),*** green ash, and red maple growth rates were significantly lower in more flooded areas than in other plots. All of these species are moderately to highly tolerant of some flooding (Hook 1984). However, as water levels continue to rise in the Lake Verret forests, the trees will eventually die as they cannot stand permanent flooding (Green 1947; Hall and Smith 1955; Eggler and Moore 1961; Broadfoot and Williston 1973). The largest increases in basal area occurred in intermediately flooded areas. Baldcypress, red maple, and sweetgum growth were significantly higher in the intermediately flooded plots than in the other plots.

In order to analyze the long-term impact of water level rise, the vegetation and water level data were used in the U.S. Fish and Wildlife Service's FORFLO bottomland hardwood succession model (Brody and Pendleton 1987). Even though baldcypress and water tupelo are flood-tolerant, there is a limit to the depth and length of flooding they can endure (Eggler and Moore 1961; Harms and others 1980; Lugo and Brown 1984), and eventually they also will die. FORFLO predicted that the total basal area of these species in the more flooded swamp areas will decline with time (Fig. 5) and no new trees will enter the understory. In the drier areas, FORFLO predicted that the bottomland hardwood species will be replaced by water tupelo and baldcypress.

Rising water levels are altering succession in the forested wetlands of coastal Louisiana. Under natural conditions, floodwaters would continue to bring sediment-laden waters into these forested areas, and the swamp forests would be replaced by bottomland hardwood forests. Human activity, however, has altered the flooding regime in many of these

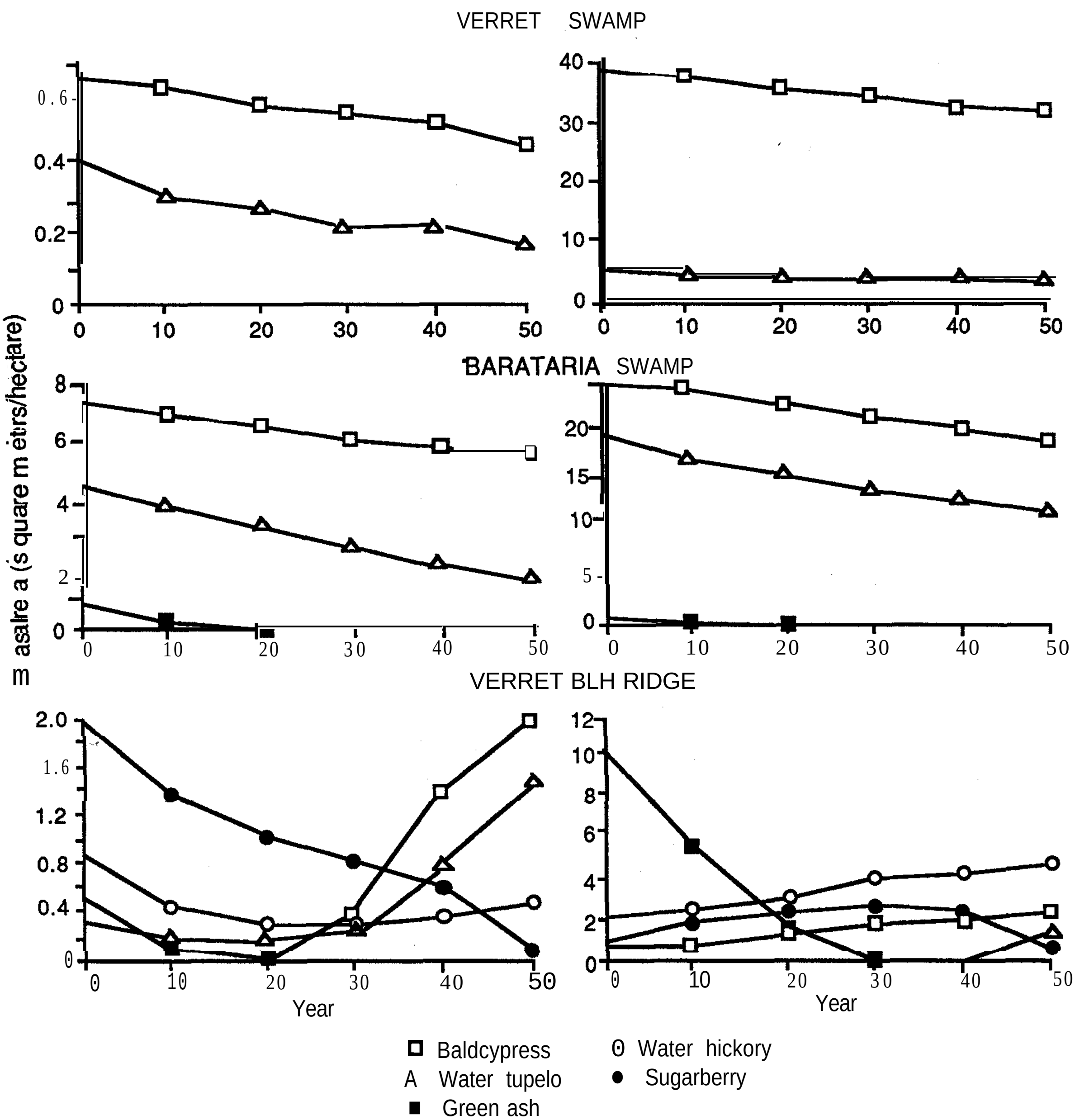

Figure 5.-Basal area (m^2/ha) through time of major canopy and subcanopy trees as predicted by the FORFLO bottomland hardwood succession model (Conner 1988).

forests, and there is no longer sufficient sediment to continue building surface elevation in the face of continuing subsidence. Based on these trends, the wetland forests of coastal Louisiana will become less productive and reduced in area, and some areas will disappear completely.

More information is needed concerning the possible consequences of sea level rise in forested areas so that techniques can be developed for effective management of this resource for the future. Natural regeneration in these areas has been affected by rising water levels (Conner and others 1986) and planting is difficult because of herbivores (Conner and Toliver 1987). More work needs to be done on how to ensure adequate survival of planted seedlings. Direct manipulation of water levels is another option that should be considered. In the Mobile, Alabama swamp forests, Scott Paper Company regulates water levels in cutover areas to let natural reproduction take place (Gilbert Sproler, personal communication, Scott Paper Company, Mobile, AL). In Louisiana, the numerous canals and spoil banks in existence in the coastal area could be used to pump out areas for one to two years to let natural regeneration occur. This is not a long-term solution, however, because of the trend of continued water level rise.

The introduction of sediments from the Atchafalaya and Mississippi rivers should also be considered to save these forests. Since the lack of sediment is what is causing the problem, it would be beneficial to these areas if sediment-laden waters were once again directed through these forests. There have been several suggestions to divert fresh water and sediments into wetlands (Gosselink and Gosselink 1985; Templet and Meyer-Ardendt 1988). For example, Templet and Meyer-Ardendt (1988) reported that diversion of 11 percent of the flow of the lower Mississippi during high discharge would offset apparent water level rise.

Salinity Intrusion

As sea level rises, more and more coastal forests will be subjected to inundation by saline water. At present, we have no idea of how widespread the problem is, but have only to drive along coastal roads of many areas on the Atlantic and Gulf Coastal Plains to observe the impact of this encroachment. Laboratory studies (Pezeshki and others 1986, 198'7, Pezeshki and Chambers 1986) have shown that low level increases in salinity cause significant decreases in photosynthesis of baldcypress and green ash seedlings (both common coastal wetland tree species). However, care needs to be taken in extending the results of these short-term studies to long-term response of vegetation in the field.

In North Carolina, Hackney and Yelverton (in press) found that sea level rise since 1889 has caused significant tidal inundation and seawater intrusion into the upper Cape Fear River estuary. They reported that disintegration of tidal swamp forest was caused by increased tidal flooding and the presence of occasional inputs of saline water. Soil salinity of 3.5 ppt were recorded in stressed areas, and they predicted that in 50 years, the trees would be replaced by tidal and brackish marshes. Another study in North Carolina found that occasional intrusions of saline water that occur as the result of a drought create acute water stress for salinities intolerant species (Brinson and others 1985). Growth and structural development (Table 2) were adversely affected by groundwater salinities greater than 2 ppt.

Table 2.-Density (number/ha), basal area (m^2/ha), and litterfall (g/m^2/yr) values for a salinity-stressed vs. non-stressed swamp area (adapted from Brinson and others 1985)

	Salinity stressed	Non-stressed
Density		
Live trees	1175	1900
Dead trees	685	325
Basal Area		
Live trees	20	40
Dead trees	15	2
Litterfall	527	816

Tropical Storms

Tropical storm activity is a normal, aperiodic part of the climatic regime of the southern United States with indications that over 40,000 have occurred in the northern Gulf of Mexico since sea level stabilized (Neumann and Hill 1976). However, the probability that storm event will strike a given 80 km section of the southern Atlantic and Gulf coasts in any given year is less than 16 percent (Simpson and Lawrence 1971), and so coastal areas may function for decades without major impacts from tropical storms.

The most extensive data on the impact of hurricanes on wetland forests come from Florida. High mortality of mangrove trees can occur (Craighead and Gilbert 1962), but evidence seems to point towards hurricanes keeping the forest in a juvenile successional state resulting in higher net production over the long term (Lugo and others 1976). Various woody species respond to hurricane damage by rapidly producing a new set of leaves, holding the leaves later in the year, and flowering a second time (Craighead and Gilbert 1962)).

On Mississippi barrier islands, there is a positive correlation between hurricanes and annual growth of slash pine (*Pinus elliottii*). In addition, hurricane-induced washover deposits stimulate pine seed germination by reducing competitive shrub understory and exposing the mineral soil surface (Stoneburner 1978).

One often overlooked role of hurricanes is the export of organic matter during storm events. Day and others (1977) noted the premature defoliation of trees in a swamp forest of the Barataria Basin of Louisiana with the passage of Hurricane Carmen in 1974. Approximately 20 percent of the annual nutrient export for the year occurred after this storm. This large input of organic matter is sometimes harmful to the aquatic system. Bryan and others (1976) reported that large amounts of foliage added to the water column depleted oxygen levels in the swamp causing large fish kills in the lower Atchafalaya Basin.

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A LITERATURE REVIEW OF EFFECTS OF DEVELOPING POCOSINS

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Abstract.-Southeastern pocosin wetlands are unique ecosystems consisting of a sparse tree canopy, a dense shrub understory on poorly drained mineral or organic soil. Hydrologically, these areas receive water from rainfall and lose the same by runoff and evapotranspiration. About one half of one percent of rainfall input moves downward to recharge underlying aquifers. The low land cost of pocosins and the availability of large tracts has attracted development for agricultural and pine plantation purposes. This development involves installing a network of drainage ditches to manage the surface runoff and the removal of the native vegetation. Agricultural drainage systems increase the size of the peak storm flow, decrease the recessional limb of the hydrograph and increase base flow. This causes concern about estuarine resources. Storm runoff enters upstream of estuaries and can cause fresh water pollution. The nutrient load of drainage water from developed pocosins is larger than that from natural pocosins. Nitrate losses are much less than from agricultural fields of a mineral soil. Preparing a pocosin site for pine plantation establishment decreases drainage water quality. Once the plantation becomes established water quality appears to improve to or above that of undisturbed pocosins. Development for agriculture and pine plantations alter some pocosin functions and values. Thus, a tradeoff is made between immmediate economic returns and an altered ecosystem. The long-term effects of the tradeoffs are unclear.

INTRODUCTION

Pocosins are plaustrine wetland ecosystems unique to the Atlantic Coastal Plain. In their natural state they have a sparse tree strata and a dense understory of broadleaved evergreen shrubs. The soils are typically very strongly to extremely acid, poorly drained organic or mineral soils (Kologiski 1977). Lilly (1981a) reported that there were from 526,000 to 607,000 hectares of peat or muck soils in eastern North Carolina. The first large-scale drainage of eastern North Carolina's deep organic soils occurred in the 1790's and by the 1830's large areas were being farmed. In 1830, 12,950 ha were being farmed around Lake Mattamuskeet (Lilly 1981a). He also reports that the success of early farming led to the state spending large amounts of money to drain additional lands for sale to farmers. This was not successful because of insufficient drainage, the Civil War, and disease. According to Lilly (1981a) large-scale timber harvesting occured in the late 1800's and this was followed in the early 1900's by the sale of cut-over land. The successful farming of deep organic soils is a relatively recent development which required amendments with lime and micronutrients.

Large-scale pocosin development during the past few decades brought about concerns that the functions and values of these areas were being significantly reduced or destroyed. On-site changes involved the removal of native vegetation, construction of drainage ditches, soil tilling, and nutrient amendments and the major off-site effects were altered hydrologic relationships and changes in water quality. *Spartina alterniflora* marshes occur occasionally immediately downstream from pocosins. Organisms that depend upon the marsh for part or all of their life cycle and are sensitive to water quality may suffer from pocosin development.

The potential short- and long-term effects of intensive pocosin development give ample justification for concern. Hence, the nature of pocosins and how current development activities are affecting their natural and economic values are examined.

CHARACTERISTICS OF POCOSINS

The published definitions of pocosin are as variable as the vegetation is impenetrable. Richardson and others (1981a) characterized North Carolina pocosin vegetation as similar to that described by Wells (1928) i.e., growing on waterlogged acid, nutrient poor, sandy or peaty soils located on broad, flat topographic plateaus, usually removed from large streams and subject to periodic burning. Similarly, Sharitz and Gibbons (1982) defined pocosins as freshwater wetland ecosystems characterized by broadleaved evergreen shrubs or low trees, commonly including pond pine (*Pinus serotina*) and commonly growing on highly organic soils that have developed in areas of poor drainage. However, Ash and others (1983) chose a strictly vegetative cover definition and included pocosins in the following three categories of the wetland classification system reported by Cowardin and others (1979): palustrine, scrub/shrub, broad-leaved evergreen, Titi-honeycup (*Cyrilla-Zenobia*) wetland; palustrine, forested, needle-leaved evergreen pond pine wetland; or palustrine, forested, broad-leaved evergreen, sweet bay-red bay-loblolly bay (*Magnolia virginiana-Persea-Gordonia*) wetland. The bay wetland type is similar to what Wharton (1978) and Nelson (1986) called bay swamp and bay forest, respectively. Ash and others (1983) supplement their definition by stating that pocosins characteristically have perched water tables usually due to impermeable clay layers at or near the mineral soil surface and have nutrient-poor groundwater derived principally from rainfall or drainage through coarse sand aquifers.

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Wharton (1978) described shrub bogs of Bryan, Cook, Coffee, and Tattnall counties in the Georgia Coastal Plain as having a tree strata of dwarfed pond pine, sweet bay, loblolly-bay, red maple (*Acer rubrum*) and red bay. The shrub strata was dominated by black titi (*Cliftonia monophylla*) or Titi (*Cyrilla racemifloria*), with fetterbush lyonia (*Lyonia lucida*) rusty black haw (*Lyonia ferruginea*) and odorless wax myrtle (*Myrica inodora*) forming a co-dominant shrub strata.

Nelson (1986) described pocosins, streamhead pocosins, and swale pocosins in South Carolina's coastal plain. The pocosin tree strata includes pond pine, red maple, sweet bay, sweet gum (*Liquidambar styraciflua*) and loblolly-bay, with loblolly pine (*Pinus taeda)* and longleaf pine (*Pinus palustris*) as minor components. The shrub strata consists of fetterbush lyonia, fetter-bush (*Leucothoe* racemosa), zenobia (*Zenobia pulverulenta),* and several other species. Streamhead pocosins and swale pocosins are floristically similar to coastal plain pocosins. Unlike coastal plain pocosins, streamhead pocosins are located in the fall-line sandhills.

Meanley (1968) recognized a pocosin or evergreen shrub bog in the Great Dismal Swamp of southeastern Virginia but Levy and Walker (1979) did not describe pocosin communities in the Dismal Swamp. The soil and topography of Virginia's tidewater region and the Maryland's Eastern shore could support pocosin vegetation but I found no reports of pocosin communities in these areas.

Early floristic descriptions of North Carolina's pocosins were by B.W. Wells, (Wells, 1932, 1942). More recent descriptions include a detailed discussion of two pocosin types in Green Swamp (Kologiski, 19'77) and a description of the pocosins south of the Albemarle Sound (Christensen and others 1981). The latter are typical pocosins with scattered emergent pond, loblolly and longleaf pines with occasional Atlantic white cedar ***(Chamaecyparis thyodides)*** and cypress ***(Taxodium distichum).*** Associated hardwood species include red maple, sweet bay and loblolly-bay. Fetterbush lyonia, zenobia and titi form the thick characteristic shrub strata.

Soil

The following pocosin soil information is derived solely from work done in eastern North Carolina, primarily the Albemarle-Pamlico peninsula and the Green Swamp in Brunswick county. Daniel (1981) presented a soils map modified from Heath (1975) showing that about half of the soil series of the Albemarle-Pamlico peninsula are mineral soils. The remaining soils are about evenly divided between shallow (less than 1.5 m) and deep (more than 1.5 m) organic soils. Gilliam and Skaggs (1981) and Barnes (1981) described these soils as mineral soils (Histic Humaquepts) characterized by a high organic matter surface horizon less than 40 cm thick. Lower horizons were stratified sand or clay marine sediments. They were very poorly drained and acidic. The pH of the organic horizon ranged from 3.5 to 4.1 and the pH of the mineral subsoil ranged from 4.1 to 4.7.

About 75% of the unaltered central section of Green Swamp in southeastern North Carolina had organic soils. Kologiski (1977) reported that the predominant organic soils were of the Dare-Dorovan series (Typic Medisaprists) or of the Ponzer-Pamlico series (Terric Medisaprists). The Dare-Dorovan series had 15 to 30 cm of an Oi or Oe horizon composed of black, partially decomposed organic matter. Under this was 127 to 230 cm of Oa horizon consisting of very dark gray to black sapric (highly decomposed organic matter) material. The Ponzer-Pamlico series had 46 to 109 cm of black, partially decomposed organic matter becoming sapric below 46 cm. Below this to a depth of 157 cm was a sandy clay loam to loamy sand C horizon. The most widespread soil in the Green Swamp was the mineral Torhunta series (Typic Humaquept). This series was characterized by up to 58 cm of a black loamy fine sand Al horizon over a 64-cm dark brown fine sandy loam Bg.

Hydrology

Daniel (1981) gave a good description of hydrologic relationships in natural pocosins. He reported a water budget for a pond-pine evergreen shrub swamp in the center of the Albemarle-Pamlico peninsula. The annual average rainfall for the 1977-1979 water years was about 117 cm, with about 1.3 cm leaving as groundwater loss. Therefore runoff and evapotranspiration losses accounted for about 99% of the rainfall input. In one water year most of the precipitation occurred during winter and spring, when evapotranspiration was low. Fifty-six percent of the rainfall left the area by runoff. This runoff was sheet flow across the swamp surface when the water table was high. When the water table was low, water moved through the upper rooting zone that had a high concentration of coarse organic debris. When rainfall was mostly in the summer and fall, evapotranspiration accounted for 60–70% of the water loss. Also, in all but the driest years, rainfall exceeded potential evapotranspiration, which results in an accumulation of water. This established and maintained a slightly elevated water table in the pocosins.

Heath (1978) presented a similar water budget for the entire Albemarle-Pamlico area. An average annual precipitation input of 129 cm was balanced by a groundwater runoff of less than 2 cm, and a potential evapotranspiration of 91 cm (71% of rainfall). This left 36 em for overland flow above and through the upper peat layer.

Carter and Novitzki (1988) reported that the Great Dismal Swamp has an artesian formation below it which prevents downward leakage of water from the swamp. Some pocosins may receive artesian water but this source of water does not appear to be significant in the pocosins of North Carolina. Heath (1975, cited in Daniel 1981) estimated a small loss of water from pocosins to groundwater recharge in the Albemarle-Pamlico peninsula. This estimate was from hydrologic properties of underlying aquifers.

What is a pocosin? I consider coastal plain areas that have the following traits to be pocosins:

Landform:	broad flat interstream topography,
Soils:	organic or poorly drained, acid, mineral series,
Vegetation:	sparse tree canopy of pond pine or evergreens,
Hardwoods:	thick shrubby understory of lyonia or zenobia,
Hydrology:	rainfall sole input, evapotranspiration and overland flow are outputs.

POCOSIN FUNCTIONS AND VALUES

Undisturbed pocosins have natural values derived from the ecological functions they perform, such as water retention and storage, or services they provide, such as providing plant and animal habitat. They also have value as a substrate for cultivation of trees and row crops and as a source of a potentially marketable natural resource, peat.

Plant and Animal Habitat

Although no endangered plant or animal species are endemic to pocosins (Sharitz and Gibbons 1982), many plant species and several animal species rely on pocosins for refuge. Richardson (1983) listed white wicky (*Kalmia cuneta*) and rough-leaf loosestrife (***Lysimachia*** *asperulaefolia*) as indigenous pocosin species that may be uncommon and in danger. Nelson (1986) adds *Syngonanthus flavidulus*, ***Peltandra sagittaefolia, Tofieldia*** tenuifolia, ***Narthecium americanurn****, Lindera* ***subcoriacea, Lysimachia*** *asperulifolia, Asclepias pedicellata*, and *Ruellia pinetorum* as elements of concern in South Carolina pocosins. These species prefer pocosin margins where the vegetation forms an ecotone from evergreen shrubs to adjacent communities.

The pine barrens treefrog (*Hyla andersoni*) has been called the only pocosin endemic vertebrate (Wilbur 1981), but the habitat of this animal is sandhill pocosins. It is not known to occur in the pocosins of eastern North Carolina. These areas do provide habitat for a number of game animals including the white-tailed deer ***(Odocoileus virginianus),*** marsh rabbit (*Sylvilagus palustris*), cottontail rabbit (*Sylvilagus floridanus*) and the gray squirrel (*Sciurus* carolinensis).

The animal most dependent on pocosins is the black bear (*Ursus americanus*). Monschein (1981) reported that hunting pressure in North Carolina forced the establishment and then reduction of hunting seasons and bag limits, until the bear population in North Carolina depends on the wise use of altered pocosins and the preservation of suitable pocosin habitat. Reduction of widespread poaching will also benefit the black bear population. Nelson (1986) mentioned the black bear as an element of concern in South Carolina's pocosins.

Hydrologic Functions

The major hydrologic value of pocosins appears to be their influence on runoff characteristics and not on their functioning as groundwater recharge areas. Daniel (1981) explained that heavy rain causes storm water to spread over a large area of flat porous soils. Pocosins therefore act a storm buffers by absorbing much rainfall, decreasing the flood peak discharges, and lengthening the discharge portion of the hydrograph. Water discharged from unaltered pocosins is not always released at a single point, rather the runoff may spread over a broad pocosin margin to enter a stream or other body of water as diffuse drainage rather than as a stream. This is especially important in areas where pocosins are upstream of ***Spartina*** *alterniflora* marshes.

Carter and Novitzki (1988) examined the argument that wetlands act as groundwater recharge areas. They concluded that many more wetlands are ground-water discharge areas than recharge areas. This apparently is the case with the Great Dismal Swamp, the area studied by them that most closely resembles a pocosin. Their data showed there was a stagnation point between local and regional flow systems. They stated that this stagnation point may prevent downward leakage of water and may account for the continued existence of the swamp despite attempts to drain it.

Working in the Big Pocosin, between the Neuse and Pamlico rivers of North Carolina, Daniels and others (1978) presented evidence that the surface groundwater aquifer was not connected to the deeper aquifer. Therefore, installing surface drainage in this particular pocosin would not affect the deep water aquifer that the adjacent residential areas use for drinking water.

Carbon Sink

Richardson and others (1981b) discussed pocosins as carbon storage ecosystems. The thick layers of peat (up to 3.6 m, Daniel 1981), contain much carbon, which, under natural conditions is stable if not accreting. However, drainage, compaction, fire and oxidation has been shown to cause subsidence which results in carbon loss from the peat to the atmosphere.

Richardson and others (1981b) calculated that a 2 cm subsidence rate on 0.5 million acres of developed North Carolina wetlands would release 7 x 10 metric tons of carbon per year. This carbon loss plus that from the Okeechobee region of Florida and the San Joaquin Valley in California is half of one percent of the entire world fossil fuel emission.

Pine Plantation Potential

Another value of pocosins is their potential for intensive management of loblolly pine. Campbell and Hughes (1981) list four advantages of managing pocosins for pine silviculture:

1. good growth potential after drainage,
2. few erosion problems,
3. relatively large uniform areas, and
4. adequate soil moisture during the growing season.

Each of these factors is important from an operational pine plantation viewpoint. Traditionally, the more accessible, fertile upland areas have been managed for more profitable crops, like corn and soybeans, leaving the less productive lands for growing trees. The realization that the large, low-cost pocosin areas could be managed to produce wood was certainly good for those responsible for growing wood for an ever-hungry pulp mill. The lack of erosional problems such as occur in the Piedmont of the Southeast makes the pocosins a more attractive, low-cost land resource than the Piedmont. Also, managing relatively large uniform areas such as the pocosins of eastern North Carolina is much simpler than trying to keep track of many small, scattered tracts characteristic of the Piedmont. Traveling from area to area consumes much non-productive time, and having to juggle a diversity of silvicultural methods to fit a diversity of sites adds to the complexity of managing scattered heterogeneous forests. Finally, the availability of soil moisture throughout the growing season, makes the pocosins an attractive site for growing loblolly pine. Piedmont sites typically suffer summer droughts that limit loblolly pine growth. Thus, purely from a forest productivity viewpoint, pocosins offer many advantages over upland or other alternative sites.

The typical sequence of activities to convert an undisturbed pocosin to a loblolly pine plantation is; install road and drainage system, harvest merchantable timber, remove most of the existing vegetation to prepare the best planting site possible, fertilize, and plant improved seedlings. Once the trees are in the ground, competition control is often necessary, and when the trees are old enough and soil conditions permit, the tract may be prescribed burned, thinned or fertilized.

Campbell (1976) and Terry and Hughes (1978) discussed the design of road and drainage ditches in pocosin areas. They propqsed two approaches: either clean-out and upgrade existing drainage-ways or, if a natural drainage pattern is not clearly functional, install a grid pattern of primary, secondary and tertiary ditches. Primary ditches connect the secondary or collector ditches to a natural drain. Secondary ditches are constructed along existing drainages or in the grid pattern. Roads are built from the ditch spoil. The third stage ditches are smaller, penetrate the area intensively, and do not have a road associated with them. If carefully engineered, such a system will effectively remove the surface water and lower the water table to allow the establishment of loblolly pine. As the established stand grows, the transpirational demand for soil water will increase. Also, natural degradation of the ditch network over the 20-40 year life of a stand helps keep water on the site longer to meet this water demand. The installation of flashboard risers at ditch intersections allows the land manager to retain water on site during the growing season to meet tree growth needs. Therefore, the installation of a ditch network should be more correctly called water management rather than simply drainage.

After the pocosin water table has been lowered sufficiently to allow heavy equipment on site, the merchantable timber is harvested and the area is site prepared. The goal of site preparation is to create a "plantable microsite suitable for survival and growth" (Campbell and Hughes 1981). The first step in site preparation is to dispose of the residual tree and shrub biomass. A sharpened, shearing bulldozer blade is pushed through tree trunks with massive bulldozers putting residual biomass on the ground. The downed material is raked into lines (windrows) by bulldozers with a special raking blade. These windrows are burned. This practice leaves a clean site. Often the site is too clean in that part of the topsoil is pushed into the windrows. If there is insufficient residual biomass to justify shearing, a large drum fitted with sharpened blades puts residual material on the ground and chops it up. The chopped area is then burned, if the soil itself is not likely to burn also.

The, area is bedded to create a microsite that is higher than groundline and is reasonably competition free. One year old seedlings are planted on the beds and phosphorus fertilizer is applied at the time of planting. Either triple super phosphate or diammonium phosphate is applied, depending on relative price. Once the seedlings are planted, some control of the competing vegetation has proved helpful to seedling growth. Such control is now being provided by the ground or aerial application of selective herbicides, or when the seedlings are 6–10 years old, by prescribed burning.

Agriculture Potential

The desirability of farming North Carolina's large eastern pocosin areas was recognized as far back as the early 1700's (Lilly 1981b). However, excessively large areas were not cleared until recent decades in response to increasing demand for cropland, the advent of the bulldozer, dragline and other earth moving machinery, and the knowledge of how to farm the organic soils (Barnes 1981).

As with pine plantations, the first step in converting a pocosin to an agricultural field is to provide drainage of gravitational water. Barnes (1981) stated that canals are dug at 805m intervals and perpendicular field ditches are installed at 91-100 m spacings. The canals are connected to natural drainages by a catcher canal. Such a system provides relatively rapid disposition of surface runoff, but does not affect the water table for large areas because of a low saturated hydrologic conductivity. Once drainage is provided, the land is cleared and residue windrowed as described in a forestry application. Windrows are burned, recombined and reburned until all of the debris is gone. The land is sloped and leveled primarily to make sure all of the surface water flows directly to a field ditch. Also, the field is raked several times to removed as much small wood debris as possible.

The low pH of organic soils is overcome with the application of 9 to 18 tonnes per hectare of lime and 2.2 tons per hectare per year every two to four years. Initial phosphorus applications of 56-112 kilograms per hectare are required beyond the normal crop requirements. Finally a copper adjustment of 2.8-5.6 kilograms elemental copper per hectare is needed. Little maintenance additions of copper are needed.

Peat Mining

Ingram and Otte (1981) described the value of North Carolina's pocosins for peat mining. Peat-rich pocosins cover an estimated 93,000 hectares with the depth of peat ranging from 0.3–2.4 m. The depth of peat in old stream channels is up to 5.8 m. Tests of this peat show that the ash content is low (2–5%) as is the sulfur content. These characteristics coupled with the high BTU values make pocosin peat a desirable source of energy.

EFFECTS OF DEVELOPMENT ON THE FUNCTIONS AND VALUES OF POCOSINS

Richardson and others (1981b), Sharitz and Gibbons (1982) and Ash and others (1983) considered changes in hydrology, sediment, nutrients, pH, temperature, pesticides, and habitat alternations as major concerns in pocosin development. Ash and others (1983) concluded that there are relatively few studies directed at water quality effects and that the data base is inadequate for accurately predicting effects of large-scale agricultural or pine plantation development of pocosins. My review of the literature concurs with the conclusions of Ash and others (1983).

Effects of Development for Pine Plantation Purposes

No references could be found to document the effect of pocosin drainage for forestry purposes on the runoff hydrograph. Thus, the hydrologic effects of converting pocosins to agricultural fields is assumed to apply to the stand establishment phase of pine silviculture. Both involve installing field ditches to remove surface runoff, both remove the native vegetation, and both forms involve tilling the soil. Once a pine stand is established, there are water quality differences. A pine stand has greater evapotranspiration than agricultural crops and forms a soil protecting litter layer that is not produced by agricultural crops. Another major difference is that agricultural fields are tilled annually; whereas with pine plantation the soil disturbing activities occur once every 20 to 40 years.

Williams and Askew (1988) appear to have conducted the only study to measure the water quality effects of drainage and site preparation for pine plantation establishment. They sampled the drainage water quality in a large mineral soil pocosin for several years. The sediment load and calcium concentrations were significantly higher and the hydrogen ion concentration was lower in the drained area as opposed to the undrained control. Water from logged areas had a higher potassium concentration and a lower nitrate, sulfate, magnesium, calcium and hydrogen ion concentration than did unlogged controls. Site preparation treatments resulted in increased calcium and potassium but decreased nitrate, sulphate, and hydrogen ion concentration in drainage water compared to controls.

Prescribed burning is a tool used by foresters to accomplish a variety of tasks, and Christensen et al. (1981) reported the effects of fire and prescribed burning of pocosins. They state that the diversity of plant species increased following a fire, and that the shrub biomass rapidly returned to prefire levels. The concentration of calcium, magnesium, potassium, orthophosphate and nitrate in the upper peat layer increased following prescribed fire, but quickly (7 months) returned to the level of the unburned control. They also explained how fire increases the heterogeneity of the area by consuming the peat in some spots, thus favoring or inhibiting the reproduction of pocosin species in this manner.

Effects of Development for Agricultural Purposes

Daniel (1981) monitored six watersheds which ranged in land use from 100% undeveloped or unchannelized wetland forest to 95% agriculture. He reported that the installation of a drainage system increased base flow in canals because the ditches were cut into the groundwater table. Also the stormflow peaks and total annual runoff was greater in areas with a ditch network than areas with natural drainage. These hydrograph changes due to land clearing and artificial drainage were a result of the increased efficiency of the canals in moving runoff, reduced interception, and reduced infiltration of cleared land. Finally he pointed out that this runoff peak was released at a discrete point, i.e., a canal entering a river or a canal entering an estuary. Heath (1978) and Street and McClees (1981) discussed the problems of a point source of fresh water entering an estuary. Daniel (1981) also found that drainage water from farms on peat soil increased pH, dissolved solids, calcium, magnesium, sulfate, bicarbonate, sodium, chloride, total nitrogen, nitrate and total phosphorus, compared to water from a natural pocosin. The increased calcium, magnesium, bicarbonate and sulfate were from lime applied to amend the pH of the peat soil.

Gilliam and Skaggs (1981) found similar trends in the hydrology of natural pocosins versus those converted to agriculture, except they found little change in total runoff. Also they reported that the peak flow from natural pocosins lagged 24 hours behind the peak flow of drained pocosins. Increased nutrient loads in drainage water was reported, but the increased loss of nitrate was small compared to the nitrate loss from farmed mineral soil.

The effects of converting 18,200 ha of pine swamp/forest, pocosin, and open grassland to pasture on runoff and water quality was reported by Kirby-Smith and Barber (1979). Conversion to pasture was achieved by constructing major drainage ditches on a 1.6km grid with smaller field ditches at 200 m intervals, followed by clearing, shaping, and heavily liming the land. Water samples were collected from stations in the farm and from the estuary that received farm runoff.

Ditch water on the farm was more turbid, more alkaline, and contained more silt, particulate organic matter, phosphate, nitrate, and ammonia than water from natural waters. Phosphate and ammonia concentrations of farm ditch water averaged three times that of the natural waters and the nitrate concentration averaged five times that of the natural water.

These changes were also seen in water samples from the linear estuary that received ditch water. Drainage from the farm had no effect on dissolved oxygen, but the turbidity and phosphate concentration were higher in samples taken near the farm ditch outfall than those at the other end of the estuary. Nitrate concentration peaks were seen during the summer, and the peaks were larger near the farm ditch outfall. In the autumn the nitrate concentrations were "normal." Ammonia concentrations were variable but were higher at stations near the farm ditch. Despite the alterations in the water quality of the estuary, Kirby-Smith and Barber (19'79) could find no large-scale changes in the basic biological character of the estuary.

Managing agricultural drainage water discharge and using buffer areas can improve the quality and decrease the impacts of agricultural drainage. Konyha and others (1988) have shown that weir control structures will reduce major runoff events in poorly drained soils. Weirs hold the stormwater, which results in a rise of the water table. Consequently, water is released slowly after the storm. Gilliam and others (1988) reported that a minimum of 90 percent of the total sediment and 70 percent of the phosphorus was removed by pumping agricultural drainage water into buffer areas. The buffer areas they tested were hydric hardwoods and loblolly pine on a medium depth organic and mineral soils.

Effects of Development on Plant and Animal Habitat

The loss or alteration of habitat for plants and animals is the most obvious effect of pine plantation or agricultural development of pocosins.

Both involve the removal of native vegetation, tilling the litter layer, and the establishing of a monoculture of species that are not naturally present (agricultural crops) or are present in an atypical condition (loblolly pine). The native plants do have a chance to recolonize areas planted to pine if the rootstocks or propagules of the native species survive. However, recolonization opportunity may end when crown closure occurs and decreases the amount of light reaching the forest floor. This would occur between 5 and 10 years after planting and would continue until maturity unless the plantations are thinned. With periodic thinning understory development and habitat can be restored with minimal impact on the plantation productivity.

Effects of Development for Peat Mining

I have not found reports on the effects of peat mining on pocosins. From the description of the mining operation given by Campbell (1981) an alteration of the stormflow hydrograph similar to that from agricultural fields is likely. However, I would not expect nutrient loading beyond increased sediment. Brooks (1988) in reviewing the hydrologic impacts of peat mining in Minnesota concluded that peat mining probably decreased the peak runoff period and increased water yield.

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RECOMMENDED MANAGEMENT PRACTICES FOR FORESTED WETLANDS ROAD CONSTRUCTION

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Abstract.-The provisions of Section 404 of the Federal Water Pollution Control Act, which must be met for construction of forest roads in wetlands without a permit, are reviewed as well as the Best Management Practices developed by the states of Georgia, Florida and South Carolina which relate to wetland road construction. Good and bad examples of wetland road construction practices are given.

INTRODUCTION

Forest road construction in wetlands presents some unique challenges even without regulations, but current regulations make the challenges even greater. To put in a road system that is environmentally sound, has low establishment costs, low maintenance costs and gets you where you want to go is often hard to do. There is no one "best" way or "right" way that can be used to establish roads in all the different types of wetland situations but there are certainly some practices that are prevented by law and other practices that common sense tells you not to use. I am no expert on road construction but Russ Lea and others who have seen Rayonier's wetland road construction practices feel that we have some good examples of how it should be done and ask that I share them with you. Since our company's experience is limited in terms of the geographic area in which we operate, mainly southeast Georgia and northeast Florida, I have received assistance with slides and techniques from Steve Kinnerly of Georgia Pacific and Rob Olszewski of the Florida Forestry Association and I am very appreciative of their help.

FEDERAL REGULATIONS

Two sections of the Federal Water Pollution Control Act (FWPCA) affect road construction in wetlands. Section 404 regulates dredge and fill operations in wetlands and Section 208 regulates nonpoint sources of pollution.

SECTION 404

The final Corp of Engineers Section 404 regulations list fifteen "baseline provision" which must be followed in order for a forest road to be constructed and/or maintained and not require a permit.

In addition to these fifteen provisions there is the general statement preceeding them that states "constructed and maintained in accordance with best management practices to assure that flow and circulation pattern and chemical and biological characteristics of waters of the United States are not impaired, that the reach of the waters of the United States is not reduced and that any adverse effect on the aquatic environment will be otherwise minimized."

That lays the groundwork for the fifteen specific provisions which are summarized as follows:

FIFTEEN PROVISIONS FROM SECTION 404

1. Permanent roads will be held to the minimum feasible number, width and total length.
2. Located sufficiently far from streams.
3. Must be bridged or culverted.
4. Fill will be stabilized to prevent erosion.
5. Discharges of fill material must minimize the encroachment of equipment outside the lateral boundaries of the fill itself.
6. Vegetative disturbance in the waters of the U.S. shall be kept to a minimum.
7. Roads shall not disrupt the movement of aquatic life.
8. Borrow material shall be taken from upland sources.
9. The discharge shall not take or jeopardize the existance of a threatened or endangered species.
10. Avoid discharge into 'breeding and nesting areas for migratory waterfowl.
11. No discharge in the proximity of a public water supply.
12. No discharge in concentrated shellfish production areas.
13. No discharge on a National Wild and Scenic River.
14. No toxic pollutants in the discharge.
15. Temporary fills shall be removed completely after use.

SECTION 208

Section 208 of the FWPCA requires each state to develop voluntary Best Management Practices (BMP's) to control nonpoint source pollution from forestry practices so our road construction practices must comply with these BMP's. The BMP's are similar for each of the southeastern states in which Rayonier operates and for wetland road construction recommend such practices as:

1. Plan before construction.
2. Minimize number of roads and stream crossings.
3. Stabilize fill material.
4. Cross streams at right angles.
5. Utilize temporary roads where possible.
6. Use sufficient bridges, culverts or fords to allow for the free flow of water.
7. Use a minimum amount of fill material.

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IMPLEMENTATION

Now that we know the Federal regulations and the state BMP's we are ready to begin planning our road. At this point you might wonder, why build a road at all? If the objective is to harvest timber, why not use a system such as a helicopter or high lead that does not require a road? Even these systems require some access roads but in our operating area, with very few exceptions, all of the harvesting of wetlands is done with conventional systems using rubber tired skidders. Since many wetland areas are accessible using conventional equipment during dry periods and the value of the hardwood is so low, it is more economical to build roads and use conventional equipment than to use the more expensive specialized equipment. If hardwood ever becomes so scarce that harvesting has to continue in wetlands even during the wettest periods and the value of the wood gets high enough, more specialized systems will become feasible.

RAYONIER EXAMPLE

The most extensive wetland road system that Rayonier has is along the Altamaha River in Wayne and Long counties Georgia. We own about 15,000 acres of hardwood bottomland in the flood plain of the Altamaha which is classified by the N.C. State Hardwood Research Cooperative as a Red River Bottom. During most years this river swamp is loggable during a three to four month dry period in late summer and fall.

The BMP's recommend planning as the first step in road construction and in the mid-1970's a plan was prepared for the primary access roads for a 6,000 acre island that is 100% river swamp. A primary concern was crossing as few streams or sloughs as possible and still access the timber. The roads were not all constructed at one time but progressed over the years as harvesting progressed.

The actual road construction process consists of harvesting the timber from the future road area as well as about fifty feet on either side, removing the stumps from the road bed area and grading the road flat and level with the adjacent forest floor except for a slight crown in the center so that rain water will drain off. When the river rises we want the water not to be restricted, but to flow freely over the road. No ditches or fills are used on the road, but when a slough is crossed either a bridge is built or a culvert is used and some fill placed over the culvert. Sloughs are always crossed at right angles. The roads are not graded if there is no logging activity on them and they are allowed to grass over, which happens very quickly. The reason for cutting the extra fifty feet of timber on either side is to let more sunlight in to dry the road quicker. These road borders are allowed to revegetate naturally. The key to keeping these roads in good shape and keeping maintenance costs low is to not use them when they are wet. When wet, they rut easily and are very slick but once they dry out they are hard as a rock.

This type of road fulfills all of the requirements I listed earlier under Section 404 and the BMP's and still serves us well in harvesting timber. The following are some of the Best Management Practices demonstrated by this road system:

A. A plan was made prior to construction.
B. Only a minimum number of roads were used.
C. Sloughs are crossed at right angles.
D. Bridges and culverts are used.
E. Very little fill material is used.
F. Roads are allowed to grass over when not in use.
G. Roads are same elevation as adjacent forest floor.
H. No ditches are used.
I. Use restricted when wet.

In other situations there are other good management practices that can be used. One example is to use a ford instead of a culvert or bridge to cross a stream. In a recent issue of the Southern Journal of Applied Forestry there was an excellent article by Steven Milauskas illustrating various types of construction for these crossings (Milauskas 1988). Three materials that are used to stabilize the bottom of the ford are hard sand if you are fortunate enough to have it, lime rock or poured cement.

In some situations fill material must be used to build up a roadbed to cross a wetland area. In these cases the road should be perpendicular to the flow of the stream, culverts or bridges sufficient to carry the water should be used, fill material should be stabilized by sowing grass or other ground cover and possibly the immediate area around the culvert or bridge abutments sandbagged to keep the force of the water from eroding the fill.

COMMON MISTAKES

Three bad management practices I have seen that should be avoided pertain to the use of culverts or bridges and fill material. Sometimes fill material is just pushed into small intermittent streams with the understanding that it will just "blow out" during the next wet season after logging has been completed. This is a very bad practice and demonstrates an attitude that needs to change.

The second is the inadequate size or wrong placement of culverts. In these cases the attitude is right but the execution is wrong and the stream washes across the road usually on one side of the culvert and removes the fill material on that side in the process.

A third that is fairly common is the use of a long fill with an inadequate number of culverts or culverts placed at the wrong height. In these cases there is a prolonged period of impounded water on the upstream side.

Another bad practice would be to grade the roads flat and leave the berm along the outside edges of the road. This does two things: 1) it prevents rain water from running off while the road is in use and keeps it wetter for a longer period of time making it impassable or causing rutting if there is traffic and 2) when the river level rises and water starts to flow over the road, these berms act like small dams and restrict the flow of water.

BEAVER PROBLEM

Sometimes the attitude and execution are both good but we still run into a problem with water standing on the upstream side of a culverted fill. In these cases the problem is one of the south's major pests-the beaver. I wish I had a Best Management Practice that would work to keep beavers from stopping up culverts but I do not. Everything we have tried has been temporary or requires alot of maintenance. One thing I saw being tried recently was a very heavy gauge welded wire placed on the upstream side of culverts and arched away from the culvert opening. The beavers will still build their dam against the wire but not inside the culvert, therefore, it is much easier to remove the dam from in front of the wire than from inside the culvert. Maintenance must be done every day since they will dam it up every night.

CONCLUSION

Section 404 and state BMP's provide guidelines for road construction in wetlands, but in addition, common sense and good judgement must also be applied since each road construction project is a little different. If attention is paid to the good and bad practices I have mentioned I believe we can have adequate wetland road systems with a minimum of environmental impact.

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WATER MANAGEMENT OF A BALDCYPRESS-TUPELO WETLAND FOR TIMBER AND WILDLIFE

Edward R. Drayton III and Donal D. Hook[1]

Abstract.-A permit was obtained from the U.S. Army Corps of Engineers to install and operate a water management system on a 600 ha (1500 acres) tract of mature baldcypress and water tupelo in South Carolina. The purpose of water management was to restore the hydroperiods of the swamp so that it favored the regeneration and rapid growth of indigenous tree species, enhanced specific wildlife habitat, and allowed control of the water table level to facilitate harvesting. Extensive environmental assessements and a management plan were required. It took over two years to obtain the permit and slightly over a year to install the water control structures. Visual observations, of the area approximately three years after the primary structures were completed and some timber harvesting had been done, indicated that the management plan had been followed and it was successful in restoring the hydrology and productivity of the site. The area is a good example of what water management can do to restore wetland functions.

INTRODUCTION

The Sonoco Products Company of Hartsville, South Carolina, depends entirely upon hardwood timber to supply its wood manufacturing plants in the Carolinas. Sonoco owns or leases 21,000 ha (52,000 acres) of predominately red river bottomland to help supply its hardwood needs. Its primary land management objectives are to grow timber to meet the needs of these plants and manage the wetland forests for game species in an environmentally compatible manner. Thus, the company is concerned with site characteristics that influence timber, wildlife, and wetland functions. A portion of the company's timberland are blackwater swamps which occur adjacent to the Great Pee Dee River and are subjected to backwater flooding when the river is in high flood stages.

During the 1970's it became apparent to company foresters that existing stands of water tupelo (*Nyssa aquatic* L.) and baldcypress (*Taxodium distichum* (L.) Rich.) were deteriorating. Many trees had die-back in the tops, mortality rate appeared to be greater than normal, and their growth rate was declining faster than normal on a 600 ha (1500 acres) tract (Causeway Unit) of land adjacent to the Great Pee Dee River. The area remained flooded almost all growing season, thus there was little or no opportunity for the tree species to germinate in the nearly continuously flooded soils. It was thought that the cause of reduced growth and vigor of the trees was due to poor water and soil aeration associated with slow moving and/or stagnant waters in Flat Creek and Tarkiln Creek, the blackwater streams that feed and drain this area. These streams were clogged with silt and organic debris. Part of the clogging appeared to be associated with natural mortality and silt carried in by backwaters from the Great Pee Dee River. However, beaver activity in the creeks had compounded the problem.

It was obvious that some action needed to be taken to alleviate the poor drainage conditions or the natural productivity of the Causeway tract would continue to decline and would probably result in a species composition change.

In an attempt to rectify the situation, Sonoco Products Company applied to the U.S. Army Corps of Engineers in 1981 for a permit to manage the water on this tract to enhance timber and game production and to facilitate harvesting of timber. A permit was granted for these purposes in 1983 and the water management plan was implemented in 1984. This paper reports on the process of obtaining the permit, describes the water management plan, and the apparent results of water management as of the spring of 1988.

SITE DESCRIPTION

Area

The area under permit is a "perched wetland" bordering the Great Pee Dee River in northeast South Carolina. The timber cover is Forest Cover Type 102, baldcypress-tupelo (Eyre 1981). A mature water tupelo and baldcypress stand occupies the deeper flooded areas with swamp tupelo (*N. sylvatica* var. *biflora* (Walt.) Sarg.), red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), and several other bottomland hardwoods on islands within and on the margins of the area.

The Causeway Unit is basin-shaped and is traversed by Flat Creek and Tarkiln Creek. The main run, Flat Creek, was once a well-defined creek. It meandered through the Causeway Unit and flooded periodically when heavy rains occurred locally or when the Great Pee Dee River flooded. It generally drained rapidly and was usually below flood stage or dry during the summer and fall. Under this regime fine stands of tupelo gum and baldcypress developed in the area and had excellent growth rates.

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History

Much of the area adjacent to and certain parts of the Causeway Unit were cleared for cultivation in the early 1800's and remained in cultivation until a series of devastating floods on the Great Pee Dee River in the period of 1900-1916. These floods broke the dikes or dams built along both sides of the Great Pee Dee River from U.S. Highway 1 crossing at Cheraw to S.C. Highway 34 at Mechanicsville. Following the floods, maintenance on all water control structures, all drainage ditches, and dams in the entire area were abandoned and farming was confined to elevations of 26 m (65 feet) above mean sea level. Most of the remaining cleared land was abandoned in the mid-1930's and the remainder was abandoned in the mid-1950's. Eventually all the abandoned farm land reverted to forest. The higher land reverted to pine or pine-hardwood, the next highest to sweetgum-mixed oaks, and the lower elevation sites to ash, maple, laurel oak, swamp tupelo, baldcypress, and other wetland species. The wettest areas were never farmed and therefore remained in baldcypress and water tupelo following extensive logging in the 1920s.

Soils

The Causeway Unit soils were poorly drained. Both light and heavy textured subsoils, overlaid with a thick layer of fine textured black muck high in organic matter were characteristic of the swamp. Some areas had organic soils but mineral soils predominated. During the study period the soil was very acid (pH = 4.5-5.0) and highly reduced. This indicates that anaerobic and reduced conditions probably persisted in the soils for long periods of time. Under such conditions, submerged-reduced soils typically produce toxic gasses and have altered chemical properties that are detrimental to the growth of plants well adapted to flooded soils (Gambrel1 and Patrick, 1978 and Ponnampurma, 1984).

PROBLEM

When the Great Pee Dee River floods, its backwaters ebb into the area through two or three inlets during the rising flood stage and flows out slowly as the river recedes. Over the years, backwater flooding and subsequent siltation have gradually clogged the outlet of Flat Creek. Also, organic debris accumulated in stream channels and beaver became active in the area in the mid-1970's. The combined forces resulted in slower runoff, caused deeper and longer flood durations, and stagnant water to occur on a significant portion of the Causeway Unit. Consequently, normal seasonal drying was reduced or precluded and tree growth and survival rates were compromised. Also, regeneration opportunities were restricted because of excessive water which interferes with germination of seed of desirable tree species. Finally, logging could no longer be conducted using conventional equipment due to the excessively wet conditions. Several costly alternative methods to tractor logging were considered including helicopter, hi-lead cable, and low ground pressure track skidders. All of these methods were ruled out because they were impractical or unavailable nor would these systems restore the productivity to the site. The only environmentally and economically sound solution to improving the growth and regeneration potential of the site's indigenous species seemed to be to restore the hydrologic characteristics of the site so that excessive surface water would drain off at a rate sufficient to restore the productivity of the swamp forest.

WATERMANAGEMENTPLAN

In order to overcome poor drainage in the Causeway Unit a Timber and Water Management Plan was developed. The plan was designed so that water regimes could be controlled to favor regeneration and growth of desirable tree species, enhance dormant season habitats for water fowl, and to facilitate logging by conventional methods. The plan called for the:

1) Construction of a water management canal 7-1/2 miles long to traverse the area (Figure 1) and the spoil from the canal to be used for construction of adjacent access road and water control structures,

2) Management of soil moisture and flooding of harvested areas for maximum natural seed germination and regeneration of tupelos and baldcypress, the preferred species following clearcutting,

3) Management of water levels in the harvested areas to benefit seasonal water fowl use of the area,

4) Designation of timber harvesting areas (100 to 150 acres each), as defined by water management capability, for controlling harvesting during the next 15 years.

The significant and new features of this management plan was the capability and flexibility to manage water levels to optimize germination, regeneration, and growth of tupelos and baldcypress without significantly interfering with the functions of the wetland. Although these species are well adapted to live and thrive in flooded environments (Hook and Brown 1973; Hook, Brown and Kormanik 1971), their seed do not germinate under water (DeBell and Naylor 1972) and their growth is hindered by stagnant water (Hook and others 1970), or by minor alterations of the water regimes (Harms 1973; Hook 1978; DeBell and others 1982; Theriot 1987). The execution of this plan required considerable effort and cost. To our knowledge no other attempt, on this scale, has been made to enhance wetland tree species and wetland functions in this manner.

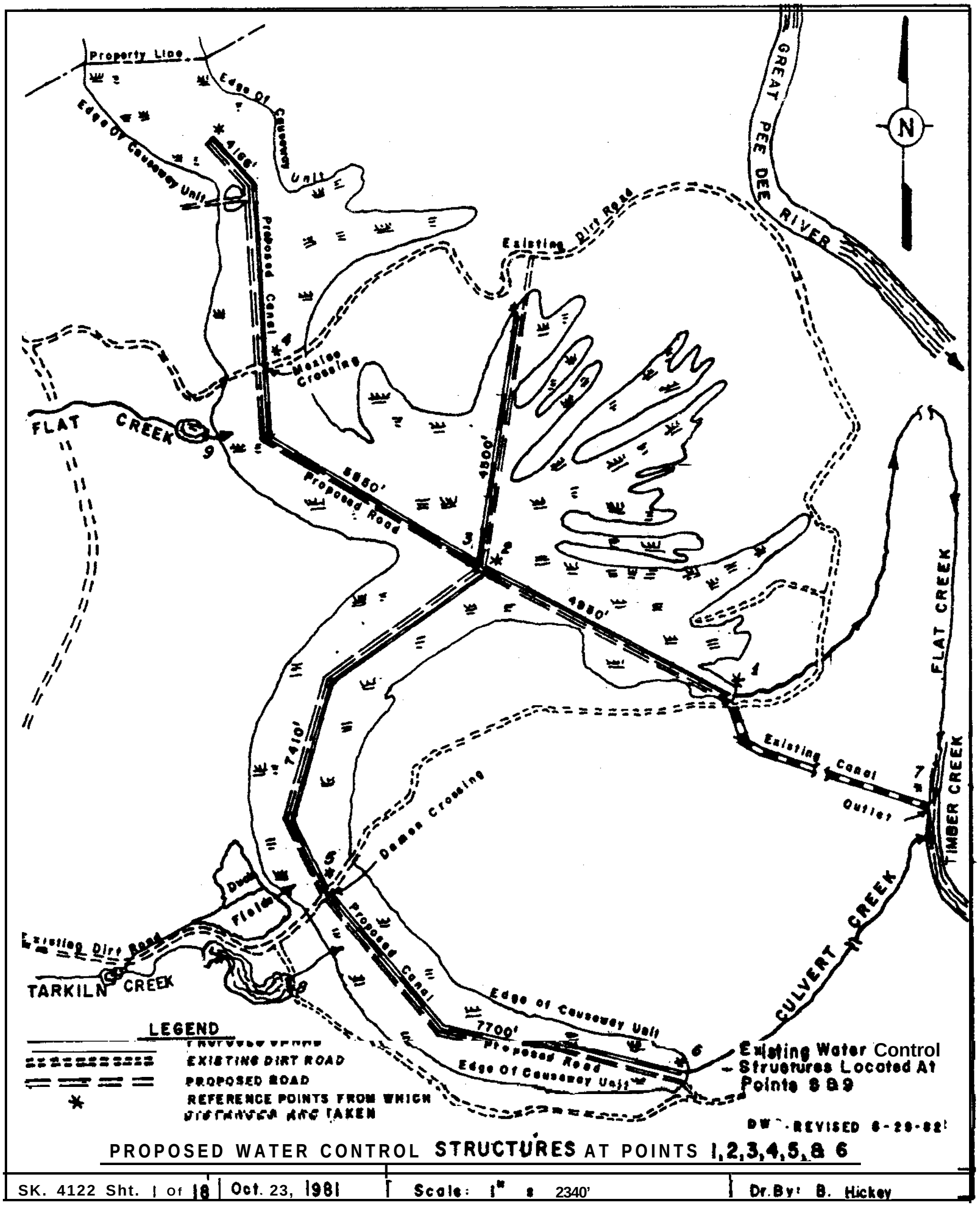

Figure 1 .-SONOCO PRODUCTS COMPANY proposed excavation and fill for: Causeway Wetlands Timber Unit, located near Mont Clare, Darlington County, SC (Flat Creek and Great Pee Dee River).

OBTAINING AN EXCAVATION AND FILL PERMIT

Since the company had prior experience in working with the Corps of Engineers on another project, some knowledge of permit steps and problems were known. The steps were:

1) Arranged for Corps personnel to visit the site and discuss the project. Subsequently the Corps notified the company that a permit would be required to deposit excavated material in wetlands adjacent to Flat and Tarkiln Creeks,

2) Filed application (form Number 4345) and a detailed Water Management Plan with the Corps of Engineers office in Charleston, South Carolina. It took four months to complete the management plan and application,

3) Upon receipt of the application the Corps determined that a public notice was sufficient and that public hearings would not be necessary,

4) A public notice was issued and a normal 30-day review and comment period scheduled. Many responses were received; they included comments from federal and state agencies and special interest groups,

5) A tour was arranged for all interested organizations to inspect the area. Most concerns were fish and wildlife values and environmental implications,

6) Based on the responses, the Corps, decided an Environmental Impact Study was not necessary but that an Environmental Assessment Study would be required (the latter is not as comprehensive as an Impact Study),

7) Sonoco retained the services of experts in wildlife, fisheries, macroinvertebrates, water quality, herpetology, hydrology, and hydraulic disciplines to examine the site, review the proposed water management plan, and do an environmental assessment. The experts in their reports did not identify any significant adverse impacts of the proposed plan (see Drayton and Rogers 1981 for details). In fact, the scientists indicated in their opinion that the plan provided an opportunity to enhance the value and productivity of the wetland habitat,

8) After several meetings, with agencies or organizations such as the U.S. Fish and Wildlife Service, S.C. Wildlife and Marine Resources, S.C. Department of Health and Environmental Control, S.C. Wildlife Federation, Sierra Club, and National Audubon Society, the Section 404 permit was issued with special constraints. The constraints were that the proposed project would be conducted in accordance with the Timber and Water Management Plan as submitted to the Corps of Engineers.

The permit was applied for on April 22, 1981 and granted on March 1, 1983. It took three months to complete the environmental assessment studies, reports, and plan development and one year to dig the 7-1/2 miles of canals and install water control structures. The canal and basic control structures were completed in July 1984. It took four years from project conception time until the canal construction was completed. At the time the permit was granted, it was reported to be the only forest industrial wetland excavation and fill permit issued in the entire United States.

COST OF THE PROJECT

A. Cost of consultants for environmental impact assessment was $20961.95. This does not include the cost of company personnel for plan development, community contacts, and permit application.

B. Cost of construction of canal, roadway, and water control structures were $187,176.

EVALUATION OF PROJECT

As of this date no quantitative assessment has been made of the project. However, several groups have visited the site and made visual assessments at various stages of progress. They include the U.S. Corps of Engineers, company technical personnel, and wetland forestry experts. The general consensus of these groups was that the project is working as designed and predicted.

The ditch captures the excess surface water and channels it out of the Causeway basin in a reasonable period of time yet it does not cause excessive drainage of the area. The terrain dries enough in the summer and fall to allow harvesting of timber using track skidders primarily, but in some drier areas conventional wheel skidders can be used. Soil displacement due to skidders has been minimal, in fact, it has been much less than anticipated. Also, by using the water control structures, flooding of designated areas for water fowl use during the late fall and winter has been achieved.

'Timber harvesting under the Water Management Plan has been in progress for only three years and only one tract has been completely harvested. Visual observations on May 25, 1988, by university, U.S. Forest Service, and company personnel of all areas that had been harvested and allowed to regenerate for one growing season or more, indicated that the sites were adequately stocked with desirable indigenous tree species. The tree regeneration of one to four years of age generally exceeded a meter in height. Therefore, tree growth rate appeared to be excellent. Water tupelo and baldcypress regeneration was predominant on most areas while the composition of red maple and green ash seemed to be slightly higher than in the parent stand. Whether this is the case can not be determined until actual regeneration counts are made. Thus, one can only conclude that regeneration appears to be more than adequate and is composed of desirable indigenous tree species. Their growth rate seems to be promising especially stump sprouts of water tupelo. Many areas had water tupelo stump sprouts that were 3 to 5 meters tall. Stump sprouting has proven to be an excellent means of regenerating this species in the Wateree River bottom near its conjunction with the Congaree River (Hook, Legrande, and Langdon 1967) and is therefore judged to be suitable regeneration in this case. It is possible that this water management scheme has maintained the diversity of tree species in these wetlands, and if so this diversity may enhance the value of these wetlands for wildlife habitat.

Removing the excess surface water appeared to create near optimum conditions for germination, establishment, and early growth of desirable tree species (DeBell and Naylor 1972). Under this water regime the soil conditions are saturated but not flooded. In addition they are flushed by periodic flooding and surface water run-off. Maintenance of saturated soil by the control structures assures that tupelos and baldcypress will be the dominant composition in the developing stand. The action of the periodic flooding and drainage of excess surface water helps flush toxic compounds from the soil and periodically restores a degree of aeration to the saturated soil. Klawitter (1962), Hook and others (1970), Gambrell and Patrick (1978), and Armstrong (1979ab) reported that moving water and periodic flushing of wetland soils is beneficial to vascular plant growth in such sites. The combination of improved soil aeration, periodic flushing, reduction in duration of hydroperiod, and increased movement of water should provide for near optimum growth for the young seedlings of baldcypress, tupelos, red maple, and green ash.

Water control during the growing season for the purpose of stimulating growth and controlling species composition will not be initiated until the transpirational demand of the stand begins to visibly influence the water table level. The age that this occurs for baldcypress-tupelo stands is not documented therefore it will be necessary to monitor the water table level closely for evidence of water table draw down as the stands develop. Water table level control will probably need to be initiated between the ages of 5 to 10 years. All indications are that the plan has been well implemented and every visible aspect of the project appears to be consistent with the objectives.

SUMMARY

A new concept in water management for timber and wildlife production in a baldcypress-tupelo swamp has been put into practice on a commercial scale. With water level management, harvesting of products can be done in an economically and ecologically sound manner without significantly altering the character of the wetland. In the process of water management favorable habitats were maintained or enhanced on a seasonal basis for wildlife.

A demonstration site or field laboratory has been made available for studying the influence of continuous harvesting and managing the water table for timber and environmental purposes that is compatible with the current federal and state regulations, specifically Section 464 of the Clean Water Act.

By using water management techniques mature timber can be harvested with conventional equipment reducing impacts to the soil and hydrology of the harvested area.

By using water management techniques, desired hardwood species can be regenerated by natural regeneration methods and the water table can be regulated to favor the soil water demands as the stand matures. Water management also permits the control of water levels during the dormant season to favor water fowl use. With this plan it is anticipated that the next generation of timber will have a natural species mix and its growth rate will be fostered by controlling the water table level to favor specific species requirements.

Water management is not recommended for all swamp or forested wetland sites. However, in specific cases as with this tract in South Carolina, when the opportunity permits this option for managing forested wetlands should be considered. The history of this area documents that this wetland forest system is not static. Other evidence indicates that forested wetlands are in a constant state of growth, consumptive regression, regeneration, and regrowth with or without man's interference. For instance, (Odum 1984) suggested that some cypress swamps in Florida may complete growth, regression, and regrowth cycles in periods as short as one hundred years. He indicated the energy input to perpetuate such cycles is provided by natural catastrophes and/or man's attempts to manage these systems on approximately the same time scale.

Thus, as we struggle to determine how to protect and manage our wetland resources, it seems that we should recognize we are dealing with dynamic systems. They will change over time due to natural causes, catastrophes, or man's activities outside the realm of the land owner's control. Siltation and accumulation of organic matter can slowly lead to stagnant water regimes and filling of swamps. Catastrophes such as fires, hurricanes, wind, disease, and insect epidemics can and do significantly alter forested wetland systems. Channelization, dams, and siltation from nearby farming and logging can also alter adjacent or down stream wetlands. If we recognize that forested wetlands are dynamic systems and we have the flexibility to manage their water regimes, we can in many cases restore severely degraded wetland systems to productive ones that have many desirable functions and values.

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FORESTLAND DRAINAGE AND REGULATION IN THE SOUTHERN COASTAL PLAIN

Robert J. Olszewski[1]

Abstract.—Drainage is a management tool which has been utilized by foresters for years in the Southeastern U.S. Regulations have been developed relatively recently to contol the level and intensity of forestland drainage. While regulations can not be written to address all specific conditions, reasonable interpretation should result in continued beneficial use of minor drainage in Southern Coastal Plain pine flatwoods.

INTRODUCTION

". . . Some agricultural and forestry activities are compatible with retention of important natural wetland functions; others are not. Depending on the kind of alterations made, wetlands may return to their natural state in the absence of cultivation or drainage."

This quotation from "Our Nation's Wetlands", a 19'78 U.S. Government Interagency Task Force Report, thrusts the forestry community squarely into the middle of the nation's relatively new-found concerns over the values of wetlands. Not long ago, few questioned the 'wisdom" of converting the "wasted" acreage into productive agricultural lands. Society has now recognized the many other values of our wetland resources and in many cases, developed regulations at the federal, state or local levels to protect these resources.

Where does this trend leave the forest manager? At least at the federal level, the 19'77 Clean Water Act Amendments exempted normal farming, forestry and ranching activities, including minor drainage activities and forest road construction from Section 404 Dredge and Fill Permit requirements. Certainly the 1977 Amendments and subsequent regulations have helped forest land managers to continue operating in forested wetlands. Perhaps the forester can even theorize that such exemption language represents a recognition by Congress that certain types of management regimes-under appropriate constraints-are compatible with the protection of wetland values.

But regulation is an inexact science. The regulator's task in developing specific language to deal with enforcement of a statute is most difficult. Inevitably, regulatory language must be interpreted in "on-the-ground" situations between an enforcement agency employee and the practioner, who could be a forest land manager.

The problems in drafting and interpreting specific regulatory language apply whether involving criteria for granting of certain permits or defining exemptions. The latter case is the most common example that foresters find themselves mired in today when tied to Federal Dredge and Fill Regulations. What are "normal silvicultural activities"? What constitutes "an established operation"? What kind of activities qualify as an "immediate or gradual conversion of a wetland to a non-wetland"? What is a "permanent road (for farming or forestry activities)"? What is a "wetland"? What is "minor drainage" and what kind of drainage activities are considered exempt? All are questions the forester and regulator are forced to address when interpreting Federal Dredge and Fill Regulations. To be fair, there is some explanatory language in the Regulations to help with interpretation but in reality there are still major areas of interpretation to be made.

The necessary interpretations are usually made as a result of interaction between the regulatory agency, the regulated interest and other interested individuals or groups. The interpretations may be made "one-on-one" in the field or office or they may be made between an agency and interest groups such as associations or environmental organizations. In our system, the ultimate "interpreter" is the courts. One other alternative to the interpretation problem exists-a change in the statute.

One of the significant emerging areas of interpretation needs in terms of forested wetland regulation involves the issue of "minor drainage." What is minor drainage in association with forestry operations, why do foresters conduct minor drainage and how do regulatory agencies deal with it?

WETLANDS DEFINITIONS

One can not enter a discussion of issues surrounding minor drainage without acknowledging first the issue of wetland definition. One widely-known case in the Tampa Bay Area of Florida involved a developer who had five different wetland jurisdictional lines on his property staked out by five different regulatory agencies. Boring et al. (1988) provide a good discussion of the wetland jurisdictional techniques used by the Corps of Engineers in enforcing Section 404. The Corps uses a three-pronged approach dependent on the presence of certain types of vegetation soils and hydrology.

For purposes of a discussion relating to minor drainage, it's important to acknowledge that the Corps technique establishes jurisdiction in many low, wet areas of the Southern Coastal Plain capable of supporting pine production. Other regulatory agencies may use other techniques which define such areas as wetlands; this is a complex subject in itself and subject to considerable debate in the scientific

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community. In spite of the lack of a clear consensus on this topic, wetland regulations have been developed and the process will continue.

WHY CONDUCT "MINOR DRAINAGE" WITH FORESTRY OPERATIONS? WHAT EFFECTS DOES IT HAVE?

The extensive areas of the Southern Coastal Plain with high water table conditions present have long intrigued forest land managers with the possibilities of benefits from forest water management. Wilhite and Sands (1964) reported on the results of a drainage test implemented in 1947 in Glynn County, Georgia. Using a dragline constructed by the landowner, a three-mile long and four-foot deep ditch was dug to drain about 800 acres. Drainage apparently failed to increase the growth of established slash pines but appeared to improve both stocking associated with natural regeneration and growth of newly planted pines.

Hughes (1982) presents a 1980's perspective of why foresters need drainage as a land management option on specific sites: "1) to increase equipment operability during wet weather and 2) to enhance tree growth." Others have discussed the interactions between nutrient uptake, fertilization, soil aeration and high water table conditions and suggested possible benefits in manipulating water table depths to improve pine growth (Tiarks and Shoulders 1982; Shoulders and Ralston 1975; and McKee et al. 1934; White and Pritchett 19'70; Miller and Maki, 1957).

The harvest of pine stands on Coastal Plain sites with predominantly high water tables results in the lowering of rates of evapotranspiration from sites and a corresponding decrease in water table depth (Trousdell and Hoover 1955). There appears to be a very distinct drainage need on such sites immediately previous to harvest and through the intitial establishment of the planted stand. Terry and Hughes (1978) prescribe pre-logging drainage at least one year prior to harvest on sites in eastern North Carolina. Pre-harvest drainage helps protect the site from damage as a result of soil compaction and poor site preparation practices. McKee et al. (1985) agree that artificial drainage may be necessary on wet, flat sites to facilitate logging and regeneration.

As stand establishment progresses, evapotranspiration rates from low, wet Southern Coastal Plain sites appear to increase rapidly. Hughes (1982) reports that "forest transpiration is a major water table draw-down factor for at least 6 months each year and occurs to a limited degree in pine stands for at least 8–10 months" in eastern North Carolina. This influence on water table draw-down increases rapidly from age one to age 6–10 and then increases less rapidly until maximum stand basal area is reached between ages 15 and 20. Further south, one can expect vegetative dominance of water table draw-down to be more rapid; in fact, Rodriguez (1981) noted in a paired watershed experiment in Franklin County, Florida, that a watershed consisting of a 4-year-old intensively managed plantation showed a significantly lower hydrologic response than an adjacent, poorly stocked control watershed. This condition implies pine plantation transpiration beginning to dominate control over water table conditions at a young age on drained sites. As evapotranspiration increases and water table depth deepens, water yield and hydrologic response can also be expected to decrease. These are important facts when considering potential effects on receiving waters downstream.

Different land managers appear to demonstrate some varying philosophies in terms of drainage practices. While some appear to use drainage infrequently and doubt its ability to provide positive returns on investment, others install well-engineered ditching systems in a grid pattern. These systems are sometimes designed to be maintained throughout the length of an entire rotation and may include various types of water control structures. Ditches may also be installed on a "spot" or prescriptive basis without much engineering design necessary. A number of land managers believe drainage can only be justified on low, wet, flat sites during the 4-5 year period surrounding the harvest, site preparation and plantation establishment sequence; after that, drainage ditches are abandoned to erode and lose hydraulic efficiency as vegetative transpiration increases. Such decisions are based on certain growth and investment assumptions, along with consideration for specific site conditions and applicable environmental regulations.

State water quality protection programs for forestry-208 programs-have emphasized sediment as the predominant potential nonpoint source pollution problem from silvicultural operations. Askew and Williams (1934) found that logging and site preparation on a low, wet, flat South Carolina Coastal Plain site did not cause an appreciable increase in suspended sediment if equipment was kept out of drainage ditches. Main haul roads and ditch installation produced highest average suspended sediment concentrations (47.0 mg/1) but even these declined rapidly downstream of the ditch. Within two years of construction, there appeared no appreciable erosion from ditch banks and bottoms. "It was obvious that ditch erosion was not a major contributing factor to sediment loads of drainage water" (Askew and Williams 1934).

REGULATORY ISSUES REGARDING MINOR DRAINAGE

On a regional basis, the Corps of Engineers Section 404 program has the most potential impact on minor drainage involving silvicultural activities. Part 232.3, Code of Federal Regulations, published June 6, 1988, defines minor drainage exemptions extensively. Any forest manager conducting minor drainage in the Southern Coastal Plain should have a copy of these regulations and be prepared to discuss them. The regulations state:

(3) [i] Minor drainage means:

[A] The discharge of dredged or fill material incidental to connecting upland drainage facilities to waters of the United States, adequate to effect the removal of excess soil moisture from upland croplands. Construction and maintenance of upland (dryland) facilities, such as ditching and tiling, incidental to the planting, cultivating, protecting, or harvesting of crops, involve no discharge of dredged or fill material into waters of the United States, and as such never require a Section 404 permit;

[B] The discharge of dredged or fill material for the purpose of installing ditching or other water control facilities incidental to planting, cultivating, protecting, or harvesting of rice, cranberries or other wetland crop species, where these activities and the discharge occur in waters of the United States which are in established use for such agricultural and silvicultural wetland crop production;

[C] The discharge of dredged or fill material for the purpose of manipulating the water level of, or regulating the flow or distribution of water within, existing impoundments which have been constructed in accordance with applicable requirements of the Act, and which are in established use for the production of rice, cranberries, or other wetland crop species.

[Note.-The provisions of paragraphs [d] [3] [i] [B] and [Cl of this section apply to areas that are in established use exclusively for wetland crop production as well as areas in established use for conventional wetland/non-wetland crop rotation [e.g., the rotations of rice and soybeans] where such rotation results in the cyclical or intermittent temporary dewatering of such areas.

[ii] Minor drainage in waters of the United States is limited to drainage within areas that are part of an established farming or silviculture operation. It does not include drainage associated with the immediate or gradual conversion of a wetland to a non-wetland [e.g., wetland species to upland species not typically adequate to life in saturated soil conditions], or conversion from one wetland use to another (for example, silviculture to farming).

In addition, minor drainage does not include the construction of any canal, ditch, dike or other waterway or structure which drains or otherwise significantly modifies a stream, lake, swamp, bog or any other wetland or aquatic area constituting waters of the United States. Any discharge of dredged or fill material into the waters of the United States incidental to the construction of any such structure or waterway requires a permit.

There appear to be clear exemptions for connecting upland drainage facilities to waters of the United States. However, the criteria for allowance of minor drainage in waters of the United States seems much less clear, and is more tied to the interpretation of three key questions:

(1) Does the area being drained constitute part of an established farming or silviculture operation?

(2) Is the drainage associated with the immediate or gradual conversion of a wetland to a non-wetland?

(3) Do constructed canals or ditches drain or significantly modify a stream, lake, swamp, bog or other wetland constituting waters of the United States?

Each of these questions must be addressed on a case-by-case basis. The regulations provide some help in defining an "established" operation, but the long rotations associated with silvicultural operations create confusion in this area. Many low, wet sites have been poorly managed in recent years creating conditions of low stocking and an unmanaged perception to the regulator. Regarding question (2), the forester utilizing drainage certainly is attempting to manipulate the vegetative mix and stocking on a site, but minor drainage often does not convert an area from a wetland to a non-wetland according to definitions used by the Corps of Engineers. All three questions require a site analysis and appropriate interpretation, but nowhere is this more true than with question (3).

Other conditions surrounding the minor drainage exemptions apply; the rule should be reviewed for clarification and specifics. If a specific site fails to meet the requirements to qualify for exemption status, the landowner may apply for a permit to conduct drainage activities. Under this alternative, the Corps and EPA will evaluate the proposal under a broad range of environmental concerns. This analysis will review not only water resource impacts, but fish and wildlife habitat impacts as indicated by the U.S. Fish and Wildlife Service.

Other agencies may regulate "minor drainage" associated with silvicultural activities using different criteria. For example, in Chapter 40C-43, Florida Administrative Code, the St. Johns River Water Management District (SJRWMD) grants general permits for:

> "Upland field ditches of a temporary nature to facilitate only harvesting, site preparation, and planting, with a maximum cross-sectional area of eighteen (18) square feet spaced no closer than six hundred and sixty (660) feet from any other parallel ditch. After seedling establishment, the ditches shall be allowed to revegetate naturally. The permittee will not be required to fill field ditches after seedling establishment."

At this time, the technique used by the SJRWMD for determining wetland jurisdiction does not generally encompass as many low, wet Florida flatwood areas as that used by the Corps. All ditching requires at least a general permit in the SJRWMD; those silvicultural drainage projects which fail to meet general permit criteria require a more detailed individual permit for approval.

WHERE DO WE GO FROM HERE?

The short review presented in the previous section should establish the fact that interpretation at the level of the individual, the agency, the company, or the court provides one of the most significant, yet overlooked, elements in regulatory programs. The minor drainage issue provides an excellent example to support this case.

Interpretations are generally supported and encouraged by facts surrounding the impacts of regulated or exempted resource management activities. The good forest manager should know:

(1) The regulations and specific exemption language regarding minor drainage if involved with such operations

(2) As much as possible regarding potential environmental impacts of his drainage activities

(3) What he can do to minimize adverse impacts

(4) Enough to respond professionally to any questions a regulator may pose regarding drainage.

Drainage on low, wet flatwood sites in the Southern Coastal Plain has limited, manageable impacts from the water resource perspective. Indeed, most of the activities conducted by the forestry community appear to fall within the definition of "minor drainage" under Federal Dredge and Fill (Section 404) Regulations. More information will be developed in future years on water resource impacts and in other areas of environmental concern such as wildlife habitat. But perhaps most important, much room for interpretation remains. The forestry community's level of preparation in dealing with such interpretations will have much to do with the long-term viability of drainage as a tool in managing the pine forests of the Southern Coastal Plain.

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WETLANDS HARVESTING
SCOTT PAPER COMPANY

Phillip W. Willingham[1]

Abstract.-Wetlands in the Mobile-Tensaw River Delta have been logged for Cypress and Tupelo Gum since the early 1700's using various systems consistent with the technology of the times. In 1984, Scott Paper Company began experimenting with cable logging designs to determine most economical and least site damaging method but found cable systems generally unsatisfactory. In 1986, helicopter logging was tested and determined to be cost effective, safe, and least damaging to wetland sites. This paper describes experiences and results using both systems and other on-going research for better wetlands logging systems.

INTRODUCTION

Over the past four years, Scott Paper Company's Southeast Timberlands has intensively experimented with wetland timber management using various harvesting techniques. As a result, several unique forestry practices have been developed.

The company currently owns 57,000 timbered acres of wetlands in the Mobile-Tensaw River Delta and an additional 17,000 acres in the Pascagoula River Delta. Abundant timber resources available in these areas provide twenty-five percent of the annual hardwood consumption at Scott's Mobile Mill. The close proximity of these lands combined with our river transportation system has resulted in shipping costs which significantly reduce the delivered price of wood to the Mill.

Wetland accessibility was greatly enhanced in 1983 with the in-house development of a river transportation system. Towboats, cranes and barges associated with the river system are the necessary tools needed to access timber resources isolated in the Delta. The development of a harvesting process was the final phase in achieving wetland timber resource utilization.

In 1984, harvesting trials and experiments began in the Lower Delta to develop a successful operation for harvesting Cypress and Tupelo. A number of contractor-operated systems were employed utilizing the principles of the early 1900's pull-boat logging operations. High cost and low productivity discouraged contractors and resulted in the development of a Company owned and operated system. Ground skidding principles were the basis of this system using cables and specialized low ground pressure machinery. Although improvement in productivity was realized, excessive equipment downtime kept costs at an unacceptable level.

In 1986, efforts continued to develop an efficient harvesting system. The inefficiencies, continuous modification, and excessive maintenance of the cable crew equipment prompted the first helicopter logging trail. The first trail showed great potential for a wetlands harvesting operation. The continued development of this technique has resulted in an aerial harvesting application which is now the preferred wetland logging system.

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BACKGROUND

Scott Paper Company's Mobile Mill consumes 950,000 cords of pulpwood annually. Quality writing and publishing papers and personal care and cleaning products manufactured at the facility demand a blend of pine and hardwood fibers. As a result, 60 percent of total raw materials used is hardwood.

To help supply these raw materials, Scott has a land base of 525,000 acres in southwest Alabama and southeast Mississippi. These lands are positioned on or near navigable waters of the Mobile, Alabama, Tombigbee, and Pascagoula Rivers with the paper mill strategically located on the lower end of the Mobile River. This unique geographic link between the Mill and its procurement area has led to the development of an elaborate water transportation system.

Since 1983, five woodyards have been constructed along the waterways. A fleet of fourteen towboats and eighty hopper barges transport almost 90 percent of annual Mill consumption from those locations to Mobile. The remaining 100,000 cords are trucked directly to the Mill from random points.

The development of this water transport system led the way to utilizing the valuable Delta hardwood timber resource conveniently located in close proximity to the Mill. A competitive harvesting operation combined with very favorable transportation costs contribute in supplying our increasing demand for hardwood fiber. Knowledge of past logging operations provided the basis for research and development of a viable harvesting system.

HISTORY - WETLANDS LOGGING

Harvesting cypress and tupelo timber in the southeast dates back to the 1700's when the Mobile Delta was inhabited by American Indians. Records indicate the construction of sawmills in the area in the mid-1700's. Timber production at that time was limited to a method of "float logging". In this application, cypress and tupelo was girdled on the stump in the late fall or winter and allowed to die and reduce its moisture content. Prior to seasonal flooding, the timber was felled, limbed, and topped. Upon flooding, the buoyant stems were floated to mainstreams, rafted together and floated down river to sawmills.

By the late 1700's, numerous settlements in the Delta were established by the French and English. Extensive areas along the river banks were cleared of timber and cultivated for row crops along with the common practice of grazing cattle.

During the early 1800's, at least two sawmills were built on the Tensaw River near what is now known as Live Oak Landing, but it is uncertain how much lumber was produced. The mid-1800's brought an increase in harvesting. During periods of high water, all were concerned with the timber harvest as indicated by the following writings:

> "No idle man was to be found on shore; everybody who could swing an ax, paddle a boat, or pilot a log was in the swamp engaged in felling and floating Cypress timber. All the field hands worked in the swamps; fields and gardens were left untouched, and even clerks from the stores were sent to the swamp as overseers. Trees of small size are as frequently cut as large ones. Saplings from 4 to 12 inches in diameter are even cut . . ." (Mohr 1884).

Just prior to the turn of the century, pull boat logging was introduced which enabled year-round timber harvesting in the Lower Delta. This system was utilized extensively in the Lower Mobile Delta through the mid-1950%.

The operation was labor intensive with a crew of fourteen men. The work force served the task of felling, limbing, topping and bucking the timber, operating the pull boat and rafting the logs. The pull boat rig consisted of a rehaul winch set (two drums) carrying at least one and one-half miles of ¾-inch to l-inch diameter cable.

Having identified the travel lane or "run", stumps were dynamited to clear the way. With winches mounted on a deck barge and cable in place, logs were attached with chokers into the mouth of a six-foot-diameter steel cone. Logs were then ground skidded by the "mainline" to the stream bank with the cone providing uninhibited travel.

At the stream bank, the timber was released. The cone was then retrieved to repeat the process with a "back 'en-upline" or rehaul cable thread through a block or pulley at the opposite end of the run.

Continued tripping of the cone and its cargo created a channel six-feet deep and often was wide. Although somewhat shallowed over time by sediment deposits, these runs are still visible today amidst stands of timber averaging 300 square feet of basal area of 60-plus cores per acre.

Harvesting practices during this era specified a minimum lo-inch diameter for cutting. Residual stems less than 10 inches were not economically operational and supplied no market. The residuals being smaller and suppressed sustained significant damage in the crowns from the felling of the 80- to 115-feet-tall cypress and tupelo. Stump heights ranged from 1 to 3 feet and occasionally higher.

In spite of the ability to move the cone at speeds up to 35 miles per hour, production was slow, a good week yielding only 35 to 40 thousand board feet. Nonetheless, the operation was successful in economically accessing a valuable resource without destroying the site.

CURRENT HARVESTING METHODS

After almost forty years of growth in the tidally influenced Cypress-Tupelo ponds, efforts are once again directed toward utilization of the renewable resource. Environmental concern is in the fore-front focusing on impacts from potential harvesting methods. All available methods have been tried and tested, each having inherent advantages and disadvantages.

COMPANY CABLE LOGGING

Encouraged by the old pull boat methods and contractor operations employed by Scott in late 1984, a Company logging system was designed. With efforts to improve upon prior operations, the following equipment and manpower was enlisted in November 1984:

Equipment
- A) 30-ton boom crane with amphibious under carriage
- B) 100 x 40 foot deck barge
- C) 80-ton boom crane on deck barge
- D) double drum winch set on deck barge
- E) 40 x 8 feet sled
- F) Chainsaws

Crew
- 3 equipment operators
- 2 chainsaw operators

The specialized equipment was designed and employed to:

- Reduce labor intensity
- Increase production (300 cords/week)
- Minimize site impact

Equipment Functions and Specifications:

A) **100** x 40 **Foot Deck Barge -** served as the operating base positioned at the stream bank. It supported an 80 ton crane and winches.

B) **Winch Set -** supplied power to transport the sled. The main pulling drum carried over one-half mile of 1-⅛ inch cable. The rehaul drum reeled over one mile of l-inch cable and served to return the sled from the stream bank to the felled timber.

C) **Sled -** replacing the cone used in earlier operations, the sled was designed to haul 3 to 5 cords of wood. It measured 40 feet long by 8 feet wide with stanchions to secure the timber during travel. Main line cable was attached directly to the front of the sled while the rehaul cable traveled from the drum around pulleys on the amphibious crane and attached to the opposite end of the sled.

D) **30-ton Amphibious Crane -** mounted on a set of pontoons measuring 14 feet wide, 28 feet long and 5 feet high, performed two functions:

1) Serve as the turn block of rehauling the sled and
2) Loading the sled.

The ground pressure of this machine is 1.5 pounds per square inch. As it tracked away from the stream bank with the rehaul cable secured by pulleys located on the machine. The crane, with its 60-foot boom, could clear a corridor 150 feet wide and ½ mile long.

E) **80-Ton Boom Crane -** pedestal mounted on the deck barge, this crane unloaded the sled and placed the timber in hopper barge for transport to the Mill.

Felling techniques for this operation included:

Pre-felling two corridors (18 acres) ahead of production.

Directional felling to maximize recovery of the timber.

Maintain stump heights less than one foot.

Limbing, topping, and removal of excessively swelled butts at the stump.

After two years' experience with this application, the following results were noted in comparison with earlier harvesting methods:

Reduced labor requirements
Increased productivity
Reduced site impact
Excessive machinery downtime
High personal injury hazard.

Although the operation appeared to be potentially successful, costly downtime and high injury rate led to the continued search for alternative harvesting methods. This search ultimately led to the first trail of helicopter logging.

HELICOPTER LOGGING

In February 1986, Scott contracted its first helicopter logging operation. Recognizing its potential, subsequent trials were performed. In these trials, contractors were paid on a per hour basis. An analysis of these trials is presented in Table 1. After months of evaluation and testing, payment for production was negotiated to a per cord basis, thus providing a production incentive for the contractor.

The resources used for a typical helicopter operation are as follows:

Crew
- 2 **Pilots**
- 2 FAA certified mechanics
- 6 Choker setters
- 2 Choker retrievers

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Equipment
- Bell 205 (UHB-1) Helicopter
- Long cable line with mechanical hook
- Wire rope or nylon chokers
- Fueling facility
- Knuckle-boom loader

Prior to aerial "skidding" activities, timber on 40 to 50 acres is felled using techniques described with the Company cable logging crew. With choker setters positioned in the felled timber and choker retrievers located at the landing, the helicopter proceeds. Hovering over the felled timber, pre-choked logs are attached to a mechanical hook suspended 100 feet beneath the helicopter. The timber is then lifted, transported to the stream bank landing, and released. Chokers are retrieved and a knuckle-boom loader stacks the pulpwood. This process is repeated at **45-** to SO-second intervals.

Production from the helicopter operations is economically triple that of the cable logging crew, yielding volumes of 800 to 1,000 cords per week.

Effectiveness of the helicopter operation in comparison with cable logging is very favorable. Although helicopter downtime remains a concern, improvements have been realized in the following areas:

Cost effectiveness
Increased productivity
Reduced injury rate
Minimal site impact

With.continued efforts to improve efficiency, helicopter logging should provide the most economical and environmentally sound means of timber harvesting in Lower Delta wetlands.

Table l-Helicopter logging trial

Barge	Total Turns	Aver. Stems /Turn	Aver. Stems /Cord	Average Cords/ Time (Min.)	Average Turn (Min.)	Total Time Cords	Total
1	683	1.93	4.16	0.46	1.07	12.22	316.24
2	413	2.08	3.48	0.60	1.02	7.02	246.80
3	188	2.23	5.48	0.41	0.96	3.02	76.44
4	699	2.06	4.40	0.47	0.95	11.10	326.90
5	650	1.87	3.13	0.60	0.87	9.38	387.67
6	777	1.78	4.42	0.40	0.91	11.75	313.44
7	768	1.98	4.52	0.44	0.91	11.62	336.39
8	252	2.18	2.88	0.76	0.87	3.65	190.36
Total	4430	1.96	4.06	0.50	0.94	69.75	2194.24

SKIDDER LOGGING

Rubber-tired skidders have been used for decades for harvesting mixed hardwood stands in the Upper Delta. This method provides desirable economical and environmental results. Although better suited for Upper Delta Red River Bottom sites, this system may also be applied in tidally influenced areas under suitable, controlled conditions.

During seasonally dry periods, an organized logging plan may be executed with favorable results. However, excessive trafficking under poor conditions may lead to significant site degradation. Studies have been initiated to determine the extent of this impact.

REGENERATION

Ecosystem functions may differ in response to each logging application. Extensive research is on-going to evaluate the degree of impact of various harvesting applications.

To enhance natural regeneration in hardwood stands through coppice and seed germination, specific management practices are applied simultaneously with felling operations. These practices prescribe sawing down all unmerchantable and undesirable stems larger than 1 inch in diameter. This effort has proven very effective in achieving adequate stocking levels of desirable timber species far exceeding that of artificial regeneration. Successful natural regeneration can be realized following most harvesting systems including properly executed and controlled rubber-tired skidder applications.

Although stump height remains an issue with respect to coppicing success, heights of two feet or less respond favorably. This standard, however, can be influenced by water inundation levels.

EXPERIMENTAL SYSTEM

Scott is currently experimenting with a new wetland timber harvesting system. A unique configuration of low ground pressure equipment has been assembled to access sensitive areas without the need for constructing permanent roads.

After residual stem control is completed by chainsaw felling, two tracked vehicles combine resources to skid and load a high flotation rubber-tired forwarder. It is then transported to an area accessible by haul truck. Merits of this system are now being evaluated for economic and environmental impact.

CONCLUSION

Through technological advancement and changing market conditions in the use of hardwood fiber, ever-increasing demands are being placed on the hardwood resource. Scott Paper Company's commitment to use environmentally sound practices in the production of this resource is pre-eminent. The success of the total approach has been recognized recently. Scott Paper Company has received the "Forest Conservationist Of the Year Award" from the Alabama Wildlife Federation and the "Forest Management Award" from the Environmental and Achievement Awards program of the American Pulpwood Institute and The National Forest Products Association.

The combined resources of water, timber, and wildlife provide immeasurable value in recreational and raw material use. We at Scott believe that to utilize one with disregard for the balance could cause irreparable damage.

SITE PREPARATION ON FORESTED WETLANDS OF THE SOUTHEASTERN COASTAL PLAIN

Thomas M. Williams[1]

Abstract.-Site preparation has been applied to remove obstructions for establishment, control competition, and improve the micro-site for regeneration. Fire, mechanical, and chemical treatments have been used in pine regeneration. Bottomland hardwood regeneration is usually successful with clearcutting and elimination of non-commercial residuals. Impact studies on wet pine sites indicate site preparation can be done on these sites and cause little degradation of runoff water quality. Based on this research best management practices should concentrate on keeping equipment, fertilizer, and herbicides out of water courses. Bottomland hardwood regeneration practices are usually less intense than pine. River flooding may complicate definition of best management practices in flood plain sites.

INTRODUCTION

The Clean Water Act of 1987 has focussed attention on identification of streams not meeting water quality goals. Section 319 of that act deals with non-point sources of pollution. The act formally recognizes Best Management Practices as a mechanism for compliance with water quality standards. State Best Management Practices will be used as a standard to judge compliance with the act. State agencies must show that two criteria are met before BMP's can become the accepted standard: 1) The state must demonstrate that operators are complying with BMP's; 2) The BMP's must be shown to adequately protect water quality.

Best Management Practices will also be important to wetland forest management in relation to Section 404 permitting of dredge and fill activities. Congress exempted silviculture from permitting requirements under this act. The Corps of Engineers need clear criteria to differentiate legitimate silviculture from other non-exempt activities which may also begin with cutting of timber (e.g. residential development). Published BMP's provide just such a clear set of criteria.

This paper will review site preparation in view of its impact on water quality. It will review current common site preparation practices, research on water quality impacts of these practices, and relate these findings to implementation of BMP's.

Goals and Methods of Site Preparation

Site preparation is a cultural treatment intended to improve forest land for renewal of desired species following harvest. Treatments have one or more of three basic goals; removal of obstructions to establishment, control of competing vegetation, and improvement of the micro-site for each new tree (Crutchfield and Martin 1982). There are several cultural techniques used to accomplish these goals. However, site preparation is not a self contained operation. Rather it must be considered an integral part of a silvicultural system. Choice of site preparation technique is made as consequence of harvest system, regeneration system, and site limitations. Malac (1982) properly points out harvest can enhance the future regeneration site or can cause damage which must be corrected by site preparation.

Site preparation techniques are mechanical, chemical, or fire used singly or in combination. Mechanical techniques are shear, rake, chop, harrow, and bed (Balmer and Little 1978). Shearing is severing of residual stems with a sharpened blade pushed by a large dozer. The K-G blade has been popular for this purpose. It is a large slanted blade with a metal spike at one end and a sharpened edge along the bottom of the blade. Some shears are also made with a spike in the middle of a V-shaped blade. Raking is the piling of sheared residuals and logging slash into piles or windrows. It is done with an open rake like dozer blade called a root rake. The rake design gathers debris while minimizing the amount of soil moved. Chopping is done with a large bladed drum filled with water. The drum is four to five feet in diameter and six to ten feet long. The blades run the length of the drum and extend ten to twelve inches. A dozer pulls one or occasionally two drums to crush and chop debris into short blocks. Harrowing is done with a double gang disc and results mixing and loosening the soil surface, severing of competing plant roots, and creation of a flat mineral surface. Bedding is done with a single gang disc harrow. The single row of disc blades are arranged to turn soil to the center of the disc creating a mound. The disc concentrates topsoil into the mound and creates a planting site several inches above the general soil surface.

Chemical site preparation can be with either soil active or foliar active herbicides (Fitzgerald 1982). Although ground application of soil active types is possible both types are more economical when applied by air. Application may be from either fixed wing aircraft or helicopters. Both types require special equipment and skilled operators to minimize drift and possible contamination of water bodies. Injection of herbicide directly into residuals is a common method of competition control. Chemical applications may also occur as a release operation during the first growing season or up to five seasons after regeneration.

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Fire is used as a site preparation tool in two ways. Prescribed fire prior to harvest is the most cost effective method to minimize competing vegetation in pine regeneration (Crutchfield and Martin 1982). Langdon (1981) demonstrated that brush understories are effectively removed by repeated application of summer prescribed fire. Fire is used after harvest either alone or with another mechanical or chemical treatment. It is often used with chopping to reduce the chopped debris. Piles and windrows created by raking are also commonly burned.

Forested Wetland Site Types

The purpose of this paper is to discuss impact of site preparation on forests on wet soils and to look at best management practices for site preparation. In doing that I propose to define the scope of the paper in terms of forest site descriptions of Kellison and others (1981) and of soil types. These are not necessarily the same criteria used in determination of Section 404 jurisdictional wetlands. Therefore, the sites and soil types do not necessarily correspond to jurisdictional wetlands. I propose to examine red river bottoms and wet flat site types (Kellison and others 1981). Soils will be limited to mineral soils in the suborders aquults, aquods, and aquepts (Soil Survey Staff 1975). The soil groups also include sites that are locally known as pocosins and pine flatwoods.

These site and soil types were chosen because they support much of the important forest types of the southeastern coastal plain and the soils are compatible with mechanical, chemical, and fiie site preparation treatments. The wet flat type will support both pine and hardwood silviculture while unaltered red river swamps will support bottomland hardwood silviculture.

Site Preparation for Hardwood Regeneration

Bottomland hardwood species regenerate from light seeds [sycamore (*Platanus occidentalis*), sweetgum (*Liquidambar styraciflua*), yellow-poplar (*Liriodendron tulipifera*), cottonwood (*Populus deltoides*), box elder (*Acer negundo*), maple (*Acer* sp.), elm (*Ulmus* sp.) and ash (*Fraxinus* sp.)], heavy seeds [oaks (Quecus sp.) and hickories (*Carya* sp.)] and vigorous sprouting [sweet gum, green ash (*Fraxinus pennsylvanica*) bitter pecan (*Carya aquatica*), sugarberry (*Celtis laevigata*) and tupelo (*Nyssa aquatica*)] (Johnson 1978). The goal of hardwood silviculture is regenerating the more valuable intolerant species such as sycamore, yellow poplar, cherrybark oak (Quercus *falcata* var. *pagodifolia*), swamp chestnut oak (*Quercus michauxii*) and nuttall oak (*Quercus nuttallii*).

Kellison and others (1981) recommend natural regeneration by complete clear cuts. Harvest operations should be during the dormant season and be as complete as possible. Following commercial harvests all residual stems should be eliminated. They recommend that this be done by shearing, although felling, chopping, girdling or herbicides are alternatives. Raking into piles is not recommended unless vines are prolific. They emphasize that care be taken not to impede natural drainage by road construction.

Gresham (1985) documents regeneration of a bottomland site to undesirable species with only clearcutting. He did not believe that more valuable oaks would become part of the next stand at this site. He restated Kellison's recommendation to shear residuals left after the clearcut.

Nix and Cox (1987) examined preharvest discing and enrichment planting with cherrybark oak to improve reproduction in a bottomland stand dominated by elm, ash, hackberry (*Celtis occidentalis*), and sycamore. They found the best results with preharvest discing and clearcutting. Post harvest herbicide spraying did not improve survival or growth of the planted seedlings.

Hardwood plantations have also been established. Site preparation for hardwood plantations must be very intense (Linde 1980). McCarity (1980) recommends clearcutting, shearing, repeated raking and burning until all debris is eliminated, discing, planting, and cultivation for two years after planting.

Site Preparation for Pine Regeneration

Pine plantation establishment has been the common practice of forest industry in the Southeast. Site preparation has been an integral part of plantation establishment. Various combinations of treatments have been tried to accomplish the three goals mentioned previously. Shearing, raking, and chopping treatments are done primarily to remove obstructions to planting. Burning can remove obstructions, provide competition control, and improve the micro-site to some extent. Harrowing and bedding are effective for competition control and improvement of the micro-site. Herbicides are primarily for competition control. A combination is chosen for each site that accomplishes the goals at a minimum cost (Moehring 1977).

Post harvest burning with chemical injection of residuals was most popular in 1980 (Crutchfield and Martin) with shear, rake and bed most popular among mechanical treatments. Bedding is most often used on poorly drained sites (Haines and Haines 1978; Terry and Hughes 1975; Shoulders and Terry 1978; McKee and Shoulders 1974). Bedding can be done after shearing and raking or after chopping, with or without burning. A recently developed technique is a single pass with a V-blade shear on the front of a bulldozer with a bedding disc pulled behind. This combination is used on sites where residuals and debris are not too heavy.

Recent work (Langdon and McKee 1981; McKee and others 1984; McKee and Wilhite 1986) has indicated phosphorus fertilization at time of planting on poorly drained sites may substitute for bedding as site preparation. Their work has shown sites which received P fertilization grew as fast as bedded plots, and apparently will equal bedded and fertilized plots by age 20.

IMPACTS OF SITE PREPARATION

Heavy mechanical disturbance, introduction of chemicals, or very hot fires all can produce drastic changes in the forest ecosystem. Site preparation may impact off-site water quality and quantity, future site productivity, and vegetation patterns affecting use by wildlife. Best management practice guidelines ***are,*** for the most part, a response to the Clean Water Act. The major stress of this section will be to address impacts of site preparation practices on water quality and quantity.

Site preparation is an integral part of pine plantation silviculture. Impact studies have focused on entire silvicultural systems. Study results do not separate influences of harvest, site preparation, and planting of young trees on water quality. Results are from entire silvicultural activities and a single site preparation combination has not been repeated among the various studies. Hollis and others (1978) reported elevated NH_4, NO_3, and total N concentrations and elevated suspended sediment. These elevated concentrations returned to. near those of the undisturbed control during the second year after harvest and site preparation. They reported a large loss of suspended organic matter in surface runoff during the first winter wet period.

The most complete evaluation of impacts of intensive pine management has been done by researchers from the University of Florida (Swindel and others 1983). Water quality and quantity research was carried on throughout the study (Riekerk and others 1973; Riekerk and others 1980; Neary and others 1982; Riekerk 1982,1983; Riekerk and Korhnak 1986). The study was located in central Florida, on fine sandy soil (Ultic Haplaquod and Arenic Plinthic Paleudult). Three watersheds were isolated and calibrated for one year. Two regeneration systems were tested on the two treatment watersheds. A minimum intensity watershed was shortwood harvested, chopped twice, bedded and planted to slash pine (*Pinus elliottii*). A maximun intensity watershed was harvested as full trees, residuals were burned sheared, and piled in windrows, the site was harrowed and bedded before planting to pines. The control watershed was not treated.

Cutting of vegetation usually results in greater runoff and the minimum disturbance watershed showed a 6 cm increase in total runoff the first year, while the maximum disturbance watershed had 13 cm more runoff and increased peak discharges. The increased peak discharge was attributed to channelling of surface runoff by windrows. Increased runoff and higher peak flows persisted for only one year after treatment on both watersheds.

Water quality changes were also small for both-treatments. There were no significant differences in nitrate or phosphate concentrations in runoff from all three watersheds. Potassium loss was proportional to extent of disturbance with greatest concentrations on the maximum disturbance watershed. The maximum disturbance watershed also showed higher calcium concentrations which the authors attributed to runoff from the windrows.

Water quality impacts of a loblolly pine (*Pinus taeda*) plantation establishment were studied in coastal South Carolina (Askew and Williams 1984, 1986; Williams and Askew 1988). In this study a chronosequence of subwatersheds were sampled from a 2300 ha watershed. The entire watershed was being converted to loblolly pine using a uniform site preparation technique. Following harvest the sites were sheared, drum chopped and burned, bedded, and planted. Triple-super phosphate was incorporated into the beds. The development of the plantation created many 70 -100 ha subwatersheds with different aspects of the sequence from undisturbed hardwood to 15 year old plantation. The subwatersheds that had been site prepared had significantly lower sulfate, nitrate, and hydrogen ion concentrations than the undisturbed hardwood control. In this study only 'installation of ditches and road crossings had negative impacts on water quality.

There have been few studies of impacts of site preparation in bottomland hardwood silviculture (see Mader and others this volume). Bottomland hardwood stands are usually subject to periodic flooding. Appropriate sampling of water quality during flood events is a problem of both position and timing which makes these studies difficult.

DISCUSSION

Site preparation used for pine plantation establishment need not result in degradation of water quality. Sensible precautions to keep equipment, herbicide, and fertilizer out of watercourses are prudent best management practices. Shearing, chopping, bedding, and fire can be safely applied to rain-fed wet sites with soils in the aquod and aquult soil suborders. Windrows may channel surface runoff and increase flows and some cation concentrations. Although these impacts are small and transitory, windrow orientations that minimize channeling of water into nearby watercourses may be warranted.

Best management practices for water quality in bottomland hardwood management is not as well researched. Extrapolation of the pine results would tend to support the recommendations made by Kellison and others (1981). Shearing and chopping were both clearly shown to have little impact on wet flats being prepared for pine. Bottomland applications should show similar results. However, a large alluvial river system presents problems in both formulating and assessing best management guidelines. Delineation of stream side management zones may be more ambiguous in river bottoms. The fate of sheared or chopped debris during floods could also present new impacts. Bottomland hardwoods sites are often nourished by sedimentation during floods. What are proper guidelines for best management for erosion in a zone of sedimentation?

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RECOMMENDED SILVICULTURAL PRACTICES IN SOUTHERN WETLAND FORESTS

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Abstract.—Silvicultural practices can be applied to wetland forest stands to maintain or enhance their use for timber production while maintaining the quality of the wetland environment. This paper addresses the effects various reproduction methods and intermediate cutting practices may have on forested wetlands in the southern United States and identifies the best management practices published in the present literature.

INTRODUCTION

Silvicultural practices are used to control forest establishment, composition, structure, and growth (Smith 1986). Within the context of this paper, these practices consist of various treatments that may be applied to wetland forest stands in the southern United States to maintain or enhance their utility for timber production while maintaining the quality of the wetland environment. Silvicultural practices usually require some form of vegetation manipulation that results in cutting and removal of trees or other vegetation to favor or enhance the growth and development of desired trees. The act of felling trees has a lower degree of potential for long-term effect on wetlands than mechanized harvesting and intensive site preparation. Since these associated activities are addressed elsewhere, they will not be discussed in detail other than to mention when they apply to given silvicultural situations. Thus, we will limit our discussion to the effects that various reproduction methods and intermediate cutting practices may have on wetland forests.

The impact these practices have on wetland forests is governed by what, when, and how much is cut. Beyond the normal changes in species composition and vegetation density or stocking, potential impacts on the wetland forest include changes in soil/site relations, hydrology, water quality, temperature, nutrient cycling, wildlife and fish habitat, and recreational, economic, and cultural opportunities. Ecosystem alterations caused by silvicultural activities are not fully understood, but certain best management practices can mitigate potential adverse effects and maintain or improve the wetland forest.

SILVICULTURAL PRACTICES

Regeneration Methods

Management objectives, coupled with economics and forest biology determine when the regeneration harvest is needed. Regeneration of well-stocked stands should occur when the stand reaches the maturity and value to meet the objectives. A sound decision must be based on knowledge of stand volume and quality, site characteristics, potential site productivity, and wood markets. The decision to regenerate understocked stands is based on the need to optimize forest productivity of the land. Hardwood stands older than 20, 30, and 40 years are candidates for regeneration when basal area of desirable trees is less than 20, 30, and 60 square feet per acre, respectively (Kellison et al. 1981). M&night et al. (1981) have created a set of tables that show the occurrence and characteristics, shade and flood tolerance, and reproductive characteristics of the principal tree species of the southern bottomland forests. This information is beneficial in determining the candidate species to manage.

Reproduction methods may be chosen to create one of two types of stands, even-aged or uneven-aged. Even-aged stands may be regenerated artificially by planting or direct seeding, or naturally by the clearcutting, seed tree, or shelter-wood methods. Uneven-aged stands are created and maintained by the selection method. The regeneration period is the most crucial time for impact of silvicultural practices on the site. Decisions are made at this time that influence the stand composition, structure, and succeeding practices during the rotation or life of the stand. It is at this time that the forest manager will decide to manage the present stand as it is or convert to a different age structure or species composition. Thus, the choice of reproduction method and stand structure is of major importance when managing wetland forest stands.

Even-Aged Stands

Artificial Regeneration.-Planting or direct seeding are methods used to establish even-aged stands and normally require biological clearcutting and intensive site preparation to control competing vegetation and create good planting or seeding conditions. Site preparation commonly used on wetland forest sites may include shear, pile, burn, and bed-or chop, burn, and bed-and often includes drainage. In addition, since most standing trees are removed, Streamside Management Zones (SMZ's) are important. Thus, this method can have an extreme impact on short-term and long-term changes in the stand ecosystem.

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Certain situations may require planting in order to maintain the present species on the site. For example, many baldcypress-tupelo sites in Louisiana are permanently impounded with water, and natural regeneration cannot be established. Harvesting the mature timber on these sites requires planting to maintain the species. Site preparation is limited to cutting competing vegetation, use of herbicides, or no control. An additional problem is nutria *(Myocastor* coypus) which, if present, destroy the newly planted seedlings very quickly. Thus, clear-cutting and planting is risky in such situations and is not recommended unless nutria can be controlled (Conner and Toliver 1987).

In many bottomland hardwood sites, it may be beneficial to increase certain species such as oaks. Planting seedlings or direct seeding of the acorns is a viable alternative to establishing a stand of oak (Johnson and Krinard 1987; Johnson 1979), an improvement both for forest management and wildlife management purposes.

Natural Regeneration.-Forested wetlands have a tremendous capacity to regenerate naturally, and many are not conducive to using site preparation equipment. Thus, natural regeneration is the common method of reproduction. Success depends on several factors including: recognizing the site type and its characteristics; evaluating the stocking and species composition relative to stand age and site capability; planning regeneration options; and using sound harvest methods that do not adversely modify natural water flow and that protect the productivity of the site while meeting the regeneration objectives (SCFC 1988).

Clearcutting Method-Natural regeneration may be established by clearcutting the existing stand and relying on regeneration from seed from adjacent stands, the cut trees, or stump and root sprouts (coppice). Areas of at least 3 acres should be cut to ensure that the regeneration receives adequate light for establishment and growth. It imperative that all vegetation is cut to reduce competition; thus, the vegetative structure and density will be heavily impacted for a short period of time. Initially, species composition will lean toward the more shade intolerant light-seeded species that are present on the site, but given time it will shift toward species in the mid-tolerant range. Relying on seed to regenerate the stand usually requires more intensive site preparation than coppicing, as the seed needs bare mineral soil to germinate and grow.

Coppicing is a reliable method of regeneration in most bottomland or wetland forests and is often recommended. Success usually depends on control of competing stems over two inches dbh. Thus, site preparation centers around cutting most standing trees. However, complete removal of debris to create bare mineral soil is not required, and impact on the site relative to soil erosion is minimal.

Clearcutting represents a dramatic habitat change for wildlife and special emphasis is appropriate if wildlife improvement is an objective (LFA 1988). Monschein (1981) recommends leaving at least two den trees per 5-acre area for cavity nesting birds and mammals. The Florida Division of Forestry (FDF 198'7) recommends leaving a 300-foot-wide strip, called a stream or lake's Discretionary Zone (DZ). Within this DZ, a 35-foot primary SMZ should be provided along all streams, and lakes of 10 acres or larger, to protect the watercourse from excessive sediment, nutrients, debris, chemical, and temperature fluctuations. These zones will help maintain a mosaic of habitat types for wildlife as well as provide an aesthetic buffer along the waterways.

In summary, clear-cutting is the most effective method of natural regeneration for many wetland forest tree species and is recommended except in SMZs and sensitive areas. The method favors reproduction of shade intolerant light-seeded species, but species composition will shift toward mid-tolerants over time. Clearcutting is recommended where stem quality, stocking, and condition of the total stand needs to be upgraded. It creates excellent wildlife habitat for certain species but must be interspersed with older stands to create diversity. Administratively, it is very easy to handle, and there is no need for reentry for the first 20-25 years. However, clear-cutting is aesthetically unacceptable to many as it intially creates a drastic change in the wetland environment.

Seed-Tree Method.-In this method of reproduction, all trees are removed from the area except for a small number (6-15) of seed-bearing trees that are left singly or in small groups. Once the new even-aged stand is established, the seed trees are removed. Thus within 5 years the area will essentially be clear cut, and most of the recommendations relative to clearcutting should be applied. This method favors light-seeded intolerant species and is not applicable to heavy-seeded species where seed distribution is limited to the ground area within the periphery of the crown. In addition, it requires a second entry within a few years to remove the seed trees unless the trees are left for wildlife purposes. For these reasons, this system is economically and biologically impractical for many hardwood species (SCFC 1988).

Shelterwood Method.-This reproduction method is unique in that an even-aged stand is established under the old canopy of trees, which is left to provide shelter for the regeneration. A seed cutting is made to establish advanced reproduction from seed, seedlings, or sprouts. The seed cutting should be from below, cutting all understory heavy-shading stems first and leaving an overstory of desirable trees to cover about 50 percent of the area. After regeneration is established, the overstory is removed in one or more successive harvests but may be maintained in the stand as long as it does not jeopardize the vigor and growth of the regeneration. Trees of undesirable species or quality should be controlled by tree injection or girdling if cost of cutting is prohibitive. The shelter-wood method is easy to implement and tends to minimize visual impacts. In aesthetically sensitive areas, final removal can be spread over several cuts, suppressing visibility of tops, slash and stumps. During reentry for the intermediate cuts, care should be exercised to avoid soil puddling and compaction and to prevent damage to the residual stand (SCFC 1988). The shelterwood method is flexible and allows one to maintain an existing canopy over the area. Density left depends on the tolerance of the species being regenerated.

Even-aged reproduction methods can be used in stands to create mosaics of uneven-aged forests. The stands can be established and intermingled among each other over the entire forest in various shapes and sizes thus, creating a wetland forest of high variability in horizontal and vertical structure. If BMP's are used effectively, site impact can be held to a minimum and limited to a relatively short period of

Table l.-Effective regeneration methods for wetland forest site types (Florida Division of Forestry, 1987)

Site type	Clear-cut	Group selection	Shelter-wood	Seed tree	Single tree selection
Flowing water					
Mineral soil					
Alluvial river bottom	A	B	B	C	C
Organic soil					
Black river bottom	A	B	B	C	C
Branch bottom	A	B	B	C	C
Cypress stand	A	C	C	C	C
Muck swamp	A	C	C	C	C
Nonflowing water					
Mineral soil					
Wet hammock	A	B	B	C	C
Organic soil					
Cypress dome	A	C	C	C	C
Peat swamp	A	C	C	C	C

A = Highly effective; B = Effective; C = Less effective.

time. In fact, the habitat can be improved through proper silvicultural practices. Quite often, many of these wetland stands have been mismanaged, high-graded, and over-harvested. Thus, the species composition and quality of the existing trees is very poor. Clearcutting or any regeneration method that establishes better species composition and quality trees should be beneficial to all long-term intended uses of the wetland forests. Relative to silvicultural practices, **BMP's** should be used to minimize short-term effects that become long-term negative impacts. With proper regeneration established, growth of the trees will slowly mitigate initial impacts, and if properly managed, impacts on the ecosystem should be minimal over the rotation or life of the stand.

Uneven-Aged Stands

The selection method of regeneration is used to manage and maintain a&uneven-aged stand structure. The uneven-aged structure is maintained by removing some trees in all size classes either singly (single tree selection method) or in small groups (group selection method). The key to uneven-aged management is to maintain a proper reverse-J diameter distribution (large numbers of smaller diameter trees, decreasing in numbers as the trees get older and larger). Many age classes should be maintained among the desired species. As the larger trees reach economic maturity, they are harvested and replaced by regeneration. All other tree size classes are thinned as needed in order to maintain the proper size distribution. No rotation is designated and the stand is managed continuously through various types of cuttings. At no time will the stand be void of all standing trees. Instead various size areas within the stand will be composed of trees of different ages and sizes. Cutting objectives should be designed to improve species composition, tree quality, and proper diameter distribution.

The selection method is actually a complete silvicultural system and not just a reproduction method. Habitat can be diversified by the size of the openings created during the regeneration cuttings and the number of trees maintained in each age class. Single tree selection is not recommended in most wetland forest situations because removal of single trees does not generally guarantee establishment and growth of regeneration. It could be used where harvesting must be held to a minimum and regeneration is not of high priority.

However, eventually more intensive cutting will have to be applied in order to establish regeneration. Group selection, on the other hand, can be an ideal regeneration and management system. In group selection various types of cuttings are applied to **groups** of trees similar in size and growth. If a group of trees is of pole size, then they may be thinned, whereas all of a group of large trees that have reached economic maturity should be harvested, creating a relatively large opening of 1-5 acres to establish regeneration. In actual practice, both single tree and group selection can be practiced simultaneously. Single trees are removed during thinning and groups are cut for regeneration. The selection method allows one to maintain a complete, but diversified, vertical and horizontal structure in the stand or forest. It should have minimal impact on the ecosystem of a stand except in small patches or areas. Thus, this method is excellent for maintaining a wetland forest. However, the logistics are more difficult and repeated entry is required. It is more difficult to keep track of the stand structure and development of the trees and harvesting techniques are limited due to the variety of trees sizes which may need to be cut or left. When harvesting is needed, the logger must move over the entire stand looking for trees designated for cutting.

Choice of a regeneration method has a major influence on the stand composition, structure, and succeeding silvicultural practices over the life of the stand. Therefore, care should be taken in choosing the best method that fits the site and objectives of management. Table 1 summarizes the most effective regeneration methods for wetland forests relative to site type.

Intermediate Cuttings and Cultural Practices

Any silvilcultural treatments applied to a stand during that portion of the rotation not included in the final harvest or regeneration period are considered as intermediate practices. Those treatments most applicable to wetland forests are thinnings, improvement cuttings, salvage and sanitation cuttings, and fertilization. Most of these practices will influence the stands depending on the degree of cutting or cultural practice applied.

Thinning

Thinnings are cuttings made to regulate stand density in immature even-aged stands, or in even-aged groups with uneven-aged stands. Trees removed are usually of the same species or shade tolerance level as those favored. The objective is to create growing space for the trees that are favored and harvest the remaining trees for financial benefit. Since regulation of stand density is the objective, the impact a thinning will have on a stand is directly related to how much is cut and left. However, the method of thinning will control the stand structure or size of trees left. For example, in low thinning, trees are removed from the lower crown classes to favor those in the upper crown classes. Thus, the smaller trees are removed leaving the larger dominant and codominant trees, and the lower or mid-strata of the stand is most heavily impacted. Unless the intensity of a cutting in low thinning is heavy enough to allow some cutting in the upper crown classes, low thinning will generally have little affect on the growth of the trees left. Another thinning may be needed in a short period of time; thus, low thinning usually results in more frequent logging. Low thinning does open up the lower portion of the stand and allows an increase in growth of the understory plants. This is beneficial to wildlife as it increases forage and cover. Low thinning should be used when a large number of poor vigor trees exist in the lower crown classes. Their value can be captured by harvesting them without having much impact on the stand.

Crown thinning, on the other band, is used to remove trees from the dominant and codominant crown classes in order to favor the best trees of those classes. More cutting is applied in the upper crown canopy and larger trees are cut. Trees in the lower crown classes (suppressed and intermediates) are left unless it is thought they will die before the next thinning. Crown thinning usually results in more intensive cutting in the stand but is recommended as it has a more positive effect on the growth of the residual trees. Stand vigor is usually better maintained by crown thinning and logging will not be as frequent as in low thinning. More logging debris may be left on the site, but it will decay in a short period of time. Crown thinning was applied in a 63-yr-old natural stand of baldcypress (*Taxodium distichum* L.) averaging 220 $ft.^2/ac.$ of basal area (Dicke and Toliver 1933). Thinning to 180, 140, and 100 $ft.^2/ac.$ resulted in 5-yr. average diameter growths of 0.44, 0.51, and 0.77 in., respectively. Trees in the unthinned control grew significantly less at 0.31 in.15 yrs. All crown thinning treatments appeared to increase sawtimber volume increment and vol/ac 5 years after thinning. In this study, the trees were cut and left; thus, there was very little logging impact on the site other than a relatively large amount of debris. The cut trees lying on the ground directly impacted the use of the area by local crawfishermen as they could no longer move their boats through the area. Thus, growth of the trees was improved, but cultural/economic activities were influenced (Dicke and Toliver 1983). The more intensive thinning opened up the canopy and allowed greater light penetration to the ground, resulting in an increase in weedy vegetation on the forest floor.

Improvement Cutting

Improvement cuttings are made in older stands to improve composition, growth, and quality by removing less desirable trees of any species from the main canopy. By nature of the objectives, improvement cuttings can be used to change species composition and tree quality. They should be used in wetland forests to enhance the stand rather than degrade the habitat. Improvement cuttings are often performed by injecting the trees with herbicides. The label instructions should be strictly adhered to as some herbicides that are labeled for normal forest uses may not be approved for use in wetland forests.

Salvage and Sanitation Cuttings

Salvage cuttings are made to remove dead trees **or** trees being damaged or killed by injurious agents other than competition, to obtain monetary value that would otherwise be lost. Sanitation cuttings are used to remove trees to prevent actual or anticipated spread of insects or disease. Most of the time the forester would like to apply both treatments simultaneously. Both treatments can have the same impact on a site. These cuttings usually call for removal of several trees in small groups but can easily be required over large areas if a major disaster occurs. For example, hurricanes are highly probable along the Atlantic and Gulf Coasts where many of our wetland forests occur. High winds from these storms can devastate large acreages of timber. Salvage operations should be applied as quickly as possible to recoup the economic value of the timber, but other considerations should be made relative to the impact on the wetland forest. Quite often, salvage operations require clearcutting; thus, the impact of this should be carefully considered. The salvage operation may be more detrimental to the forest than the impact of the hurricane. A decision must be made relative to the objectives and best practice for the site.

Sanitation cuttings require yet another decision. If an insect or disease is threatening a whole wetland forest, then a sanitation cutting should be applied. Insect and disease problems appear to be less of a problem in most of our wetland forests, but they do exist and may become problems in the future. For example, in Louisiana tupelogum (*Nyssa aquatica* L.) trees are defoliated 2 or 3 times per year by the forest tent caterpillar (*Malacosoma* ***disstria*** Hbn.), and recently, baldcypress have been defoliated in large areas by the fruit tree leaf roller (*Archips argyrospila*). The tent caterpillar has been present for many years and is not a real problem other than it does slow the growth of the tupelo. The fruit tree leaf roller is a relatively new insect pest to baldcypress and is spreading fairly rapidly. Little is known about its affect on the growth of baldcypress, but it does not appear to be a major problem yet. Sanitation operations could require cutting if chemical control is not feasible.

Fertilization

When sites appear to be nutrient-deficient, fertilizer may be applied to improve tree vigor and growth. It can be applied at the time of site preparation or later in the rotation. Pelletized formulations of nitrogen and phosphorus are most commonly used, and can be easily applied from the air or by ground-based equipment. The nitrate form of nitrogen leaches fairly readily under wet conditions. Phosphorous is largely tied up once it moves into the soil; however, it can stimulate lake eutrophication if moved by flooding into the water (FDF 1987). To minimize movement of fertilizer on a site, one can apply slow release fertilizer, incorporate it in the soil, or leave an unfertilized buffer strip adjacent to open water.

The Florida Division of Forestry (198'7) recommends the following BMP's for fertilization:

1. Develop a prescription plan based on soil and/or foliar analysis.
2. Do not apply fertilizer in an SMZ.
3. Apply fertilizer in the early spring to maximize the uptake of nutrients and minimize leaching from the site.
4. Apply slow release fertilizer when available and always leave an unfertilized vegetated strip adjacent to open water.

SUMMARY

Dempster and Stierna (1978) indicate that BMP's may have a variety of beneficial and adverse effects on economic development and environmental quality. Many environmental impacts cannot be readily identified as beneficial or adverse, since judgement varies among individuals. However, the effects should be identified, measured, and determined for purposes of decision-making. The lack of physical data on yield response, changes in water quality, and impacts on the wetland forest ecosystem due to silvicultural practices is a major problem. Many of the recommended practices are based on inferences from using such practices on non-wetland sites rather than from actual studies in wetland forests. Our wetland forests are a valuable but fragile ecosystem, and until more research is completed, the wetland forest manager should use a conservative approach and utilize the BMP judged to have the least impact on the site. Most southern states have established BMP guidelines that are available to anyone who needs them.

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STRATEGIES FOR UTILIZATION OF TIMBER AND NON-TIMBER RESOURCES

Willie H. Tomlinson[1]

Abstract.-Forested batture lands adjacent to major stream or river systems provide important but diverse and complex ecosystems. Present and future strategies which seek to manage and conserve these systems require innovation and planning if they are to remain intact through the test of time.

INTRODUCTION

Mr. Webster defines utilization as something which is put into action, made use of, or the term may suggest the discovery of a new, profitable, or practical use for something (Webster's Seventh New Collegiate Dictionary 1967). With that definition in mind, the ownership, management and ultimately the utilization of Anderson-Tully Company lands began nearly 100 years ago in what might be considered one of the largest streamside management zones in the United States. Our land holdings are primarily located in a 'I-state area from Cairo, IL., south to below Natchez, MS., largely encompassing the Mississippi, White, Arkansas and St. Francis River systems. The alluvial floodplains which were created by these river systems provide some of the most productive soils in the United States (MacDonald and others 19'79). Extensive man-made levee systems provide protection from flooding, the result of which has been the extensive clearing of bottomland hardwood ecosystems in favor of agriculture. The lands which are located between the protective levee system and the river system itself remain unprotected from seasonal flooding. These batture lands are still largely timbered and it is in this unprotected floodplain which we operate. For our company, logging has changed from the days of old when mules and oxen were used to pull log wagons (Heavrin 1981). However, while some modes of woods transport may have changed considerably, we still depend heavily upon the associated river systems for transport of raw material to our sawmill facilities in Vicksburg, MS.

SYSTEM CHARACTERISTICS

The batture lands provide a diverse and complex ecosystem. The timberland is composed of mixed bottomland hardwoods ranging from the riverfront hardwood component; ie., elm (*Ulmus spp.* L.) green ash (*Fraxinus pennsylvanica* var. *lanceolata* Sarg.) sycamore (*Platanus occidentalis* L.) sweet pecan (*Carya illinoensis* (Wang.) K. Koch) and sugarberry (*Celtis laevigata* Willd. L.) to the oak (Quercus *spp.* L.) gum (*Liquidambar styraciflua* L.) cypress (*Taxodium distichum* (L.) Richard) timber type (Radford and others 1978; Sargent and others 1965). Xeric sandfield habitats which resemble the Serengeti Plains of Africa are also common components of this system. Building sandbars covered with cottonwood (*Populus deltoides* Marshall) and willow (*Salix nigra* Marshall) seedlings gradually give way to mature cottonwood stands and ultimately mixed stands of riverfront hardwoods. On older soils, oak becomes an established part of the batture ecosystem. Oxbow lakes abound as do many other wetland sites, all being in various stages of decline due to excessive siltation and vegetative encroachment. Such wetlands gradually give way to vegetative types which are more mesic than hydric in nature. Wildlife populations are equally diverse for both game and nongame animals alike. Recreational pursuits focus on the total mix of habitats available; i.e., land, water and timber.

UTILITY

The recreational land use policy for Anderson-Tully provides areas which are open on a free and unrestricted basis as well as lands which are leased to the states of Tennessee and Mississippi for inclusion in their respective wildlife management area programs. However, the majority of our holdings in the batture lands are leased to a large number of hunting clubs, several of which have organizational charters dating back to the early 1900's.

Change is one of the few certainties which exists in the batture lands. It can be nature induced as in the case of insect, disease, environmental or animal damage, or it can be man induced through prescriptive management or changes in land use. In an effort to impact our bottomland hardwood timberlands and in fact all of our land holdings in the most positive and calculating manner possible, Anderson-Tully adopted a document in 1984 called The Resource Management Guide. This field manual is "a comprehensive plan for the integrated management and protection of soil, timber, water and wildlife" and represents best management practices for the valuable natural assets associated with our company's land holdings. Obviously, there are practical, economical, social and biological constraints within which we all must work. However, it is vitally important to seek, as much as possible, a point of balance with the natural ecosystem.

Management of the batture lands requires a considerable expenditure of time in both planning and plan implementation. Timber management decisions reflect a number of variables including species/site relationships, grade, size, age, basal area, length of rotation, and mortality

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rates, as well as regeneration of the future stand. Wildlife considerations are then plugged into the final management process in order to achieve the best overall management result. For many wildlife species in the bottomland hardwood ecosystem, failure to properly manage often yields largely negative results. A dense overstory typically yields a relatively clean understory having very little if any understory or midstory development. Such low diversity stands often yield a similar lack of wildlife diversity.

Timbered openings are created during logging operations via loader sets or small regeneration openings. Intermediate thinning or cleaning cuts also reduce the basal area of the stand and allows sunlight penetration to the forest floor. Understory vegetative response is almost immediate. Herbicide treatments are also used to eliminate undesirable hardwood species such as boxelder (*Acer negundo* L.) from the remaining desirable hardwood component. Such treatments have been used for not only timber stand improvement but also for improvement of wildlife habitat. Hunting clubs which are desirous of more abundant wildlife openings may, with prior approval, be allowed to create such openings for further enhancement of wildlife habitat. Clearcuts are not typically utilized as a management technique on Anderson-Tully lands, our management being geared more toward group selection than any other silvicultural system.

During the late 1960's and early 1970's, our company like several others was involved in the establishment and cultivation of planted cottonwood plantations. Initial clearing costs were high and cultivation was required for optimum plantation survival. Deer populations in most batture habitats far exceeded carrying capacity and the resulting depredation problems were severe. Defoliating insects (i.e., cottonwood leaf beetles, *Chrysomelia scripta* Fabr.) were also of concern and control was expensive. In order to produce a high quality sawlog, it soon became apparent that pruning would be necessary as the plantation developed. Current policy does not provide for establishment of new cottonwood plantations. Sites with established cottonwood plantations will continue to be managed on a lawlog rotation with intermediate thinnings as needed. However,at the end of rotation age (70 years +) the future stand will be what is now the understory and midstory vegetation; i.e., elm, ash, pecan, hackberry, sweetgum, oak and boxelder.

Roads play an important role in the management of timber, wildlife and recreational interests on Anderson-Tully Company lands. However, too many roads can and do create negative impacts on timber productivity, wildlife utilization and distribution within the habitat, as well as recreational quality. Anderson-Tully is currently involved in a program of road planning and enhancement whereby road systems are critically reviewed and ultimately receive the designation of permanent, secondary, or closed. Permanent road systems may be accompanied by a cleared right-of-way approximately 60 feet wide. Secondary road systems may occupy a IO-foot right-of-way. Closed roads may be gated or otherwise marked so as to disallow vehicular access for recreational purposes. Road systems are spaced approximately one-half mile apart and the road edges are maintained as long continuous wildlife openings which are planted to summer and/or winter food crops. They may also be mowed on a regular basis. Such road systems, when finally completed, also provide better all weather travel, easier maintenance, and an aesthetically pleasing drive through the forested system. Many of our hunting clubs have embraced this road management technique and are providing road system upgrade at their own expense.

In addition to wildlife openings which are created as a result of our road enhancement program, Anderson-Tully provides the opportunity for its hunting clubs to implement an overall food plot/permanent wildlife opening program. In fact, up to 2 percent of a particular club's leased acreage may be planted or otherwise managed strictly for wildlife enhancement. The most typical plantings include agricultural crops such as corn, soybeans, milo, wheat, millet, or combination plantings such as wheat/clover mixes.

Ongoing efforts to utilize, as effectively as possible, those lands located in the batture often necessitates involvement with the U.S. Army Corps of Engineers. Development and construction of waterfowl impoundments as well as lake impoundments often require appropriate permits before construction can begin. Most such activity occurs in a marginal wetland area which, if left untended, will soon revert from a hydric to a mesic site. The management emphasis by Anderson-Tully Company on these sites is primarily directed toward wildlife, waterfowl, and fisheries development and enhancement. The Corps, at the local District level, has to date, been most supportive in our ongoing wildlife and fisheries development projects.

CONCLUSION

In looking toward the future, I have little doubt that at least in the major bottomland hardwood zones, wetland reclaimation will be an important strategy in preserving the integrity of the batture ecosystem. Increased channelization of major river systems have yielded fewer natural oxbows, and fewer building sand bars; the result of which will be a somewhat altered plan of natural diversity. The oxbows, sloughs, bayous, etc., which remain will need renovation, water/siltation control or other innovative management considerations if they are to remain intact through the test of time. Without man's intervention, these systems are doomed to follow natural successional trends; trends which will take them away from the wetland utility which they serve today.

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ROLE OF STREAMSIDE MANAGEMENT ZONES IN CONTROLLING DISCHARGES TO WETLANDS

Wade L. Nutter and Julia W. Gaskin[1]

Abstract.-Various aesthetic and environmental qualities have been assigned to streamside management zones (SMZ's) but the attributes of the zones themselves are poorly defmed. It has been demonstrated that SMZ's may have beneficial impacts by ameliorating upslope discharges of pollutants and water to adjacent watercourses. The exact role that SMZ's play is, however, not readiiy predicted due to each site's unique physical and biological characteristics and processes and how they are integrated with the adjacent watercourse characteristics and processes. By understanding the processes the manager may evaluate the sensitivity of the SMZ, the role it will play in ameliorating upslope inputs and the potential management impacts to functioning of the streamside management zone.

INTRODUCTION

Protection strips, or zones, adjacent to watercourses have been recommended and/or required for many years by some land management agencies and are now usually required as part of best management practices (BMP) programs for most all forest land owners. Various benefits and values have been assigned over the years to riparian zones but there are few data to support their exact role, due partly to the complex nature of the physical and biological processes that occur in the zones and each site's unique configuration and linkage of processes between the protection zone and the watercourse itself.

Although definitions and expectations are many, the principal benefits of riparian protection zones are to limit practices within the zone that may have a direct impact to the watercourse and to act as a sink of limited capacity for sediment, nutrients and other chemicals introduced from upslope. Easily identified benefits include shading of the water surface to control temperature increases, maintenance of stabilized stream banks and reduction of erosion potential from disturbed soil. Less obvious benefits, but ones which may be as important, are the trapping and/or transformation of potential pollutants (e.g., nutrients, chemicals and sediment) by surface and subsurface hydrologic processes. Early functions assigned to protection zones were centered around surface processes but in recent years benefits from subsurface processes have been verified and may, in many cases, be more important than surface processes.

One function that cannot be assigned to riparian protection zones is the correction or amelioration of poor upslope practices. The zones may serve as a sink for upslope sources but those sources must not exceed the often finite, or short-term, capacity of the protection zone. The assimilative capacity can often be restored but requires some type of management activity such as harvesting.

Specification of protection zone width has usually been arbitrary and assigned on the basis of principal expected function or benefit to be achieved and, if limited harvesting is permitted, the practical distance from which equipment may remove logs by cable winching or other similar techniques without direct access into the protection zone. There are no definitive studies or guidelines which verify zone width given site specific conditions and benefits to be derived except in the case of shading for protection of surface water from temperature increases (Brown and Krygier 1970). Modifications to erosion prediction equations such as used in the model CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) and demonstrated by Foster (1980) could predict on a site specific basis the length of channel, and thus the width of the protection zone, necessary for sediment to be deposited. Such techniques have not been utilized for this application.

The protection zones have been known by various names that usually reflect particular expected function or benefit. Filter strips, buffer strips and streamside management zones have been the most commonly used names.

Until recently, with the advent of best management practices, filter strip was the most common name applied to riparian protection zones. As the name implies, filter strips were expected to filter sediment and other impurities from upland source areas, particularly from surface flows. This concept implied that vegetation within the filter strip was to be left in an undisturbed or limited management condition and access of equipment was permitted only if the filtering properties could be maintained to control the impacts of upslope forest or agricultural management practices. The principal shortcoming of this concept, particularly for control of sediment delivery to a watercourse, is rarely does surface flow enter a riparian zone as sheet flow such that a complete filtering may occur. Rather, flow by the time it gets to the riparian zone is usually channelized with sufficient velocities to keep a good bit of the sediment in suspension. Even if velocities are reduced due to reduced gradients in the riparian zone such that much of the suspended sediment is

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deposited, the sediment is not stabilized and can be moved to the watercourse during a subsequent, larger storm runoff event.

The preferred name today for the riparian protection zone is streamside management zone (SMZ). Streamside management zones recognize the complex function of the riparian zone to provide protection to a watercourse by both physical and biological processes and that limited management of the zone may be permitted that recognize the need to preserve its attributes.

STREAMSIDE MANAGEMENT ZONES

A universal definition of a streamside management zone (SMZ) does not exist. Therefore, for the purposes of further discussion the following definition, or statement of function, is offered:

> A streamside management zone is an area with often undefined boundaries adjacent to a perennial, intermittent or ephemeral watercourse (stream or wetland) with recognized sensitive biological and physical attributes that serves to ameliorate impacts of upland influences to the watercourse.

A number of questions regarding the role and function of streamside management zones may be asked. Several of the most crucial are:

- What should SMZ's accomplish?
- Can SMZ's be managed?
- Should SMZ's be managed?

Before answers to these questions may be offered an understanding of the processes that occur within the SMZ are necessary.

A distinction is necessary between an SMZ's function and its degree of importance to protection of wetlands in comparison with free-flowing streams. Wetlands themselves often provide the same amelioration of upslope inputs (see paper by Kuenzler in this Proceedings) as expected of streamside management zones. In addition, since the boundary of a wetland is not universally defined, many delineated SMZ's include portions of wetlands. The following discussion will beg the issue of inclusion of wetlands within SMZ's and will focus on processes that are common to riparian zones, wetland or not.

Surface Processes

Streamside management zones are areas of potential infiltration for both sheet flow and channelized flow from upslope areas. Potential for infiltration of sheet flow is greatest because water is spread over a large surface area. Infiltration through, the bottom of channels is usually low because the soil pores tend to become clogged over time. However, as previously discussed, sheet flow to riparian zones rarely occurs. Flow is usually channelized when it, reaches the base of a slope. Water that does infiltrate will carry with it into the soil matrix any dissolved nutrients and/or chemicals that then may be subjected to subsurface processes.

Surface deposited materials may become permanently trapped within the SMZ due to physical and biological processes. Soil particles and organic debris are physically trapped by the forest floor, variations in microtopography and other physical features. The subsequent decomposition of organic debris is an example of a biological process. Other deposited materials may only be detained, often being mobilized later by large storms. Detention is most likely to occur when channelized flow to the riparian zone carries particulate matter that clogs the channels. The detained material can have adverse impacts to water quality when moved to the watercourse and can lead to a change in the timing of flow because little infiltration occurs.

Cooper and others (1987) report one of the few studies that documents the role of riparian zones in trapping sediments. Using Cesium ^{137} activity in sediment as a dating technique, the authors measured the depth of sediments deposited in ephemeral and intermittent streams, floodplain swamps and at the forest edge of riparian zones in two large Coastal plain watersheds in North Carolina. Approximately 50 percent of each watershed was cultivated. The depth of sediment trapped at the forest edge ranged from 15 to 50 cm which was approximately three times the sediment deposited in the streams and up to 10 times the sediment deposited in the floodplain swamp. This study illustrates that the greatest depth of sediment produced by upland practices is deposited at the edge of the forested riparian zone where gradients are greatly reduced and not in channels where it can be continually moved downstream. The lack of deposits in the floodplain swamps attests to the efficiency of the riparian zone (forest edge) for retention of sediments.

Results of the study by Cooper and others (1987) defines average sediment deposition conditions over the two watersheds and not total sediment produced in the watersheds. No specific studies have been reported or specific situations presented in the literature that will aid in definition of SMZ conditions necessary to achieve sediment retention and water quality objectives.

Subsurface Processes

Subsurface processes may be the most important to controlling upland discharges to watercourses. Subsurface flow into the riparian zone, either saturated (i.e., groundwater) or unsaturated, presents the greatest opportunity for reduction of potential impacts to adjacent watercourses. Because subsurface flow is much slower than surface flow the delivery of water, particularly stormflow, is delayed resulting in a more regulated flow regime (Hewlett and Nutter 1970).

The fate of nutrients and other chemicals contained in subsurface flow entering and flowing through the riparian zone is not always certain because there are numerous biological, physical and/or chemical processes that may occur. Lowrance and others (1984) developed a nutrient budget for a natural hardwood forest riparian zone adjacent to an agricultural watershed in the Coastal Plain of Georgia. All nutrient inputs to the riparian zone were by subsurface flow except precipitation and in the case of nitrogen, fixation. The authors demonstrated that retention within the riparian zone followed the following pattern:

$$N > Ca > Cl > Mg > P > K$$

The budgets for all ions, except chloride (which is an anion), were negative which means that more of each ion was retained within the riparian zone than delivered. In addition, about 69 percent of the input nitrogen was lost to denitrification. Similar results have been reported by Peterjohn and Correll (1984).

No specific studies on the fate of other chemicals in the riparian zone, such as pesticides, have been conducted but it is expected that their behavior would be the same as demonstrated on upland sites. That is, many would be adsorbed to soils in the riparian zone and/or continue to degrade due to prolonged retention times.

DISCUSSION AND CONCLUSIONS

From the previous discussion we can conclude that riparian zones have an important role in ameliorating the impacts of upslope practices to adjacent watercourses. Undisturbed forest riparian zones appear to have the greatest potential for retention of water, nutrients and chemicals due to the maintenance of favorable conditions for physical, chemical and biological processes. The effects of both surface and subsurface processes were studied by Nikitin and Spirina (1985) who compared nutrient removal characteristics for three types of riparian zones in Russia; young pine plantation, natural vegetation and meadow. The percent of nitrogen and phosphorus removed from water and sediment inputs from agricultural fields were greatest in the natural vegetation and least in the meadow riparian zones. Thus, the natural vegetation had the greatest surface trapping efficiency and greatest potential for utilization of nutrients. This study, as well as the one by Lowrance and others (1984), indicate surface processes are particularly important for reducing impacts of soil-adsorbed nutrients or chemicals while subsurface processes reduce the effects of soluble compounds.

Biological processes such as nutrient uptake and storage by vegetation, maintenance of viable soil microbial populations and maintenance of good hydrologic properties through incorporation of organic matter are probably the most critical processes protecting-water quality. Thus, riparian zones play an important role in determining the quality of water passing from an upslope area to an adjacent watercourse. However, the assimilative capacity of riparian zones is not infinite, it can become overloaded at which point no amelioration will occur and it is possible that, for some materials, a flushing from storage may occur.

Because riparian zones have a limited capacity and operate to cleanse upslope inputs by natural means, overpowering the natural processes through poor upslope practices will likely lead to degradation of the watercourse the riparian zone is meant to protect. In other words, the designated streamside management zones are not meant to clean up results of poor upslope practices.

The width of the streamside management zone, i.e., that portion of the riparian zone that will be subjected to special management conditions (including protection), necessary to achieve the desired protection of water quality and quantity has not been demonstrated by specific studies. No doubt, if sufficient shading is provided to control temperature increases in the watercourse, only a relatively narrow SMZ would be necessary for protection from upslope practices involving minimal disturbance and nearly immediate revegetation so leaching of nutrients is minimized. As the intensity of disturbance increases an&or the time of revegetation is delayed, the width of the required SMZ must become greater but not at a linear rate of increase. Other conditions that must be factored into determination of optimal SMZ width are slope, depth to water table, vigor of the vegetation, nature of the hydraulic connectivity between the SMZ and the watercourse, degree of management (e.g., harvesting) within the SMZ and other similar conditions. In summary, no scientific means are available for exact definition of the optimal SMZ width. Managers must rely on knowledge of the processes and nature of the riparian zone and watercourse to aid in selection of the optimal width. The current practice of requiring a certain width is probably adequate for most cases and if there is an error it likely occurs on the conservative side. However, the manager should be aware of the site specific conditions described above that may require a widening beyond that required to account for special site conditions and to minimize potential impacts.

Can streamside management zones be managed? Again, there are no specific studies that definitively compare the function of SMZ's before and after selection cutting permitted by many best management practices. Elmore and Beschta (1987) present a stimulating discussion on issues and concerns in management and use of riparian zones in Western Oregon. If SMZ's are to be managed, several critical conditions within the SMZ must be protected or maintained. They are:

- Protect mineral soil from disturbance and compaction.
- Preserve the forest floor.
- Preserve natural surface and subsurface water flow paths.
- Maintain vigorous and diverse vegetation systems.
- Limit exposure to direct radiation so temperatures are not significantly increased.
- Maintain moist soil conditions conducive to soil microbial activities.

Should streamside management zones be managed? In most cases the answer to this question rests squarely with the manager and how much control he/she exerts over specification of field operations. If strict specification and control of practices is not possible, it is best that activities within the SMZ be avoided because the impacts of poor practices often outweigh the small monetary benefits gained from the practice.

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VALUE OF FORESTED WETLANDS AS FILTERS FOR SEDIMENTS AND NUTRIENTS.

Edward J. Kuenzler[1]

Southern region has extensive freshwater forested wetlands. Those along streams can remove major percentages of suspended sediments from cropland runoff and of nitrogen and phosphorus from both point - and nonpoint-sources of pollution. Continuing losses of forested wetland area and function reduce sediment- and nutrient-removal capability with consequent adverse effects on water quality.

INTRODUCTION

The Southern states, from Viriginia to Florida to eastern Texas to southern Illinois, have extensive freshwater forested wetlands (Brinson and others 1981a; Wharton and others 1982; Tiner 1984). These wetlands, termed palustrine forested wetlands by Cowardin and others (1979), vary greatly in size, hydrology, soils, and tree species composition. Functionally, however, they have many similarities, especially in their processing of particulate matter and nutrients and their response to antbropogenic waste loadings. One important wetland type consists of bottomland hardwood (BLH) forests along the streams and rivers crossing the Gulf and Atlantic Coastal Plains and extending up the Mississippi River to Illinois (McKnight and others 1981; Mitsch and Gosselink 1986). Other important riparian wetland systems of the Southeast include cypress strands, willow strands, and small headwater branches and drains (Wharton and others 1982). Riparian wetlands occupy only a small proportion of most watersheds. The abundant cypress domes and Carolina Bays, and the extensive pocosins of the Southeast generally have little flow-through of surface water.

The term "filter" as used in the title connotes a physical structure and associated processes which remove from stream and swamp waters excessive or undesirable materials, including particulates and solubles, organics and inorganics, nutrients and toxins. The processes which effect removal from water include sedimentation of suspended matter, adsorption and fixation onto soil particles, metabolism of organics, and microbial conversion to gases (CO_2, N_2, H_2) which escape to the atmosphere. The gaseous products remove carbon and nitrogen from the entire wetland system. Details of these processes vary markedly. Wetlands, however, are not simply sources or sinks for nutrients and other materials, they are also major transformers. The Apalachicola wetlands transformed much of the inorganic N and P inputs to organic detrital outputs (Elder 1985). Swamp and bottomland waters of the Barataria region, Louisiana, also increased their organic N at the expense of inorganic N while major losses of particulate N and P were occurring (Kemp and Day 1984). Finally, wetlands are ecosystems with critically important living constituents. The biotic structure of wetlands generally has sufficient resilience to adapt to moderate loads, although upper limits exist beyond which system functioning is damaged. Harmful effects of pollutants on the wetlands are certainly of concern, but will not be reviewed here.

Riparian wetlands have several values to mankind: hydrologic values, organic productivity values, biotic values, biogeochemical values, geomorphic values, and others (Brinson and others 1981a). Important among these is improvement of surface water quality by removing or retaining in the wetland suspended sediments, plant nutrients, and toxic chemicals. Kuenzler and Craig (1986) constructed mass balance models of nitrogen and phosphorus yields of the Chowan River watershed in Virginia and North Carolina. Their calculations suggested that the riparian systems removed 64 percent of the total N and 43 percent of the total P from upland, mostly nonpoint, sources. The values attributable to these ecosystem filters depends on both on the materials being removed and on local and watershed characteristics; the values are not perceived to be the same everywhere.

This report summarizes studies of Southeastern forested wetlands which have shown removals of nutrients and suspended sediments coming from agricultural runoff and municipal wastewaters. Most studies were conducted in cypress domes and riparian wetlands bordering streams and rivers. The riparian location permits interception and processing of waterborne wastes, thereby reducing siltation and contributing to water quality of downstream rivers, lakes, and estuaries. The approach taken here is to describe the structural and functional attributes of forested wetlands which affect their ability to filter substances from water, to give examples of removal processes and efficiencies, and to suggest possible mechanisms of removal. The goal is to improve understanding of these riparian system functions and to show the importance of conserving their values.

SALIENT FEATURES OF WETLANDS AS FILTERS

The general characteristics of Southern forested wetlands are becoming well known (Brown and others 1978; Wharton and Brinson 1978; Wharton and others 1982). Many of their structural features and functional capabilities relate directly to their ability to process waste materials (Kadlec and Tilton 1979).

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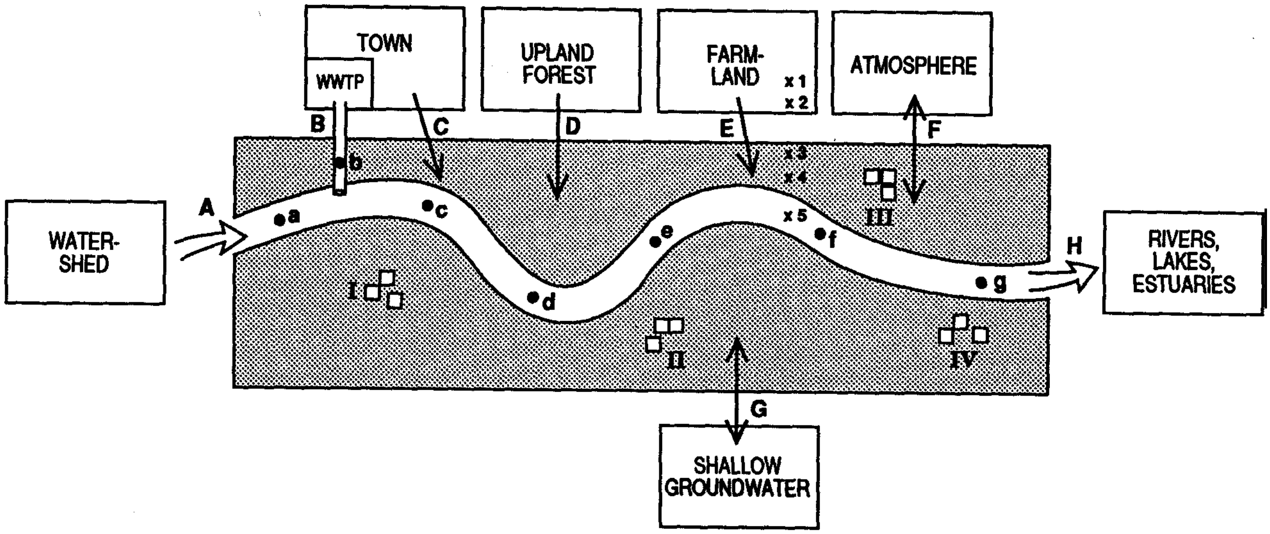

Figure l.-Diagram of a tract of riparian forested wetland (stippled) with a meandering stream. Mass balance sampling should include hydrologic inputs and outputs (A, H), wastewater input(s) (B), nonpoint source fluxes (C, D, E), and two-way exchanges (F, G). Other approaches to sampling require stations down a longitudinal section (a-g) or along a transverse section (l-5). Replicated blocks represent locations of plots or microcosms for intensive study.

Location and Hydrology

The location of riparian systems along streams interposed between upland sources (forests, towns, agricultural operations) and downstream surface waters (rivers, lakes, reservoirs, estuaries) is the spatial element which permits efficient processing of materials (Fig. 1). Most of our riparian forests occur on broad, flat floodplains bordering low-gradient streams. The water in natural, unimpacted, Coastal Plain streams, bottomlands, and swamps is relatively clear, dark with humic color, and low in pH, dissolved solids, dissolved oxygen (in summer), and nutrients (Beck and others 1974; Kuenzler and others 1977; Brown 1981). Rivers arising in the Piedmont, however, typically carry higher loads of suspended sediments and dissolved salts and nutrients from their watersheds. The stream and its floodplain are intimately connected physically, geologically, chemically, and biologically. As it passes through a tract of wetland, it may receive additional loads from towns, tributaries, and farm land as well as net gains from (or losses to) the atmosphere before continuing to downstream surface waters (Fig. 1). Stream velocities are usually low, even in the channel, but may be very low over the floodplain, permitting sedimentation of silts, clays, and organic detritus. Water tables are high. Inundation of the floodplain often persists for months during winter and spring, although storms may cause flooding in other seasons also. Stream waters are in contact with channel sediments and during flood events also spread out over floodplain soils. Such intimate contact of relatively shallow water and its particulate and soluble burdens with the riparian system for substantial periods of time provides opportunity for removal of many particulate and soluble materials.

Cypress domes are moderately small but very abundant wet depressions in Florida and southern Georgia dominated by pond cypress (Mitsch and Gosselink 1986). They are hydrologically different from riparian systems because they fill and empty mostly in response to precipitation, evapotranspiration, and water-table depth rather than responding to a flowthrough stream. They have been studied in relation to their use for wastewater treatment. Mitsch (1984) summarized the physical, chemical, and metabolic seasonal patterns of cypress domes.

Substratum

The substratum of the wetland systems considered here are generally fine-grained. The riparian systems tend to function as sediment traps, creating alluvial sediments and soils. Although soil texture may vary considerably, even across one stream's floodplain, it is usually dominated by clay and silt and is rich in organic matter (Wharton and others 1982). The organic fraction is usually highest in the leaf litter, decreasing through the duff layer to the more mineral horizons below, although some wetlands have deposited abundant organic matter and produced peat. The smallest clay and organic particles are of colloidal dimensions, strongly increasing the sorption capacity of the soil. When the soils are saturated with water, aeration becomes inadequate and microbial respiration depletes the oxygen. At low redox potentials, microbial activity shifts to anaerobic pathways (Armstrong 1982). Spatial and temporal patterns of soil redox potential, pH, and other chemical characteristics affect the distributions and processing of several critical elements, including nitrogen and phosphorus (Ponnamperuma 1972; Patrick and others 1976; Gambrel1 and Patrick 1978; Krottje and others 1982; Armstrong 1982; Bohn and others 1985; Richardson 1985).

Biota and Energy Flow

The vegetation is dominated by trees. Species composition and diversity vary from region to region, even within a watershed or across a transect of bottomland forest (Larson and others 1981). Trees are distributed in relation to the likelihood of flooding and anoxic soils, the most flood-tolerant species occurring at lower elevations (Huffman and Forsythe 1981; McKnight, and others 1981). Primary productivity is generally high; the range of total annual biomass production values summarized by Brinson and others (1981a) was from 800 to 160'7 g dry weight/m^2 yr. The richness of the bottomland soils contributes to the productivity of those trees which can tolerate the ambient flooding regime. Other vegetation includes herbaceous annuals and perennials, vines, mosses and liverworts, and filamentous algae growing on the floodplain when water and sunlight are sufficient.

The vegetation directly affects the filtering ability of a wetland system in several ways. It contributes to the roughness coefficient, decreasing water velocities and thereby promoting sedimentation. Some particles are removed from the water by direct impingement onto plant surfaces. Filamentous algae, herbaceous plants, and litter microbes of the forest floor assimilate inorganic phosphorus and nitrogen from the water (Kuenzler and others 1980; Atchue and others 1983; Qualls 1984). Oxygen diffuses from the roots of many flood-tolerant plants (Armstrong 1982), creating sharp redox gradients close to roots in anoxic soils. Such gradients in the rhizosphere are dynamic zones for important microbial metabolic reactions involving carbon, sulfur, and nitrogen, and affecting redox reactions of other elements as well.

Bacteria and fungi in the litter and soil are especially important to processing of waste materials in reparian wetlands. A major role of these microbes is the decomposition of autochthonous organic matter such as leaf litter, but they also can degrade allochthonous organic detritus, including wastewater organic constituents (e.g., Gambrel1 and others 1987). Rapid microbial activity in flooded soils results in anoxic conditions and low redox potentials. Finally, microbes participate in many characteristic oxidation-reduction reactions in soils (e.g., ammonification, nitritication, denitrification, sulfate reduction, sulfide oxidation, methanogenesis, and transformations of iron transformations) (Armstrong 1982). These and other reactions add to the metabolic diversity of wetland soils, contributing to effective wastewater treatment.

APPROACHES FOR MEASURING FILTER EFFECTIVENSS

Several approaches have been used to assess how effectively forested wetlands remove waste materials from water (cf. Kadlec 1979). The mass balance, or black box, method (Table 1) requires recognition of wetland boundaries, for example, a tract of bottomland hardwoods (Fig. 1) within which one determines net gains or losses based on all inputs and outputs of one or more elements (fluxes A-H). From the ratio of total outputs to total inputs, the efficiency of removal is calculated. Because of its utility for management purposes and the comparability of its results among different types of wetlands, the mass balance method is often used.

The second approach (Table 1) is based on samples of water or soil collected down a longitudinal section (Fig. 1; Stations a-g) hydrologically above, at, and below the outfall. This approach provides more detail of spatial patterns of nutrient removal than does the mass balance approach. The third approach (Table 1) establishes a transect from an upland system across the riparian zone to a stream (Fig. 1; Stations l-5). This method has been used to measure deposition of suspended sediments from overland runoff or removal of fertilizer nitrate from shallow groundwater. The final approach (Table 1) is based on intensive study of subsystems within the wetland-the water, the soil, the vegetation, or some other discrete compartment (Fig. 1; replicated plots or microcosms (I-IV). Field studies may consist of chambers, for example, enclosing portions of the forest floor. Laboratory experiments may be conducted on water samples or soil cores. Such intensive studies are necessary to understand details of the processes which remove nutrients.

RETENTION OF SUSPENDED SEDIMENTS IN FORESTED WETLANDS

Suspended sediment is a natural constituent of running waters. Activities which disturb watershed soils-cultivation of fields, road and highway construction, surface mining, and urban development-increase the delivery of particulate matter to watercourses, loading the water with suspended sediments. Delivery of heavy sediment loads to slow-moving streams shifts the natural erosion-deposition balance to the right, resulting in more sedimentation on riparian floodplains.

Table l.-Approaches for assessing waste removal in riparian wetland systems (cf. Kadlec 1979)

A. Mass balance. Removal of wastes assessed from difference between sum of all input loads (A + B + C + . . .) and all output yields (F + H + . . .) of a defined tract of riparian system (see Fig. 1).

B. Longitudinal section. Removal of wastes, often from point sources, assessed from decreases in surface water concentrations or from accumulation in soil or sediment at stations above, at, and below an outfall (Fig. 1; a-g).

C. Transverse section. Removal of wastes from nonpoint sources assessed from decreases in surficial groundwater concentrations at wells or from accumulation of sediments along a transect from the upland source, across the riparian zone, to the stream (Fig. 1; #1 - 5).

D. Intensive study. Removal of wastes assessed by observation or experimentation in replicated microcosms (Fig. 1, I-IV) where controlling factors can be measured or manipulated.

Deposition of suspended materials in bottomlands is qualitatively evident both from the thickness of accumulated alluvium and from decreased streamwater turbidity below forested wetlands. Thick alluvial soils are characteristic of floodplains serving turbid low-gradient rivers. Low concentrations of suspended solids strongly suggests trapping of sediments in forested coastal plain bottomlands (Sheridan and Hubbard 1987). Kitchens and others (1975) showed turbidity reductions as floodwaters moved by sheetflow over the Santee River, SC, floodplain. Channelized streams in eastern North Carolina had significantly higher turbidity levels than did streams which could still inundate their floodplains (Kuenzler and others 1977). The decreases in suspended sediments as pumped agricultural drainage waters flowed through forested buffer areas were used to calculate a 20-year removal efficiency of 92 percent (Chescheir and others 1987).

Sedimentation rate and concomitant nutrient trapping has also been assessed directly using sediment traps. Mitsch and others (1979) measured annual sedimentation rates onto the floodplain of an alluvial cypress swamp in southern Illinois. Although this swamp constituted less than 1 percent of total wetland area in the watershed, a 5-day flood in March deposited 447 g/m^2, about 3 percent of the entire suspended sediment load passing over the swamp.

Sedimentation rates were also determined from the thickness of material accumulated above the ^{137}Cs layer deposited by the 1963-1964 fallout peak. Along the lower edges of agricultural fields in the 1350 ha Cypress Creek, NC, watershed, 15-50 cm of relatively sandy soil were dropped where sheet-wash and gully-wash first entered riparian forest. The finer silt and clay particles traveled onto the floodplains before being dropped (Table 2). It was calculated that 84 to 90 percent of sediments eroded from tilled land during the last 20 years was retained in these riparian forests (Cooper and others 1987). Studies elsewhere (Boto and Patrick 1979) showed large differences in accretion rates among riparian systems, especially marshes. Rates in Southeastern forested wetlands are probably highly variable because of the large range of sediment loads and stream velocities. The removal from runoff and stream waters of sorbed nutrients, pesticides, heavy metals, and other materials when suspended sediments settle out is an important topic, but will not be discussed here.

REMOVAL OF NUTRIENTS IN FORESTED WETLANDS

Many chemical elements are required for plant growth, but only a few are generally scarce in the environment relative to the needs for plant growth. Nitrogen and phosphorus will receive major attention here because, as critical limiting nutrients for algae, they are the key to eutrophication control in most Southeastern surface waters-rivers, lakes, reservoirs, and estuaries. One or both elements usually occur in high concentrations in runoff from agriculture and urban areas relative to the amounts in runoff from upland forests (Omernik 1976). Reckow and others (1930) compared statistically the differences of nutrient yields from watersheds having different land use patterns. Municipal wastewater constitutes the major point source of nutrients; such loadings to wetlands vary enormously depending on proximity to towns. Although sources vary, nutrient removal processes are similar in most wetland systems, usually resulting in decreased nutrient concentrations as the water flows through.

NONPOINT SOURCE NUTRIENT REMOVAL

Nitrogen Removal

Measurements of nitrogen concentrations above and below some tract of wetland often show nitrogen removal. Relatively unimpacted streams and rivers with low total-N concentrations generally show only small changes and appear to be at steady state. Although transformations among chemical forms may occur, when inputs from precipitation, minor nonpoint sources, and cryptic point sources approximately balance wetland removals, net total-N removal will not be apparent (Kuenzler and others 1977; Elder 1985). Mass balance calculations based on all imports and exports for a relatively natural stream in a low-intensity agricultural

Table 2.-Distributions of cropland-derived sediments deposited at the riparian forest edge, on the floodplain of emphemeral and intermittent streams, and on the floor of larger floodplain swamps in North Carolina (Cooper and Gilliam 1987; Cooper and others 1987). Distributions of sediment mass and total P are shown as percentages of all sediments deposited since the ^{137}Cs peak in 1963-64

Landscape category	Forest edge	Ephemeral stream	Intermittent stream	Floodplain swamp
Percentage of riparian area (pct)	<1	5-10	20-30	60-70
Sediment deposited (cm)	15-50	5-15	5-15	o-5
Est. sediment mass (pct)	19	19	41	21
Fractions				
Sand (pct)	75	32	40	38
Silt (pct)	19	57	45	38
Clay (pct)	6	11	15	24
Total P (pct of total)	6	12	37	44

Table 3.-Efficiencies of nutrient removal from agricultural and mixed inputs by forested riparian systems of the Southeastern coastal plain

State	Nutrient Source	Notes	Study Type	Pct TN	Removal TP	Reference
	MOSTLY AGRICULTURAL SOURCES					
Md.	watershed = 64 percent agric.	a	C	89	80	Peterjohn and Correll 1984
N.C.	watershed = 32 percent agric.	b	A	22	37	Yarbro and others 1984
N.C.	intensive agric.	c	B	ca 80	81	Chescheir and others 1987
Ga.	watershed = 54 percent agric.	d	C	68	30	Lowrance and others 1984
La.	largely sugarcane	e	B	26	41	Kemp and Day 1984
	MIXED AGRICULTURAL AND URBAN SOURCES					
S.C.	agric., urban wastewater	f	B		ca 50	Kitchens and others
Ga.	argic., urban runoff and wastewater	g	B		20	Tietjen and Carter 1981

NOTES:
a) 16.3-ha sub-basin of Rhode R.; non-wetland riparian forest; 1-yr. study.
b) Creeping Sw.; 3200-ha bottomland hardwood (BLH) forest; summer-intermittent stream; 1976 only.
c) drainage pumped to BLH buffer zone; computer simulation based on field data.
d) 1568-ha watershed = 30 percent riparian forest; south Georgia; 2-yr. study.
e) Barataria swamp; 320 ha cypress, tupelo, BLH swamp; 9-mo. study.
f) Jan.-Apr. only; BLH floodplain swamp.
g) SW. Georgia; 1-yr. study; site extended 5.3 km below main outfall; alluvial swamp.

watershed (Creeping Swamp, NC), however, showed the following removals: nitrate, 17 percent; ammonium, 42 percent; total organic N, 4.8 percent; and total N, 22 percent (Yarbro and others 1984) (Table 3). Agricultural inputs of ammonium, nitrate, and particulate N were removed in a Louisiana swamp and bottomland system (Kemp and Day 1984). The annual removal of total N amounted to 26 percent of inputs (Table 3), mostly because of settling of particulate N.

There are chemical form changes and net losses as shallow groundwater carries nitrogen across riparian zones to the streams. Two recent studies of agriculture-dominated watersheds, using data from gauged streams and groundwater wells, showed relatively high removal efficiencies. Aquicludes underlying each study site prevented loss of nitrogen to deep aquifers. In Georgia, 57 percent of water input to a wet riparian area was precipitation, 41 percent was shallow groundwater; and very little was surface runoff (Lowrance and others 1983). Most of the annual total N load (41.2 kg/ha) from cropland to riparian zone was nitrate in groundwater (29 kg/ha) (Table 4A). Nitrate in shallow groundwater of this zone decreased to about 18 percent of total N, while organic N increased to about 76 percent, values similar to those in stream water (Lowrance and others 1983). The annual nitrogen yield from the riparian wetland (13 kg/ha) was measured in the surface water of the stream. The difference between nutrient load and yield constituted net removal; 68 percent of total N from the watershed was removed in the riparian zone (Tables 3, 4A) (Lowrance and others 1984). Non-wetland riparian forests also remove N from shallow groundwater. In Maryland, groundwater flux (51 kg/ha) dominated (Table 4A), but precipitation and overland flow also contributed to the riparian zone's annual load of 83 kg/ha. Groundwater flux from the riparian zone dominated total yield of 9.2 kg/ha (Petejohn and Correll 1984). The authors calculated that 89 percent of total-N loading was removed in the riparian forest zone (Table 3, 4A).

Other studies of nitrogen processing have contributed to our understanding. Denitrification rates in stream channels alone could not account for nitrate decreases in runoff from cultivated fields (Jacobs and Gilliam 1985a). Nitrate levels decreased in streams below relatively narrow riparian wetlands, however, probably by denitrification in the soil (Jacobs and Gilliam 1985b). On the lower coastal plain of North Carolina, broad areas of natural hydric hardwoods and loblolly pine were used as agricultural wastewater buffers; they removed about 92 percent of suspended sediments, 82 percent of nitrate, 79 percent of TKN, and 81 percent of TP from drainage water pumped over the forest floor (Table 3)

(Chescheir and others 1987). These examples indicate that forested wetlands along streams can intercept and remove 22 to 89 percent of nonpoint source total N, either in shallow groundwater and in surface floodwaters.

Phosphorus Removal

Forested wetlands usually retain nonpoint source phosphorus delivered in floodwater runoff. A broad alluvial swamp system in Louisiana removed 41 percent of the annual total-P inputs (Table 3); there was rapid sedimentation of particulate P while soluble organic and inorganic P fractions increased somewhat in the water (Kemp and Day 1984). The Santee Swamp field study (Kitchens and others 19'75) showed removal of about 50 percent of phosphate and of total P during winter flooding of the Wateree River (Table 3). Because turbidity did not decrease consistently, they attributed phosphorus loss primarily to biological removal in the extensive beds of aquatic vegetation. An Illinois cypress swamp removed by sedimentation about 4.5 percent of the phosphorus in a summer flood event, depositing 3.6 g P/m^2 on the floodplain (Mitsch and others 1979). A Georgia floodplain system removed about 20 percent of the phosphorus load (29 g $P/^2yr$) derived from agricultural runoff, urban runoff, and urban and industrial wastewaters (Tietjen and Carter 1981). This relatively low retention efficiency, however, is consistent with other sites having similarly high loading rates (Nichols 1983).

In a smaller system, Yarbro (in Kuenzler and others 1980) showed that 160 mg P/m^2 was deposited in particulate form on the Creeping Swamp floodplain during December–May, representing about half of the net loss of phosphorus from swamp water there. Mass balance calculations by Yarbro and others (1984) showed annual removal efficiencies of 52 percent for phosphate, 13 percent for particulate P, and 37 percent for total P (Table 3). Yarbro (1983) also showed seasonal patterns of phosphorus retention in Creeping Swamp. Algal uptake, soil and litter uptake, and sedimentation removed phosphorus from the water during the winter-spring period of flooding; phosphorus accumulated in the swamp during the warm, drier periods in spite of mobilization because stream discharge was insufficient to remove it then. Exports of N and P by several natural swamp streams were less than inputs from precipitation alone, demonstrating high retention and removal efficiencies. Channelization of streams to improve agricultural drainage, however, increased the exports of nutrients, especially nitrate and particulate P (Yarbro and others **1984).**

Other bottomland systems in agriculture-dominated watersheds also retain phosphorus. Runoff from the Cypress Creek, NC, watershed carried phosphorus along with suspended soil material; almost all phosphorus lost from the watershed during the last 20 years was accounted for in sediments deposited in riparian forest (Cooper and Gilliam 1987). There was a positive relationship ($R^2 = 0.80$) between phosphorus and clay contents of the deposits, presumably because of the affinity of phosphorus for iron and aluminum of the clay (Wauchope and McDowell 1984). Because of higher clay content, the percentage of P deposited on the floodplain was, therefore, twice the percentage of sediment mass deposited (Table 2). In Georgia, precipitation delivered about 1.7 times as much total P to the riparian zone as did groundwater flow; only about 30 percent of total-P input was removed (Lowrance and others 1984) (Tables 3, 4B). Non-wetland riparian forest removals of P are also efficient. In Maryland, surface runoff delivered the bulk of the total P,

Table 4.-Output yields of (A) total N and (B) total P from the riparian zone compared to the input loadings from agricultural runoff and precipitation in Georgia (after Lowrance and others 1984) and Maryland (Peterjohn and Correll 1984). The Maryland riparian forest was not a wetland system. Units are kg/ha.yr

Site		Precipitation	Ground water	Surface water	Total	Fraction of Loading (pct)
		A. Total Nitrogen				
Georgia	Load	12.2	29		41.2	
	Yield			13.0	13.0	
	Net				28.2	68
Maryland	Load	14	51	18	83.0	
	Yield		6.9	2.3	9.2	
	Net				73.8	89
		B. Total Phosphorus				
Georgia	Load	3.5	2.1		5.6	
	Yield			3.9	3.9	
	Net				1.7	30.4
Maryland	Load	0.14	0.091	3.4	3.63	
	Yield		0.30	0.43	0.73	
	Net				2.90	80

presumably on suspended particles, and there was significant loss of total P from the riparian zone in groundwater flow (Peterjohn and Correll 1984). A much larger fraction (80 percent) of total P was removed in the Maryland study (Tables 3, 4B). These studies reported a range of 20 to 81 percent removal of nonpoint source phosphorus by forested riparian systems (Table 3).

POINT SOURCE NUTRIENT REMOVAL

Other studies have demonstrated that freshwater wetlands remove nutrients effectively from wastewater (see summaries by Sloey and others 1978; Van der Valk and others 1978; Kadlec and Tilton 1979; Nichols 1983). Several factors affect the rate of removal of nutrients, but a few seem generally important. Nichols (1983) showed the importance of loading rate in several types of freshwater wetland systems. Wetlands receiving light loads usually stripped nutrients from the water with efficiencies in excess of 90 percent, whereas heavy loads resulted in much lower efficiencies. Available organic carbon and low redox potential are necessary for microbial denitrification (Burford and Bremner 1975; Patrick and others 1976; Krottje and others 1982). Sorption capacity is important for phosphorus removal. Saturation of sorption sites apparently decreases P removal efficiency after a few years of sewage loading (Nichols 1983), whereas the availability of the atmospheric sink permits N removal to remain high (DeBusk and Reddy 1987). Some organic soils retain P very effectively (Krottje and others 1982), as do many fine-grained (clay) mineral soils rich in extractable aluminum (Richardson 1985). High redox potentials in wetland waters and soils favor phosphate retention (Kuenzler and others 1980, Kemp and Day 1984) through sorption onto ferric oxyhydroxides (Gambrel1 and Patrick 1978). Nutrient processing controls and rates in the Southeast deserve more study.

Nitrogen Removal

Domestic sewage discharges into forested wetlands of the Southeast have been intensively studied in Florida cypress domes. Typically there are large pond-cypress and other swamp trees growing in and around a shallow, stagnant, dark, acidic central pond (Mitsch 1984). Mass balance calculations based on three years of study showed that 90 percent of the nitrogen inputs to an experimentally enriched dome came from the wastewater (Table 5) (Dierberg and Brezonik 1984a). The dome waters were of low redox potential (Dierberg and Brezonik 1984b) and the effluent nitrogen was mostly ammonium. Because of low nitrification and denitrification rates, 74 percent of the nitrogen was deposited in the bottom sediments or taken up by the cypress trees (Table 6); total removal was about 88 percent (Table 5).

Wastewater nitrogen is also effectively removed by forested bottomlands. Nitrogen concentrations in water

Table 5.-Efficiencies of wastewater nutrient removals by forested riparian and cypress dome systems of the Southeastern coastal plain

State	Nutrient Source	Notes	Study Type	Pct Removal TN	Pct Removal TP	Reference
	MOSTLY MUNICIPAL WASTEWATER					
N.C.	sewage lagoon	a	B	92	102	Kuenzler 1988
N.C.	secondary treatment	a	B	80	87	Kuenzler 1988
Fla.	secondary treatment	b	B	90	98	Boyt and others 1977
Fla.	secondary treatment	c	B	87	62	Winchester and Emenhiser 1983
Fla.	secondary treatment	d	A	81	-55	Knight and others 1987
Fla.	municipal septic tank	e	B		46	Nessel and Bayley 1984
Fla.	secondary treatment	f	A	88	92	Dierberg and Brezonik 1984

NOTES:

a) 2-year study; 3-4 km of cypress-gum swamp; summer-intermittent streams;
b) Wildwood, Fla.; 3.7 km of marsh and swamp; 1-yr. study.
c) Pottsburg Cr., Fla.: 206-ha hardwood swamp; 4-mo. of dry season study.
d) Reedy Cr.; 35-ha swamp forest; 7-yr. study.
e) Waldo, Fla.; 2.6 ha cypress strand; 1-yr. study.
f) N-central Fla. 1 ha cypress dome; 3-yr. means.
A) mass balance approach.
B) longitudinal section approach.
C) transverse section approach

decreased markedly in wetlands which had received secondarily treated sewage from Wildwood, FL, for 20 years (Boyt and others 19'77). Except for somewhat erratic variations in nitrate levels, inorganic nitrogen concentrations dropped from about 10-15 mg/L to nearly undetectable values within 3.7 km of the outfall. Organic N concentrations decreased 75 to 85 percent, leveling off at 1 to 2 mg/L, very close to the mean total-N concentration in control swamp water. The authors calculated 90 percent reduction in total N by the swamps (Table 5).

The nutrient status of waters below a wastewater outfall in Pottsburg Creek Swamp in northeastern Florida were studied during April-July during a drought period (Winchester and Emenhiser 1983). The hydrology was complicated; hydrologic inflow exceeded outflow most of the time whereas chloride concentrations were not different, suggesting substantial infiltration to groundwater. A mass balance model showed 87 percent of total-N loading (mostly from wastewater) was removed by the wetland (Table 5). About half of the total-N input was ammonium; this was apparently removed by nitrification followed by denitrification. Discharge to a natural wetland in part of the wastewater treatment system at Reedy Creek, FL (Knight and others 1987). Interpretation of results at Reedy Creek is complicated by shallow groundwater exchanges and by ungauged storm runoff, but more than seven years of data suggest mean annual total-N removal efficiencies of 71 to 95 percent, averaging 81 percent (Table 5). Total-N removals tended to increase with temperature, but efficiencies were high even at concentrations up to 20 mg/L and loadings up to 0.5 g/m^2d (Knight and others 1987).

Coastal plain swamps in North Carolina also remove wastewater nitrogen rapidly. Water samples collected monthly in two small, summer-intermittent streams passing through relatively broad cypressgum-hardwood bottomlands were analyzed for effluent nutrients (Kuenzler 1988).

Table 6.-Nitrogen and phosphorus mass balances in a sewage-enriched Florida cypress dome (after Dierberg and Brezonik 19843)

	Total N	*Total P*
Annual *Flux* (g/m^2 yr)	14.92	11.39
Inputs (percentage of annual flux		
Precipitation	7	1
Overland Runoff	2	1
N-fixation	1	
Sewage Effluent	90	98
Total	100	100
Outputs (percentage of annual flux)		
Denitrification	14	
Cypress tree uptake	18	1
Sediment deposition	56	91
Infiltration to groundwater	8	2
Overflow	4	6
Total	100	100

Nutrient concentrations were corrected for dilution to calculate net losses. More than 50 percent of all forms of nitrogen were usually removed within 200 to 300 m of the outfall, and more than 80 percent within 3 to 4 km (Tables 5, 7), presumably mostly by sedimentation, ammonification, nitrification and denitrification. Brinson and others (1981b) used ^{15}N-labeled ammonium and nitrate to measure nitrogen immobilization, nitrification, and denitrification in experimental chambers on the swamp floor. In other experiments they added sewage effluent, ammonium, nitrate, or phosphate each week for nearly a year to several microcosms on the swamp floor (Brinson and others 1984). Although nitrate disappeared rapidly, ammonium accumulated in the soil and litter until a drydown period permitted the redox potential to rise and nitrification-denitrification to proceed (Brinson and others 1984). These studies showed that forested bottomland systems, if not overloaded, can actively process additional nitrogen loads and can decrease concentrations to those of unimpacted streams.

Phosphorus Removal

Forested wetland systems usually strip phosphorus from wastewater effluents. Mass balance calculations of Dierberg and Brezonik (1984a) showed that cypress domes removed 92 percent of the phosphorus load, mostly by sedimentation (Tables 5, 6). Bottomland hardwood systems showed similarly high removals. Boyt and others (1977) found consistent removals of total P, with an average removal from the effluent of 98 percent within 3.7 km (Table 5). The Pottsburg Creek Swamp study (Winchester and Emenhiser 1983) showed 62 percent removal of total P from the water (Table 5). Some was removed by soil and vegetation, but much was probably carried away by infiltration to groundwater. Municipal wastewater from Waldo, FL, had been discharged to a cypress strand for more than 45 years. A mass balance model showed 4.39 g P/m^2 .yr inputs (throughfall and surface runoff) and 2.36 g P/m^2 .yr of outputs (surface outflow and groundwater export) (Nessel and Bayley 1984); this constituted about 46 percent removal (Table 5), mostly attributable to movement of water through the soil profile. Knight and others (1987), however, found more export than import of total P in six of the seven full years of data at Reedy Creek, giving negative removal efficiencies (Table 5).

North Carolina swamps rapidly removed sewage phosphorus (Kuenzler 1988). More than 70 percent of phosphate and of total P were removed within 0.2 to 0.32 km of the outfall, and more than 85 percent within a few kilometers (Tables 5, 7), probably because of sedimentation and soil retention. The experimental microcosms of Brinson and others (1984) demonstrated that most of the P added as phosphate or as sewage effluent was removed by forest soil and litter. Thus the major portion of wastewater P appears to be retained by forested wetland systems when small towns discharge to moderately large swamps.

Table ‘I.-Percentages of wastewater nutrients removed at sampling stations below outfalls on North Carolina swamp streams (after Kuenzler 1988). Values are net percentages removed, after correction for dilution, based on medians ± 95 percent confidence interval

Distance below outfall (km)	Nitrate	Ammonium	Total N	Phosphate	Total P
			Brown Marsh Swamp		
0.32	89±44	42±35	53±24	71±23	68±25
4.42	84±82	99±1	92±31	100±0.1	102±3
			Cashie River		
0.20	93-t-183	83±23	59±25	77-c-11	63±34
3.23	105±67	102±4	80±38	102±4	87±19

SEDIMENT AND NUTRIENT REMOVALS: WETLAND VALUES

The water quality improvement provided by forested wetlands depends upon their areas and their functional health. Unfortunately, wetlands have been destroyed rapidly in recent decades. About 54 percent of 215 million acres of wetlands in the coterminous United States in the mid-1950’s was lost over a 20-year period. About 87 percent of these losses are attributable to agriculture, but other kinds of activities have also caused losses, especially to bottomland hardwood forests, swamp lands, and freshwater marshes (Tiner 1984). Turner and others (1981) reported losses of bottomland hardwoods from about 1960 to 1975 as follows: 141,000 acres/yr in Georgia; 140,000 in Arkansas; 60,000 in Louisiana; 52,000 in Missouri; 50,000 in Florida; 30,000 in North and South Carolina; and 28,000 in Alabama. Such enormous reductions in area must be significantly affecting water quality. Although net losses of wetlands continue today, the National Wetlands Policy Forum is developing recommendations designed to stop, then reverse wetland losses. Damages to the functional properties of existing wetlands are not easily quantified, but they might also be reducing water quality significantly even though the wetlands appear structurally normal.

Existing wetland areas are often multipurpose. Large tracts tend to receive protection and management for commercial timber harvest, as refuges for endangered plant and animal species, as natural heritage, and for other values (Brinson and others 1981a). Reports discussed above suggest that large wetland tracts, as well as relatively narrow zones of riparian forest, wetland or not, can substantially reduce sediment, nitrogen, and phosphorus loads to streams. For example, the Cypress Creek system which so efficiently removed suspended sediments (see above) drained a watershed of only about 19 km^2 (Cooper and others 1987). The small streams (1st to 3rd order) of a watershed are the most abundant (Morisawa 1968) and usually comprise most of total stream length (Leopold 1974). Their riparian systems would thus provide the most opportunity for initial nonpoint source pollution control by retaining sediments and reducing nutrient concentrations. Laney (1988) called attention to the fact that recent Corps of Engineers regulations allow deposition of fill material in isolated and headwater wetlands with discharges of less than 5 cubic feet per second, equivalent to watersheds of the order of 5 square miles in the North Carolina coastal plain. No permit is required for fills to such wetlands of less than 1 acre, and only circulation and approval of a pre-discharge notification for fills of 1 to 10 acres. Examination of two counties in North Carolina (Laney 1988) showed that isolated and headwater wetlands comprised 22.8 to 99.0 percent of their total wetland area. It thus appears that a substantial proportion of wetland area as well as wetland length may be at immediate risk of loss, with serious implications for both water quality and habitat values.

The freshwater forested wetlands in the Southeast tend to be very effective at water quality improvement, removing suspended sediments and nutrients with efficiencies similar to those of wetlands elsewhere (Kadlec and Tilton 1979; Nichols 1983). Nitrogen ultimately transferred to the atmosphere may be considered permanently removed from a particular stream or wetland. Inorganic particulates, phosphorus, and many other materials transferred from the water to stream sediments and to soils, however, are stored only temporarily. Eventually the stream will erode them into suspension again, or chemical transformations will solubilize or mobilize them. Thus “removal” is more nearly permanent for some elements than for others. Furthermore, many wetland systems apparently reach limits beyond which removal efficiency for phosphorus and other elements greatly declines (Nichols 1983; Kadlec 1985). High removal efficiencies measured when light loads of wastes are released to large tracts of forested wetlands will not be achieved when heavy loads are released to small tracts.

Water quality maintenance by forested wetlands takes place in addition to provision of many other values. Increasing population density and industrialization of the region will produce ever larger volumes of wastes, although better municipal and industrial wastewater treatment should drcrease the concentrations of some pollutants. We cannot predict whether net wastewater loading will increase or decrease. Best management practices for agriculture, for forestry, and for other land uses are also very important to keeping loadings down to levels that can continue to be processed satisfactorily by forested wetlands. The waste-removal capabilities depends upon properly functioning wetlands with healthy soils and biota. Sufficient area of riparian and other wetlands must be retained in order to prevent excessive loadings which decrease the removal efficiencies. In particular, the headwater riparian systems, wetland or not, may prove to be especially important to water quality management. Critical study is urgent in order that such systems not be filled, drained, or otherwise destroyed before their values are fully recognized.

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STREAMSIDE HABITATS IN SOUTHERN FORESTED WETLANDS: THEIR ROLE AND IMPLICATIONS FOR MANAGEMENT

Rebecca J. Howard and James A. Allen[1]

Abstract.-This paper summarizes recent literature concerning the value of streamside forested wetlands of the Southern United States as fish and wildlife habitat. The role of these wetlands in providing fish spawning and nursery habitat during inundation, protecting water quality, and supplying cover as well as food to channel-dwelling fish is discussed. The importance of habitat edge and vegetation composition and structural complexity to wildlife is reviewed, as are the effects of soil moisture and the proximity of permanent surface water on wildlife species distribution. Recommended widths for forested streamside buffer zones are presented along with suggested management practices within the zones.

INTRODUCTION

The value of streamside forests to fish and wildlife and the influence of forest management on their value have been recognized in a general sense for decades. However, in today's climate of increasing environmental regulation and intensive forest management, there is need for more detailed understanding of the value of streamside forests to fish and wildlife. Dickson and Huntley (1987:38) described the problem well when they wrote that "quantitative data on the effects of riparian zones on wildlife populations are insufficient to enable wildlife managers to justify the retention of riparian zones in land-use plans on a biological and economical basis."

Due in large part to the passage of water pollution control legislation, as well as legislation mandating multiple-use management in our national forests, progress is being made. During the last 10–15 years, a great deal of research has been directed at understanding the value and appropriate management of the riparian zone (Brouha and Parsons 1985).

The vast majority of research on riparian habitats has been conducted in western forests and/or narrow zones in otherwise upland areas. Also, much of the work done in southern forested wetlands has applied to entire floodplain forests. In this paper, we review the literature on streamside habitats within southern forested wetlands and, for reasons described in the next section, we make a distinction between streamside forests and floodplain (or riparian) forests. We also discuss in less detail the value of streamside habitats within other southern forest types, such as pine or mixed pine-hardwood.

STREAMSIDE FORESTS IN SOUTHERN FORESTED WETLANDS

The streamside forest as treated in this paper is equivalent to the forestry term "streamside management zone," which is commonly used in association with best management practices. The streamside forest is different from what are traditionally considered riparian forests. Brinson and others (1981), in their excellent review of the ecology and status or riparian ecosystems, used the term riparian to refer to riverine floodplain or streambank ecosystems. Mitsch and Gosselink (1986) treated the entire bottomland forest, including all five forested zones described in Larson et al. (1981), as riparian forest. Partly because of such treatments and partly because of our perceptions of the needs of forest industries and regulatory agencies, we do not use the terms riparian and streamside interchangeably.

We regard the streamside forest as it applies to southern forested wetlands to be a somewhat arbitrary concept. While useful for the development of non-point pollution control regulations and best management practices, it is not necessarily ecologically distinctive. In many cases, the streamside forest will blend seamlessly into the larger floodplain forest. Nevertheless, streamside forests have several features that make them of potentially high value to wildlife.

One of the most valuable features of streamside forests is their high plant species diversity. There are many types of forests that occur along streamsides, and often several of these types occur within a limited geographic area. These associations (Figure 1) range from cottonwood (*Populus deltoides*) and willow (*Salix nigra*) on newly formed sediment deposits, to baldcypress (*Taxodium distichum*) and tupelo (*Nyssa* spp.) along sloughs, to sweetgum (*Liquidambar styraciflua*) and willow oak (Quercus *phellos*) along intermittent streams in second bottoms. Wharton and others (1982) listed '75 dominance types that occur in bottomland forests of the southeast, almost all of which could potentially be present in streamside forests.

There is often high plant species diversity within a single tract of streamside forest, particularly if the forest is wide enough to include a range of elevations (representing a range of hydroperiods). Plant species diversity is also increased by a "double edge effect," with one side of the forest bordering the stream and the other bordering an area that may have been clearcut or subject to some other form of

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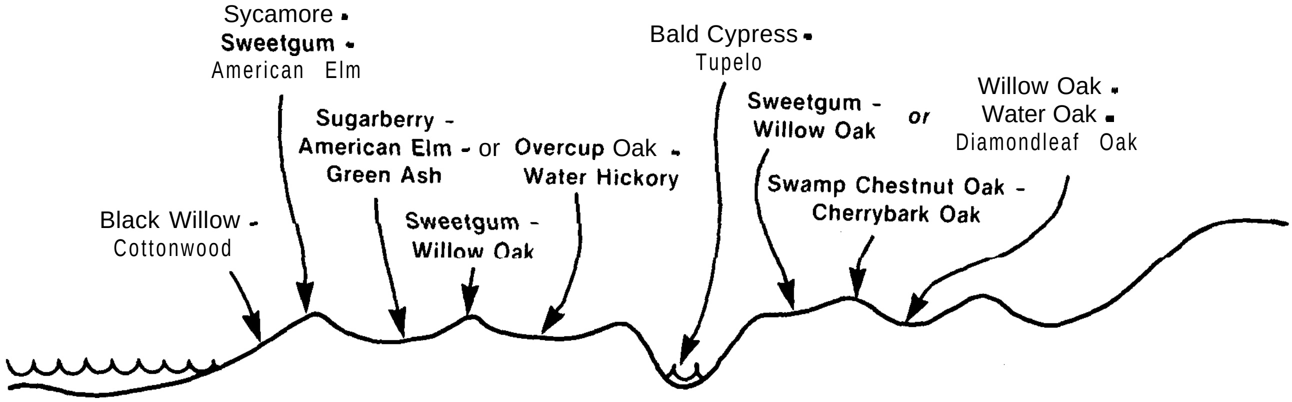

Figure l.-Cross-section of forested floodplain showing dominance types that may occur within streamside management zones (adapted from Wharton and others 1982).

forest management. Associated with-high species diversity and the edge effects, streamside forests often have high levels of structural complexity.

Streamside forests have high primary productivity **compared with nearby upland forests or with adjacent** forested wetlands. Several authors have contrasted southern forested wetland versus upland forest productivity (Brinson and others 1981; Mitsch and Gosselink 1986; Wharton and others 1982), and concluded that, in most cases, primary productivity in forested wetlands is higher. Productivity in streamside forests may often exceed that of adjacent forested wetlands due to a more favorable flooding regime; forested wetlands characterized by flowing water (versus very slow moving or stagnant water) and favorable water table levels and soil aeration have been found to be more productive (Conner and Day 1976; Mitsch and Gosselink 1986).

Related directly to the high primary productivity of streamside forests are high amounts of litterfall. Conditions for decomposition of littlefall are close to optimal in streamside forests. Both adequate soil moisture and aerobic conditions generally result in faster decomposition than in **sites that** are too wet or too dry (Brinson 1977; Peterson and Rolfe 1982; Yates and Day 1983). With rapid decomposition of organic matter, nutrients became available faster and, because of the location of streamside forests, are available to support both terrestrial and aquatic food chains.

FORESTED WETLANDS AS HABITAT

Since little research has dealt directly with the streamside fauna of southern forests, we will rely heavily on information available for southern forested wetlands in general and relate this information to the streamside zone. Forested wetlands, as productive systems, generally have a high capability for providing food and cover to many animal species. The literature concerning the fauna of southeastern bottomland hardwood forests has been thoroughly reviewed by Wharton and others (1981). They noted that bottomland hardwood forests have a distinct fauna that includes both terrestrial and aquatic species, and that "while not as rich in species diversity as uplands in some animals (beetles, ants, lizards, and snakes), it is higher in other (diptera, oligochaete worms, amphibia, birds, large and small mammals, crawfish, turtles)" (Wharton and others 1981:121). They concluded that bottomland hardwood areas supported denser populations of many species than upland forests. Permanently flooded cypress/tupelo wetlands tended to have a depauperate (impoverished) animal community when compared with temporarily inundated forests, but have an important function as travel routes for many animals.

The zone within 200 meters of a stream or other open water appears to be the most heavily used by terrestrial wildlife (Brinson and others 1981). The location of this zone may vary over time depending on the hydrologic characteristics of a site. Streams with a small watershed, steep slopes, and surrounded by relatively impermeable soils will have rapid runoff into the stream and, consequently, **little flooding of the forest adjacent to the channel. In** contrast, the large watershed and low topographic relief associated with areas along the lower Mississippi River system result in broad vegetated floodplains subject to frequent flooding in the spring. Many animals have adapted to the hydrologic cycles, following the rise and retreat of flooding waters, and use the highly productive shallow water zone (Harris and Gosselink 1986). A reduction in the extent or duration of inundation in a wooded wetland may reduce the productive capacity of the swamp (Pollard and others 1983).

Fisheries Habitat

Riverine habitat types in southern forests vary greatly across the region from fast-flowing mountain streams to sluggish bayous in the coastal plain. The associated fisheries resource is, therefore, diverse and ranges from cold-water to warm-water species. A survey conducted in the mid-1970's of the fishes found in waters on southeastern national forest lands lists 470 species (Seehorn 1975). Bottomland hardwood ecosystems support prolific fisheries; the bulk of the commercial catch consists of buffalo (*Ictiobus* spp.), catfish (*Ictalurus* spp.), **carp** (*Cyprinus carpio*), drum (*Aplodinotus* spp.), suckers (*Catostomus* spp.), and-crawfish (*Procambarus*) while the sport catch is predominately bass (*Micropterus* spp.), crappie (*Pomoxis* spp.), sunfish (*Lepomis* spp.), catfish, and crawfish (Roelle and others 1987). Bottomland forests are used by nearly all the fishes of the adjoining river as feeding, spawning and/or nursery grounds (Larson and others 1981). During spring flooding, Guillory (1979) noted that Mississippi River fishes apparently migrated laterally into the floodplain, perpendicular to the direction of flow. Of 22 fish species captured in a North Carolina blackwater creek and its floodplain during winter and spring, more individuals of 18 species were found in the floodplain than in the main channel (Wharton and others 1981). In a creek in Mississippi, Ross and Baker (1983) found 42 fish species in the channel-26 of these on the inundated floodplain. Species found only in the channel were termed "flood-quiescent" and were believed to benefit indirectly from flooding by nutrient transport into the channel. Pollard and others (1983), working in the Atchafalaya River basin in Louisiana, found that adult finfish and crawfish heavily used habitat at the floodwater edge as spawning areas and nursery grounds. Large concentrations of zooplankton were also available as a food source at the ephemerally flooded edge. They concluded that the success of the fisheries is dependent on the forested habitat that is inundated for short periods.

The value of a particular section of streamside forested wetland to the fisheries resource depends on the timing and duration of flooding. Early and prolonged flooding is advantageous because organisms and materials transported with the floodwaters and the additional habitat area provide an abundant food source. This allows rapid growth of larval fishes to a size where predation, which is very intense on the floodplain, is reduced. Hall (1979) found that 7 of 10 common taxa of the Atchafalaya River Basin in Louisiana spawned in backwater habitats. Carp and pickerel *(Esox americanus)* required newly inundated vegetation as a site for egg deposition; the vegetation also provided fish larvae with shelter from predators. Higher numbers of larval fish were collected in backwater habitat of the Atchafalaya River, although greater species diversity was observed in the main stream environment (Hall 1979).

Wharton and others (1981) provided a summary of fish use of southeastern floodplain wetlands based on several studies involving collections of adults, eggs, and larvae. They noted that young fish are abundant in the drowned forests of large rivers from late winter until the water recedes. Some species spawn on the floodplain; the larvae of other species may be passively moved by water onto the floodplain. Large top-level piscivores, such as gar, bowfin, and pickerel, spawn early; the young then forage over the floodplain, feeding on the larvae of later-spawing species. Fish that are characteristic of small feeder streams and floodplain lakes, including darters (*Etheostoma* spp.), some minnows (Family Cyprinidae), topminnows (*Fundulus* spp.), and mosquitofish *(Gambusia affinis)*, may spawn early in the tributaries or may migrate to the inundated floodplain to spawn. Larvae of primary consumers or detrital sifters (carp, some minnows, buffalo, shad (*Alosa* spp.)) are associated with quiet backwater areas. Wharton and others (1981) noted that pelagic spawners, such as drum, are among the few fish with life histories that do not involve bottomland hardwood forests directly.

In addition to providing an expanded habitat area and food resources for fish during flooding, the streamside forest has an important role in protecting the water quality of the stream. It provides shade that helps to regulate stream temperature during summer months. In North Carolina mountain streams with small watersheds, maximum stream temperature in summer increased from 18.9" C to 22.8" C or more when trees and understory vegetation were completely removed (Swift and Messer 1971). These temperatures exceeded the optimum for brook trout (*Salvelinus fontinalis*) and adversely affected the population. Where streamside vegetation was only thinned, leaving shade over the channel, only minor temperature changes occurred (Swift and Messer 1971). Seehorn (1987) noted that removal of shading streamside vegetation and the resultant increase in temperature can cause fish to migrate from an area.

Streamside vegetation serves as a source of food and cover for fish during non-flood periods. Forest streams small enough to be completely covered by the forest canopy have a large portion of the food base for aquatic organisms supplied by the streamside vegetation in the form of leaves, twigs, fruits, and insects (Miller 1987). As stream size increases, the relative proportion of terrestrial input of organic matter decreases and input from upstream systems and autochthonous sources becomes more important (Bilby and Likens 1980). Streambank cover in the form of overhanging woody and herbaceous vegetation close to the water surface as well as submersed vegetation is used by many fish species, including trout. The woody debris that falls from fringing trees also provides cover for many fish and invertebrates (Seehorn 1987). Bilby (1984) described how large woody debris in a stream channel influences both the physical and biological processes within a stream. The debris tends to form dams which trap organic matter and influence channel morphology by forming pools. In fast-flowing streams, the still water provided by pools is required for successful spawning and feeding by some species. Indiscriminant removal of large woody debris that is anchored in streambanks can have a major short-term influence on channel stability, which may have negative impacts on a fish population (Bilby 1984).

Vegetated streambanks are also important in controlling soil erosion. Soil disturbance caused by vegetation removal and consequent erosion may result in increased stream sedimentation. The increased sedimentation can, depending on intensity, adversely affect the quality of instream habitat for fish that require a firm substrate for spawning or egg deposition (Seehorn 1987). Increased suspended solids in the water column, also a result of soil erosion, may be detrimental to species that locate food items visually.

A study conducted in California showed a clear association between forest buffer strip effectiveness and strip width in terms of impact of a logging operation on a stream macroinvertebrate community (Newbold and others 1980). Most or all of the impact was prevented by buffer strips 30 meters or wider. The authors, however, cautioned that their results should not be construed as an absolute recommendation for a 30-meter buffer strip because of wide variability among watersheds and logging practices. In some situations, careful partial cutting near the stream bank may be possible. In others, such as logging in areas where the risk of debris slides is high, a wider buffer zone may be necessary to prevent such impacts. It was concluded that the buffer strip's influence on factors such as light, temperature, organic matter inputs, and nutrients was important in protecting the stream biota (Newbold and others 1980).

Because the reproductive strategies of most riverine fish species are linked to spring floods, the standing stock is lowest just prior to flooding and greatest during the flood event (Roelle and others 1987). Many fish are stranded in backwater areas as the water recedes. Carryover success of the fish community is largely dependent on the amount of water that remains during the dry season (Roelle and others 1987). Ross and Baker (1983) believed that the fish assemblage of the Black Creek system in Mississippi was controlled in part through structural habitat suitability and in part by stochastic events, such as the intensity of spring flooding. A complex interdependence therefore exists between a river and its floodplain wetlands when fisheries value is examined.

Wildlife Value

Important aspects to consider when examining the role of streamside forests as wildlife habitat include soil moisture levels and the proximity of permanent surface water; vegetation composition, diversity, and structural complexity; and amount and type of habitat edge. Many animal species use more than one habitat type; food and cover needs may vary with life stage or season of the year. Some species are habitat generalists and can use any of several habitats to meet their life requisites. Species that are limited to a single habitat type are often the most vulnerable to the effects of habitat modification. An example of such a vulnerable species in the streams of southern forests is the ringed sawback turtle ***(Graptemys oculifera)***, which was listed as a threatened species by the U.S. Fish and Wildlife Service in 1986. This turtle is restricted to the Pearl and Bogue Chitto Rivers in Mississippi and Louisiana. Habitat modification from reservior construction and channelization and water quality degradation resulting from floodplain alterations are believed to be the primary causes for this species' decline (J.H. Stewart, U.S. Fish and Wildlife Service, Atlanta, Georgia; unpubl. report).

The relative importance of migrant birds and of amphibians and reptiles is accentuated in the southeastern forest because of paucity of breeding bird species and resident mammals (Harris 1980). About 150 species of birds migrate to or through southern wetlands (Gosselink and Lee 1987); one hectare of bottomland hardwood forest may support the number of wintering birds that would require 6 hectare of northern forests during the breeding season (Harris and Gosselink 1986). A study of year-round bird populations in a Louisiana bottomland hardwood forest indicated that the number of species peaked in spring during migration, but that population density was greatest during the winter (Dickson 1978a). Winter populations of 1,235–2,035 birds per square kilometer were four to five times greater than densities observed during the summer.

Floodplain forests tend to support a more abundant fauna at any time of the year than do the surrounding upland forests. Pearson and others (1987) sampled the herptefauna of four age classes of longleaf pine (*Pinus palustris*) and slash pine ***(P. elliottii)*** stands and in a mesic-hydric hardwood habitat (bayhead) in Mississippi and collected a total of 61 species. The highest number of salamander species was found in the bayhead habitat. Salamanders, toads, and frogs were most abundant and lizards were least abundant in bayheads when compared with the pine stands. Bayheads help to maintain anuran populations during dry periods so that there are sufficient numbers to expand into new areas when conditions are more favorable (Pearson and others 1987). A similar study on small mammal populations of Mississippi longleaf/slash pine forests identified 11 species (Wolfe and Lohoefener 1983). Bayheads also proved to be the overall best small mammal habitat, exhibiting the highest abundance and species richness of the five habitats examined. Many bird species that over-winter in the Southeast prefer bottomland hardwood forests over upland forests (Gosselink and Lee 1987). Dickson (1978b) found that breeding bird densities in bottomland hardwood forests in Louisiana were two to four times that in the best upland sites. He also found higher bird species diversity in bottomland forests than in younger pine and pine-hardwood stands, but about the same diversity as in more mature stands. North Florida habitat islands of cypress and hardwoods in pine flatwoods support twice as many breeding birds per hectare as upland habitat islands (Harris 1980). Greater species abundance in floodplain forests, than in surrounding uplands, has also been demonstrated for breeding birds in Iowa (Stauffer and Best 1980), and for birds year-round in South Carolina (Reese and Hair 1976). White-tailed deer (*Odocoileus* virginianus) were more abundant in bottomland hardwood forests of Missouri than in upland habitat (Zwank 1979). Squirrels (*Sciurus* spp.) were more abundant in hardwood ravines than in surrounding pine plantations in east Texas (McElfresh and others 1980). Squirrel densities were also higher in a streamside bottomland hardwood forest strip averaging 100 meter in width that was surrounded by pine plantations than in mature pine–hardwood forest tracts similarly located (Warren and Hurst 1980). Improvement cutting in riverfront hardwood stands was found to increase small mammal populations; this effect was attributed to the addition of logs, stumps, slash and ground cover to the forest floor (McComb and Noble 1980).

Soil Moisture Levels And Proximity To Water

A relationship between abundance and distance from streams within forest habitat is apparent for many animals. Definite soil moisture preferences were exhibited by three species of salamanders in deciduous forests of southern Pennsylvania; few individuals of the ***Desmognathus*** species studied were collected farther than 3 meters from open water (Krzysik 1979). Tilley (1973) found that populations of the salamander Desmognathus ***ochrophaeus*** tended to concentrate in the vicinity of seepage areas, springs, and small streams. These sites provided brooding areas for females, aquatic habitat for larvae, and over-wintering sites for the entire population. Many species of amphibians, toads and frogs as well as salamanders, depend on surface water as a medium for life as adults and/or larvae. Numerous reptiles are also dependent on water. Although some turtle species may travel a distance from water to nest (e.g., the red-eared slider (*Chrysemys scripta elegans*)), others such as the Alabama map turtle ***(Graptemys pulchra)*** dig nests in river sandbars or in sandy streambanks (Behler and Ring 1979). Turtles and several species of snake, including the watersnakes ***(Nerodia*** spp.) and the cottonmouth

(*Agkistrodon piscivorus*), use overhanging branches and woody debris for sunning and resting sites.

Many birds are associated closely with streamside forests. A study of the distribution of eight common birds in a small forested watershed in Arkansas indicated that the soil moisture gradient had an important influence on species distribution (Smith 1977). The hooded warbler (*Wilsonia citrina*), ovenbird (*Seiurus aurocapillus*), and Acadian flycatcher (Empidonax virescens) were obligatory moist-forest species. Swift and others (1984) found that the most poorly drained sites in forested wetlands had the most abundant and diverse bird populations. The prothonotary warbler ***(Protonotaria citrea)*** is strictly limited to thick deciduous forests bordering streams, rivers, and lakes; individuals are distributed linearly along the water's edge (Simpson 1969). The belted kingfisher (*Ceryle alcyon*) is usually seen perching in trees along water edges and often digs nesting burrows in the banks of creeks, rivers, ponds, and lakes. The colonial nesting wading birds (herons, egrets, and ibises) are highly visible components of the southern avifauna and are often found in wooded wetlands. All of these species, expect the exotic cattle egret (*Bubulcus ibis*), feed in shallow water along the water's edge. In freshwater areas, wading birds nest in groups of up to several thousand individuals in woody vegetation above water, often in cypress/tupelo stands. The heights at which birds in multispecies colonies build their nests depends on the size of the birds (Burger 1978). Therefore, great blue herons (*Ardea herodias*) and great egrets (Casmerodius *albus*), the largest species, nest highest in the vegetation. Mid-sized species, such as tri-colored herons ***(Egretta tricolor)***, nest at an intermediate height and small-bodied species, such as white-faced ibises (*Plegadis chihi*), build nests on branches at a low level in the canopy.

Furbearers such as the beaver ***(Castor canadensis)***, muskrat (Ondatra ***xibethicus***), mink (*Mustela* vison), and raccoon ***(Procyon Zotor)*** are common mammals that use forested streamside habitat. The beaver can affect tree species distribution and composition through selective feeding and dam building activities. Although the benefits of beaver pond habitat to other wildlife species, especially biis (Beard 1953; Reese and Hair 1976) is well known, excessively high populations can cause significant losses to forestry and agriculture in some areas (Woodward and others 1976.)

Vegetation Composition, Diversity, and Structure

The species composition, height, and arrangement of the canopy, shrub, and herbaceous vegetation influence the habitat value of streamside forests. Dickson and Noble (1978) found a significant seasonal shift in the vertical distribution of a bottomland hardwood, forest bird community. A nearly equal distribution at all levels in winter changed to a predominantly mid-story and canopy distribution in summer. The shifts were attributed to the response of the birds to seasonal changes in the foliage profile and consequent variations in the cover and food supply.

The fruits and seeds (mast) of many plants are food sources for many wildlife species, and many mast-producing species are found in streamside forests. When the full spectrum of southeastern coastal plain vegetation is considered, the mast of one or more plants is available throughout the year (Harris and Vickers 1984). The importance of hard mast, including acorns, in the diet of game species such as wild turkeys (*Meleagris gallopavo*), squirrels, and white-tailed dear is widely known (Allen 1982; Lay 1975; Harlow and others 1979).

Mast is also important in the diet of two species of waterfowl that winter in southern forested habitat-the mallard (*Anas platyrhynchos*) and the wood duck (*Aix sponsa*). Waterfowl species, always of interest due to their commercial and recreational importance, are currently of great interest to resource managers due to the highly publicized decline in the North American continental populations. The importance of the waterfowl resource is emphasized by the North American Waterfowl Management Plan (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1986), which proposes waterfowl population goals and outlines actions needed to achieve those goals. The lower Mississippi River Delta and gulf coast area was identified in the Plan as one of five priority habitat ranges on the continent. Delnicki and Reinecke (1986) found that 10 to 11 percent of the mallard's diet in Mississippi consisted of the seed of moist soil plants while 83 percent was rice and soybeans. In contrast, the wood duck's diet consisted of 74 percent acorns of three different species of oaks and 23 percent soybeans. They concluded that wood ducks, both resident and migrant, depend on foods from forested areas. The importance of forested wetlands to wood ducks also has been emphasized in other studies (Drobney and Fredrickson 1979; Fredrickson 1980). While mallards appear to be less dependent on forested wetlands, they concentrate on fewer wintering areas and in lower quality sites if this habitat is lost (Heitmeyer and Fredrickson 1981). Heitmeyer and Vohs (1984) concluded that mallards in Oklahoma especially used bottomland wetlands and rivers and avoided reservoirs in areas where natural wetlands were abundant. Conservation of bottomland forests is considered necessary to maintain highly productive mallard populations (Fredrickson 1980).

The value of snags, which are standing dead or deteriorating trees, to wildlife is the final aspect of streamside vegetation considered. Many mammals, including mice, the big brown bat ***(Eptesicus fuscus)***, raccoon, and opossum (*Didelphis* virginiana) use hollows in snags as resting and den sites, Approximately 85 species of North American birds excavate nesting holes in trees or use natural cavities or holes created by other species (Scott and others 1977). Cavity nesting birds of the Southeast include the wood duck; several species of woodpeckers; owls (the barred owl (*Strix varia*) and the eastern screech owl ***(Otus asio))***; and several species of passerines (e.g., the Carolina chickadee (*Parus carolinensis*), white-breasted nuthatch ***(Sitta carolinensis)***, and the prothonotary warbler). Other bird species, including the bald eagle (*Haliaeetus leucocephalus*) and the osprey (*Pandion haliatus*), prefer to nest in the branches or at the top of dead trees. In addition to functioning as nesting sites, snags are used by birds as feeding sites, singing perches, and as predator or prey lookout posts.

Snags have often been considered undesirable by forest managers because they harbor insect pests, are fire or safety hazards, and conflict with forest management goals. However, the majority of cavity nesting birds are insectivores (Scott and others 1977) and may have a involved in snag management efforts. Stand rotation time and time required for fungal rots to decay the trees to the extent needed for excavation must be considered.

Habitat Edge

The streamside forests that remain after logging operations have two edges, one between the stream aquatic environment and the remaining uncut forest, and one between the uncut forest and the logged area. Both positive and negative impacts can be associated with the creation of habitat edges. Typically, the clearing of forest patches is thought to be beneficial; the "edge effect" causes increased density and diversity of many animal species, including invertebrates, birds, and mammals. The positive effects are attributed to the proximity of habitats with diverse vegetation composition and structure, which provides many food sources and cover types that can be used by a variety of animal species. Edges where three or more community types meet are believed to be superior to those where only two community types meet (Harris 1980). The edge between cypress ponds and surrounding pine flatwoods in Florida supported higher numbers of reptiles and amphibians than did either the cypress or the pine habitats (Harris and Vickers 1984). In this same region, birds responded favorably to clearcutting of the pine surrounding the ponds; the density, number and diversity of species were greater in significant role in controlling insect pests. Therefore, maintaining snags is increasingly being accepted as a valid practice for integrated forest and wildlife management. Conner (1978) noted that factors causing trees to become suitable potential sites for primary cavity nesting species, which typically excavate their own cavities rather than using natural or abandoned cavities, are the most important factors sharp, clearcut edges than in the ecotones between cypress and pine (Harris and Vickers 1984). Forested strips left along streams in areas disturbed by logging, residential or industrial development, or agriculture are often important travel corridors for animals. This is especially true for large-sized, far-ranging species with extensive home ranges, such as the black bear (*Ursus americanus*); the corridors are also important for maintaining genetic diversity within these species (Gosselink and Lee 1987).

Although attractive to many species, especially those seeking early successional habitats, forest edges can have adverse impacts on forest birds (Kroodsma 1984). Several bird species are characteristic of forest interiors and require large, unbroken expanses of mature forest. Askins and others (1987) documented the loss of forest-interior birds with decreasing forest area. In the South, the swallow-tailed kite (*Elanoides forficatus*) and the southern bald eagle are examples of raptors that historically have been associated with bottomland hardwood forests; both species have declined due to range restriction and fragmentation (Gosselink and Lee 1987). Bachman's warbler (*Vermivora bachmanii*) and the ivory-billed woodpecker (*Campephilus principalis*), both listed as endangered species by the U.S. Fish and Wildlife Service but which may actually be extinct, are forest birds that have been severely affected by habitat loss.

Forest clearing can also be detrimental to species that are not restricted to forest interiors. Brittingham and Temple (1983) found that brood parasitism by brown-headed cowbirds (*Molothrus ater*) on forest songbirds is highest near open habitat. They believed that high parasitism rates within isolated fragments of forest habitat reduces the reproductive success of some birds and may be responsible for the decline of some species.

Streamside Buffers

Although many researchers have documented the value of forested wetlands as wildlife habitat, few studies have resulted in definite management recommendations for streamside forests to meet a goal of protecting as many species as possible. However, some recommendations for management of selected species, especially birds, do exist. In Virginia, Tassone (1981) examined the distribution of birds in hardwood leave strips in pine plantations in relation to vegetation structure and strip width. Although his data were inadequate, due to small sample size, to form definite recommendations regarding optimal buffer widths to ensure viable forest-breeding bird populations, he noted that many forest-interior species were most common in buffers exceeding 62 meters in width. He found the following relationships between bird species and forested strip width: the pileated woodpecker (*Dryocopus pileutus*), hairy woodpecker (*Picoides villosus*), and Acadian flycatcher were rarely found in strips less than 50 meters wide; the Louisiana water-thrush (*Seiurus motacilla*), yellow-throated vireo (*Vireo flavifrons*), and blue jay (*Cyanocitta cristata*) seldom were present in strips less than 60 meters wide; and the northern parula (*Parula americana*) was restricted to strips exceeding 60 meters in width. To provide breeding habitat for neotropical migrant bird species, Tassone (1981) suggested a minimum buffer strip width of 60 meters. On larger streams, which were not defined, he recommended a minimum buffer width of 100 meters.

In other studies, the prothonotary warbler was absent from waterways where the woody border is less than 30 meters wide (Simpson 1969). Stauffer and Best (1980) found that bird species richness in riparian habitat in Iowa increased with the width of the wooded zone; 13 species bred only in relatively wide zones (greater than 20 meters), and 3 of the 13 species required zones of at least 200 meters width. A study on squirrel use of stream management zones in east Texas concluded that a wooded zone at least 55 meters wide is needed to maintain squirrel populations (Dickson and Huntley 1987).

Implications for Management of Streamside Forests

The first step in managing any resources, including fish and wildlife species associated with streamside forests, should be to set a goal or goals (Giles 1978; Smith 1962). Because the U.S. Fish and Wildlife Service has the primary mission of protecting fish and wildlife resources, we think that the two most important goals are the protection of endangered and threatened species and of waterfowl and other migratory bird species. Other important goals include providing diverse habitats in order to meet the needs of the full spectrum of animals that normally occur in southern forested wetlands; ensuring that there are fish- and wildlife-related recreational and educational opportunities; and developing areas that are esthetically pleasing to people.

Based on the above goals, a critical first step in the management of any streamside forest area is a fish and wildlife inventory, with emphasis on endangered, threatened and/or sensitive flora and fauna. There are a variety of sources of information on critical species that may occur within a given area, including Federal and State endangered-species lists, State Natural Heritage Program lists, and the regional U.S. Fish and Wildlife Service Ecological Services offices.

Specialized management strategies may be required if critical species are found, and these should take precedence over general management guidelines. For instance, if nests of species that are relatively intolerant of human activity, such as the bald eagle or the swallow-tailed kite, are found, disturbance should be minimized in an area of at least 150 meters around the nests (Chamberlain 19'74; U.S. Fish and Wildlife Service 1985). For some species such as the wood stork (*Mycteria americana*), lack of suitable nesting sites is a critical habitat deficiency, and any nesting sites found should be completely protected (Chamberlain 1974).

There are many management strategies that can be employed to provide suitable habitat for specific migratory bird species. It has been shown that there are many migratory species that use streamside and southern forested wetland habitats, and these species may require habitat for breeding, stopover and feeding, or wintering. As a general strategy, therefore, a variety of habitat types should be maintained. The goal here is to provide diversity, and to cite one researcher, "preserving biodiversity in temperate regions requires the maintenance of all successional stages" (Franklin 1988:167).

Management for successional stages in streamside forests should not be done in isolation from the surrounding forested wetland or other habitat types. Early successional stages may be well represented in the areas surrounding the streamside forest, particularly if the goal of the landowner is management for pulpwood. In situations of intensive forest management, with rotations of about 60 years or less, it may be appropriate to consider the provision of mature and over-mature (old-growth) forest habitat as the major management objective for streamside forests.

Old-growth habitat has been shown to be critical to a wide variety of species throughout the United States (Bent 1939; Bull 1978; Luman and Neitro 1980). Even in relatively narrow corridors, it is likely to be of very high value in southern forested wetland settings. Old-growth forests provide more cavities per unit area than younger forests and more cavities of sufficient size to support species such as the pileated woodpecker, which generally requires cavity trees of 76 centimeters dbh or greater (Conner 1978). The abundance of taller trees provides suitable nest sites for species such as bald eagles, red-shouldered hawks (*Buteo lineatus*), and swallow-tailed kites (Bent 1937). Some species often associated with earlier successional stages, such as the white-tailed deer, also make extensive use of mature and overmature forest habitats (Mott and others 1985; Schoen and others 1981).

Another key consideration for the management of streamside forests is their width. Recommended widths vary widely depending mainly on objectives, slope, and soil type (Table 1). Quantitative bases for these recommendations are generally lacking, and recommended widths have been

Table l.-Recommended streamside buffer widths

Width (meters)	Purpose	Source
8	Water quality	St.. Tammany Parish, LA 1988
11	Water quality (small streams)	Scott Paper Company 1988
12 - 24	Water quality	
20	Fisheries management	Seehorn 1987
24	Fisheries Management and water quality	Scott Paper Company 1988 U.S. Bureau of Land Management 1979
31	Water quality (large streams and rivers)	U.S. Department of Agriculture 1980
104	Water quality and wildlife habitat (large streams and rivers)	U.S. Fish and Wildlife Service 1988
400	Maintain wild and scenic values of rivers	Wild and Scenic Rivers Act (P.L. 90-542)

described as "largely an intuitive factor that is determined based on reliable local experience" (Metropolitan Washington Council of Governments 1987:9-6).

In general, desirable widths of streamside forests are likely to be wider for fish and wildlife purposes than are required for water quality protection, especially in relatively flat southern forested wetlands. We recommend for fish and wildlife management purposes that protected zones along perennial streams be at least 60 meters wide. On streams or rivers wider than about 10 meters, ideally 60 meters should be left along both banks. On smaller streams, the 60-meter-wide zone could be divided between the two sides, since most wildlife can cross by swimming, on logs, or through overlapping tree crowns.

Intermittent streams, small sloughs, and isolated wetlands also should be protected by a forested buffer, but a total width of 30 meters may be adequate in most cases. A buffer of 15 meters on each side is probably about the minimum width that will serve such valuable functions as shading the water when present, acting as a source for large organic debris, stabilizing the streambank, and providing a travel corridor.

There does not appear to be any reason why occasional, limited selection cuts should not be made in streamside forests, as long as they do not adversely affect water quality and sensitive areas are not disturbed. It is possible that partial removal of the overstory may actually enhance the water-quality protection function of streamside forests by allowing a denser cover of herbaceous plants, shrubs, and tree seedlings. Also, periodic thinning encourages tree crown development, which favors increased mast production (Shelton 1982).

Trees that are likely to fall into the stream should be harvested only in cases where navigation or recreational use of the waterway may be affected, since large organic debris has been shown to be of value to invertebrates, fish, reptiles, and even some bird species. A high proportion of mast-producing trees (which are also often good timber species) and all trees with cavities should be left uncut.

Some of the above recommendations for the management of fish and wildlife may not be readily acceptable to forest landowners, and may be difficult to justify strictly from a water-quality protection perspective. However, the general climate in which forestry is practiced in the Southeast and elsewhere is changing, and practices such as these recommended will increasingly become common.

The trend toward extensive leasing of industrial forest land for hunting is now familiar to most forest landowners. It has been demonstrated that trade-offs in timber production for wildlife production can actually increase a landowner's profits through leasing of hunting rights (McKee 1986). Computer software that allows landowners to determine what types of timber-wildlife management tradeoffs may be most profitable is available (Cooney 1987). In addition, these recommended practices should result in enhanced public relations, particularly if some land is kept open to hunting for the general public. The practices will also result in more wildlife and a more pleasing environment for recreationists. While less tangible than hunting leases, this may ultimately prove to be as important. It is increasingly difficult for large forest landowners to operate in isolation, and some of the same pressures for multiple-use management that government agencies are accustomed to may also become important issues for them.

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AQUATIC AND TERRESTRIAL LINKAGES: FLOODPLAIN FUNCTIONS

J. Vaun McArthur[1]

Abstract.—The relationships between aquatic and terrestrial ecosystems are discussed from the basin through several orders of scale down to bacteria within a stream reach. Organic matter produced on the floodplains or riparian forests provides most of the nutritious carbon available to organisms living within the aquatic ecosystem. The retention of this organic matter by biological or physical means determines the quality of the aquatic ecosystem. Since the biota in aquatic systems have evolved in response to the natural organic matter loading it is very important that we understand how pristine systems operate to fully understand how impacted systems may behave.

INTRODUCTION

The realization that processes within flowing water systems may be controlled, in part, by the terrestrial ecosystem through which the stream flows, is relatively new. Beginning in the early to mid-1970's, research in lotic (flowing water) ecosystems began to show that import of organic matter and nutrients from terrestrial sources constituted linkages between the two systems (Hynes 19'75; Likens and Bormann 1974). This early work resulted from several important research projects that determined energy (carbon) and nutrient budgets for streams (Fisher and Likens 1972, 1973; Fisher 1977). While carbon budgets are an important component of the interaction between terrestrial and aquatic systems, the focus on the direct input of organic matter from riparian vegetation may have affected the development of current stream ecological theory (see below).

To understand the degree of interaction between aquatic and terrestrial systems we must begin at the largest scale and move down. It is my contention that linkages between these systems occur at all levels of scale. This paper will begin with the catchment basin and proceed downward through trophic levels to microbes and finally molecules (genes). Since the area of greatest overlap and hence greatest potential interaction, is found on the floodplain, understanding of processes ensuing on the floodplain is critical in developing a meaningful floodplain policy.

STREAM DIMENSIONS

Ward (1988) has described stream ecosystems as four dimensional entities. These four dimensions are: 1) longitudinal, 2) lateral, 3) vertical (hyporheic) and 4) temporal. Although each of these dimensions may influence the nature of aquatic/terrestrial linkages only the longitudinal and lateral dimensions will be discussed. The movement of groundwater through the hyporheic zone is just beginning to be explored. Although it has been found that complete assemblages of organisms exist (see Danielopol 1980) below the surface sediments their role in floodplain processes is not known.

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Longitudinal

Catchment

Much of the actual surface topography of a catchment is a result of water action. The geomorphological features of the landscape control the amount of direct contact between terrestrial and aquatic ecosystems (Figure 1). The drainage density (total area of the catchment divided by the total length of active channel) controls the speed of run-off following storm events. The higher the drainage density, the more peaked the hydrograph and the greater probability of flooding. Catchments with low drainage density require longer periods of precipitation before flooding occurs but the flood time may be prolonged. The timing of the flood event and the amount of time required for the flood to abate will influence processes on the floodplain to varying degrees. For example, the movement of nutrients immobilized on the floodplain into the water is partially controlled by the redox conditions of the overlying water. Although flood waters are often highly oxygenated, the heavy accumulation of organic matter quickly creates anaerobic conditions at the sediment-water interface and these reduced conditions may result in the release of nutrients. While floods that remain for long periods of time may see little movement of carbon and nutrients out of the floodplain and into the actual stream, the biogeochemical cycling on the floodplain may be intense and result in complete turnover of accumulated organic carbon. Floods that are more peaked may move more material from the floodplain into the stream.

River Continuum

The River Continuum Concept (RCC) has been used to help relate the functional properties of lotic ecosystems to the geomorphology of the catchment (Vannote et al. 1980). This concept describes the changes in stream biota along a longitudinal gradient in terms of the trophic functions (Figure 2). The concept was developed based on research in eastern deciduous and western coniferous forests where headwater streams originate under closed canopies. The RCC predicts that organisms capable of consuming (shredding) coarse particulate organic matter will be found predominantly in headwater reaches (orders 1-2) where the most direct import

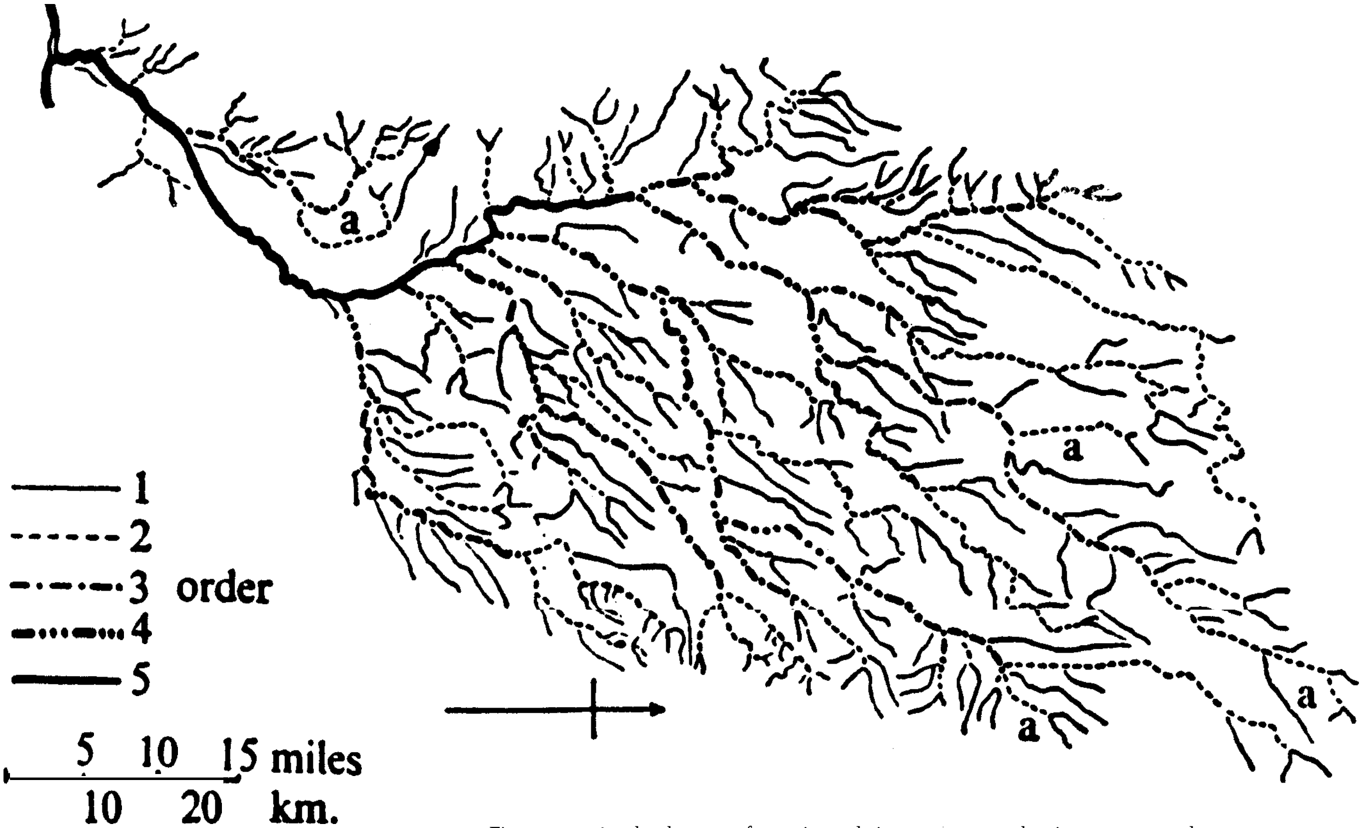

Figure 1.—A sketch-map of a river drainage system, showing stream orders.

of terrestrial carbon occurs. In the headwater reaches total stream community respiration (R) is predicted to exceed total primary production (P). Therefore the P/R ratio will be less than one. This system is heterotrophic since most of the energy in the system is derived from detritus that has originated from outside the systems, i.e., terrestrial sources.

In the mid-reaches (orders 3-5) the canopy opens and aquatic macrophytes become an important component of the system. Measurements of respiration and primary production in these reaches will result in P being greater than R. The system would be driven more by instream production and considered autotrophic since it derives most of the energy from primary production within the system, in this case algae and macrophyte growth.

Lateral

It is interesting to note that the original RCC (Figure 2) suggests that floodplains become less important with an increase in stream order. Later modifications of the RCC (Minshall et al. 1933, 1985) expanded the concept to include the floodplain. In many large river systems, e.g., Mississippi, the predictions of the RCC could not be verified. The movement of material out from the floodplains or main channel border areas often exceeded the amount of material being imported from upstream. Failure to account for this influx of material that was terrestrially derived resulted in faulty assumptions relative to the trophic status of a particular reach, that is, the stream reach may have been considered autotrophic instead of heterotrophic. The RCC failed to show the importance of the floodplain to the function of the lotic system.

Figure 3 shows the extent of the Mississippi River floodplain across one transect in Illinois. Were one to stand at the river's edge, the size of the river would suggest, with such a wide channel, the limited importance of the immediate riparian vegetation. When the actual presettlement floodplain is placed in perspective to the main channel it is clear that the potential for interaction between terrestrial and aquatic systems must have been great. Within these floodplain ecosystems there exists as complex of food webs as those found in the main channel areas (Figure 4).

Minshall et al. (1985) described how various ecosystem parameters respond to changes in the geomorphic features of the stream as a result of differences in hydraulic conditions (Figure 5). For example, the mid-reaches (orders 4-7) of many unimpacted southeastern streams are highly braided. The consequences of braiding include: 1) increased bank habitat, 2) greater potential for debris dam accumulations (see discussion below), 3) increased riparian input and 4) shift of stream function back to conditions similar to those in headwater reaches. This shift from functions predicted for the generalized mid-reach stream described in the RCC to functions similar to headwater has several implications. First, the organic matter imported from the terrestrial system will increase and provide most of the energetic and structural carbon available to aquatic organisms. Second, large particulate carbon imported into the headwater reaches has, in unimpacted streams, been reduced to fine particles in the mid-reaches. This fine particulate organic matter would be the primary energy resource in an unbraided stream. This imported fine particulate carbon coupled with direct import from the adjacent riparian zone in a braided stream will provide a more diverse food base than described by

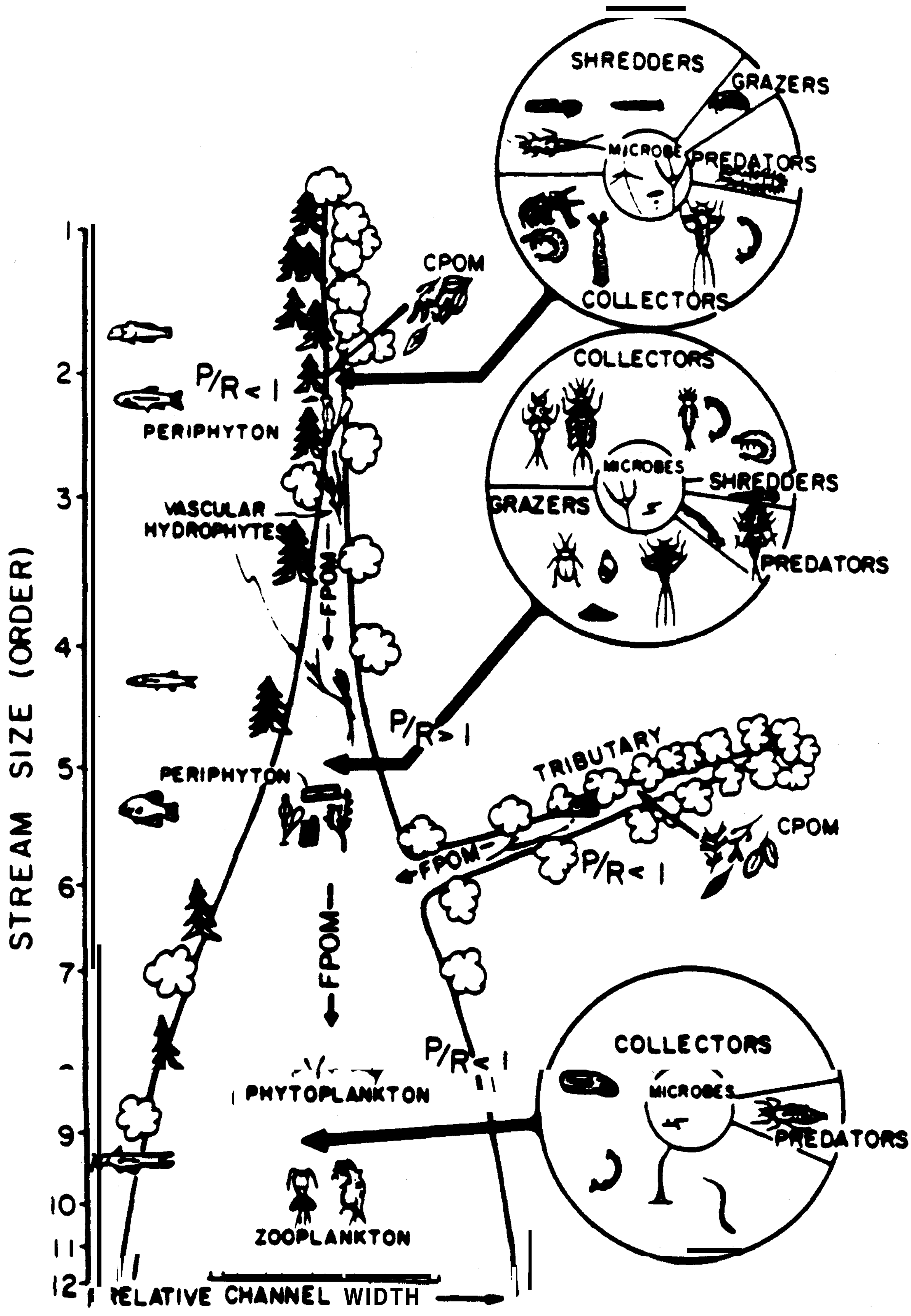

Figure 2.-A diagrammatic representation showing proposed relationships between stream size (order) and the progressive shifts in structural and functional attributes of stream communities. (From Vannote et al. 1980; used with permission of the publisher).

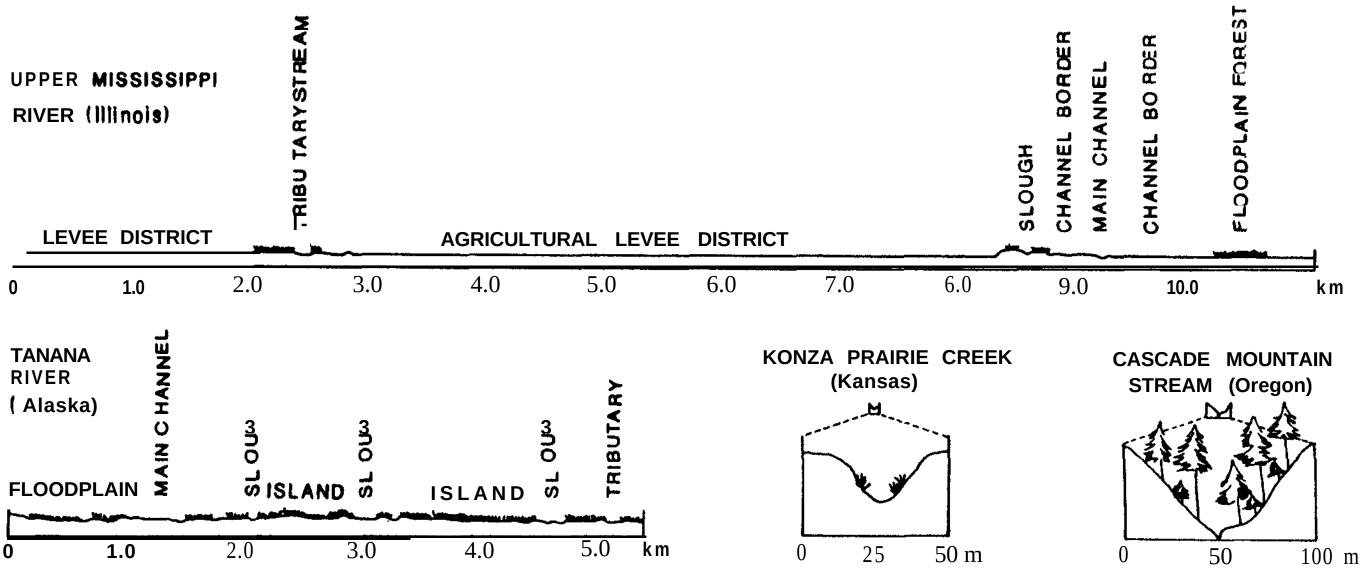

Figure 3.—Graphical representation of several streams/rivers and their floodplains. Note the size of the main channel in both the Mississippi and Tanana river systems relative to the floodplain.

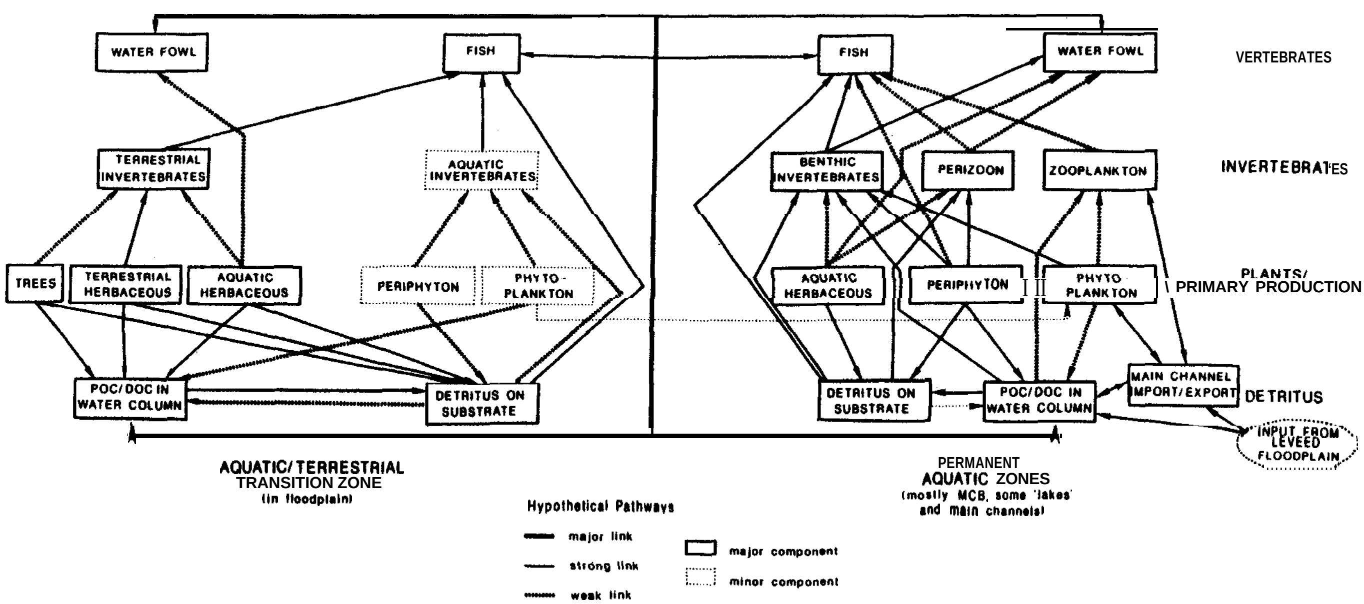

Figure I.-Carbon and organic matter flow between principal components of a river/floodplain ecosystem.

the RCC. Therefore, one prediction of increased lateral dimension is that the biological diversity of braided stream reaches should be higher than streams of comparable order that do not braid.

As mentioned above braiding increases the probability of debris dams since narrowing of the active channel retains more wood and hence increasing structure (Triska and Cromack 1982). The accumulation of woody debris then in turn increases the probability of braiding. The effects of debris dams on stream function include increased habitat diversity which acts to retain organic matter within a reach. While debris dams are not the only retentive devices in streams they are the predominant type in southeastern coastal plain stream systems. Debris dams not only retain coarse material such as wood and leaves but because of the increased habitat for invertebrates and vertebrates, they increase biological retention.

The concept of nutrient cycling takes on new dimensions when applied to lotic ecosystems. The strong longitudinal component (water flow) of streams does not allow nutrients to remain long in any one particular reach. Since the nutrient continues to move downstream passing through both biotic and abiotic phases, the concept of nutrient spiraling was proposed to describe nutrient dynamics in lotic systems (Webster and Patten 19'79; Newbold et al. 1982a,b). Minshall et al. (1983) described the'effects of different interactions between biotic and abiotic retention of any particular nutrient (Figure 6). The cycling of a nutrient is portrayed by a spiral, where length between the spirals indicates the distance downstream the nutrient has been displaced before being retained. The diameter of the loop represents the rate of recycling, i.e., the smaller the loop the faster the recycling. The thickness of the spiral line indicates the quantity of material being cycled. In highly conservative (retentive) stream systems, e.g., braided reaches with debris dams, nutrients travel relatively short distances before they are captured or retained either by biological means (partial incorporation into biomass) or by physical structures and reduced discharge rates.

The effect of snagging or the removal of woody debris from the streams results in conditions where most of the nutrient would travel long distances before being available to stream biota or physical retention. The effect of reduction in stream function within these mid-reaches is integrated into higher order reaches. That is, the biota in streams have evolved in response to the organic and nutrient loading experienced within a particular reach. Higher order reaches (large rivers) would not be expected to have biological assemblages capable of utilizing unprocessed material transported directly out of lower order reaches. Consequently, coarse particulate organic matter will accumulate in the sediments of these large rivers or be imported into estuaries. The effects of this loading of organic matter has not been fully studied. Since most rivers were snagged to accommodate navigation, the function of the river in processing organic matter has been greatly altered.

Wallace and Benke (1984) suggest that the productivity of invertebrates and fishes in snagged rivers will be greatly reduced. Additionally the removal of the snags will increase the velocity of flow (lower roughness) which could reduce the frequency and duration of floods and thereby further alter nutrient and carbon recycling. One may speculate that snagging or the removal of debris has influenced the productivity of esturaries and coastal fisheries by altering the nature of the carbon imported into the estuaries. Work done by Cuffney (1988) indicates that movement of organic material off of floodplains in the Ogeechee River, Georgia exceeds the amount of litterfall that typically enters heavily forested headwater streams. Presettlement transport of carbon would have been primarily fine material and the biota of the estuary should have been adapted to utilize this resource. Now, a large import of coarse material occurs and probably has favored a shift in the abundance of various functional feeding groups capable of using this new resource. How this has affected the overall fishery would require comparative studies between snagged and unsnagged river systems.

	GEOMORPHIC FEATURES		
	CANYON	BRAIDED	MEANDERING
PARAMETER			
Streom Surfoce Area : Discharge	LOW	HIGH	MEDIUM
Riporian Inputs	LOW	HIGH	MEDIUM
Detritol Storage	LOW	HIGH	MEDIUM-HIGH
Area Flooded	SMALL	LARGE	MEDIUM

Figure 5.-Relationships between several ecosystem parameters and changes in geomorphic features from differences in hydraulic conditions. (From Minshall et al. 1985; used with permission of the publisher).

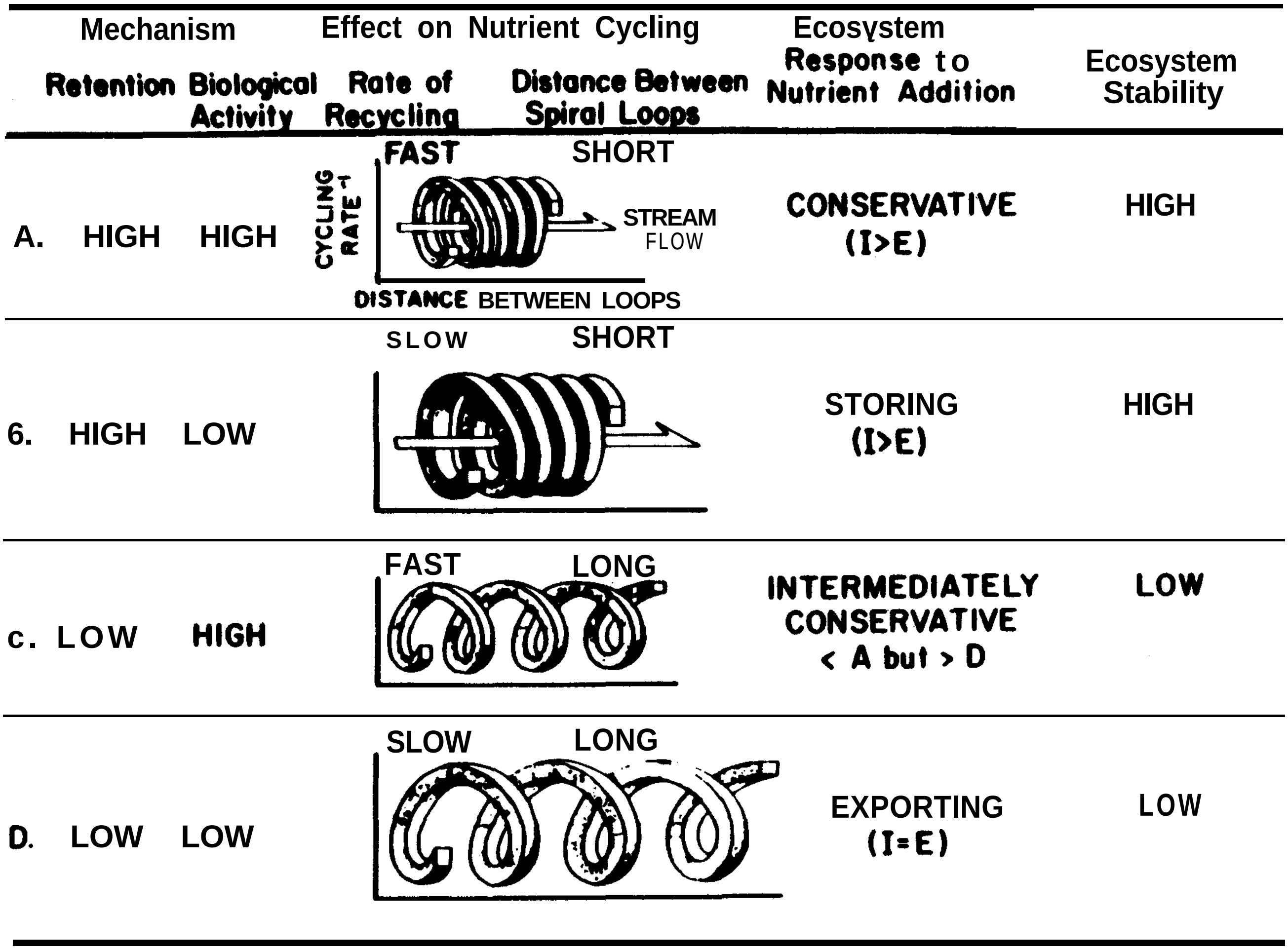

Figure 6.-Effect of biological and physical retentive devices on the distance nutrients travel in stream ecosystems. (From Minshall et al. 1983; reprinted by permission of the publisher).

FOOD WEB LINKAGES

Vertebrates

Floodplains provide habitat for a variety of vertebrates including birds, mammals, reptiles, anurans, salamanders, and fish. Wood ducks are permanent residents of floodplains and require nesting sites within this habitat. Other waterfowl such as mallard ducks use floodplains seasonally. Moler and Franz (1988) have shown that at least 10 species of anurans and 5 species of salamanders are exclusively or primarily dependent on riparian and forested wetlands of the southeastern Coastal Plain. Meffe (personal communication) has found 10 species of fish during flood events in streams of the Savannah River Plant using the floodplain as habitat. Finger and Stewart (1987) have shown that the assemblages of fishes using floodplains during seasonal events to be very different from the assemblages found on floodplains that are manipulated by man. Beaver are a conspicuous organisms associated with floodplains. Although considered by many to be pest, the feeding and geomorphology modification activities of beaver may act to increase the lateral movement of materials across terrestrial aquatic interfaces (Johnston and Naiman 1987).

Invertebrates

The diversity of invertebrates that use floodplains and/or debris dams associated with the flood event is extensive. Zooplankton populations have been monitored in tropical river-floodplain systems. Saunders and Lewis (1988) have shown that zooplankton abundance is dependent on hydrologic events. As the river rises zooplankton densities on the floodplain increased rapidly and after the connection between the river and the floodplain disappears abundance declines. The importance of zooplankton in temperate and sub-tropical river-floodplain systems is not known.

Macroinvertebrates, primarily insects, comprise the preponderance of invertebrate taxa inhabiting floodplains and debris dams (Dudley and Anderson 1982). Included in this diverse assemblage are mayflies (Ephemeroptera), stoneflies (Plecoptera), damsel and dragonflies (Odonata), beetles (Coleoptera), caddisfly larvae (Trichoptera), dobsonflies (Megaloptera), and true flies (Diptera). Many of these organisms have life cycles that are keyed to the annual import of organic matter during autumn. Several species of invertebrates rely totally on coarse particulate organic matter retained in debris dams. These invertebrates shred the coarse material and in the process of feeding and generating fecal matter, the coarse material is reduced to smaller and smaller particles. Filter-feeding invertebrates, e.g., caddisfly larvae and blackflies utilize this fine material. Several researchers have shown that macroinvertebrate control the rate of organic matter processing in lotic ecosystems (see McArthur et al. 1988 for review). Not only leaf material but the woody debris is processed by these macroinvertebrates (Pereira et al. 1982).

Snags provide the most stable habitat in coastal plain river systems. Benke et al. (1984) and co-workers (Hauer and Benke 1987; Benke and Jacobi 1986) have shown that most invertebrate production and biomass is associated with the wood either on the floodplain or in the channel. Cuffney and Wallace (1987) have shown that in the Ogeechee River more organic matter gets entrained than can be processed by the present day assemblage of invertebrates. This suggests that although the Ogeechee has not been snagged for over one hundred years the stream has not yet recovered. Leff and McArthur (1988) have shown that a severly impacted stream that had been recovering for 15 years transported more organic matter during baseflows than a similar unimpacted stream.

Invertebrate activity in the sediments of the floodplain may directly affect the nutrient availability and subsequent productivity of the floodplain forest. Smith and Boto (1988) have shown that removal of burrowing crabs in a mangrove forest in Australia resulted in increased sulfide and ammonia concentrations and decreased productivity of the trees and decreased reproductive output. Many floodplains of the southeast have high densities of burrowing crayfish. It is not known whether crayfish affect southeastern floodplains as do the crabs, but the possibility is intriguing.

ORGANIC MATTER

The nature, timing and source of organic matter imported into a stream can greatly affect the processing of that material. Organic matter may originate either from direct import from riparian vegetation, from the floodplain litter, from aquatic macrophyte production and from material imported from upstream. The quality associated with this material is similarly dependent on the timing and source of the input. Quality can be a function of the chemical properties of the organic material such as, carbon/nitrogen ratios, chemical composition, etc. or quality can refer directly to the nutritional utility as perceived by the biota. McArthur et al. (1986) have shown that the timing of import greatly affects the ability of the biological assemblage to process the material. Summer shed leaves were not processed as efficiently as autumn shed leaves even though their chemical quality was higher. This was due to the fact that the invertebrates necessary for shredding were absent or dormant during the summer.

As mentioned above, the River Continuum Concept failed to include linkages from floodplains in the original conceptualization (Vannote et al. 1980). This oversight resulted in a what appeared to be refutations of the concept. Figure ‘7 shows the relationship between floodplains and flowing systems when viewed simply as input/output from a given reach. At this level the linkages between the two systems appears to be negligible since the import and export of either total or nutritious (easily assimilated) carbon is equal and most of the carbon in the system is refractory (not easily broken down). Therefore one might assume that

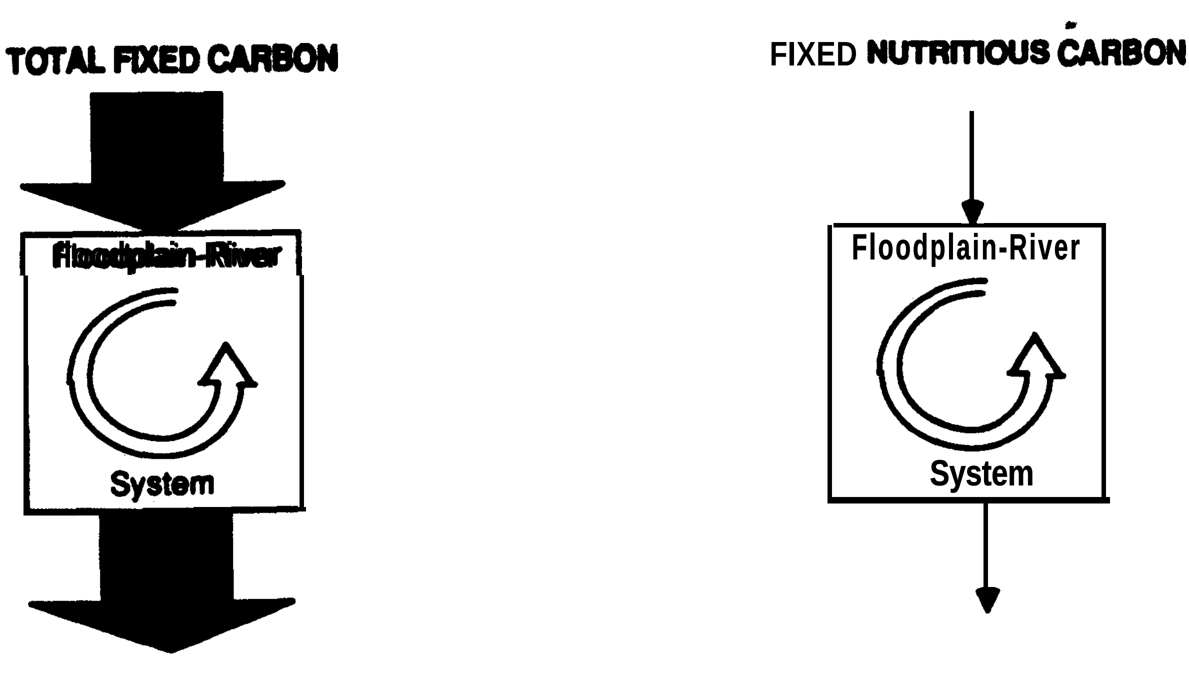

Figure ‘I.-Model showing the transport of total and nutritious carbon through an idealized floodplain-river reach as measured by input output of carbon.

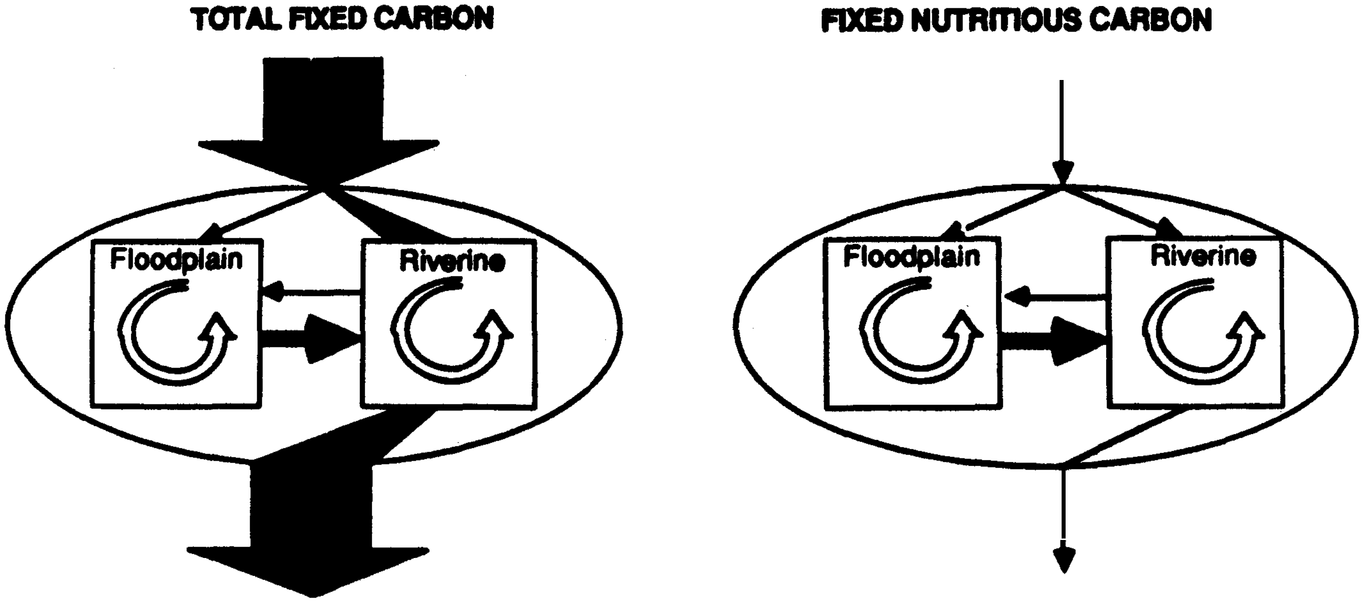

Figure 8.—Model showing further resolution of the transport of total and nutritious carbon. Note fairly large import of carbon off from the floodplain into the river reach.

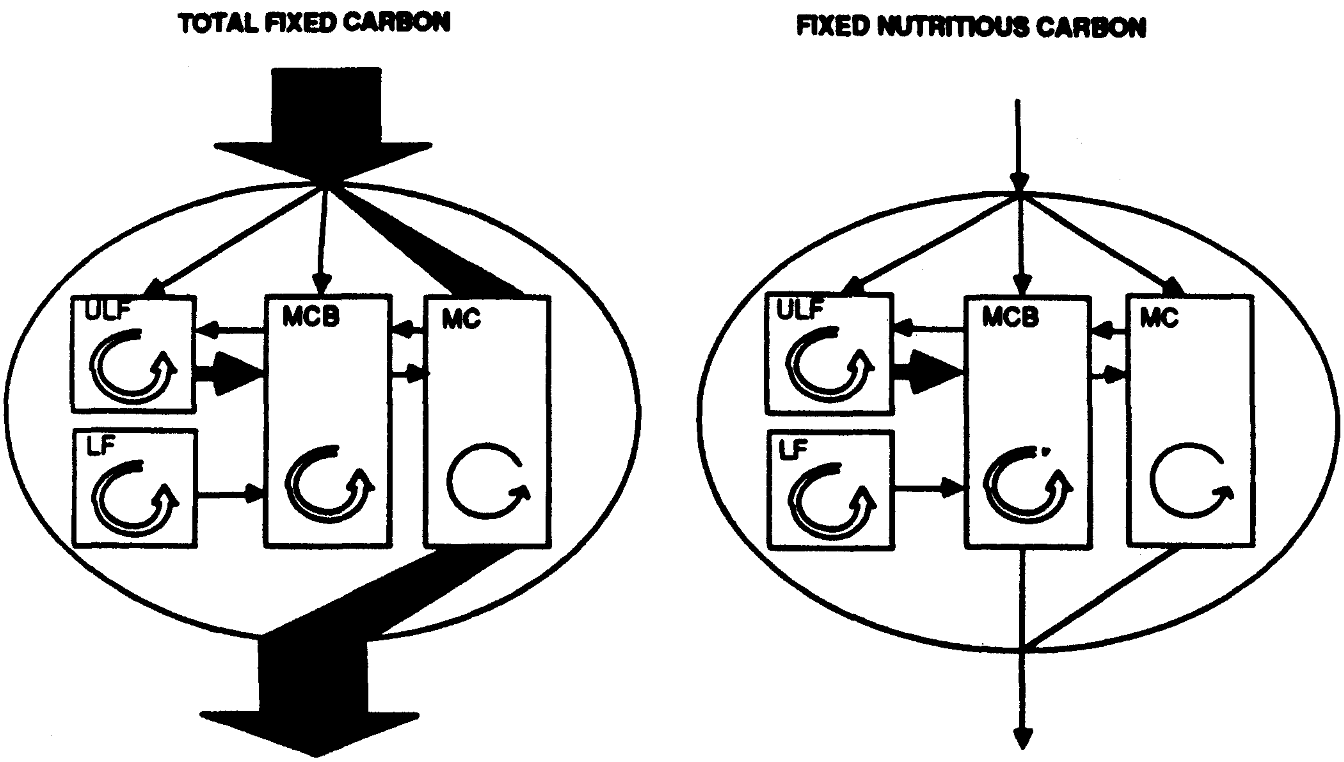

Figure 9.-Final resolution of model showing movement of carbon within a floodplain-river system. ULF = unleveed floodplain. LF = leveed floodplain. MCB and MC refer to main channel border and main channel areas respectively. Note that most of the carbon is originating off from the unleveed floodplain.

organic matter derived from floodplain sources is not important. If we improve the resolution of our conceptulazation to include the exchange between the floodplain and the stream (Figure 8) a very different picture emerges. At this level we prediet a significant import of carbon from the floodplain into the reach and most of this input will be nutritious carbon. Since the carbon is nutritious it is processed rapidly within the reach and very little will be exported out of the reach. In most river systems, the floodplains have both leveed and unleveed floodplains that are associated with main channel border areas and the main channels (Figure 9). At this scale of resolution it is suggested that most of the nutritious carbon imported into the reach is coming from the unlevied floodplains. Therefore the effects of disrupting this linkage should include lower productivity within the reach even though there exists movement of carbon into the reach from upstream. Clearly the quality of the carbon resource is linked to its origin.

BACTERIA

The closest link between terrestrial and aquatic ecosystems is bacterial response to dissolved and particulate organic matter. Research conducted by myself (McArthur and Marzolf 1985; McArthur et al. 1985) has shown that bacterial assemblages respond to both the concentration and source of dissolved organic carbon. This response appears to be associated with previous exposure of the bacterial assemblage to the resource. That is bacteria that have never experienced a specific type of dissolved organic compound can not utilize this material as a resource. This response may be either genetic or physiological. If genetic then the bacterial assemblage has constitutive enzyme systems (enzyme systems that are always present) that respond only to certain substrates. In order to respond to a new substrate a mutation must occur that allows for the processing of the new material. Alternatively, if the response is physiological, then the bacteria have inducible enzyme systems (enzyme systems that remain inactive until a suitable substrate triggers a response in the bacterium to make more of that enzyme). In a physiological response the bacteria may respond to the new source only after several hours of exposure. A genetic response would be most efficient during pulses of previously experienced substrates, e.g., during floods. A physiological response would be most efficient under baseflow conditions when new material may be transported by a site over a long time interval. These strategies are not mutually exclusive and many bacteria may have both types of response.

To further investigate the linkages between bacteria and their location along a continuum, we (McArthur et al. 1988) investigated the ecological genetics of a species of bacteria. Populations of a bacterium had genetic compositions that were site specific. Frequency of alleles coding for certain metabolic enzymes was correlated with the habitat from which the bacterium was isolated. This data suggests that the selective pressures associated with a specific habitat (floodplain/riparian/stream reach) are a function of the linkages and interactions between these compartments and that alterations in floodplain that effect either the timing, quality or source of organic matter into a stream reach will affect the overall response of the aquatic ecosystem.

CONCLUSIONS

Interactions between floodplains and streams are at many orders of scale. Natural loading of wood and organic matter provides both structure, stability and food resources for most streams. Stream biota have evolved adaptations to utilize this normal organic loading and typically, seasonally imported organic matter is completely processed. This processing of terrestrially derived carbon forms the trophic basis of many streams. Alterations that restrict the normal import of organic matter or that change the nature of this material will affect the productivity, diversity and stability of aquatic organisms from microbes up to vertebrates. Resulting in a decreased ability of the stream to function in the processing and cycling of carbon and nutrients. The overall effect of this decrease in function should be manifest along subsequent reaches of the stream and may ultimately impact processes in estuaries.

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EXTRACTABLE IRON AND MANGANESE AND REDOX CHANGES IN BOTTOMLAND HARDWOOD WETLAND-NONWETLAND TRANSITION ZONE SOILS

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Abstract.-Iron and manganese are two relatively abundant metals in most soils that are subject to chemical transformations affecting the ease with which they can be extracted from soil. An exploratory study was conducted in upland-to-wetland transects in several mature, bottomland hardwood forests of Louisiana and Mississippi to determine if Fe and Mn levels recovered with a relatively weak chemical extractant would be a useful tool for delineating wetlands from non-wetlands. Soil pH and redox potential measurements were also made. Though Fe and Mn levels were elevated in many of the hydric plots, this technique by itself could not be relied upon to identify all of the wetland sites. Soil pH was believed to be an important interacting variable influencing the amount of iron and manganese recoverable by the extractant used.

INTRODUCTION

Some of the iron (Fe) and manganese (Mn) in soils can transform between different valence states forming compounds that differ greatly in solubility, plant availability, and, in their response to various chemical extractants. These transformations and the amounts released are influenced by the amount of potentially mobile iron and manganese present and by soil pH and redox potential conditions (Gotoh and Patrick 19'72; 1974).

Well-drained upland soils typically have oxidized forms of ferric iron (Fe^{3+}) and manganic manganese (Mn^{4+}) that are essentially insoluble. In permanently or seasonally flooded soils, chemical and microbial processes may contribute to the presence of the more mobile reduced ferrous iron (Fe^{2+}) and manganous manganese (Mn^{2+}). Transformations between these forms may occur seasonally in soils as a result of seasonal changes in the water table and the subsequent effect of soil saturation on oxygen transport and microbial utilization of available electron acceptors in respiration.

The purpose of this study was to determine if extractable levels of soil iron and manganese, seasonal changes being considered, can serve as a technique for delineating wetlands from nonwetlands or compliment existing procedures. Extractable soil Fe and Mn levels were determined seasonally over a 2-year period on upland-to-wetland transects in several mature, bottomland hardwood forests of Louisiana and Mississippi. Soil redox potential measurements were also made to give an indication of the oxidation status of the transect soils.

Soil oxygen content, redox potential, depth to water table, soil temperature, soil moisture content of unsaturated zones, as well as characterization of the soil profile for classification purposes were measured monthly in a separate project. These measurements are labor intensive and require installation and long-term use and maintenance of equipment in the field. In contrast, measuring easily extractable Fe and Mn is a procedure requiring no advanced field site preparation and minimal field and lab efforts. Thus, this technique was evaluated to determine if it would be useful as a simple and rapid wetland delineation tool.

MATERIALS AND METHODS

Transects were selected along an elevation gradient to include upland sites (plots numbered 1) and wetland sites (plots numbered 4 or 5, depending on the location) as well as intermediate or transition zones.

Table l.-Sampling locations and sampling dates

Location	Sampling date
Red River (Avoyelles Parish, LA)	17 August 1984
	7 September 1984
	8 November 1984
	13 November 1984
	7 June 1985
Quimby (Madison Parish, LA)	30 August 1984
	5 February 1985
	11 July 1985
Rolling Fork (Washington County, MS)	24 August 1984
	8 February 1985
	27 June 1985
Spring Bayou (Avoyelles Parish, LA)	13 November 1984
	29 January 1985
	11 June 1985
Pearl River (St. Tammany Parish, LA)	11 September 1984
	27 May 1985

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Extractable Iron and Manganese

Replicate soil core samples (3-5 cm in length) were collected with a core auger at 15- and 60-cm depths from each plot in the transect. A triple beam balance was used in the field to weigh out 10 (+/– 0.5) grams of soil into a 50-ml polycarbonate centrifuge tube. The tubes were sealed with a cap. Tubes containing soil that might have been reduced were purged with nitrogen gas from a portable cylinder and sealed such that the reduced soil would remain in an inert atmosphere until the samples could be extracted in the laboratory the following day.

Soils were extracted in the laboratory with 25 ml of 1*N* sodium acetate adjusted to pH 2.0 with hydrochloric acid. The extractant was designed primarily to remove cations relatively weakly absorbed to exchange sites on colloidal clay minerals and humic materials. The soils were shaken with the extractant for 24 hours and then centrifuged for 22 minutes at 10,000 rpm (Du Pont Sorvall SA-600 rotor) to obtain a clear supernatant. A 2-ml aliquot of the clear supernatant was transferred to acid-rinsed, 20-ml glass vials and diluted with 15 ml of distilled, deionized water. One ml of concentrated nitric acid was added as a sample preservative to insure the metals remained in solution until analyzed.

Soil pH

At the same time samples were obtained for Fe and Mn, an approximately 15 gram quantity of soil from the same sample was placed in 60 ml plastic bottles for pH analyses. In the laboratory the next day, 15 ml of distilled deionized water was added to each bottle, the mixture shaken for 1 hour and the pH measured by inserting a calibrated combination electrode directly into the bottle.

Soil redox potential

Soil redox potential measurements were made with duplicate, platinum electrodes permanently installed at four depths in each plot of each transect. Details of their construction, installation, use, and reliability evaluation for field measurements are given elsewhere (Faulkner [and others], 1986).

Redox potential is a measure of electron availability in chemical and biological systems. Chemical species that lose electrons become oxidized while reduction is a gain in electrons. Thus redox potential indicates the intensity of reduction (or oxidation) of a system. Though a number of compounds and elements influence soil redox potential, a few predominant chemical species often regulate the potentials measured as well as the redox status of soils. An initially well-drained, well-oxidized soil will have a redox potential greater than 500 mv (Eh). If flooded, chemical processes and especially microbial demands for electron acceptors for respiration will soon deplete dissolved oxygen. Once depleted, nitrate, if present, is utilized as an electron acceptor. If the soil continues to become more reduced, oxidized forms of manganese and iron are reduced, then sulfate may be reduced. If intensely anaerobic conditions develop, methane may form from carbon dioxide or small organic acids. The oxidation-reduction status of the soil for each of these chemical and microbial transformations is associated with a particular redox potential range. Redox measurements have gained wide acceptance as an indication of the degree of reduction of soils and sediments. The measurements are commonly made with a platinum electrode as the working electrode coupled with an appropriate reference electrode.

RESULTS AND DISCUSSION

Extractable Fe and Mn

A number of interacting soil factors and processes affect the levels of Fe and Mn that can be recovered by a chemical extractant. The major soil factor is the oxidation-reduction status as previously indicated which is indicative of hydric conditions. The more easily extractable ferrous and manganous forms are favored by reducing conditions. An acid pH (especially a moderately acid pH coupled with reducing conditions) tends to increase extractable Fe and Mn levels as well. Other factors include the amount and type of clay minerals that determine how much Fe and Mn is initially present and clay genesis processes. Conditions favoring leaching of metals (acid, reducing soils where considerable water movement occurs through the soil profile) and no new additions of Fe and Mn (little or no new soil deposits from sedimentation) will, after a long period of time, deplete the amount of Fe and Mn that can become associated with the dissolved and exchangeable forms.

There were some clear trends in the data from the five field locations that fell into three groupings.

The Red River and Quimby sites had substantially greater amounts of exchangeable Fe and Mn on poorer drained plots at both depths sampled compared to better drained plots (Figure 1). These differences ranged from two to three orders of magnitude for iron. Normally, there is less Mn than Fe in soils. This is reflected in the lower Mn levels extracted in this experiment.

While the Rolling Fork site exhibited substantial differences in most of the other measured soil physical and chemical properties down the transect, extractable Fe and Mn increased only slightly in the wetland plots relative to upland plots (Figure 1). However, the differences were small.

The Spring Bayou and Pearl River sites tended to be intermediate to the other two groups in terms of the amount of increase in extractable Fe and Mn going from upland to wetland plots (Figure 1). Though clear differences were noted comparing well to poorly drained soils, the levels of Fe and Mn recovered were less than the Red River or Quimby sites. Higher levels of extractable Fe and Mn were recovered from the 15-cm depths of the better-drained plots even during warm months when the water table was low compared to the other sites. Perhaps the greater soil acidity at the Pearl River site contributed to increased exchangeable metals. An explanation for the Spring Bayou site is not as easily discerned, but the relatively low, wet conditions of even the highest plot at this location may have contributed to greater levels of reduced metals.

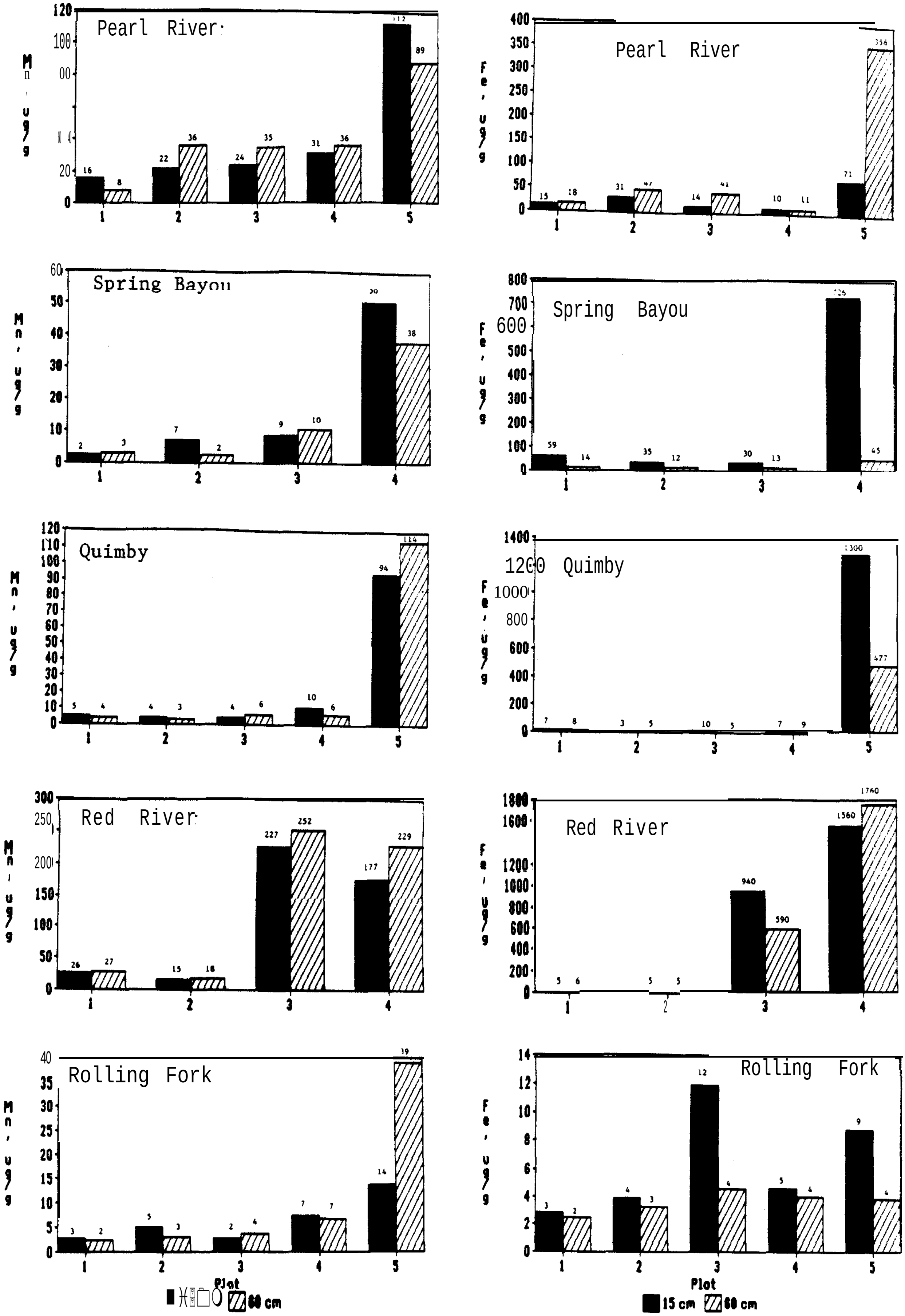

Figure 1.-Extractable Mn and Fe in soils from five transitional wetland locations.

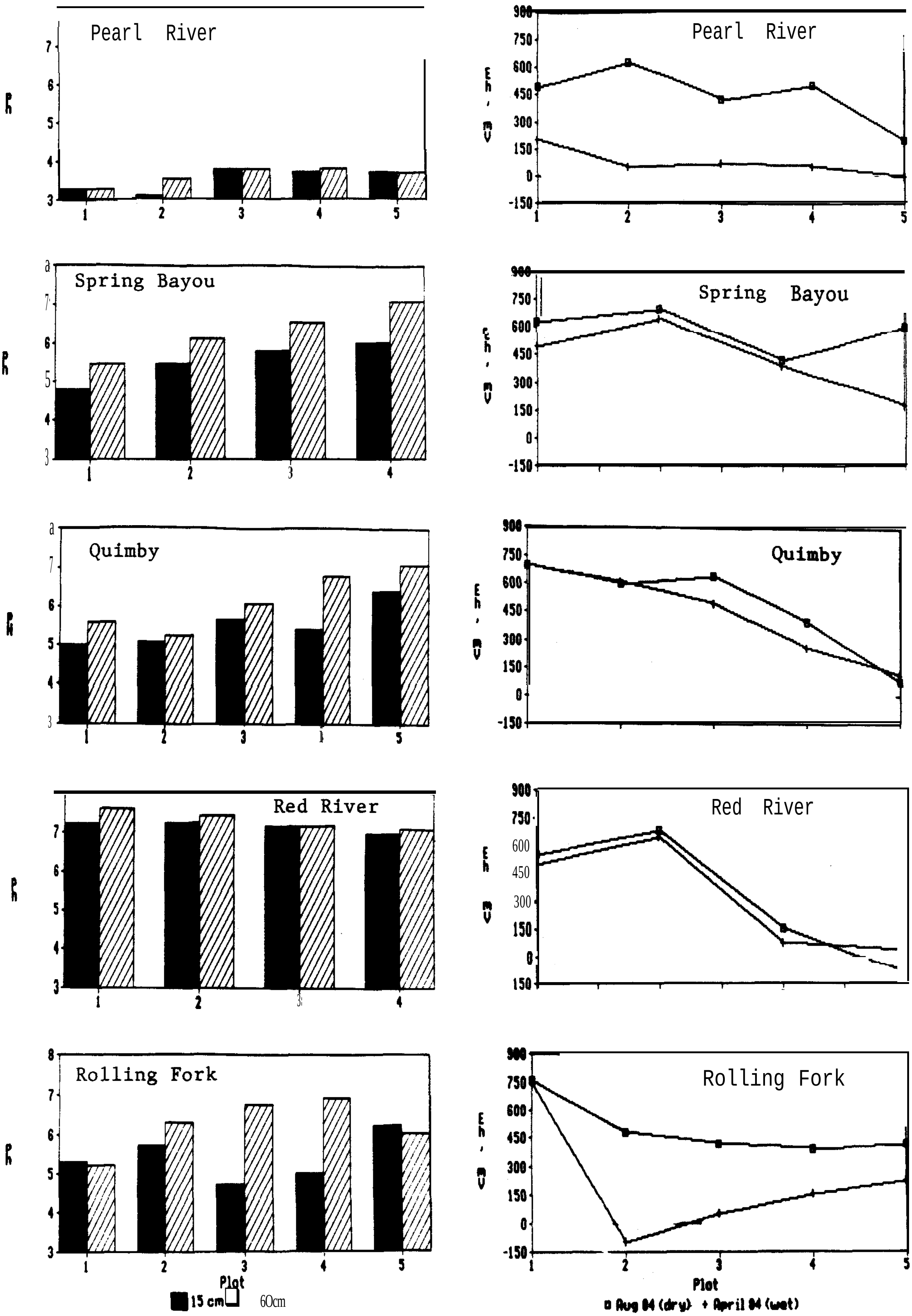

Figure 2.-Soil pH, and redox potential in soils from five transitional wetland locations.

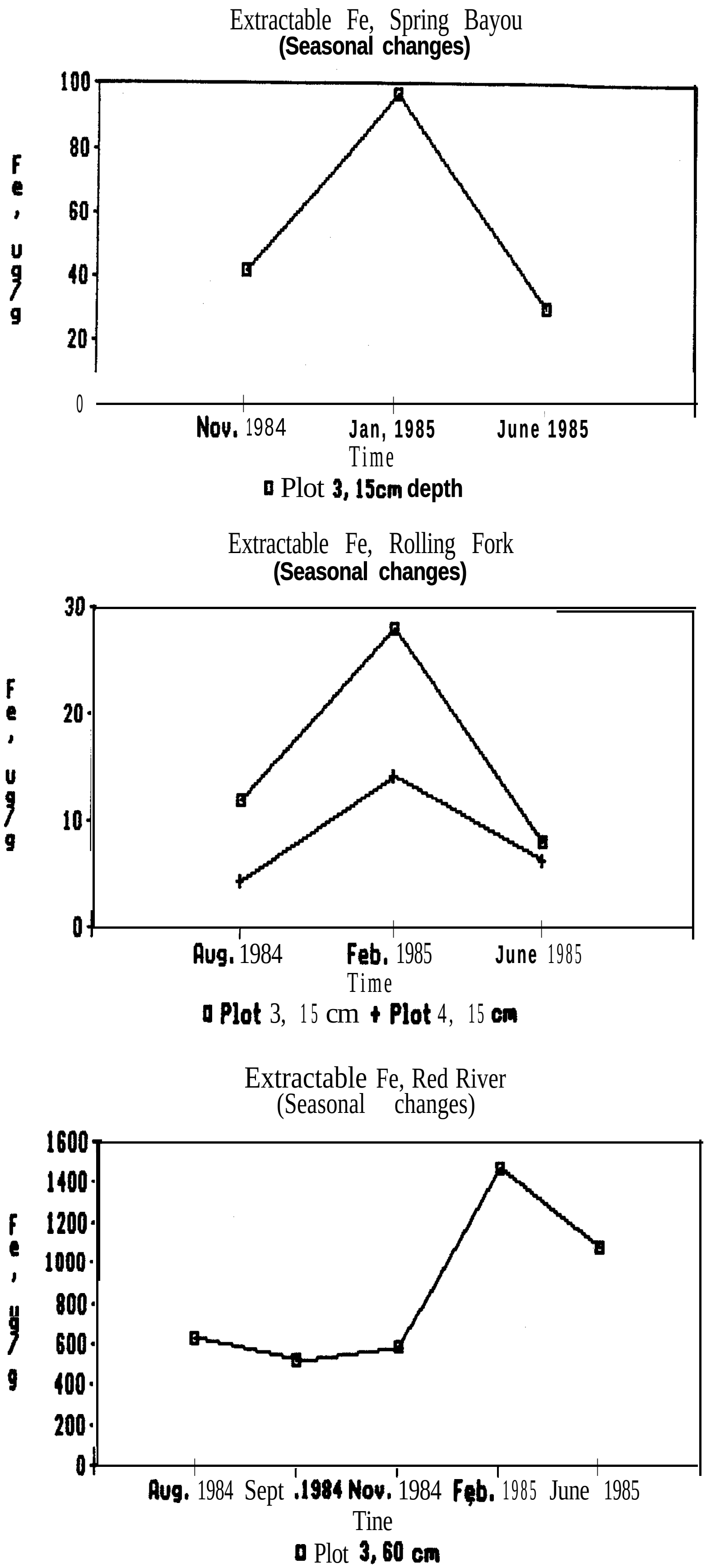

Figure 3.-Seasonal changes in extractable soil Fe for three of the five sites.

Though some of the sites showed seasonal effects on extractable Fe and Mn levels in the transition plots, they were not consistent at all locations (Figure 2).

Soil pH

Three different pH trends were observed for the five research locations as well, though the groupings were not the same as those reported for Fe and Mn (Figure 3).

The pH of both depths of the Red River site showed a very small change in soil reaction in the near neutral to weakly alkaline range. Apparently, the soil at this transect is well buffered.

The pH of the Quimby site was moderately acid (around 5) at both depths at the highest elevation and tended to increase almost sequentially going down the transect to the wetter plots. This is a classic example of soil oxidation effects on pH in noncalcareous soils where the soil pH often approaches neutrality as the soil becomes more reduced (Gambrel1 and Patrick 1978).

The pH of the Pearl River soil was moderately to strongly acid and showed only a slight increase in the lower, wetter plots. This low pH and small increase in pH with reduction on wet plots may be due in part to the sandy nature of the soil at this site.

Soil Redox Potential

In the larger project, soil redox potential measurements proved to be a useful indication of flooded soil horizons or anaerobic conditions, though there was a fair amount of variability in the data. In some cases, seasonal effects were noted, particularly on the wetter and transition plots in the transects. During the wet season, redox potential generally decreased as expected on most measurement dates going down the transect from upland to wetland plots (Figure 3).

CONCLUSIONS

Soil pH showed expected differences related to plot positions on some of the transects. Soil pH was useful in explaining some of the other differences observed in extractable Fe and Mn between plots and especially between locations, but pH measurements should not be expected to be a major useful parameter for delineating wetland from upland soils.

Both redox potential and extractable Fe and Mn levels reflected differences between wetland and upland plots at most (but not all) of the five bottomland hardwood research locations.

On their own, extractable Fe and Mn levels would not have identified all of the wet, reducing soil horizons included in this study. The reasons for this are related to the interaction of the factors affecting exchangeable Fe and Mn levels discussed elsewhere in this paper. For example, the uniformly high pH at the Red River site tends to favor the much less soluble oxidized forms of iron and manganese even in flooded soils. The low pH conditions at Pearl River enhance levels of reduced iron, or iron forms extracted by the reagent used, even in oxidized soils. Additional work correlating the levels obtained with other soil data obtained in the larger project may reveal more quantitative explanations for the observations reported.

At present, the data from this exploratory study suggest the absence of appreciable reduced Fe and Mn with the extractant employed in this study cannot be used to establish that a soil horizon is oxidized (Rolling Fork data). Likewise, the presence of easily measureable levels of extractable Fe and Mn does not provide conclusive evidence that a soil is reduced (Rolling Fork and Pearl River data). However, additional work along the lines indicated above may improve the utility of this type of measurement in characterizing wetland soils. Substituting a weaker extra&ant and/or an aquous extract with appropriate modifications to sampling, sample preservation, and analyses procedures might improve the utility of Fe and Mn measurements for helping to delineate wetland from upland soils.

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AMERICA'S WILD & SCENIC RIVERS: THE DILEMMA OF PROTECTION - A QUESTION OF VALUES

R.H. Becker'

Abstract.-Issues related to natural resource preservation in the context of social values are examined. A paradigm is presented which displays resources management strategies, considering levels of agreement on societal values and extent of agreement of quantifiable facts. From the discussion, popular strategies based upon technical options for resource management are shown to be inadequate as agreement of values is rarely obtained. Clarification of values is framed in the context of public choice theory and public trust theory. An example of the inadequacies of resource preservation policies is presented using the Wild and Scenic Rivers program.

INTRODUCTION

The theme for this paper extends beyond the notion of special rivers as sensitive environments and encompasses questions associated with the protection of any resource. Indeed, the tenet of this paper centers on the concept of "RESOURCE" and the values associated with a resource. In 1951 Zimmerman coined the phrase "Resources Are Not, They Become." In other words, objects do not possess inherent value. Objects become resources when given importance or worth by some group of people. These people claim the object as a resource for a particular value or set of values. Often objects are viewed as resources by different groups of claimants who seek legitimate but imcompatible uses of the objects. Thus, the relationship between people and their environment is marked by a procession of benefits and costs associated with use of natural resources. It is rare that these benefits and costs are evenly distributed; some resource claimant groups derive the majority of benefits while the costs are borne by other resource claimants, user groups of society as a whole.

The connection in this human-resource equation is between the concept of value and the element of scarcity. If no group of claimants arise for a specific object, it is often labeled wasteland, weed (often with the adjective noxious), or trash. In historic parlance, wilderness, desert, or swamp (quagmire or morass) were used as descriptive terms to identify natural settings in need of human intervention, before they became places having worth or value; before they became resources. Hence, the "great American desert" west of the Mississippi River became the nation's breadbasket, swamps became bottomland farms and wild rivers became hydroelectric stations and waterways for commerce.

These conversions of land and water environments were easily justified by the concept of abundance-scarcity and by economic worth. There were, after all, many miles of wild rivers, many million hectares of prairie and economic expansion was an imperative. Those natural environments possessed value in the most widely acknowledged form: monetary value. To the vast majority of persons the term economic value is synonymous with monetary value. Economic value, however, is much broader than the simple monetary component. As Hite (198'7) points out, "a thing has value . . . because it possesses utility. And what we mean by utility is . . . the thing in question is capable of serving some human need." Hite elaborates that anything that serves a human need, whether or not it can be bought or sold, has economic value.

Now, I do not wish to argue the anthropocentric bias of this focus on human values, nor do I wish to enter philosophical debate concerning the rights of animals, plants or inanimate objects. I do recognize that human center value systems may be inadequate. The act of preserving natural areas for noneconomic values is, however, a decidedly human action. Wilderness areas, wild rivers, and nature preserves are artifacts of our culture. Their identification as a "RESOURCE" is a direct link between society valuing what is rare and unusual rather than a statement of the inherent rights of plants, animals and inanimate objects. For example, a river may be viewed as a source of power for community and industrial expansion by one group of claimants; and valued for aesthetic appreciation and recreation by another group. Both resource definitions of that river are legitimate and mutually exclusive. Under those circumstances, if one group of claimants wins, the other must lose. Thus, allocation and management of natural areas becomes the control of access to resources and the balancing of legitimate claims for resources.

This balancing of claims must involve an examination of trade-offs, which requires the enumeration of impacts and the evaluation of the consequences of an action. Thus selection of options becomes a statement of values; an expression of the legal and administrative structures by which resources are made available or are withheld.

Resource management professionals typically seek technical solutions to societal problems. This search for technical, quantitative solutions for assessing impacts of specific situations is rational. Management based upon science is, on the surface, more appealing than management based strictly upon judgement. The awe effect of an equation often overrides the conventional wisdoms of applying the meaning or offering understandable explanations. Weinberg (1975), suggests, however, that "by using words, we shall

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sacrifice the appearance of elegance, but we shall stay closer to the things we want to think about." So why the drive for explanations of outcomes based upon a quantitative foundation rather than a qualitative approach? Perhaps we believe that "The stature of a science is commonly measured by the degree to which it makes use of mathematics" (Stephens, 1962). Or perhaps we were, and possibly still are, obsessed with what Egler (1983) terms "Physics Envy". So we push for the technical solution-objective answers to the often subjective questions. For technical solutions to occur, however, we need a high level of concurrence on social values and on scientific facts, a condition rarely met.

AGREEMENT ON FACTS

EEMENT ON VALUES	HIGH	LOW
HIGH	TECHNICAL/ **COMPUTATION**	**JUDGEMENT**
LOW	POLITICAL (compromise)	INSPIRATION

4

Figure 1.-Paradigm of decision making strategies.

Figure 1 (suggested by Thompson (1962)) offers a paradigm for decision making strategies. To understand this paradigm, let's track a decision regarding whether a particular river is to be used for dispersed recreation or power generation. The initial decision is political and occurs in an arena where elected officials consider the arguments of various interest groups that claim the resource, and the social benefits of the competing claims as perceived by decision makers. Once agreement has been reached on values (to recreate or to dam), an assessment of management options can begin. A technical, computational solution is possible only if agreement is reached regarding facts associated with management parameters. This resource allocation assessment is therefore only possible when values have been agreed upon. The review of facts regarding the allocation decision will result in a solution when facts can not be agreed upon.

THE DILEMMA OF WILD RIVERS

Today, too many programs start with a "vaporous wish" phrased in eloquent but elusive language. This penchant for stating policies in vague terms, leaves further definition and clarification to the implementation process. Yet, as Nakamura (1981) stated, as the implementation process gets underway and policies are more clearly defined, conflicts erupt. Those charged with the implementation find disagreement over what should be done and how; policy makers intervene to reformulate priorities or to shift direction and the program bogs down in conflict among various interest groups. The breakdown, encountered during implementation, started much earlier and is rooted in a lack of consensus and a lack of agreement.

The establishment of a protected system of wild and scenic rivers began with a laudable, but vaguely stated policy. The 1968 National Wild and Scenic River Act stated:

"It is hereby declared to be the policy of the United States that certain selected rivers of'the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations."

A subsequent report by the Comptroller General of the United States, however, was critical of the Wild and Scenic River Program (Comptroller General 1978). Reporting that the designation process has been slow and costly, the GAO study gives credence to program critics who claim the act of designation adversely affects certain rivers. The Wild and Scenic River Act has had success in curbing some forms of development along various rivers. Yet, protected status has not been successful in protecting rivers from damage by recreational overuse and other development activities in sensitive boundary areas. It may be argued that national designation has accelerated the degradation of the very characteristics the act was designed to preserve. The Act does not identify appropriate levels of use, determine the type of recreational experience an area should provide, or protect the resource from exploitative boundary development.

Protected rivers have become subject to what has been termed the "Rand McNally Syndrome". The title "National Wild River", the identification on maps and guide books, and exposure through popular magazine features are as much an attraction for use as the physical characteristics of the river itself. Problems arise when new users and other claimants attracted to these rivers hold expectations and definitions of acceptable recreational behavior and appropriate levels of development, which differ from pre-designation users of the river (Becker 1981).

New users may be louder or quieter, enjoy social contacts, or participate in forms of recreation which conflict with previous river use patterns. Engers (1978) reports the change of Michigan's Au Sable River from a fly-fishing resource to a social-canoeing river. There were no specific management actions taken to attract these new users' Engers reports the designation as the drawing feature for this urban-based recreational group.

Criticisms and observations such as Engers have given rise to questions regarding the intent of designation. Specifically, if the area is to be 'preserved and protected for enjoyment' -preserved for or from what, and for whose enjoyment? While it was not the intent of the Wild Scenic River legislation to stimulate use, but rather to preserve the rivers' resource base, the political popularity of "preserving" natural areas has overshadowed questions of counterproductive affects of such programs. This popularity is evidenced by the number and the locations of rivers under consideration for designation.

DILEMMA OF COMMON PROPERTY

Rivers, wetlands, estuaries and other special places are not owned by private individuals or by firms. They are "common property." They belong to all of us. Through government actions they are held in trust for all of us. Government agencies serve as the agent for the public, trying usually to maximize some bundle of benefits for that public. Their management results in excluding some interests and favoring other interests with the everpresent dilemma of defining public benefits.

There are many theories and schemes for defining public benefits and public interests. One might adopt the public choice theory of Nobel Prize winning-economist James Buchanan and say that public interest is the summation of the individual interests of all those persons living in a particular society at a given time (Hite 1987). Under a public choice theory allocation decisions are easy to arrive at via the metaphor of the ballot box. On the other hand, if you accept the idea that society is something more than the simple summation of the wishes of persons living at any one point in time, then public interest involves the values of unborn generations facing unseen situations and retention of values from a bygone era. That leads to a public trust theory of resource management and allocation. Public choice theory is an expansionist theory allowing for maximum utilization. Public trust is a minimalist idea; it requires actions be taken to maintain diversity of resources while retaining flexibility for future resource allocation needs.

The dilemma arises in the self-centered idea of popular opinion alone directing government action, prevalent in public choice theory and in the foregoing of immediate benefits required under public trust theory.

Because we live in a world of choice and possibilities, no one can predict the future. Therefore, projecting probable futures and the consequences of a proposed action is a function of assumptions and stochastic scenarios based upon empirical data rather than prediction. Yet, the actions taken, or differed, today form that future. So to anticipate some future, we should examine our current actions and decisions and evaluate if the foundations upon which those actions are predicated give us comfort or concern.

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THE FAUNAL SIGNIFICANCE OF FRAGMENTATION OF SOUTHEASTERN BOTTOMLAND FORESTS

Larry D. Harris[1]

Abstract.-The term wildlife refers to all free-ranging animals and does not differentiate between species such as native, highly valued forms and exotic, less highly valued forms. The term fauna is very much older and refers to the characteristic assemblage of animals that identify a region or geological era. While it is difficult and confusing to quantify the effects of forest fragmentation on wildlife diversity, changes in native fauna resulting from habitat fragmentation are more easily assessed.

Habitat fragmentation occurs at many levels of scale; what constitutes an isolated fragment to a specialist species may be neither isolated nor a fragment to the wide-ranging generalist species. Conversely, fragmenting forces such as roads and heavy traffic may amplify mortality and inbreeding and cause extinction of wide-ranging species while not affecting sedentary specialists.

Effects of habitat fragmentation and isolation on native fauna involve at least the following classes of phenomena: loss of wide-ranging species, loss of interior or area-sensitive species, erosion of genetic diversity from within rare species, and increased abundance of weedy species.

Recommendations for the mitigation of fragmentation effects are offered.

INTRODUCTION

Habitat fragmentation has emerged as a major issue associated with the continued maintenance of fauna1 resources of the globe. An increasing number of ecologists share the suspicion that "Habitat fragmentation is the most serious threat to biological diversity and is the primary cause of the present extinction crisis" (Wilcox and Murphy 1985).

Several regional analyses of the fragmentation phenomenon have been conducted (e.g. Burgess and Sharpe 1981; Harris 1984; Saunders et al. 1987), and additional key papers address individual taxa and specific situations (e.g. Robbins 1979; Howe 1984; Lynch and Whigham 1984; Brown and Dinsmore 1986; Wilcove et al. 1986; Wilcove 1987). But until now, little of the habitat fragmentation literature deals with southern wetlands, and I know of no paper that deals specifically with fragmentation in bottomland hardwood forests (BLH). This is unfortunate, because I believe that the consequences of fragmentation in the BLH are more serious than those described for upland forests. This is because of certain unique characteristics and functions associated with the southern BLH that can not be duplicated in other forest types. These attributes can be classified into those that occur 1) within the forested wetlands themselves, 2) those that result from the natural juxtaposition of forested wetlands with certain other community types (between stand effects), and 3) those that result from the distribution and configuration of forested wetlands in the regional and continental setting (among stand attributes). The most salient of these attributes are summarized in Table 1.

Despite the lack of research focused directly on fragmentation of southeastern swamplands, there are sufficient data that bear indirectly on the topic so as to warrant summarization. Hopefully, this will stimulate the focused research necessary to document the nature and magnitude of the effects.

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FAUNA OF SOUTHEASTERN FORESTED WETLANDS

The term fauna is not synonomous with wildlife. As used since Linnaeus in 1746, fauna refers to the assemblage of animals that is characteristic of a particular region or geological era and distinguishes it from the animal life of other regions or eras. For example, the southwestern desert fauna exhibits distinctive characteristics that allow differentiation from others such as the eastern deciduous forest or the grassland faunae. Throughout the 18th and 19th century the discipline of biogeography focused on the description, delineation, and mapping of faunae of different areas. Dice's 1943 delineation included the Southeastern Coastal Plain in the "Austroriparian" province, a clear reference to the dominant role of the southern riverine forest. The high number of endemic and characteristic taxa such as the crocodilians, venomous snakes, primitive fish, large wading birds, and subtropical species such as the Carolina parakeet (Conuropsis *carolinensis*) constituted distinguishing elements.

Unlike the term "fauna" which puts emphasis on the species that are characteristic of a region, the term wildlife refers to all free-ranging animals that are not under the direct physical control of humans. The term is of very recent origin and had not yet been coined when Leopold (1933) wrote his now classic text, Game Management. The alternative title available at the time would have been "wild life management," a clearly contradictory term that begged the question how it could be wild life if it were managed. Not until 1937 were the two terms officially combined and used to initiate The Wildlife Society, and The Journal of Wildlife Management. Wildlife did not appear in American dictionaries until the 1960's and did not appear in the Oxford English Dictionary until 1986 (Hunter, in press).

The term wildlife does not distinguish between animals that are endemic and characteristic of an area and those that are not, nor does it distinguish between those that are desirable and belong in an area and those that are not or

Table l.-Salient characteristics of southern bottomland hardwood ecosystems that contribute to their wildlife habitat superiority

Within-Community Characteristics	
	rich alluvial soils
	surface water that moderates temperature extremes and serves as escape habitat
	predominance of broad-leaved evergreen species in understory
	predominance of mast-producing species in overstory
	abundance of buttrot, bole, and branch cavities
	abundance of arthropods and mast for over-wintering migrants
Between-Community Characteristics	
	high contrast with conifer-dominated uplands
	phenology and mast production non-synchronous with upland communities
	receiver system for upland and stream energy and nutrient subsidies
	aquatic food chain support when flooded, terrestrial food chain support when dry
Among-Community Characteristics	
	linear distribution throughout landscape facilitates local and regional movement of animals
	water flow facilitates propagule (e.g., larvae) dispersal

do not. But most importantly, it does not allow for discrimination between what a fauna1 conservationist and a game manager target as success. Florida's gain of 100 species of exotic, free-ranging vertebrates in the last century is a clear increase in vertebrate wildlife diversity, but it is not fair trade for the loss of 10 endemic species.

CONSEQUENCES OF FRAGMENTATION

Concept of Fauna1 Relaxation

Historian Alfred Crosby signalled the fauna1 consequences of the discovery of the New World by Columbus when he observed that, "The long-range biological effects of the Columbian exchange are not encouraging. If one values all forms of life and not just the life of one's own species, then one must be concerned with the genetic pool, the total potential of all living things to produce descendants of various shapes, sizes, colors . . . . The Columbian exchange has left us with not a richer but a more impoverished genetic pool. We, all of the life on this planet, are the less for Columbus, and the impoverishment will increase" (Crosby 1972:218-219).

This impoverishment does not refer only to the loss of swampland species such as Ivory-billed woodpecker ***(Campephilus principalis)*** and Carolina Parakeet, but equally to the loss of regional fauna1 identity. It refers to the homogenization of faunas which can be accomplished by expansion of the range and abundance of common species just as well as by the loss of endemics.

As early as 1855, the French ecologist de Condolle (in Browne 1983) observed that, "the breakup of a large landmass into smaller units would necessarily lead to the extinction or local extermination of one or more species and the differential preservation of others . . . ." This simultaneous loss of some species (or other categories of biological diversity) and the increase in abundance of others in response to habitat fragmentation and fauna1 isolation is termed "fauna1 relaxation". In forested landscapes, fragmentation of expansive tracts into patches that are too small to contain viable populations of sedentary species or to encompass the necessary home range of wide-ranging species, and that are too isolated by inhospitable surroundings to allow ready emigration and immigration of animals is the principal cause of relaxation. Small isolated populations are prone to a variety of amplified mortality sources and probabilistic extinction factors, including catastrophic events and unpredictable shifts of gene frequencies. Thus, homogenization and the erosion of biological diversity occurs at several levels of hierarchy ranging from gene frequencies within a species, to loss of species, and even the homogenization of entire landscapes caused by conversion of BLH to expansive agricultural tracts or forest plantations. For discussion purposes, I will describe what is known of these processes in the categories of within, between, and among site relations introduced earlier.

Within-Site Responses to Tract Size

At least three different phenomena associated with biological diversity hinge directly on the size of the tract of forest under consideration. These involve, 1) the concept of minimum critical area, 2) effect of tract size on species abundance, and 3) effect of tract size on species composition.

1. Minimum Dynamic Area and Area-Sensitive Species

Crowley (1978) introduced the concept of minimum effective area which has since been referred to as minimum dynamic area (Pickett and White 1985). This concept asserts that in order to remain viable, tracts of forest must be of sufficient size to allow regenerative processes that may seem catastrophic when viewed at the scale of the individual tree or regenerative unit but are totally necessary for maintenance of species composition and structure when viewed at the scale of the forest landscape. For shade-intolerant species, the regenerative phase depends upon canopy openings or light gaps and the species associated with these gaps are referred to as gap-phase species.

Table 2.-Southeastern breeding birds that are "area-sensitive species" because their presence and reproduction are dependent upon sizes of the tracts of forest available (from Hamel et al. 1982)

Species	Species
Swallow-tailed Kite	Solitary Vireo
Mississippi Kite	Red-eyed Vireo
Red-shouldered Hawk	Black-and white Warbler
Broad-winged Hawk	Bachman's Warbler
Ruffed Grouse	Northern Parula Warbler
Wild Turkey	Black-throated Grn. Warbler
Black-billed Cuckoo	Yellow-throated Warbler
Barred owl	Pine Warbler
Pileated Woodpecker	Scarlet Tanager
Red-cockaded woodpecker	Summer Tanager
Yellow-throated Vireo	Rose-breasted Grosbeak

Many southeastern vertebrates are known to require these regenerative stages, but they can only subsist when the gaps are embedded in mature forest, not when the entire landscape consists of gaps or openings or cleared fields. The Ivory-billed woodpecker ***(Campephilus principalis)*** was one such species, it required an abundance of dead trees for foraging but these had to occur in an extensive matrix of mature forest. The Swallow-tailed kite (*Elanoides forficatus*) is another inasmuch as it seems to depend upon extensive areas of bottomland forest and yet it actually requires openings for foraging. This species is in sharp decline and now only occurs in very limited areas in the Southeast (Cely 1979).

Thirty-seven southeastern bird species are known to require extensive forest areas of one size or another (Table 2). It is important to note that this category of species is distinguished by the fact that they require large contiguous tracts but the tracts do not necessarily need to be closed canopy.

2. Effect Of Tract Size On Species Richness

Attention was first drawn to the general relation between sample plot size and the number of species found in the plot by Arrhenius (1921, 1922), and Gleason (1922, 1925). Both the concept and its applications to sampling strategy and conservation were advanced by Cain (1938), Hopkins (1955), Preston (1962), MacArthur and Wilson (1967), and Conner and McCoy (1979), among others.

Given any woodland tract, whether apparently homogeneous or not, the average number of species (S) per sample quadrat will increase as the area (A) of the sample quadrat increases. The conventional expression of this Species-Area relation is given as:

$$S = cA^z$$

This power function is conveniently linearized by use of logarithms such that:

$$\log S = \log c + z(\log A)$$

This expression will be quickly recognized for its similarity to a regression equation where log c is the intercept and z is the slope of the linear relation.

McElveen (19'78) was one of the first to collect data on the abundance of birds in tracts of southeastern swamps of different sizes. Although the swamps consisted of predominantly cypress ***(Taxodium distichum)*** rather than bottomland hardwoods, the work is compelling because of the replicated nature of the sampling and the clarity of result.

The average number of breeding bird species in Cypress ponds surrounded by a matrix of 10 year-old planted slash pine (*Pinus elliottii*) is expressed by the relation:

$$S = 4.26\ A^{0.51}$$

In approximate terms, this reveals that the number of bird species breeding in north Florida cypress ponds doubles with every four-fold increase in area.

McElveen's study also assessed how the species-area relation was affected when the surrounding matrix of vegetation is changed. An equal number of cypress ponds of comparable size, shape, and composition were chosen and the surrounding matrix of woody vegetation was removed by clearcutting and site preparation. Again, breeding birds were censused for two years, and when the average number breeding in these cypress ponds is regressed against area the following relation derives:

$$S = 7.08\ A^{0.37}$$

The correct interpretation of these two sets of data seems to be that within two years after manipulation, small, discrete cypress swamps that have a high degree of contrast with the surrounding landscape and a very sharp edge support about 75% more breeding bird species than comparable cypress swamps surrounded by a pineland matrix and a less easily distinguishable edge. On the other hand, the rate of increase in breeding bird species with increasing patch size is about 25% less in the habitat isolates and therefore a six-fold increase in area is required to double the number of breeding bird species.

To the extent that extrapolation is warranted, the two regression lines intersect and suggest the hypothesis that cypress ponds would need to be greater than 35 ha. in order to avoid the consequences of the surrounding clearcut operations (Figure 1).

Similar research was conducted in isolated fragments of mesic hardwoods in an agricultural matrix (Harris and Wallace 1984). Because hardwoods are generally superior wildlife habitat, it is not surprising that the mesic hardwood fragments supported more breeding birds acre-for-acre than did the cypress fragments, but the rate of increase of species with increasing fragment size appears lower than the rate of increase for cypress swamps. Recent work suggests that the nature of these response curves is not restricted to breeding birds inasmuch as Cox (1988) reports a similar result for spring migrant birds in coastal hardwood hammocks of northeast Florida.

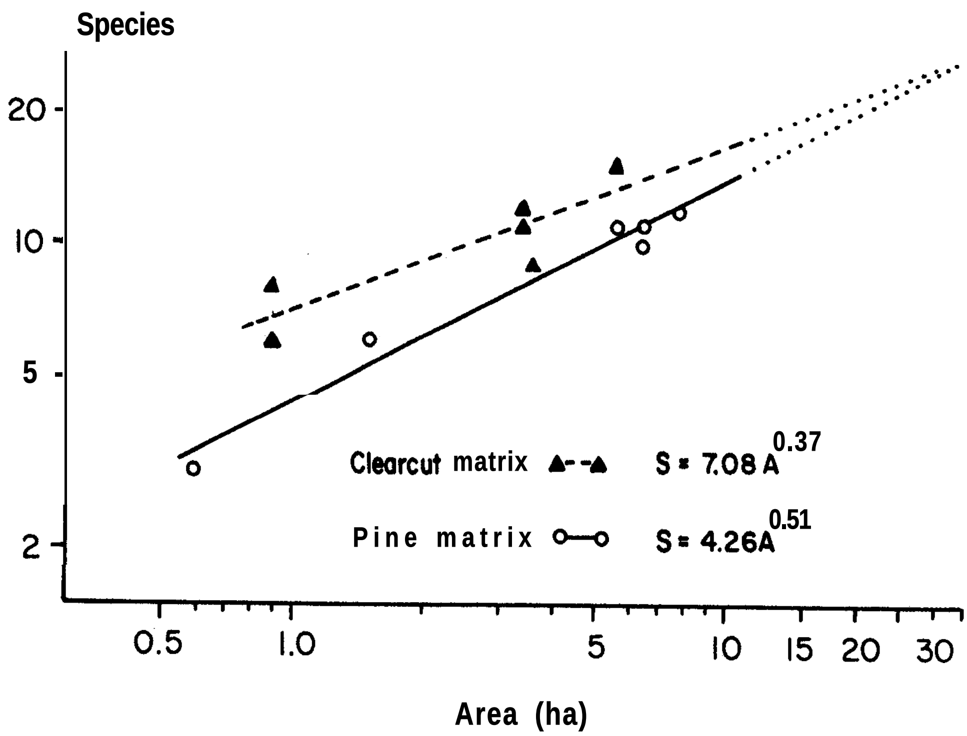

Figure l.-Species-Area relations for birds breeding in cypress ponds of north-central Florida. Extrapolation of the regression lines suggests that ponds must be larger than 35 ha in order to overcome the conseauences of different types of surrounding land management (data from McElveen 1978, analysis by B. Swindel).

3. Effect Of Tract Size On Species Composition

Although the above results are useful for diversity management, the effects of tract size on species composition are even more germane to current issues of management for biodiversity. As has been known for 50 years (since Leopold 1933), there is commonly an increase in abundance of certain species associated with the edges between ecological communities. Human interventions such as roads, powerlines, and clear-cuts create openings with associated edges that favor species such as white-tailed deer (Odocoileus *virginianus*). The species that are favored may have been scarce or rare at times in the past, but they are typically common or abundant today. For this reason, most wildlife conservationists are not enthusiastic (although hunters are) about further increases in the abundance of these already common species.

Moverover, some of these species exert direct negative impacts on less abundant forest inhabitants because they are either nest predators [e.g. crows (*Corvus spp*), bluejays (*Cyanocitta cristata*)], competitors for tree cavities [e.g. starlings (*Sturnus vulgaris*), red-bellied woodpeckers (*Melanerpes carolinus*)], or nest parasites [e.g. brown-headed cowbird (*Molothrus ater*)]. Not infrequently, these common species may exert additional indirect effects by altering biotic community structure. For example, Harrison (1984:251) reports that, "The biggest limiting factor on population size [of Kentucky warbler, (*Oporonis formosus*)] is not the cowbird', snakes, or small mammal predation; it is the White-tailed Deer." This is because high populations of deer significantly alter understory vegetation by browsing.

Species such as the Kentucky warbler, whose occurrence or reproduction is limited to the interior of rather large tracts of forest are not tolerant of numerous light gaps or artificial openings are referred to as interior species (Kendeigh 1944). Seventeen of these species occur in the southeastern U.S. (Table 3). Historically, these birds seem to have minimized nest cavity competition, parasitism, and predation from edge and open environment species by nesting in the interior of expansive tracts of forest.

As long as the expansive mature forest constituted the matrix and the openings constituted a small proportion of total area there was no issue. Wildlife managers could be circumspective about the tradeoff and simply note that while some species were disadvantaged by forest openings, others

Table 3.—Southeastern breeding bird species that only nest in the interior of closed canopy forests (from Hamel et al. 1982)

Species	Species
Forest Areas	
Sharp-shinned Hawk	Prothonotary Warbler
Cooper's Hawk	Worm-eating Warbler
Hairy Woodpecker	Swainson's Warbler
Acadian Flycatcher	Black-throated Bl. Warbler
Winter Wren	Ovenbird
Wood Thrush	Louisiana Water-thrush
Hermit Thrush	Kentucky Warbler
Swainson's Thrush	Hooded Warbler
Verry	

were benefitted. But circumstances and the issues surrounding management for edge-effects have now significantly changed (Harris 1988a).

The zone of negative influence associated with openings and edges, the negative edge effect, has been quantified in several different regions and is known to extend beyond 100 meters into the forest, climatic and more subtle species composition effects are known to extend 1000 m (e.g. Brittingham and Temple 1982; Wilcove 1985; Lovejoy et al. 1986; Janzen 1986).

Former mature-forest landscapes where openings and early successional communities were less common have been modified so that openings and early stages are now dominant and tracts of uninterupted forest are rare. Concurrently, many North American breeding birds that require forest interior conditions have declined sharply (Robbins et al. 1986; Morton 19'79; Briggs and Criswell 19'79; Wilcove 1984). This is in spite of the fact that we have set aside numerous tracts as natural areas and refuges, and we have tried to maintain their within-boundary integrity.

But it can be noted from McElveen's cypress pond study, for example, that even when no activity occurred within the cypress fragments themselves, there were dramatic differences between the bird communities of the cypress surrounded by pine versus those surrounded by clearcut. And in neither treatment did even the largest cypress ponds (8 ha) support such forest interior species as Prothonotary warbler (*Protonotaria citrea*), Swainson's warbler ***(Limnothlypis swuinsonii),*** yellow-throated warbler (*Dendroica* ***dominica),*** yellow-throated vireo (*Vireo flavifrons*), or several species of raptors. Thus, it should be clear that not only the number of species but the composition of the animal community is impacted by surrounding land management even when small forest fragments are set aside. It seems that the magnitude of the effect is ameliorated by large tracts.

Between-Tract Relations . . . the Adjacency Criterion

Harris and associates (Harris 1984; Noss and Harris 1986; Harris 1988) have emphasized that in many situations it is not so much what is contained within the forest (i.e. the content) as what the forest is contained within (i.e. the context). Forest management decision makers who use scheduling models incorporate this concern by considering the adjacency criterion, that is, what occurs next to the stand in question. Because many animal species require different community types during different seasons or life stages, and must move between communities on a regular basis, the arrangement of ecosystem types within the landscape is of critical importance to the animal's continued existence. Synergistic effects such as greatly reduced energy expenditures may occur when two or more ecosystem types are juxtaposed appropriately, but consequences may be antagonistic when other arrangements occur.

Gray squirrels (*Sciurus carolinesis*) commonly occur in conifer forests of pine or cypress during summer and fall, but can not live there throughout all seasons unless hardwoods are in close proximity. Bottomland hardwoods are used during winter months (Goodrum 193'7, Jennings 1951), and hardwood stringers or riparian strips seem to constitute essential movement corridors. At least four studies (Hedrick 1973; McElfresh et al. 1980; Nixon et al. 1980; Dickson and Huntley 1986) conclude that hardwood stringers are essential for the maintenance of gray squirrels in managed conifer or agricultural landscapes where the hardwoods have been isolated into, disjunct fragments. At least two of these studies reveal that higher squirrel densities are associated with the wider dispersal corridors (Hedrick 1973; Dickson and Huntley 1986). Thus, only when conifer or developed landscapes contain hardwoods in certain configurations do the subsystems interact to produce gray squirrel habitat.

Antagonistic effects resulting from the juxtaposition of certain community types are commonly reported, but only recently have we gained sufficient precision of knowledge to manage these effects. For example, the brown-headed cowbird is North America's only obligate brood-parasite. It only reproduces by laying its eggs in the nests of host species which incubate the eggs and feed the nestlings. Since brown-headed cowbirds are creatures of openings and edges, their nest parasitism is largely restricted to the 100 m of forest adjacent to clearings (Brittingham and Temple 1983).

During this century Bachman's warbler (*Vermivora* ***buchmanii)*** was a rare species that only nested in natural light gaps within the swamp forests of the Southeast (Hamel 1986). This species has not been recorded to breed within the last decade and is now presumed extinct. The demise of Bachman's warbler is coincident with the dramatic losses of bottomland forest and concurrent increase in open field acreage in the Southeastern Coastal Plain. Land use activities that create fields and openings have facilitated an explosive increase in brown-headed cowbird abundance throughout the east (Brittingham and Temple 1983), and for various reasons it is plausible to infer that a consequent increase in brood parasitism contributed to the extinction of Bachman's warbler (Harris 1988b).

Among-Site Issues . . . When Fragmentation Means Isolation

When largely unbroken tracts of riparian forest interconnected hundreds of miles of streams and rivers, the consequences of upland settlement and development probably mattered little of the bottomland wildlife species. As long as the level of connectivity among the BLH forests was high, movement of the wide-ranging species among the river bottoms ("branches", or "stringers") could occur freely. Human settlement, agricultural development, and more recently, commercial development has reduced habitat connectivity and impaired movement of most ground dwelling creatures. Thus, even species that were adapted to move among communities of various types have become increasingly isolated into discrete nodes of habitat. Impacts on large-bodied mammals has been severe.

With the exception of some grazing mammals, vertebrates generally face the dual handicap of population densities being inversely related, but territory size being directly related to body size and trophic level. In addition to the enhanced probability of stochastic extinction, small populations are also more vulnerable to genetic drift, genetic swamping, and the consequences of inbreeding. Intrusive forces such as highways not only amplify mortality, they can serve as effective barriers to genetic interchange. Thus, a major highway that bisects a forested wetland and contains no provision for ground or water dwelling animal movement may not only fragment the two parcels, it may well isolate the populations.

This is especially relevant to furbearing mammals. Of the 30 commercially important species of furbearer in North America, 26 (87%) are true carnivores such as otter (*Lutra canadensis*) and mink (*Mustela vison*) or omnivores such as black bear (*Ursus americanus*). Virtually all of them have large home ranges. The majority of these 26 species are associated with the water's edge and their home ranges tend to be long and narrow. This exacerbates the problems associated with their large home range size because it greatly increases the prospect that their movement will intersect some form of human occupation. The implications of this emerge from the following analysis.

1. Discrimination Against The Large-Bodied Species.

Since the Pleistocene somewhat over half of the large mammal species of the Southeastern Coastal Plain have gone extinct (see Webb and Wilkins 1984). A linear relation between percent of size class becoming extinct and body size exists; whereas there is no paleontological evidence that any of the very small (<10g) taxa have gone extinct, 100% of the very large have gone extinct (Harris and Eisenberg 1988). This trend continues in the present time.

Until 200 years ago, eleven species or subspecies of native mammal larger than 5 kg occurred in Florida (Table 4). Of these, three are now extinct or locally extirpated, three are Federally listed as Endangered Species, and three are listed as threatened by the state of Florida or are listed by the International Convention on Trade in Endangered Species (CITES). Reasons for the recent extirpations are varied, but the principal known mortality source on the endangered panther (*Felis concolor*), Key deer (0. v. *clavium*), and manatee (*Trichechus manatus*), and on the threatened black bear outside legal hunt areas is due to collision with motor vehicles.

In addition to the short-term effects of amplified mortality deriving from the impacts of vehicles and other human forces, longer term mortality rates may be increased indirectly because of inbreeding, genetic swamping, or genetic drift as a result of isolating a small subpopulation.

Table 4.-Native Florida mammal species greater than 5 Kg in body size and their status (1 = Federally listed as an endangered species, 2 = listed by the State of Florida, 3 = Convention on International Trade in Endangered Species (CITES)

Species	Listing
Bison	locally extinct
Manatee	endangered[1,2]
Black Bear	threatened'
Monk Seal	extinct
White-tailed Deer	none
Florida Panther	endangered[1,2]
Red Wolf	locally extinct
Key Deer	endangered[1,2]
Bobcat	Appendix 2[3]
Otter	Appendix 2[3]
Raccoon	none

Genetic factors such as these are identified as contributing to the demise of both the red wolf (*Canis rufus*) and the Florida panther (Harris 1988b).

2. Genetic Swamping As Result Of Invading Species

As with the brown-headed cowbird described above, opening of the landscape east of the Mississippi facilitated the eastward range expansion of the coyote (*Canis latrans*). With the natural ecological barrier between the southeastern red wolf and the midwestern coyote broken, and with the behavioral barriers to interbreeding stresses by wolf population reduction, and fragmentation in seasonlaly inundated swamps and marshes, the red wolf became increasingly vulnerable to cross-breeding and hybridization with the smaller, more omnivorous, and more adaptable coyote. A rescue evacuation from the southern swamplands and captive breeding program had to be initiated in order to preserve the genetic identity of the few remaining wild red wolves.

3. Inbreeding As Result Of Isolation

In the case of the panther, the combination of the peninsular shape and heavy mortality associated with the human occupancy of northern and coastal areas of Florida had the effect of isolating a panther subpopulation in the swamplands of southern Florida. The restriction of gene flow has apparently been sufficient to cause inbreeding and the expression of distinct morphological traits. In addition, of all the adult male Florida panthers tested to date, there exists about 95% sperm infertility. This may well be a consequence of reduced gene flow and inbreeding over long periods of time (U.S.F.W.S. 1987).

4. Ecological Release Of Middle Sized Omnivores

Similar to the range expansion of the cowbird and coyote, many other species have benefitted from human occupancy and manipulation of the landscape. Raccoon (*Procyon lotor*), opposum (***Didelphis*** virginiana), and armadillo (*Dasypus novemcinctus*) are three such medium-sized mammals that do well in landscapes that are highly fragmented and subsidized with many sources of human-generated food. Although they were formerly important as human food themselves, these species are no longer consumed in significant numbers, and hunting them for sport has decreased considerably. Banned useage of steel-jaw traps and depressed fur prices has meant lower levels of trapping. Thus, a combination of factors ranging from habitat fragmentation and the removal of large carnivores that formerly preyed on and competed with these species to overt habitat management has caused the range expansion and population increase of these middle-sized ground nest predators. Aside from the nuisance aspects and human health hazard associated with rabies carried by raccoons, there are additional concerns. About 200 species of native Florida vertebrates nest on or near the ground surface may be jeopardized because of overly high populations of these nest predators that were formerly kept in check by the spectrum of forces listed above. Here is a prime example of how the increase in abundance and diversity of a few species might be viewed as a success by some, while in fact, it may seriously detract from the fauna1 conservation efforts of others.

SUMMARY AND RECOMMENDATIONS FOR IMPACT MITIGATION

If all BLH fauna occurred within stands of BLH and it were possible to set-aside representative stands of sufficient size to maintain viable populations of these species, then maintenance of fauna1 diversity and integrity could be achieved by simply creating replicated BLH refuges. This is consistent with traditional conservation programming. But evidence suggests that this approach will not suffice in and of itself; the number and size of set-aside tracts that would be necessary to achieve viable populations of the larger, wider-ranging species would be too great. Moveover, it seems that the species requiring southern forested wetlands form a continuum from specialists that require specific habitat conditions within the community (e.g. interior species) to those that depend on certain arrangements between communities, and finally, species that move widely among communities. This implies that a management and conservation strategy biased in favor of any one group will probably fall short when it comes to maintaining viable populations of the full gamut of species.

A successful fauna1 conservation strategy will begin with the goal of maintaining the identity and integrity of the regional biota and attempt to ensure the maintenance of representative communities within it. Because of the existence of wide-ranging and area-sensitive species, considerable emphasis must be given to the landscape configuration within which the communities occur, not just the structural content within the communities themselves. For certain species, the landscape setting that the BLH occurs within may be as important as the habitat structure within the BLH.

An endangered species approach will serve as an important tactic within the overall strategy, but it is important to consider the full gamut of endemics that characterize the biotic province and pay as much attention to the wide-ranging generalist carnivores such as red wolves, Florida panthers, and mink as is given to highly localized specialists such as Bachman's warbler.

The overall strategy must include at least these elements:

1. Forested wetland sanctuaries that ensure the existence of several patches of closed-canopy mature and over-mature forest necessary for the maintenance of viable populations of interior species. Even if they occur in a forested landscape these tracts of old-growth will need to be at least 30 ha in size in order to abate the negative consequences of edge effects.

2. Although still open to scientific debate, evidence suggests that the functional size of old-growth tracts can be effectively increased by surrounding them with pole timber or closed-canopy stands that are not necessarily removed from forestry operations. This zone of low intensity forest management can serve as a buffer to create forest-interior conditions within smaller tracts of old-growth forest without having to exclude massive acreages from forestry operations.

3. Certain consequences associated with both natural and man-induced edges will negatively impact the forest interior species and therefore tracts of mature and old-growth forest will need to be of considerable size. Evidence suggests that these negative effects will increase as the sharpness of the edge increases and that the magnitude of the edge effect is inverse to the quality of the habitats involved. Thus, while dramatic edge effects may occur in conjunction with clearcuts and conifer plantations, only modest edge effects may be associated with old-growth forests that already contain a variety of stages and sizes of natural light gaps (see Noss 1988).

4. Numerous species of wildlife move over wide expanses of landscape during the course of a year in order to complete their life cycles. Although these area-sensitive species are commonly tolerant of light gaps and modest habitat disruption, they are vulnerable to intrusions such as roads, and residential or industrial development. Fish, amphibians, reptiles, and mammals that must move on the ground or along rivers or watercourses are especially impacted by developments that block their natural movement pathways. Land management and conservation activities that focus on linear ecosystems and the need for animals to move are increasingly called for.

5. In landscapes dominated by human activities, highway underpasses and other forms of movement corridors must be maintained in order for the large mammals such as otter, mink, bobcat (Lynx *rufus*), bear, and panther to survive. The only alternative to this is the setting aside of very large tracts of habitat where these mammals are not subject to road-induced mortality.

6. Where high speed highways and heavy automobile traffic must bisect forested wetlands it will be necessary to construct fences along the right-of-way in order to prevent human injury and property loss due to collision with large mammals such as deer and bear, and to deflect dispersing or migrating animals into the movement corridors and/or underpasses.

7. Traditional within-habitat management principles are no less important because of increased awareness of landscape level phenomena.

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CONSERVING ENDANGERED SPECIES ON SOUTHERN FORESTED WETLANDS

John P. Ernst and Valerie Brown[1]

Abstract.—Several species of endangered plants and wildlife are dependent on forested wetland habitat. Human activities have caused southern forested wetlands to become an "endanagered ecosystem."

The Endangered Species Act (Act) is designed to protect endangered and threatened species and their habitat, and thus provides a valuable tool for conserving forested wetlands. Due to political and biological weaknesses, however, the Act has only limited effectiveness in protecting entire, functional ecosystems necessary to preserve the full compliment of species associated with forested wetlands. Regulations and decisions based on the Act can be influenced by political considerations. By design, the Act forces attention on relatively few species instead of entire ecosystems. This may result in patchy ecosystem protection which ultimately could endanger many other species. Attention also tends to be focused on glamorous, popular species, often neglecting important low-profile species. Also, we lack sufficient knowledge of many species, and their critical habitat may be lost before their needs are ascertained. Finally, the Act is designed to protect species only when they have reached a crisis level in their numbers, a point at which it is often too late.

INTRODUCTION

Southern forested wetlands of the United States represent an "endangered ecosystem." The loss of these wetlands through conversion to other uses and degradation threatens species dependent on the habitat with extinction. The U.S. Congress enacted the Endangered Species Act with strong powers for conserving species threatened with extinction, and this legislation clearly recognizes that the conservation of endangered species requires the protection of their habitat. The Endangered Species Act should be a valuable tool for conserving southern forested wetlands to the extent that they provide habitat for protected species. The purpose of this paper is to evaluate the Act as a tool for conserving these wetlands.

FORESTED WETLANDS

Forested wetlands are characterized by woody vegetation 6 m tall or taller in areas with hydrophytic vegetation, hydric soils, and/or saturation by water sometime during each growing season (Cowardin and others 1979). These wetlands occur in intertidal estuarine and palustrine wetland systems. These two systems are primarily distinguished by the concentration of ocean-derived salts-estuarine systems having at least 0.5 percent salinity from ocean-derived salts and palustrine systems having less than 0.5 percent salinity. Forested wetlands generally include an overstory of trees, and under-story of young trees or shrubs, and a herbaceous layer. The U.S. Fish and Wildlife Service (FWS) defined 5 subclasses of forested wetlands, each of which occurs in the southern U.S. (Table 1).

Current status

Abernethy and Turner (1987) estimate there are approximately 20 million hectares (50 million acres) of forested wetlands in the conterminous United States, representing about 2 percent of the total land area in the United States and accounting for approximately 60 percent of all U.S. wetland area, exclusive of deepwater habitat. Of this forested wetland acreage, 57 percent is found in the states of Alabama, Arkansas, Georgia, Florida, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia.

In the last 200 years, over 50 percent of our nation's total wetland area has been destroyed. While approximately 38 million hectares (93 million acres) of wetlands remain, an estimated 180,000 ha (450,000 acres) of wetlands are lost annually (Tiner 1984). The annual loss rate for forested wetlands is about 68,300 ha (169,000 acres), or 0.3 percent annually. Abernethy and Turner (1987) cite a selective loss of forested wetlands, up to 5 times higher than upland forests, in the last 40 years. One of the most dramatic reductions of forested wetlands has ocurred in the Mississippi River Delta, where 75 percent of the original wetland area has been destroyed (Fredrickson 19'78).

PROTECTION OF ENDANGERED SPECIES

Human activities have dramatically accelerated the extinction of species (Ehrlich and Ehrlich 1982, Myers 1986, Opler 1977, Wilson 1988). The United States Congress first acted on this problem with the passage of the Endangered Species Preservation Act of 1966. Even in this early form, the Act identified habitat as the crucial component of endangered species preservation (Bean 1983). The Endangered Species Act of 1973 forms the basis for current federal protection of endangered species. Protection of habitat is even more clearly identified in this Act, the purpose of which includes providing ". . . a means whereby

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Table l.-Subclasses of forested wetlands of the Southern U.S.[a]

Subclass	Dominants	Scientific name
Broad-leaved deciduous	Red maple	*Acer rubrum*
	American elm	*Ulmus* americana
	Ashes	***Fraxinus** pennsylvanica*
		F. nigra
	Gums	***Nyssa sylvatica***
		***N.** aquatica*
	Oaks	***Quercus bicolor***
		Q. *lyrata*
		Q. michauxii
Needle-leaved deciduous	Bald cypress	*Taxodium* ***distichum***
Broad-leaved evergreen	Red bay	*Persea* ***borbonia***
	Loblolly bay	***Gordonia lasianthus***
	Sweet bay	***Magnolia virginiana***
	Red mangrove	*Rhizophora* ***mangle***
	Black mangrove	***Avicennia** germinans*
	White mangrove	***Languncularia racemosa***
Needle-leaved Evergreen	Atlantic white cedar	***Chamaecyparis thyoides***
	Pond pine	*Pinus* ***serotina***
Dead		

[a] adapted from Cowardin and others 1979.

the ecosystems upon which [threatened and endanagered species] depend may be conserved." 16 U.S.C.§1531 (b). Rare and endangered species are also protected to various degrees by state programs, an analysis of which is beyond the scope of this paper.

Species may be listed under the Act as either threatened or endangered. While endangered species are at a higher risk of extinction than threatened species, the Act affords similar protection to both categories. In discussing the effectiveness of the Act, no distinction will be drawn between management for threatened and/or endangered species, though subtle differences exist.

The Secretary of Interior, acting through the Director of the U.S Fish and Wildlife Service (FWS), is responsible for administering the Endangered Species Act. (The Secretary of Commerce, acting through the National Marine Fisheries Service, has jurisdiction **over** marine animals.) An understanding of key provisions in the Act will allow analysis of its effectiveness in protecting threatened and endangered species, and the habitat on which they depend. These provisions include: 1) a requirement that actions of U.S. agencies not jeopardize the continued existence of a species or population, and 2) a prohibition on "taking" of these species, 3) actions to list species, and 4) designation of critical habitat.

Agency Jeopardy to Endangered Species

The Endangered Species Act provides a process for insuring that the actions of any federal agency are not likely to jeopardize the continued existence of any threatened or endangered species. Pursuant to Section '7 of the Act, all federal agencies must consult with the FWS on any project or action that may affect these listed species. The FWS then determines, either informally or through a formal biological opinion, if the proposed agency action will jeopardize the species in question. If so, the action must be altered or cancelled to remove the threat to the species, regardless of other objectives (Harrington 1981).

Prohibition on Taking of Endangered Species

The second major protection provision of the Endangered Species Act is a prohibitation on the "taking" of threatened and endangered species as set out in Section 9. As defined, taking includes:

> "'. . . to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."'
>
> 16 U.S.C.§1532 (19) (Supp. V 1981)

Certain exemptions are included in the Act ". . . for scientific purposes or to enhance the propagation or survival of the affected species . . ." 16 U.S.C.§1539 (a)

The Section 9 restrictions on taking of endangered species also provide a means to protect the habitat of those species. In 1979, the word "harm" in the definition of take was interpreted by the courts to include habitat destruction. Palila v. Hawaii Department of Land and Natural Resources, 471 F. Supp. 985 (D. Ha. **1979),** ***aff'd*** **on** *other* **grounds, 639F.2d495** (9th Cir. 1981). When the FWS attempted to overturn this court decision by defining harm to exclude habitat destruction, the agency met resistance (Bean 1983). The FWS then issued regulations with the following definition of "harm" which is currently in effect:

> 'Harm' in the definition of 'take' in the Act means an act which actually kills or injures wildlife. Such act may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering.
>
> 50 CFR 17.3 (198'7)

This definition clearly affirms that actions which destroy or degrade habitat and have a significant direct effect on an endanagered or threatened species can be regulated under Section 9. This is particularly significant because Section 9 applied broadly to any person subject to U.S. jurisdiction, whereas Section '7 applies only to federal agencies.

Listing Species as Threatened or Endangered

The FWS is responsible for listing species for protection under the Endangered Species Act. This process includes appropriate notices and public hearings. In addition, private citizens are permitted to petition the Secretary to list a species.

A species being reviewed for listing is considered a candidate species. Candidate species are listed in three categories: Category 1 (Cl) includes taxa for which the FWS currently has substantial information on hand to support listing the species, Category 2 (C2) includes taxa for which information on hand indicates listing is possibly appropriate, but for which conclusive data is not available, and Category 3 (C3) includes taxa which are no longer being considered for listing. While the Act does not specifically protect candidate species, government agencies are required to consider any actions that could affect a candidate species and to consult with the Secretary before taking such action.

Designation of Critical Habitat

Critical habitat is defined as "... the specific areas ... on which are found those physical or biological features essential to the conservation of the species and which may require special management considerations or protection." 16 U.S.C.§1532 (5) (A). Designation of critical habitat may be done either at the time of listing or at a later date to the extent that such designation is "prudent" and "determinable". 16 U.S.C.81533 (b) (6) (C). The FWS is required to consider costs and benefits when designating critical habitat. Bean (1983) argues that this requirement does not reduce the effectiveness of the Act because Section 7 has full effect regardless of critical habitat designation.

ENDANGERED SPECIES IN SOUTHERN FORESTED WETLANDS

While a precise list exists for all threatened and endangered species, it is difficult to determine an exact number of threatened or endangered species that are dependent on forested wetlands. Species use wetlands to varying degrees, and it is difficult to quantify just how important wetlands are to the survival of each species. Some species, particularly plants, live all of their lives in southern forested wetlands. Other species, such as migratory birds, may utilize these wetlands during only part of their daily or seasonal activities.

Species Dependent on Southern Forested Wetlands

Most reviews of wildlife on wetland areas (Brinson and others 1981, Wharton and others 1980) have concentrated on common wildlife species. Williams and Dodd (1978) identified the percentage of threatened and endangered species in several categories that are dependent on some class of wetland (Table 2). Brinson and others (1981:101) list 79 endangered and threatened species associated with riparian ecosystems nationwide, which includes a substantial portion of the southern forested wetlands.

Table 2.-Percentage of listed species dependent on wetlands (figures from Williams and Dodd 1978)

	Total Listed	Wetland Dependent	Percentage
Mammals	33	5	15
Birds	70	22	31
Reptiles	5	3	60
Amphibians	6	3	50
Fish	41	22	53

For this report, we attempted to compile a list of endangered, threatened and candidate taxa dependent on forested wetlands in the southeast U.S. during some part of their life cycle. We received information from state Natural Heritage Programs in Arkansas, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, and Virginia which identified rare and endangered species and, to varying degrees, their association with forested wetlands. The list of animal taxa (Table 3) and plant species (Table 4) should not be considered a complete list of threatened and endangered taxa dependent on southern forested wetlands. First of all, the degree of dependence on forested wetlands does not represent the application of a standardized criteria, but instead represents the best judgements of biologists at the Natural Heritage Programs and at FWS field offices. Furthermore, plant lists were not available from Arkansas and Mississippi; animal lists were not available for South Carolina and Virginia, no lists were received from Alabama, Florida, Missouri and Tennessee; and an invertebrate list was only available from Arkansas.

Table 3.-Endangered, threatened, and candidate plants species on southern forested wetlands

Scientific name	Comman name	Status[a]	Source[b]
Amsonia ludoviciana	Louisiana bluestar	c2	LA
Arenaria godfreyi		c2	SC
Asplenium heteroresiliens	Carolina spleenwort	c2	NC
Aureolaria patula	Spreading foxglove	Cl	GA
Baptisia arachnifera	Hairy rattleweed	E	GA
Betula uber	Virginia round-leaf birch	E	N
Brickellia cordifolia	Flyr nemesis	c2	GA
Brickellia mosieri	Florida thoroughwort	c2	GA
Cacalia diversifolia	Variable-leaf indian-plantain	c2	GA
Cacalia rugelia	Rugel's ragwort	Cl	NC
Calamovilfa brevipilis	Riverbank sandreed	c2	NC,SC
Cardamine longii	Long's bitter cress	c2	VA
Cardamine micranthera	Small-anthered bittercress	Cl	NC
Carex barratti	Barratt's sedge	c2	GA,NC,SC,VA
Deeringoghamnus pulchellus	Beautiful pawpaw	Cl	N
Deeringoghamnus rugellii	Rugel's pawpaw	Cl	N
Eupatorium resinosum	Resin boneset	c2	SC
Euphorbia purpurea	Glade spurge	c2	NC,VA
Fimbristylis perpusilla	Harper's fringe-rush	Cl	NC,SC
Geum geniculatum	Bent avens	c2	NC
Glyceria nubigena	Smoky mountain mannagrass	Cl	NC
Helonias bullata	Swamp pink	PT	GA,NC,VA
Hexastylis lewisii	Lewis's heartleaf	c2	NC
Ilex amelanchier	Sarvis holly	c2	LA,NC,SC
Ilex collina	Long-stalked holly	c2	NC
Illicium parviflorum	Yellow anise-tree	c2	GA
Isoetes louisianensis	Louisiana quillwort	c2	LA
Isoetes virginica	Virginia quillwort	c2	SC
Kalmia cuneata	Whitewicky kalmia	Cl	NC,SC
Lilaeopsis carolinensis	Carolina lilaeopsis	c2	NC
Lilium grayi	Gray's lily	c2	NC
Lindera melissifolia	Swamp spicebush, Jove's fruit	E	LA,NC,SC
Lindera subcoriacea	Bog spicebush	c2	LA,NC,SC
Lobelia boykinni	Boykin lobelia	c2	NC,SC
Lysimachia asperulifolia	Rough-leaf loosestrife	E	NC,SC
Mimulus ringens	Square-stemmed monkey flower	c2	LA
Muhlenbergia torreyana	Torrey's muhly	Cl	NC
Narthecium americanurn	New Jersey bogasphodel	C2	SC
Oxypolis canbyi	Canby dropwort	E	GA,NC,SC,N
Parnassia caroliniana	Carolina grass-of-parnassus	c2	NC,SC
Physostegia leptophylla	Physostegia	c2	SC
Physostegia longisepala	False dragon-head	c2	LA
Plantago cordata	Heartleaf plantain	c2	GA,KY,NC
Platanthera integrilabia	White fringeless orchid	c2	GA,NC
Quercus oglethorpensis	Oglethorpe oak	c2	GA
Rhexia aristosa	Awn-petaled meadow-beauty	c2	NC,SC
Rhododendron chapmanii	Chapman's rhododendron	E	N
Rhynchospora punctata	Pineland beakrush	c2	GA
Rudbeckia heliopsidis	Sunflower blackeye susan	c2	GA,NC
Sagittaria fasciculata	Bunched arrowhead	E	NC,SC
Sarracenia oreophila	Green pitcher plant	E	NC,N
Saxifraga caroliniana	Carolina saxifrage	c2	NC
Solidago pulchra	Carolina goldenrod	Cl	NC
Solidago verna	Spring-flowering goldenrod	c2	NC,SC
Spiraea virginiana	Virginia spiraea	c2	NC
Sporobolus teretifolius	Wireleaf dropseed	c2	NC,SC
Synandra hispidula	Synandra	c2	KY
Thalictrum cooleyi	Cooley's meadowrue	Cl	NC
Trillium pusillum var pusillum	Carolina least trillium	c2	N C
Trillium pusillum var virginianum	Virginia least trillium	c2	NC,VA
Vaccinium sempervirens		Cl	SC
Xyris drummondii	Drummond yellow-eyed grass	c2	GA,LA
Xyris scabrifolia	Harper yellow-eyed grass	c2	GA

[a] Status Codes: E = Endangered, T = Threatened, PT = Proposed Threatened, Cl = Candidate, Category 1, C2 = Candidate, Category 2, X = Extinct.

[b] GA = Georgia Natural Heritage Inventory, LA = Louisiana Natural Heritage Program, NC = North Carolina Natural Heritage Program, SC = South Carolina Heritage Trust Program, TN = Tennessee Department of Conservation, VA = Virginia Natural Heritage Program, N = Niering (1987).

Table I.-Endangered, threatened, and candidate animal species on southern forested wetlands

Scientific name	Common name	Status[a]	Source[b]
Birds			
Aimophila aestivalis	Bachman's sparrow	c2	NC
Ammodramus maritima mirabilis	Cape sable sparrow	E	N
Ammodramus maritima nigrescens	Dusky seaside sparrow	X	N
Campephilus principalis	Ivory-billed woodpecker	E	AR,KY,LA,MS,TN
Crus canadensis pulla	Mississippi sandhill crane	E	N
Dendrocygna bicolor	Fulvous whistling-duck	c2	AR
Elanoides forficatus	American swallow-tailed kite	c2	GA,LA,TN
Faleo peregrinus	Peregrine falcon	E	KY,N
Haliaeetus leucocephalus	Bald eagle	E	AR,KY,LA,MS,NC,TN,N
Mycteria americana	Wood stork	E	AR,GA,NC,N
Picoides borealis	Red-cockaded woodpecker	E	NC
Plegadis chihi	White-faced ibis	c2	AR
Rosthrhamus sociabilis plumbeus	Florida snail kite	E	N
Vermivora baehmunii	Bachman's warbler	E	AR,KY,LA,MS,TN,N
Mammals			
Canis rufus	Red Wolf	E	AR,N
Condylura cristata	Star-nosed mole	c2	GA
Felis concolor coryi	Florida panther	E	LA,NC,N
Myotis austroriparius	Southeastern bat	c2	AR,NC
Myotis sodalis	Indiana bat	E	MS
Neotoma floridana floridana	Eastern woodrat	c2	NC
Odocoilius virginianus clauvium	Key deer	E	N
Sorex longirostris fisheri	Dismal swamp southeastern shrew	T	NC,N
Sorex palustris	Water shrew	c2	NC
Reptiles and Amphibians			
Alligator mississippiensis	American alligator	E	AR,MS,NC,N
Ambystoma cingulatum	Flatwoods salamander	c2	GA
Clemmys muhlenbergii	Bog turtle	c2	GA,NC,TN
Crocodylus acutus	American crocodile	E	N
Eurycea junaluska	Junaluska salamander	c2	NC
Graptemys barbouri	Barbor's map turtle	c2	GA
Graptemys oculifera	Ringed map turtle	Cl	LA
Hyla andersonii	Pine barrens treefrog	c2	NC
Macroclemys temmineki	Alligator snapping turtle	c2	TN
Nerodia erythrogaster neglecta	Northern copperbelly water snake	c2	TN

[a] Status Codes: E = Endangered, T = Threatened, PT = Proposed Threatened, Cl = Candidate, Category 1, C2 = Candidate, Category 2, X = Extinct.

[b] AR = Arkansas Natural Heritage Commission, GA = Georgia Natural Heritage Inventory, LA = Louisiana Natural Heritage Program, MS = Mississippi Natural Heritage Program, NC = North Carolina Natural Heritage Program, TN = Tennessee Department of Conservation, N = Niering (1987).

Keg Habitat Components in Southern Forested Wetlands

A review of the key habitat components of southern forested wetlands helps define the value of this ecosystem to all wildlife, including endangered species. Brinson and others (1981) note the high productivity and diverse-wildlife habitat values of riparian ecosystems, which include many southern forested wetlands. They identify four primary habitat components:

1. **Predominance of woody plant communities. Trees** provide roosting, foraging, and nesting sites, and a favorable microclimate for many species. Trees also provide detritus which supports food chains, and they shade water courses which moderates water temperature.

2. **Presence of surface water and abundant soil moisture.** Wildlife foods (vegetation, seeds, insects) are generally more abundant on moister sites, and periodic flooding significantly affects use by fish and wildlife by providing a variable wetted edge.

3. **Diversity and interspersion of habitat features.** Close proximity of diverse structural features (live and dead vegetation, water bodies, nonvegetated substrates), results in extensive edge and structurally heterogenous wildlife habitats. Wharton and others (1980) suggest mature trees with abundant holes and cavities may be necessary for the survival of many fauna.
4. **Corridors for dispersal and migration.** Riparian corridors provide protection pathways for wildlife to migrate and move between disjunct habitats.

Kroodsma (1979) notes that southeast bottomland forest ecosystems are inherently stable and postulates that certain avian species, such as Bachman's warbler, Swainson's warbler, and the ivory-billed woodpecker, evolved to exploit that stability and thus were especially succeptible to habitat alteration.

Examples of Threatened and Endangered Species Associated with Southern Forested Wetlands

Several threatened and endangered species are associated with southern forested wetlands. This section identities the basic habitat requirements of selected species to illustrate some of the issues involved in protecting southern forested wetland endangered species and their habitats.

Key Deer

The key deer is a distinct subspecies of the Virginia white-tailed deer (Odocoilius *virginianus*) which occupies several islands in the lower Florida Keys. The deer inhabit a small, insular habitat and have declined rapidly. The population was reduced to 25 individuals in the 1950's because of habitat loss, unregulated hunting and fire suppression. Improved management, including closed hunting seasons and habitat manipulation, had allowed the population of key deer to increase to approximately 250–300 individuals.

The deer depend on a variety of habitats and use hardwoods, mangroves and hammocks for cover and bedding areas. Red and black mangrove are two of the most important food items for the deer. Limited habitat, and problems such as the availability of fresh water, continue to constrain population growth. Additional wells and sewage facilities will continue to strain the water supply available to the deer. The recovery plan for the Key deer states that delisting will more than likely never be possible because of limited habitat and pressure from development (U.S. Fish and Wildlife Service 1985a).

Florida Snail Kite

Another endangered species dependent on wetlands is the Florida snail kite, previously known as the Everglades snail kite. Once abundant throughout the peninsula of Florida, the snail kite is now estimated at approximately 400 individuals (U.S. Fish and Wildlife Service 1986a). The species depends on freshwater wetlands, and its breeding success is correlated closely with water levels.

Kites nest over the water in trees and shrubs. If these sites are not available, they will sometimes nest in cattails (*Typha* sp.). However, nesting is not as successful in cattails because the nests are more subject to damage from wind. As many as 95 percent of nests constructed in cattails may fail.

The decline in kite populations is attributed to drainage of South Florida wetlands for agriculture and residential development. Early kite population estimates are not available but extensive drainage began in the early 1900's and kite populations were estimated as low as 50-100 individual animals in the 1940's.

Remaining kite populations are threatened by the drainage of smaller marshes and the increasing demand on fresh water supplies. Drought has also had a signficant impact on kite populations, and although kites may be adapted to natural drought cycles, human impacts have shortened the wet cycles, and this has in turn exacerbated the effects of periodic drought.

In addition to habitat loss, kites may be threatened by degradation of water quality. Agricultural run-off and municipal drain water contain environmental contaminants that may accumulate in the apple snail (*Pomacea paludosa*), the kite's primary food source, and adversely affect the kites (U.S. Fish and Wildlife Service 1986a).

Wood Stork

The wood stork is another endangered bird dependent on Florida wetlands. This species nests in cypress stands or mangroves and once occurred in all coastal states from Texas to South Carolina. Its range is now largely restricted to Florida, with some rookeries in Georgia and South Carolina (U.S. Fish and Wildlife Service 1986b).

The wood stork is a specialized forager. It captures fish by wading with its beak submerged and open; when the stork "feels" a fish, it snaps its beak shut. Because of this feeding adaptation, the stork population is impacted by any factor that reduces the density of prey fish. Other wading birds, such as herons and egrets, are not as affected by fluctuation in fish densities because they are visual foragers. Fish densities decline as a result of the loss of wetlands and the change in wetland hydroperiods by artificial manipulation of natural water regimes in south Florida (Ogden 1985).

The loss of nesting and foraging habitat has resulted in a shift of nesting locations for the wood stork. From 1900-1973 over 35 percent of the wood stork's foraging habitat in south Florida was destroyed. As a result, larger numbers of wood storks have begun nesting in the northern part of the range and are now using more coastal nesting sites and man-made impoundments. In 1959, 10 percent of the wood storks in North and Central Florida nested in man-made impoundments, as compared to 40 percent in 1984. Similarly, in 1959 there were two pairs of nesting wood storks on coastal habitat, while by 1984 this number had increased to 680 (Ogden 1985).

Florida Panther

The Florida panther inhabits the Big Cypress National Preserve and the Everglades in south Florida. Originally this subspecies inhabited Texas, Arkansas, Louisiana, Mississippi, Alabama, Georgia, South Carolina, Tennessee, and Florida. Now, 30 to 50 individuals remain..

The panther utilizes a variety of habitats in south Florida, most of which are very heavily vegetated. Radio-collared panthers use mixed swamp forests, hardwood hammocks and mixed-pine woodlands during the day, and open wet prairies, freshwater marshes and agricultural land at night (U.S. Fish and Wildlife Service 1987).

Panther populations were decimated by unregulated hunting seasons, bounties, and human intolerance of the animal resulting largely from fear. Subsequently, development encroached on the remaining habitat of the panther. Malnutrition from lack of a sufficient prey base has exacerbated such health problems as anemia, feline panleukopenia and hookworm.

There is some hope of restoring the Florida panther in the northern part of its historic range, and a captive breeding program and preliminary release program are underway. Habitat acquisition programs have been particularly important to the recovery of the panther. If these programs are successful, the panther may no longer be a species dependent on forested wetlands.

Green Pitcher Plant

The green pitcher plant is an endangered carnivorous, perennial plant. This plant extracts needed minerals from insects and small vertebrates and is therefore adapted to living in mineral-poor habitats.

The pitcher plant is at risk because its habitat is naturally limited. The optimum conditions under which it occurs are found only occasionally and at widely scattered sites. Elimination of these sites poses the greatest threat to this species. Other threats to the green pitcher plant include fire suppression-the plant is fire adapted and periodic fire seems to reduce competition. In addition, the plant has been a victim of over collecting by fascinated horticulturists.

Management attempts by the FWS include the negotiation of conservation plans for plant populations that occur on private lands. Federal listing often does not adequately protect plants on private land, so conservation plans provide for the FWS to manage the populations or remove them if destruction of the site occurs. By 1985, ten of these plans had been negotiated and signed for the green pitcher plant (Smith 1985).

Dismal Swamp Southeastern Shrew

The Dismal Swamp southeastern shrew, an example of a species totally dependent on forested wetland habitat, is restricted to the Great Dismal Swamp National Wildlife Refuge in Virginia and adjacent lands. It is threatened by human-induced alterations of the swamp. Originally the Dismal Swamp covered approximately 5000 km^2 (2000 square miles). Over 85 percent of the area has been destroyed and today only 840 km^2 (328 square miles) of the swamp remain (U.S. Fish and Wildlife Service 198513).

Activities such as burning, which maintained various successional stages beneficial to the shrew, were stopped in 1973 when the Great Dismal Swamp National Wildlife Refuge was established. This resulted in the succession of the swamp to more mature forests, where shrew densities are low (U.S. Fish and Wildlife Service 198513).

Flattened Musk Turtle

The rare flattened musk turtle, which inhabits the Black Warrior River system in northern Alabama, provides an example of a species indirectly dependent on benefits from forested wetlands. The turtle depends on good water quality. While most of its habitat requirements are met within pools and vegetated shallows, habitat quality can be degraded by activities in surrounding forested wetlands, such as surface mining, poor forestry practices, road building, and pesticide application (U.S. Fish and Wildlife Service 1985c).

HABITAT PROTECTION UNDER THE ENDANGERED SPECIES ACT

Conservation of adequate habitat is clearly the key to ensuring the ultimate survival and recovery of threatened and endangered species. Yet, as currently implemented, the Endangered Species Act has only limited effectiveness for protecting full, functional ecosystems necessary to preserve the full complement of species that may be threatened with extinction. The Act's implementation is limited by both political and biological considerations.

Political Limitations

The protection of habitat under the Act is directly dependent on the enforcement of the Act's provisions by the agencies charged with implementation of the Act. While the Act requires scientific objectivity, in reality, agency decisions can be significantly influenced by political considerations.

Implementation of the Jeopardy Standard

Protection of habitat for threatened and endangered species under Section 7 of the Act can only be accomplished with accurate biological opinions on the effects of a proposed federal agency action on an endangered species. FWS personnel involved in these consultations are trained professionals using the best available information. Unfortunately, political considerations can enter into the process even before a biological opinion is issued. For example, a recent newspaper article (Day 1988) cited documents showing that a FWS regional director instructed staff not to consider issuing a jeopardy opinion during a formal consulation for the highly controversial Two Forks water project in Colorado.

Section 7 consultations are subject to these political pressures because they frequently place a single species against a development project (Heinrichs 1983). The costs of protecting the endangered species-including research, mitigation, and, sometimes, lost opportunity costs-incur almost entirely to developers who must cancel or modify a project. While, in principle, a biological opinion addresses whether a project will jeopardize the continued existence of a species, the real question FWS biologists face is how much the project should be modified to avoid risk to a species. This results in a balancing process between project development and endangered species protection (Harrington 1981) that, while not authorized under the Act, becomes the focus of political pressure.

One trend in Section 7 consultations has been an increase in consultations that do not result in a formal biological opinion. These informal consultations increased significantly from 1979 to 1986 (Figure 1). While formal consultations remained relatively constant over this time period, informal consultations increased from 1585 to 10,504 annually. Informal consultations are clearly subject to less outside scrutiny, and thus may serve to limit outside influences on FWS personnel. They also remove portions of the decision-making process from public review. The net effect may be that fewer jeopardy opinions are issued, though this is often very difficult to prove. A current example of an informal consultation in southern forested wetlands is the U.S. Forest Service review of the possible effects of their timber harvesting plans for the Delta National Forest in Mississippi on pondberry.

Taking

Regulations to prevent takings of threatened or endangered species are also subject to political pressure. For example, reluctance of shrimp fishermen in the gulf coast states to use “turtle excluder devices” to prevent their accidental taking of endangered and threatened sea turtles led to a specific amendment in the bill to reauthorize the Endangered Species Act that would delay a portion of the regulations. H.R. Rep. No. 195, 100th Cong., 2d Sess. (1987). The debate over these regulations has been a major factor in the delay of the bill reauthorizing the Act in the Senate. While the biological information on this issue is clear (National Marine Fisheries Service 1987) political pressure has resulted in delay in implementing the regulations in all but a few areas.

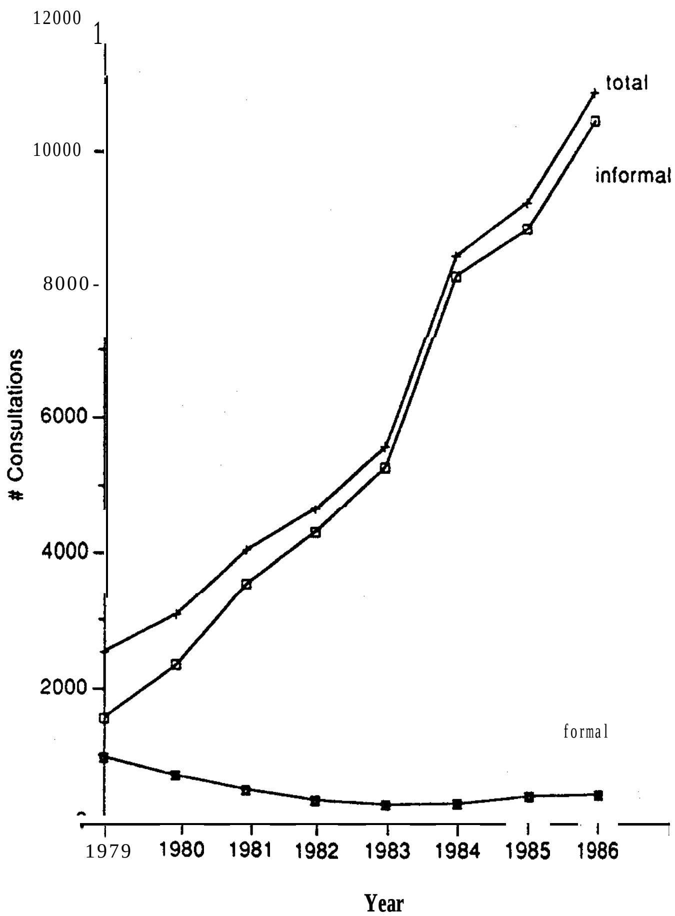

Figure 1.-U.S. Fish and Wildlife Service endangered species consultations under Section 7.

Legal action can also affect the implementation of the takings provision. The court decision on the palila discussed above more clearly defined the power of this provision to protect habitat (Bean 1933). The takings provision can also be used to influence actions of federal agencies outside of the Section 7 jeopardy determination. The FWS did not implement a plan to eliminate the use of steel shot for waterfowl hunting until legal action by the National Wildlife Federation helped create enough political pressure to force them to act in order to comply with the takings provision of the Endangered Species Act. *National Wildlife Federation* v. *Hodel*, 23 Environmental Reporter-cases 1089 (E.D. Cal. 1985). The National Wildlife Federation demonstrated in court that the use of lead shot resulted in the taking of endangered bald eagles that fed on lead-poisoned waterfowl.

Listing

Decisions to place a species on the threatened and endangered species list frequently result in controversy. Individuals likely to be impacted by the listing exercise a variety of political pressures.

Controversy over proposed listing of the flattened musk turtle resulted in Senator Howell Heflin of Alabama blocking reauthorization of the Endangered Species Act in 1986. Hefflin succeeded in persuading FWS Director Frank Dunkle to postpone a final decision on the turtle's listing (Bean 1987). The flattened musk turtle, originally designated a category 1 candidate species on December 30, 1982, was not listed as threatened until June 11, 1987. Fed. Reg. 52(112).

As perhaps the ultimate evidence of political pressure placed on listing, Congress has considered direct legislative override of listing decisions. For example, Representative Wes Watkins of Oklahoma, believing the leopard darter (*Percina pantherina*) was interfering with a proposed water project, attempted to legislatively delist the darter with a floor amendment to the bill reauthorizing the Endangered Species Act. The amendment was defeated.

Biological Limitations

In addition to political constraints on protection of endangered species, limitations in biological knowledge have forced attention on relatively few species. Problems in identifying species and their habitat requirements, and a basic conflict between the species and ecosystem approaches to species protection, severely limit application of the Act. In addition, implementation of the Act suffers from built-in crisis management.

The Species Approach to Endangered Species Protection

The Endangered Species Act requires an individual species approach. While the necessity of maintaining habitat is clearly recognized in the Act, consultation, listing, recovery, and taking provisions all focus on individual species. The merit of concentrating on individual species has been the subject of substantial scientific debate.

Problems with Species Level Management.— Protection of an individual species does not necessarily result in protection of a sensitive ecosystem. Wilcox (1979) noted that American crocodiles preferentially sought out habitat areas disturbed by Florida Power and Light for a cooling canal system. Noss (1988) feels that the narrow and patchy distributions of rare species results in little protection for intact longleaf pine communities.

In addition, two endangered species in the same ecosystem may conflict with each other. Scott and others (1987) report two examples in California where efforts to enhance habitat for one endangered species reduces the value of that habitat for another endangered species. As more species are listed, especially invertebrate species lower on the food chain, the potential for these conflicts increases.

Several authors (for example, Hutto and others 1987; Kroodsma 1979; Noss 1988) call for a more holistic, ecosystem approach. Hutto and others (1987) object to the species approach, questioning the assumption (Graul and others 1976) that protection of indicator species will protect the entire ecosystem. Harris (1984) emphasizes management on the community level, but feels that focusing on the species level, when necessary, is complementary to the community approach.

Noss (1988) proposes "endangered landscape types" instead of species, going beyond even individual ecosystems to preserve landscapes of intact, interacting ecosystems. Graul and Miller (1984) reviewed some potential approaches for ecosystem management, but concluded that, for now, efforts must still be targeted at the species level. They feel a habitat-diversity approach is still premature because of limitations in knowledge of species-habitat and area relationships.

Nevertheless, protecting endangered species on southern forested wetlands may produce especially complex problems with the species level approach. Wharton and others (1980) point out the interdependency of different floodplain habitats. They note the importance of emigration from swamps and bayous, when they have become anoxic, to headwater lakes and lotic habitats. The latter serve as hatcheries, refuges and distributaries. They further identify that waterways may be critical for fauna at certain times of the year, though the fauna may be completely absent during other times.

Identification of Species.-One of the problems in protecting endangered species is the lack of knowledge about species, their population biology and habitat requirements. Many areas have not been surveyed for rare species or communities (Harrington 1981), and, as Wilson (1988:10) states: "The vast majority of species are not monitored at all."

Some studies indicate the potential for undiscovered species in southern forested wetlands, especially among invertebrate communities. Wharton and others (1980), noting that few floodplains have ever been collected for insects, cite a high variability between micro-invertebrates from one river system to the next. In addition, Brinson and others (1981) noted the tremendous variety of herptiles in riverbottom riparian areas.

Emphasis on Selected Species.-The listing process favors highly visible, glamorous species. Less glamorous species, particularly invertebrates, tend to be overlooked during research and listing. An examination of the endangered species list confirms this. Worldwide, only 58 invertebrates were listed as of April, 1987 as compared to 313 listed mammals and a total of 703 listed vertebrates. Since, on a worldwide basis, invertebrate animals likely outnumber vertebrate species by a magnitude of 100 to 1 (Wilson 1988), they are clearly under-represented on the endangered species list. Another example of the bias in the listing process is that while the Act allows protection of geographic ***populations*** of animals, only entire species of plants or invertebrate animals can be protected. This directly affects the listing of several plant species in south Florida that cannot be listed as an endangered population because other members of the species exist in Mexico or the Carribean archipelago.

Wilson (1988) considers the emphasis on individual species a political necessity and cites the advantages of arousing public sympathy over the plight of furry, cuddly, or spectacular animals. However, he emphasizes that the less cuddly, less spectacular organisms are more important to the human future.

Hutto and others (1987) argue that the emphasis on individual species actually scatters public support. They feel the Endangered Species Act is not effective for general conservation because protection is dependent on the presence of specific organisms.

Crisis Management

The Endangered Species Act can be rightfully accused of being a crisis approach to the problem of decreasing species and decreasing biological diversity (Hutto and others 1987). The Act is designed to protect species only when they have reached the crisis level of facing extinction, a point at which it is often too late to save the species (Wilson 1988). Scott and others (1987) refer to this as 'Emergency Room Conservation', and complain that it channels economic support into the species least likely to benefit from it.

CONCLUSION

Despite its limitations, endangered species protection does provide an opportunity for protection of some southern forested wetland ecosystems. However, hundreds of invertebrate species that should be protected by the Act may be going extinct unnoticed as southern forested wetlands are destroyed. While political considerations have, in general, weakened the ability of the Act to protect species and habitats, the simple fact that the Act receives so much political manipulation testifies to the power of the basic provisions of the Act. In addition, the current concentration on individual species and crisis management inherent in the Endangered Species Act, while in some ways a liability, does have the ability to help focus public attention on the plight of southern forested wetlands.

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WATER QUALITY STANDARDS AND MONITORING FOR NPS ACTIVITIES IN WETLANDS

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Abstract.-Water quality standards (WQS), and in particular numeric and narrative criteria, were designed to control particular chemical contaminants in point source discharges. Guidance came from EPA in the form of national criteria recommendations. The water quality impacts from nonpoint source (NPS) activities, including silviculture practices in wetlands, are not adequately addressed by the existing criteria developed by EPA and contained in State water quality standards. Criteria for NPSs need to be developed and will likely be substantially different from chemical criteria. Criteria based on the resident biota (i.e., biocriteria) have been developed by a few States for streams and rivers and show promise for wetlands. These biocriteria must be developed on a regional, rather than national, basis. Therefore the development of meaningful and effective criteria to address NPS activities must involve individuals and groups outside EPA.

EPA's Office of Wetlands Protection

The EPA created the Office of Wetlands Protection (OWP) within the Office of Water to highlight the importance of wetlands and the need to develop programs to control activities that impact wetlands. The Office has doubled in size over the last six months to expand 404 program activities, most notably in advanced identification, and to expand the development of broader programs to better conserve wetland resources. In the near future, EPA will be providing greater support in these areas.

The Office of Wetlands Protection is working on the development of approaches to better conserve wetland resources, in particular activities that build on existing programs within EPA, other Federal Agencies and the States. This paper will focus on a few topics that relate to the development of a water quality-based program for controlling NPS impacts to wetlands. Specifically, they are:

- general theme of OWP
- wetlands protection under the Clean Water Act
- BMPs as technology-based controls
- water quality standards and monitoring

Theme of OWP

The intent of OWP is not to halt development, and in particular forest development practices, in wetland areas. The intent is to encourage the development of programs and projects to protect the existing uses of the Nation's wetlands. Wetlands provide a variety of functions including flood protection, nutrient and other pollutant assimilation, recreation, and fish and wildlife habitat. For example, the protection of certain wetlands for their capacity to assimilate nutrients may be necessary to protect downstream water quality for recreation. If these relationships can be identified, it may be possible to avoid impacts by seeking environmentally preferable and cost-effective alternatives.

In many cases, planned approaches that anticipate problems are considerably less costly than remedial controls designed to fix problems after they have occurred. In some cases, impacts cannot be remediated such that the resource is usable for either development or conservation activities. Therefore, much can be gained on the part of both the development and conservation interests by pursuing a planned approach to development in wetland areas.

Wetlands are Protected by the General Provisions of the Clean Water Act

Congress intended that the Clean Water Act jurisdiction include waters to the broadest extent permissible under the Constitution, and all wetlands with the link to the commerce clause are regulated. Because the commerce clause connection is commonly met (e.g., waters that cross State lines and are used by out-of-State visitors and migratory birds), wetlands are waters of the U.S.

Many State WQS do not specifically recognize wetlands as "water of the State" and many do not classify their wetlands or have criteria specifically developed for wetlands. Part of the problem is clearly the lack of scientific information on the appropriate criteria that define the many functions of wetlands. Much can be done to identify, manage, and protect the remaining wetland resources while the science is being developed. At the rate that wetlands are being lost, no other choices are available. The first step is to get the States to specifically recognize wetlands as waters which are covered by State water laws and to apply existing authorities. The Office of Wetlands Protection and the Office of Water Regulations and Standards will be working together to assist the States in this area.

The 1987 amendments to the CWA include several provisions for addressing NPS pollution. The control of NPS pollution and the protection of wetlands are activities that are closely related. Section 101(a)(7) establishes NPS control as a national policy and Section 319 requires the States to assess and control their NPS problems.

The NPS program at EPA is currently involved in reviewing the Section 319 assessment reports being

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submitted by the States. (Section 319 of the Clean Water Act Amendments of 1987 requires the States to submit reports to EPA for review and approval regarding the extend of their nonpoint source problems and a plan for how they will address these problems.) These reports vary widely in detail and complexity. Regarding NPS impacts to wetlands, a few States have begun to include wetlands as a separate category of state waters impacted by NPS. For example, the State of Idaho has identified 118 impacted wetlands in their draft assessment report. Incidentally, these States are not necessarily the States that have a strong wetlands provision in their water quality standards. They are using their narrative criteria as the basis for including these waters in their assessment reports. General provisions of State standards, including their narrative criteria, are sufficient to carry out various NPS control activities, including those that impact wetlands.

In general, State assessment reports have been limited in scope, including their coverage of NPS impacts to wetlands. It is not clear at this time how EPA is going to address deficiencies in its review and approval/disapproval of the reports.

Water Quality vs Technologg-Based Approaches

The installation of BMPs is not equivalent to attainment of water quality goals. The Agency policy on the control of NPS pollution states that while BMPs may attain water quality standards[2], monitoring is required to ensure that the BMPs have protected existing uses. A decision of the Ninth District Court of Appeals in California, referred to as the "Go-Road" decision, concluded that the installation of BMPs is not equivalent to attainment of water quality standards. While cost-effective BMPs are installed to reduce NPS impacts to wetlands, it must be recognized that the controls are not an end in and of themselves. They are a means of attaining water quality goals. In a practical sense, this means that NPS activities and the effectiveness of BMPs need to be monitored.

A comparison can be made between BMPs for nonpoint sources and effluent guidelines for point sources. Effluent guidelines for point sources were established in the 1972 CWA in order to make progress in controlling pollution in a cost-effective and equitable manner, recognizing that it will take years to understand all the intricacies of the many types of pollution problems. These technology-based controls for point sources also provide information on where additional controls are needed to attain water quality goals, provided monitoring is conducted.

While much of EPA's focus over the last 15 years (since the 1972 Act was passed) has been in the development of effluent guidelines in support of the technology-based approach, it has always been understood that water quality standards are needed to meet the goals of the Act. And in fact, many water quality-based controls for point sources have been implemented during this time.

The 1987 Act signals a focus on NPS, with the development of both technology-based controls (BMPs) and water quality-based controls (water quality criteria). While progress is being made with BMPs, the ultimate goal is to protect and maintain existing water uses, and to begin to develop a water quality-based approach for NPS. It is likely that this will involve basic changes in the chemical-by-chemical approach that has traditionally been the focus of the water quality standards and monitoring programs.

New Focus for Water Quality Standards and Monitoring

Chemical criteria are not adequate to address NPS impact, including those that occur in forested wetland areas. EPA is in the process of developing a research plan to develop criteria that are applicable to wetlands for use by EPA Regions and the States.

While we develop new types of criteria, we need to build on what we already know. Existing chemical-specific criteria may be directly applicable to wetlands. The organisms used to develop many chemical specific criteria are typical of the organisms found in wetlands. Certain of these criteria may require some modifications to reflect the unique characteristics of certain wetlands; for example dissolved oxygen, and criteria that may be affected by low pH such as ammonia.

Wetlands functions may not be maintained strictly by looking at chemical-specific criteria. Criteria do not exist for many of the most prevalent NPS pollutants, most notably sediment and nutrients, and these "pollutants" are difficult to test in the laboratory for the purposes of developing numeric criteria. A wholly different approach may be needed.

Many wetland systems are impacted primarily by nonpoint sources. Biologically-based criteria show promise for assessing NPS impacts and the effectiveness of BMPs. Biological criteria are developed from data collected on the resident aquatic biota; e.g., invertebrates and fish. Various techniques have been established for monitoring the biota of small streams and developing numerical representations of the biotic health; most notably Karr's Index of Biotic Integrity (IBI). Such an approach has received support from EPA and the States recently as a cost-effective way to assess impacts from both point and nonpoint sources, as evidenced by the following contemporary activities.

- "Surface Water Monitoring: A Framework for Change"[3]
- Workshop on Biological Criteria and Monitoring[4]
- 5 States have biological criteria in their standards[5]
- Patuxent Meeting Summary[6]
- CWA, Section 304(a)(8)
- Nez Perce National Forest Monitoring Plan

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[2] Memorandum from the Chief, Nonpoint Sources Branch to the EPA Regions, "Subject: Nonpoint Source Controls and Water Quality Standards", dated August 19, 198'7.

[3] U.S. Environmental Protection Agency, Office of Water, Office of Policy Planning and Evaluation, Washington, D.C., September 1987.

[4] "Report of the National Workshop on Instream Biological Monitoring and Criteria", U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, D.C., held December 2-4. 1987.

[5] Maine, Ohio, Arkansas, Vermont, Florida

[6] Memorandum from the Director, Office of Water Regulations and Standards to the EPA Regions, "Subject: Meeting Summary; Review Committee on Water Quality Standards", dated May 10, 1988.

In addition to the fact that many NPS pollutants are difficult to test in the laboratory, probably the single greatest appeal of biological criteria is that they are cost-effective. Chemical measurements represent conditions that were in existence at the time the samples were taken (i.e., "snap shot") while biological measurements represent water quality conditions over a long period of time and the effects from all pollution sources. Therefore, much more information can be gained from a single biological measurement than with a single chemical measurement. The fact that NPS controls are not implemented on a chemical-by-chemical basis (e.g., permits) also makes this biological approach to NPS control appealing,

The development of criteria applicable to wetlands and their adoption into State water quality standards will take several years. However, in order to develop meaningful and effective guidance, the help of the States and local organizations, such as those in attendance at this conference, is needed. EPA is not going to issue "the answer" on how to monitor and develop criteria for wetlands. We have limited resources like everyone else and will rely on progressive states and organizations to help us develop a national program. More importantly, based on what we have learned from that few States that have developed biologically-based criteria, meaningful and effective criteria and monitoring protocols for wetlands must be developed at a regional or State level. A "grass roots" type of effort will be the most effective for a "grass roots" type of pollution problem.

Summary

- OWP is giving greater emphasis to programs that anticipate, and to the extent possible, prevent impacts to wetlands.

- Most wetlands are "waters of the nation" and subject to the provisions of the CWA. EPA will be pushing the recognition of wetlands as "waters of the State" in its review of State water quality standards.

- **BMPs** are not necessarily equivalent to WQS attainment.

- Traditional WQS and monitoring programs are not specifically designed to address NPS impacts to wetlands. Biologically-based assessment methods show promise. EPA's Office of Research and Development is developing a research plan to develop criteria for wetlands.

- The assistance of organizations at the source of the NPS problem is needed to help EPA develop effective guidance.

A Final Note

The demand for information on the various impacts to wetlands and how to properly monitor them and develop meaningful criteria is not coming just from EPA. There also a demand for this information from the public. The public is becoming more aware of the multiple uses provided by wetlands through various public information vehicles. Therefore, developing programs to ensure the protection of wetlands is now more than ever in the public interest and not just in the interest of EPA.

CHANGES IN FUNCTIONAL VALUES OF A FORESTED WETLAND FOLLOWING TIMBER HARVESTING PRACTICES

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Abstract.-An ecosystem approach was used to assess relative impacts of forest management on some important functions of a forested wetland. On-site ecological responses following timber harvesting with helicopter and rubber-tired skidder systems were compared to a harvested, herbicide-treated area and an undisturbed stand. Results, which showed several response patterns among treatment effects, can be used to shape performance standards for forestry operations.

INTRODUCTION

Impacts of timber harvesting operations on the functions provided by upland forests have been well documented (Bormann and Likens 1979; Vitousek 1983; Vitousek and others 1981). Although several investigators have described timber harvesting impacts on wetland ecosystem functions (Cairns and others 1981; Johnson 1979; Wharton and others 1982), few studies have quantified these impacts. Referring to perturbations in general, Adamus and Stockwell (1983) stated, "At present, there is insufficient information to categorically and universally specify the amount (threshold) of degradation any type of wetland can withstand without its functions being seriously impaired". Threshold establishment is difficult to determine, but relative impact of a variety of harvesting methods may be quantified through experimental procedures.

Uncertainty arises regarding the selection of sufficient parameters which enables relative impact assessment (McIntosh 1980). Ecologists agree, however, that assessment of a site disturbance, such as timber harvest, should focus on ecosystem-, rather than organism- or community-, level changes (O'Neill and others 1977). Suggested indices of relative ecosystem recovery rate are: soil nutrient loss (O'Neill and others 1977), detritus processing rate (Reiners 1983), and plant productivity and biomass accumulation (Bormann and Likens 1979). Therefore, data collection should focus on soil physical and chemical charateristics, vegetation response, and organic matter decomposition, although other types of data may be required to evaluate impacts on ecosystem functions of particular concern.

This paper describes preliminary findings from a study designed to assess relative impacts of two regionally-available timber harvesting methods. The evaluation pertains to on-site impacts and has application for Best Management Practice validation monitoring and preparation of performance standards for site-specific forestry activities (Solomon 1988).

SITE CHARACTERISTICS

A 32-hectare study site was established in southwest Alabama's Mobile River Delta along the Tensaw River (USGS latitude North 30 degrees 57 minutes and longitude West 87 degrees 53 minutes). The site supports a broad-leaved, deciduous, palustrine wetland (Cowardin and others 1979) and lies within Bottomland Hardwood Zone II: nearly permanently inundated and saturated substrate (Larson and others 1981). Hydrology is influenced by diurnal tides and discharges from the 114,400 square kilometer Tombigbee-Alabama Rivers watershed (Riccio and others 1973). The two-aged forest is predominantly water tupelo (*Nyssa aquatica* L.), bald cypress (*Taxodium distichum* (L.) Richard), and Carolina ash (*Fraxinus caroliniana* Mill.) that originated 120 and 70 years ago from float and pull boat logging, respectively. Stand basal area is 74 square meters per hectare and contains 1355 stems/hectare greater than 4 centimeters dbh. Soil is deep, level, poorly-drained clay with 0.7 percent humic matter, 4.7-5.2 pH, 13-17 milliequivalents per 100 cubic centimeters CEC, 71-86 percent base saturation, and 0.3–0.75 grams per cubic centimeter bulk density.

METHODS

A 23-hectare clearcut of a uniform stand was performed in Fall, 1986, adjacent to a similar undisturbed reference stand. Clearcutting resulted in removal or felling of all trees greater than 5 centimeters dbh. Chainsaw felling left 0.3–0.6 meter stump heights.

Within the clearcut, three treatments were imposed, representing currently operational timber harvesting technology and a range of impacts. In the first treatment, a Bell 205 helicopter transported merchantable stems to a cleared landing deck along the Tensaw River. Choke setters chose loads of l-4 stems (2000 kilograms maximum) and attached them to a cable suspended from the helicopter. The second treatment used a Franklin 105 rubber-tired skidder with 86-centimeter-wide tires to simulate impact from an operational timber harvest. The soil was water-saturated when the treatment was imposed, Ruts were commonly 20 centimeters deep and covered 54 percent of plot surfaces. No loads were carried. The third treatment was application of a 1.5 percent glyphosate herbicide (Rodeo™) solution by backpack sprayer and manual cutting of coppice following helicopter harvest. Complete removal of regenerating vegetation was intended. Although forest management

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prescriptions for the Delta do not include herbicides, the treatment provides control over the contribution of vegetation to recovery of ecosystem functions.

Treatments were randomly assigned to square 0.36 hectare plots. Each treatment had nine replications. Blocking attempted to account for variability along environmental gradients parallel and perpendicular to the Tensaw River. Additionally, 9 "dummy" replications were established in the adjacent undisturbed reference stand.

Parameters and methods of data collection were chosen to directly or indirectly quantify ecosystem functional values. Aboveground net primary productivity (NPP) of clearcut plots was sampled with 0.5 square meter clip plots (n=332) and 25 square meter nondestructive coppice regeneration plots (n=288) (Boring and others 1981; Boring and Swank 1984). NPP estimates of reference stands used 0.2 square meter litterfall traps (n=36), 1 square meter slash biomass plots (n = 21), and harvest volume records. Soil cellulose decomposition was estimated by 9-day tensile strength losses of soil burial cloth to a depth of 30 centimeters (n = 1008) (Hill and others 1985). Soil temperature, oxidation-reduction potential, and acidity were measured by a Markson portable Model 95 meter at lo-centimeter intervals to a depth of 50 centimeters (n = 1440). Soil mechanical resistance was measured with a Soil Test™ cone penetrometer (n= 1620) (Bradford 1986). Soil saturated hydraulic conductivity was determined by the auger-hole method (n = 720) (Amoozegar and Warrick 1986). Total nitrogen and phosphorus concentrations in the soil water were obtained from lysimeter water samples (n = 144) analyzed on a Latchett analyzer. Sedimentation rates were determined from vertical accumulations at permanently-placed iron rods (n=324).

RESULTS

Soil Saturated Hydraulic Conductivity

Water flux was greatest in undisturbed forest soil where movement was 13.0 centimeters per hour (Table 1). Saturated hydraulic conductivity was significantly reduced after all clearcut treatments and was least following skidder treatment (2.9 centimeters per hour). All flux rates are high.

Table l.-Saturated hyraulic conductivity across a 50-centimeter-deep soil profile (late July 1987). Values are treatment means (±SE) of nine replications

Treatment	n	Saturated hydraulic conductivity
		Centimeters per hour
Herbicide	180	8.1 (1.4)
Skidder	180	2.9 (0.6)
Helicopter	180	8.0 (1.1)
Undisturbed	180	13.0 (2.1)

Soil Oxidation-reduction Potential

Soil oxidation-reduction potential (reclox) was greatest in the undisturbed reference stand (115 millvolts), although soil was reduced across all treatments (Table 2). Redox values were lowest following skidder treatment (80 millivolts).

Table 2.-Oxidation-reduction potential across a 50-centimeter-deep soil profile (late June 1987). Values are treatment means (± SE) of nine replications

Treatment	n	Redox value
		Millivolts
Herbicide	180	98.4 (5.5)
Skidder	180	80.3 (5.2)
Helicopter	180	106.1 (8.3)
Undisturbed	180	115.4 (5.6)

Soil Acidity

Soil acidity was lowest on plots receiving skidder treatment where average pH value was 5.5 (Table 3). Soil acidity of the reference stand (4.8 pH) was significantly greater than all other treatments. Acidity decreased with increasing soil depth.

Table 3.-Acidity across a 50-centimeter-deep soil profile (late June 1987). Values are treatment means (±SE) of nine replications

Treatment	n	Soil acidity
		pH
Herbicide	180	5.1 (0.1)
Skidder	180	5.5 (0.1)
Helicopter	180	5.1 (0.1)
Undisturbed	180	4.8 (0.1)

Soil Water Chemistry

Soil water total nitrogen concentrations were significantly lower for the skidder treatment (7.4 ppm) when compared with all other treatments (10.6–11.1 ppm) (Table 4). Total phosphorus in soil water ranged from 8.8 to 11.4 ppm among treatments, but only the helicopter treatment was significantly diierent from the reference stand (Table 4). By comparison, concentrations of total nitrogen (1.9 ppm) and total phosphorus (0.1 ppm) in Tensaw River water were much less.

Table I.-Total nitrogen and phosphorus concentrations in soil water. Values are treatment means (±SE) of nine replicatons

Treatment	n	Nutrient concentration	
		TN	TP
		Parts per million	
Herbicide	36	11.1 (2.1)	9.8 (2.6)
Skidder	36	7.4 (1.0)	10.1 (2.1)
Helicopter	36	10.6 (1.4)	11.4 (2.0)
Undisturbed	36	11.0 (1.6)	8.8 (2.0)

Aboveground Plant Biomass Accumulation

Total aboveground net primary productivity (NPP) of the undisturbed reference stand was estimated from peak herbaceous biomass, annual litterfall, merchantable yield, and residual slash as 839 grams of dry matter per square meter per year. NPP after skidder and helicopter treatments was 84 percent ('702 grams per square meter per year) and 54 percent (455 grams per square meter per year) of reference stand NPP, respectively (Table 5). NPP of herbaceous plants was over twice as great on skidder plots as helicopter plots (568 vs. 273 grams per square meter per year), but NPP of woody plants was greater on helicopter plots (134 vs. 182 grams per square meter per year).

Table 5.-Aboveground net primary productivity for the first-year clearcut and reference stand. Values are treatment means (±SE) of nine replications unless noted otherwise

	Net primary productivity		
Undisturbed	Herbaceous	Woods	Total
	Grams per square meter per year		
Herbicide	0	0	0
Skidder	568 (70)[a]	134 (14)	702 (68)
Helicopter	273 (29)"	182 (21)	455 (34)
Undisturbed	7 (1)[b]	832[c]	839

[a] June 26, 1987 peak biomass.
[b] July 12, 1986 peak biomass.
[c] Assume: 45% moisture content of logs, stand age = 70 years, 21276 grams per square meter (dry) merchantable pulpwood and sawtimber yield, 8273 grams per square meter (dry) residual slash, 419 grams per square meter per year (dry) litterfall.

Soil Temperature

Average temperature across 50-centimeter soil profiles showed no difference between plots which received helicopter and skidder logging impacts. Both were 25.4 degrees (Centigrade) (Table 6). Following herbicide application which inhibited vegetative regeneration, soil temperature significantly increased to 26.8 degrees. These values contrasted with the cooler 24.0-degree soil temperature under undisturbed forest. Soil temperature decreased with increasing soil depth for all treatments.

Table 6.-Temperature across a 50-centimeter-deep soil profile (late June 1987). Values are treatment means (±SE) of nine replications

Treatment	n	Soil temperature
		Degrees (Centigrade)
Herbicide	180	26.8 (0.2)
Skidder	180	25.4 (0.2)
Helicopter	180	25.4 (0.1)
Undisturbed	180	24.0 (0.1)

Cellulose Decomposition Rate

Loss in tensile strength of soil burial cloth provides an index of cellulose decomposition and soil biological activity. Significant differences in annual rates of cotton rotting (CRR) were not found between skidder and helicopter treatments (Table 7). Both, however, showed a 31 percent increase over the CRR of the undisturbed reference stand. The greatest CRR was measured where glyphosate herbicide removed nearly all of plant cover. CRR generally decreased with increasing soil depth, except on exposed soil surface where degradation was slower than below.

Table 7.-Annualized cotton rate of rotting across a 30-centimeter-deep soil profile (July 1987). Values are treatment means (±SE) of nine replications

Treatment	n	Annual cotton rate of rotting
Herbicide	252	64.1 (2.1)
Skidder	252	57.0 (1.9)
Helicopter	252	57.0 (1.5)
Undisturbed	252	43.4 (1.2)

Soil Strength

Significant differences in soil mechanical resistance, related to soil bulk density, were not detected among timber harvest treatments (Table 8). Within plot variation was greatest for the skidder treatment. Soil strength was lowest in the undisturbed reference stand, but tensions high enough to inhibit root penetration were not detected on any treatment. Soil strength increased with increasing soil depth.

Table S.-Soil mechanical resistance across a 50-centimeter-deep soil profile. Values are treatment means (±SE) of nine replications.

Treatment	n	Mechanical resistance
		Bars
Herbicide	405	13.6 (0.3)
Skidder	405	14.7 (0.5)
Helicopter	405	14.1 (0.8)
Undisturbed	405	12.9 (0.4)

Sedimentation Rate

Sediment accumulation was greatest on the helicopter treatment (2.2 millimeters) and least on the herbicide treatment (0.7 millimeters) (Table 9). All differences are significant. Sedimentation for the period ranged from 0 to 16 millimeters.

Table 9.-Sedimentation during wet season flooding. Values are treatment means (±SE) of nine replications.

Treatment	n	Sediment accumulation
		Millimeters
Herbicide	81	0.7 (0.3)
Skidder	81	1.2 (0.5)
Helicopter	81	2.2 (0.6)
Undisturbed	81	1.1 (0.1)

DISCUSSION

Several patterns of response were observed among indices of ecosystem functional values. Net production of woody plants and a number of soil physical and chemical indices—saturated hydraulic conductivity (SHC), redox, acidity, and total nitrogen in soil solution-showed a pattern of lowered rates or values for all clearcut treatments with greatest decrease for the skidder treatment (Figure 1).

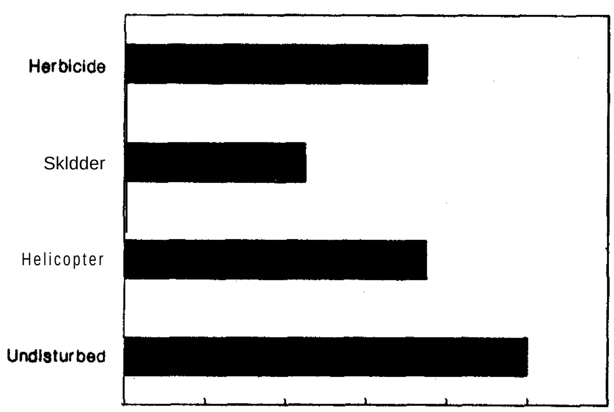

Figure 1.-Generalized response pattern of soil saturated hydraulic conductivity, redox potential, and acidity, total nitrogen in soil solution, woody plant productivity, and the inverse of herbaceous plant productivity.

Redox and acidity were positively correlated and both appeared to respond to SHC. Mature forest cover of the reference stand likely influenced the high SHC recorded there. Rutting caused by skidder treatment probably reduced SHC by severing or blocking soil chambers and channels. Low woody NPP after skidder logging apparently was related to damage of root systems by ruts, as well as the more water-logged soil conditions. Low levels of total nitrogen in soil water following skidder logging are best explained by uptake from the great herbaceous NPP response. Herbaceous NPP follows the inverse of this pattern for skidder, helicopter, and undisturbed treatments. Increased levels of sunlight and soil surface disturbance accelerated herbaceous NPP.

A second pattern held for soil temperature and soil cellulose decomposition rate, such that values or rates increased for clearcut treatments over the reference stand. Revegetating skidder and helicopter plots had soil temperatures and cellulose decomposition rates intermediate between herbicide-sprayed and reference stand levels (Figure 2).

Figure 2.-Generalized response pattern of soil temperature and soil cellulose decomposition rate.

Irradiance and temperature differences among treatments controlled this response pattern. As vegetative cover developed, soil temperatures cooled and soil cellulose decomposition rate slowed.

A third pattern describes soil mechanical resistance and total phosphorus (TP) in soil water where clearcut treatment levels were elevated over the undisturbed reference stand (Figure 3).

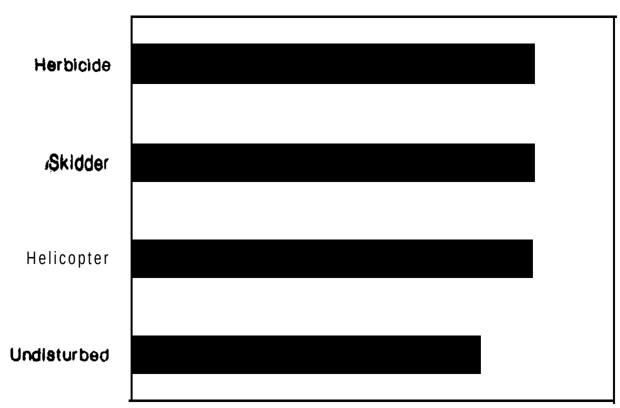

Figure 3.-Generalized response pattern of soil mechanical resistance and total phosphorus in soil water.

Saturated soil conditions when the skidder treatment was imposed reduced soil susceptibility to compaction. Lower soil strength of the undisturbed stand may reflect the absence of timber felling impacts. TP concentrations are related to soil redox value; water-soluble phosphorus increases as redox value decreases. TP concentrations of the herbicide treatment were surprisingly low relative to other treatment levels, since phosphorus leaching is thought to be greatest when plant uptake is low and nutrient mineralization rate is high, as expected after herbicide application.

The fourth pattern of sediment accumulation was unique (Figure 4). Roughness of plot surfaces creates frictional drag on sheet flow of flood waters. Herbicide-sprayed plots had the least vegetation and, therefore, lowest roughness. This may account for the low sedimentation rate there. Slash piles of logging debris were tallest when skidder traffic was absent. High slash piles, combined with presence of herbaceous ground cover, may explain the higher sedimentation rate after helicopter treatment. Sedimentation rate differences between treatments may have been greater had flooding been for a longer duration or associated with higher flow energies.

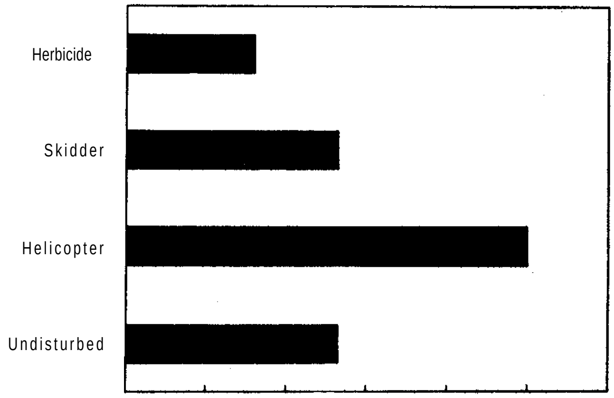

Figure 4.-Response pattern of sediment accumulation.

CONCLUSION

Deltaland ecosystem resilience after clearcutting appears high, indicating functional' recovery following disturbance. Natural revegetation is rapid. As a result of revegetation, 'soil temperatures and organic matter decomposition rates are approaching reference stand levels after only one growing season. Plant productivity following clearcutting with skidder or helicopter harvest treatments is high and should reach the rate of the undisturbed reference stand within a few years. Alterations of soil physical and chemical characteristics were not reflected by changes in total net primary productivity or cellulose decomposition rate. Degradation of soil physical and chemical properties favorable to plant growth due to skidder logging have not been manifest in total net primary productivity. Biological activity shows an integrated response to the numerous abiotic and biotic stimuli in the operational environment. Soil changes should be ameliorated within a few years due to tidal influence, swelling and shrinkage of silicate clays, regaining of subsurface hydraulic flux rates, and sediment accumulation.

The Best Management Practice for minimizing impact on or facilitating ecosystem recovery of a particular function will not likely hold for all wetland processes. Evidence for this is suggested by the four different response patterns. Certain functional values may be enhanced, while others may be degraded. Preliminary findings suggest that both helicopter and skidder logging are acceptable Deltaland timber harvesting practices, although more rigorous statistical tests must be performed before such statements can be made emphatically. Amelioration of their functional impacts is expected to continue over time. Monitoring of recovery indices will be maintained through at least the second growing season to determine if trends continue.

Indicators of wetland functional value chosen for this study yield a detailed picture of important ecosystem-level responses induced by timber harvesting practices, but are not comprehensive. The sufficient set of parameters chosen for future assessments of impacts on wetland functions must be custom-fit to the prioritized wetland values of concern.

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IMPLEMENTING NONPOINT SOURCE CONTROL: SHOULD BMPs EQUAL STANDARDS?

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Abstract.-A nonpoint pollution control strategy is presented that emphasizes the prevention of pollution through the use of Best Management Practices (BMPs). This strategy consists of four distinct steps that comprise an iterative process:
(1) Design/selection of BMPs, (2) Application of practices, (3) Monitoring, and (4) Evaluation. In this strategy, BMPs serve as a landowners performance standard while State water quality standards function as an attainment standard.

INTRODUCTION

The extent and magnitude of nonpoint pollution, from a national perspective, can appear overwhelming. Even limiting consideration to forested lands, over 20.6 million hectares and vast numbers of activities can contribute to nonpoint pollution. Added to technical problems are the institutional considerations that will play a role in the ultimate management of nonpoint sources. All of these obstacles can lead to a feeling that nonpoint pollution is too large to overcome or that strict regulatory programs are required.

Most people knowledgeable in water pollution and water pollution control strategies openly advocate that nonpoint source pollution has to be controlled differently than the successful approach used for point source (Thomas 1985). The reasons for this difference are varied. However, as limited progress is made in controlling nonpoint pollution, many regulators are evaluating water quality based control involving strict compliance with numeric water quality criteria.

Most point source problems are generated from "closed systems" while nonpoint problems emanate from "open systems." Closed systems, which are manipulated at almost any point by man's influence can be regulated with either performance criteria or design criteria (Harrington and others 1985). Because of our ability to understand and precisely control closed systems, point source pollution control has been, technically, a relatively easy problem to solve, although institutional and political problems have caused delays. The manipulation of open systems is far more complex and requires fundamentally different approaches than closed systems.

AN ESTABLISHED NONPOINT STRATEGY

The nonpoint strategy advocated by the U.S. Environmental Protection Agency (EPA) is unchanged since the initial direction issued in 1978 (EPA 1978). This guidance was clarified subsequent to the Water Quality Act of 1987 and reissued in 1987 (EPA 1987). This nonpoint control strategy continues to recognize Best Management Practices (BMPs) as a means to achieve protection of beneficial uses. The BMPs are not the ends in and of themselves as has been argued by some special interest groups. The emphasis of the control program is attainment of State water quality standards. Standards consist of two components and an additional policy: (1) the beneficial uses of water, (2) numeric and narrative criteria, and (3) the antidegradation policy. However, from a practical perspective, the numeric criteria are generally used to determine and substantiate violations of standards.

Further, the EPA strategy states that cost effective and reasonable BMPs should be applied in a manner designed to achieve water quality standards. Once BMPs are applied, the States should evaluate their effectiveness in protecting water quality (i.e., monitor the water quality). If the standards have been violated then the State should take action to: (1) revise the BMPs, (2) revise the water quality standards, or (3) cease the activity. In essence, the EPA is advocating a nonpoint control program that appears, at first glance, reasonable and based on nonpoint control strategies already practiced by many states and Federal agencies. However, a number of questions are left unanswered which need resolution if any understandable, implementable, and equitable nonpoint strategy is to be successful. Such questions as: What is the landowner's obligation to meet State water quality standards, to implementing State mandated BMPs, or both? What might the performance criteria be: compliance with BMPs or meeting water quality standards? Who is responsible for monitoring; the State or the landowner? With specific reference to the U.S. Forest Service and other Federal land management agencies, what levels of involvement and approval does the State have for the design of BMPs, monitoring, and regulating activities on Federal lands?

A PROPOSED STRATEGY FOR FEDERAL LAND MANAGEMENT AGENCIES

The strategy for management of nonpoint sources of pollution is founded in guidance from the EPA (EPA 1987). The EPA guidance recognizes BMPs as the primary mechanism to ensure State water quality standards are achieved. The strategy identifies a process to control nonpoint sources through selection and design of BMPs;

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monitoring to ensure practices are correctly designed, applied, and effective; and adjustment of BMPs when it is found that water quality is not being protected.

The EPA guidance identifies three key items for a successful control strategy: (1) selection and design of BMPs, (2) monitoring of water quality, and (3) feedback of monitoring results. This approach is simply displayed in Figure 1.

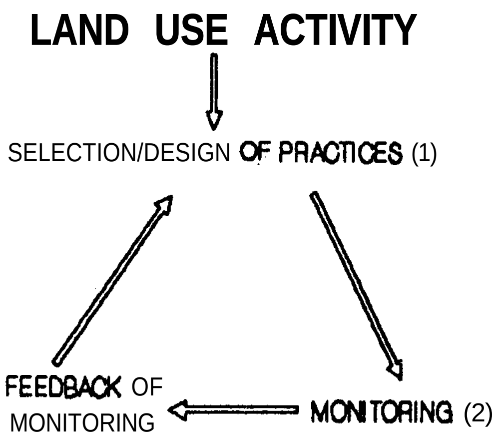

Figure 1.-Basic EPA strategy.

This approach clearly displays that control of nonpoint pollution is an iterative process. Continual refinement of BMP design and water quality standards is necessary. The final objective is the protection of beneficial uses of water.

However, the use of this general iterative approach is not sufficient to ensure protection of water quality. Many Federal land managers have found, through experience, that mere design and planning of practices does not guarantee implementation. All too often, practices called for in a planning document or contract are not carried out on the ground. Therefore, a step has been added between "Design of Practices" (Step 1) and "Monitoring" (Step 2). This added step has been labelled "Application of Practices." This step involves quality controls to ensure that BMPs are applied on the ground.

An additional step is also needed between monitoring and redesign of BMPs. This step us labelled "Evaluation". This last step is implied in the EPA guidance; however, it is not specifically outlined. Few, if any, changes in either BMPs or water quality standards are likely unless monitoring results are properly used as a feedback loop for redesign of future BMPs and mitigation of resultant water quality problems.

We now have a four step strategy: (1) selection and design of BMPs, (2) implementation of nonpoint control measures, (3) monitoring of controls and their effectiveness, and (4) evaluation of monitoring results with necessary adjustments and redesign of future BMPs (see Figure 2). Again this is an iterative process, resulting in ultimate protection of beneficial uses.

REFINEMENT OF STRATEGY FOR LAND MANAGEMENT AGENCIES

The Clean Water Act and the EPA guidance clearly give responsibilities and authorities for nonpoint pollution control to States. However, this strategy is being applied by the Forest Service on National Forest System lands. Obviously, the roles and responsibilities of the State have not been clearly defined as part of the strategy displayed in Figure 2. Refinements in this strategy are needed to more clearly define the roles and responsibilities of States and land management agencies.

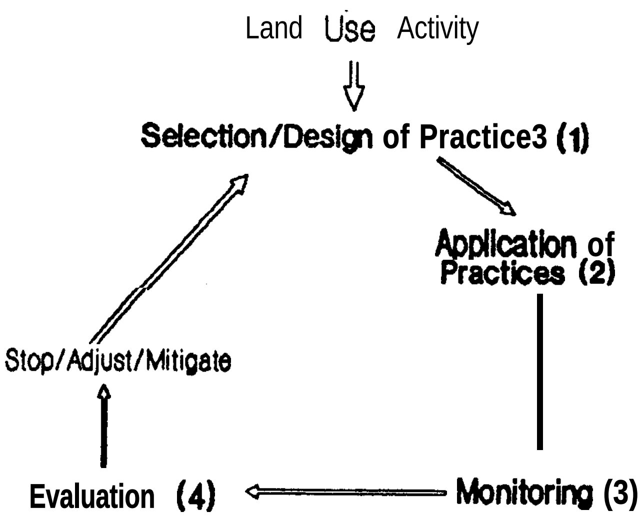

Figure Z.-Modified EPA nonpoint strategy.

State Responsibility

Although States have a clear responsibility for the oversight of BMP selection and design (many States have established BMPs as part of forest practices acts or as separate BMP lists), few States have extended this oversight to the project level. Such an aggressive regulatory position would quickly inundate the States with thousands of project plans and BMP proposals for which they would be incapable of processing. Therefore, the direct involvement of the State in project level design and selection of BMPs is not outlined as a component of the strategy; their role in this step will be more clearly defined later.

The State cannot devote the resources to Step 2 (Application of Practices) for the same reason as in Step 1. The manpower needed to oversee application of selected BMPs could far outstrip the resources available to fulfill such requirements.

The State does, however, have a direct interest in both Monitoring (Step 3) and Evaluation (Step 4). The EPA guidance as well as the Clean Water Act (Sections 208, 305, 319, and 401) clearly give direct responsibilities to the States in these areas. Many Federal and State land management agencies have the capability and desire to monitor, evaluate monitoring results, and make adjustments to BMPs and management. It seems appropriate that the Federal agency designing and implementing BMPs should also be directly involved with monitoring and adjustment where needed.

Additionally, the evaluation of monitoring results may indicate a need for adjustments in water quality standards. Federal Agencies have no authority to adjust water quality standards; this is clearly a responsibility of the State that cannot be delegated to a Federal agency. Therefore, the two steps of Monitoring and Assessment require both the land management agency and the State regulatory agency to take direct actions in gathering information and evaluating that information to make decisions about modification of practices and/or adjustments to water quality standards, State BMPs, or State regulations. This role of the State regulatory agency is shown in Figure 3 by the soild box around steps 3 and 4 to indicate direct State involvement. To formalize the roles of both the land management agency and the State, Memoranda of Understanding (MOUs) need to be agreed to by both parties. These MOUs should establish the responsibilities, authorities, shared resources, and requirements for steps 3 and 4. The EPA encourages such formal agreements in their guidance to the States (EPA 198'7). These setps (Steps 3 and 4) should be developed mutually by both the land management agencies and the State; one party should not abdicate to the other.

State Approval

Federal land management agencies desire to maintain their management flexibility for the lands they administer. These agencies also want to use a strategy for control of nonpoint pollution that satisfies the State. Federal land management agencies can ill afford repeating litigation such as the G-O Road ***(Northwest Indian Cemetery Protective Ass'n*** v. ***Peterson;*** 565 ***F. Supp*** 586) where the agreed upon roles and responsibilities for control of nonpoint pollution were not clearly defined in a legally accepted framework (i.e., stated as part of State water quality regulations or State water quality management plans). The State and the federal agencies must have clearly defined legal requirements prior to initiation of land management activities. Therefore, as part of the proposed strategy, a solid line box around the entire iterative process represents what the State would approve as an acceptable process for compliance with State requirements for protection of water quality (see Figure 3). If the State were to approve this process, it would be delegating responsibilities to the federal land management agencies as a "Designated Management Agency" for protecting water quality associated with lands managed by that agency. Adherence to this strategy would constitute compliance with State regulations. This approval by the State would also be consummated through MOUs between the Federal agencies and the State. Responsibilities, roles, and requirements for all 4 steps would be clearly defined in these MOUs and incorporated into program level plans, such as Forest Plans (36 CFR 219). Such agreements if properly tied to water quality regulations could eliminate the type of litigation where State water quality standards are used as a pre-project regulatory requirement prior to any violation of the standards.

SPECIFIC STEPS TO THE PROPOSED STRATEGY

This strategy has been developed with a focus on Federal land management agencies. However, the individual steps and the overall strategy can be applied to all land owners. The following discussion will elaborate on the individual steps as applied by Federal land management agencies it will also discuss the extent of application to private land where appropriate. A more complete discussion of application to private land, however, is reserved to later sections.

Design of Practices

The selection and design of BMPs, to be used on a particular project, is no trivial task. The Forest Service, as an example, tailors water quality controls to each site and integrates these controls with other uses of the land. This approach evaluates a multitude of "control opportunities" for preventing and mitigating impacts from nonpoint pollution sources (EPA 1980). However, many states now have blanket BMPs that are required as part of any land

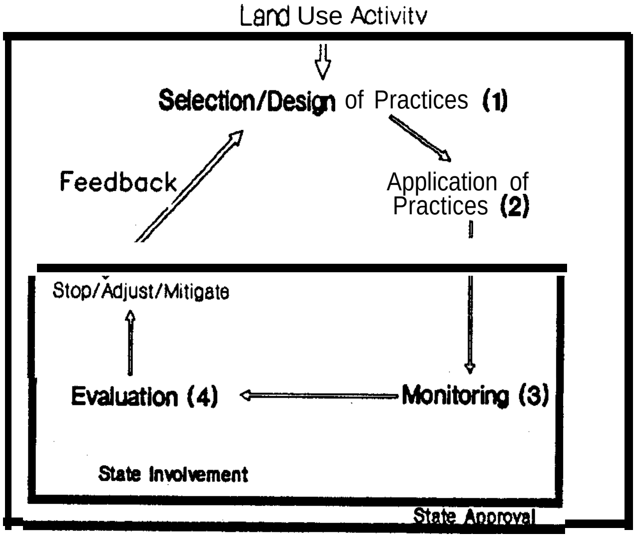

Figure 3.-Proposed nonpoint source pollution management strategy.

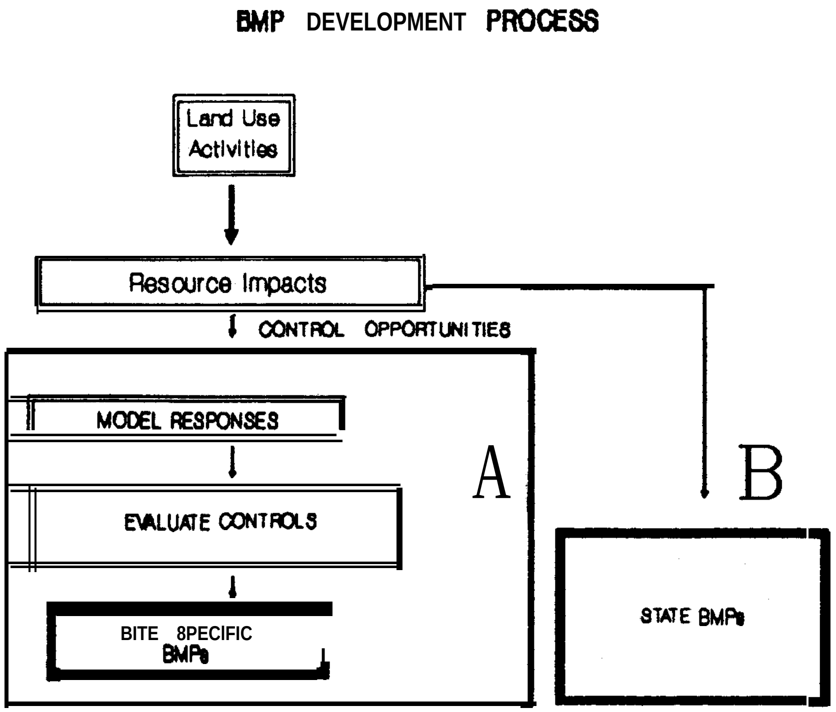

Figure 4.-The BMP development process.

management activity. These States BMPs have been selected using conservative assumptions and average conditions of soil, slope, geology and climate. State BMPs will protect water quality if properly implemented on those sites where conditions are appropriate for the BMP success. However, these State BMPs can be modified to accommodate other resource needs yet still protect water quality. It seems appropriate that BMPs be tailored to the site based on management objectives, physical conditions, feasibility and risk.

However, it cannot be expected that every landowner or operator has the resources to adjust for site specific conditions (i.e., expertise in fisheries, forestry, hydrology, soils, or ecology). The BMP development process, therefore, may involve one of two approaches, depending on the expertise brought to bear on the selection and design of BMPs. The first and simplest is the strict adherence to State prescribed practices (Approach A, Figure 4). These practices are usually simple in design and easy to implement; they require little knowledge of the physical or biological processes affecting water quality. This approach is suited for the landowner or operator that has few resources and skills available for extensive planning.

The second approach is to custom fit the BMPs to the specific site and activity (Approach B, Figure 4). To take advantage of this approach, the landowner must demonstrate, to the State's satisfaction, that the expertise for site specific design is at his/her disposal and will be used. An example might be consultation with the Soil Conservation Service in farm planning, the use of the State Forester, or the use of a State certified forester. The requirements for selecting this flexible approach, however, is up to the State.

In following this second option, the BMPs are selected and modified to fit site specific conditions by first evaluating the water quality objectives and resource impacts that are likely. This involves considering soils, topography, geology, vegetation, and climate and the beneficial uses of water that are to be protected.

These resource impacts can be controlled by evaluating "control opportunities" (i.e., controls that affect excess water, erosion, excess sunlight, etc). Impacts and control opportunities are modeled and alternative mixes of practices are evaluated (EPA, Chapter II 1980). A final collection of practices are then selected that not only control nonpoint pollution but can meet other resource needs. These final selected practices constitute the BMPs.

This second approach must result in water quality protection that equals or exceeds the protection provided by applying State BMPs. The relationship of these approaches is displayed in Figure 4. It must again be emphasized that to use the flexibility of Approach B, the landowner must demonstrate that appropriate professional skills will be applied to ensure water quality protection.

Application of Practices

The step of applying practices is highlighted only to ensure that well thought-out practices get put on the ground. This involves three distinct steps for successful application: (1) documenting the BMPs, (2) scheduling the BMP, and (3) actually applying the practices. Sometimes, the best of plans are poorly documented or the water quality protection practices get buried in the documentation. Therefore, as the first step to ensure application, the BMPs should be documented in writing so there is no confusion by the operator what is expected for water quality protection. Sometimes, BMPs are applied at an inappropriate time. As an example, a skid trail may be water barred after initial harvest, only to have this same water bar obliterated during site preparation or brush disposal. Therefore, documentation should include requirements for when the BMP will be applied. The last component of Application is to ensure the operator or person responsible for applying the BMP actually does it. This could involve a checklist or sign-off sheet that is marked off when the particular practice or requirement is completed.

Monitoring

To secure protection of the beneficial uses of water, four distinct questions need to be answered: (1) Are BMPs implemented as designed? (2) Are practices effective in meeting the desired objectives? (3) Are beneficial uses protected? (4) Is water quality changing over time?

Therefore, a monitoring framework is proposed that separates monitoring into four distinct levels. The four monitoring levels are: (1) "implementation" monitoring, (2) "effectiveness" monitoring, (3) "validation" monitoring, and (4) "trend" monitoring (see Figure 5). Implementation monitoring is the broadest level with extensive coverage of most projects. As one moves from implementation monitoring to effectiveness monitoring and, subsequently, to validation monitoring, the scope is narrowed and fewer projects are monitored (Solomon and Avers 198'7). In general, approaches move from qualitative and simple to complex as the level changes from implementation to validation. Implementation and effectiveness monitoring can be viewed as short-term efforts whereas validation and trend are usually more comprehensive and longer-term.

All four levels of monitoring are necessary to provide decisionmakers with information that can lead to changes in management.

Implementation Monitoring

Implementation monitoring is the most common form of monitoring. It is accomplished as part of regular management procedures on nearly ail projects. The purpose is to document whether project plans and prescribed practices are implemented as designed, and in accordance with requirements, standards, and guidelines. The basic question being addressed is, "Did we do what we said we were going to do?" This will be the dominant monitoring effort. A great amount of information, in various forms, can be generated from a wide variety of projects. Documentation and reporting should be required. Documentation may be brief. Evaluation of results of implementation monitoring will most often provide fine tuning of project plans and practices. Examples of implementation monitoring have been documented by Bauer (1985), Leister (1985), and the Forest Service (1986). These monitoring efforts evaluated whether BMPs were designed and implemented as called for in planning documents or by State requirements.

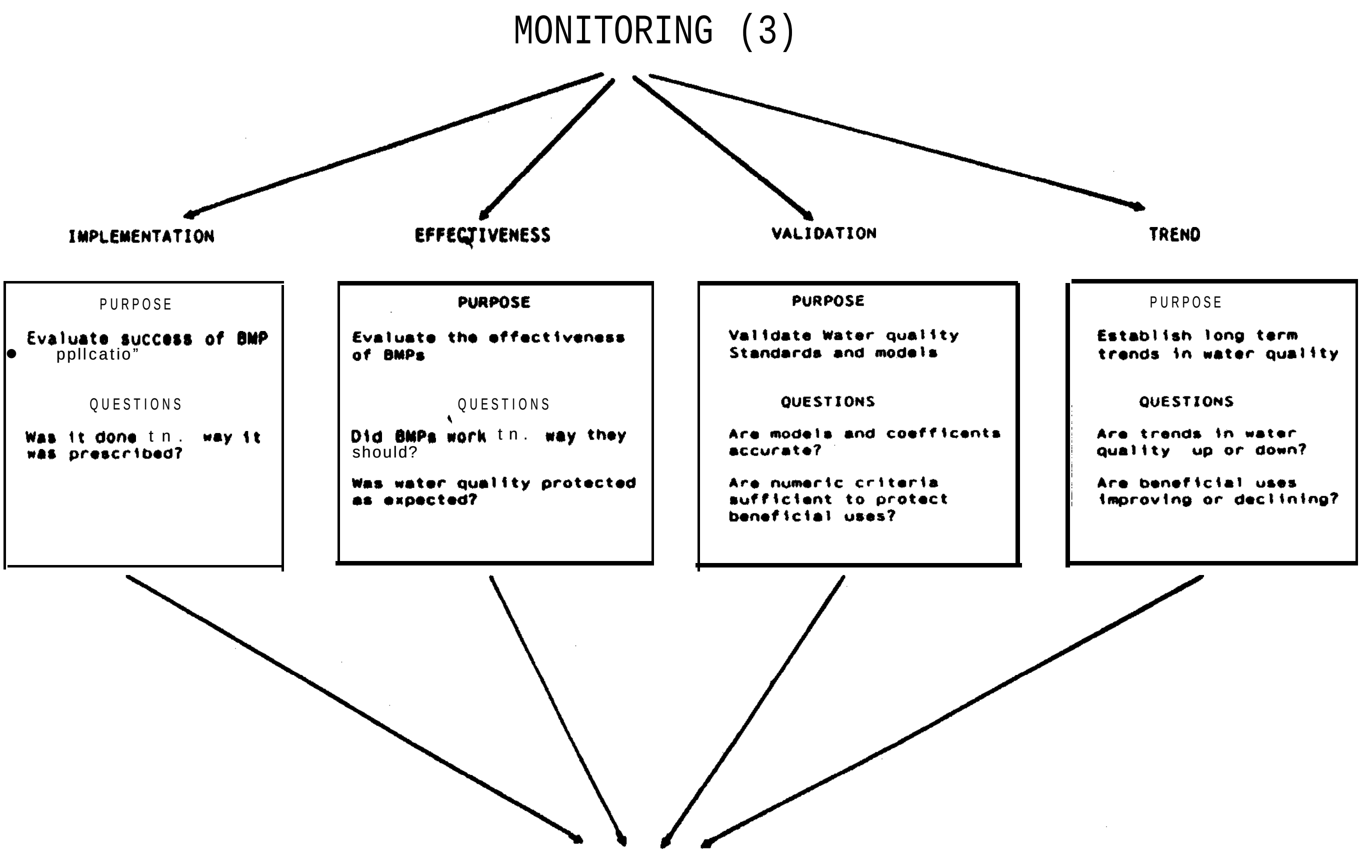

Figure 5.-Monitoring framework for nonpoint source management.

Effectiveness Monitoring

The objective of effectiveness monitoring is to determine if the plans, practices, measures, etc., were effective in controlling pollutants to planned levels and obtaining management objectives. This monitoring will be done mainly where, (1) there are issues or concerns relating to unknown effectiveness of practices and (2) There is a need to demonstrate the effectiveness of BMPs. As a general rule, effectiveness monitoring should focus on the least complicated measurement with observations close to the source of disturbance. The specific yardstick(s) chosen will have to be calibrated and related to the water quality objective. This kind of monitoring may be quantitative or qualitative and of various degrees of detail. Work presented by Swift (1985 and 1986) serves as an example of effectiveness monitoring.

Any effectiveness monitoring that is data intensive may need to be coordinated with adjacent landowners and State water quality management agencies to prevent duplicaton and assure maximum application of results. Appropriate land and resource stratification will permit effective extrapolation of results.

Information gained from effectiveness monitoring will be used to adjust prescription standards and guidelines, BMPs, and management objectives.

Validation Monitoring

The objectives of validation monitoring are to determine if water quality criteria are sufficiently well defined to protect beneficial uses and if model relationships are valid. For example, research could determine the effects of sediment levels on the health and population of a cold water fishery. As appropriate, with new knowledge from research, adjustments may be needed in water quality criteria. If these changes are made, then standards, guidelines, and design of BMPs may also need to be adjusted. Another way to look at validation monitoring is that the objective is to test, (1) whether the criteria limits are sufficient to protect beneficial uses, and (2) if a criterion is an appropriate surrogate to protect the beneficial use. Validation monitoring, more often than not, will be data intensive and/or require long-term investigations to be conclusive.

Work presented by Shepard and others (1984), serves as an example of validation monitoring. In this monitoring effort, bull trout embryo survival and subsequent fry emergence success was correlated with fine sediments in substrate gravels. This study developed prediction relationships of substrate characteristics with effects on one beneficial use of water. A linear relationship was developed that showed a decline in embryo survival with increases of bed material smaller than 6.4mm in diameter. This work could serve as a basis for using substrate characteristics as a water quality objective.

Validation monitoring needs to be closely coordinated with, or in many cases conducted by, researchers resulting in the establishment of permanent plots or administrative studies. This kind of monitoring will be limited, and should be coordinated with the States to have wide application and to prevent duplication, Appropriate land and resource stratification will allow extrapolation of results. Validation monitoring feedback will be used to adjust model coefficients, water quality standards, minimum requirements, goals, and policy. Results may also be used to recommend changes in laws and regulations.

Trend Monitoring

The objective of trend monitoring is to establish long term trends in water quality. Are the trends in water quality and beneficial uses improving or declining?

The effects of BMPs may not be reflected in immediate improvements or deterioration in water quality. Trend monitoring is necessary to gain a snapshot of water quality and beneficial uses at different points in time. Putting these snapshot together gives a picture of general trends in water quality.

States have a primary role in assessing trends in water quality and should take a leadership role in designing networks and sampling requirements for trend monitoring.

Evaluation

Evaluation is the process where by monitoring results are analyzed and reviewed to make recommendations to appropriate decisionmakers.

The evaluation should address the following questions as shown in Figure 5:

1. Are practices applied as called for in plans?
2. Are practices effective in meeting objectives?
3. Are water quality standards being achieved?
4. Are beneficial uses being protected?
5. Is water quality being maintained over time?

The ultimate purpose of all monitoring is feedback into management decisions about future land use activities. This feedback loop is shown in Figure 3. Implementation monitoring will feedback into modification and adjustments to contracts, administrative procedures, performance appraisals, and other incentives to ensure BMPs are implemented as designed. The results of implementation monitoring serve as a check against results of effectiveness monitoring. When inconsistencies in results occur, one of two causes may be at fault: (1) the practices may be ineffective, or (2) the‘practices were not implemented properly. It is this second question that implementation monitoring will answer. Without implementation monitoring to show that practices were carried out as designed, it is impossible to interpret results from effectiveness monitoring.

Effectiveness monitoring serves two functions in the feedback loop: (1) it functions to pinpoint inadequacies in BMP design, and (2) it helps identify water quality standards that pose economic, political, or social hardships and need evaluation through validation monitoring.

Validation and trend monitoring can be done separately from implementation and effectiveness monitoring. Validation and trend monitoring typically involved statistical design, model development and statistical regression analyses. The accuracy of this data is critical, since water quality numeric criteria and prediction model coefficients are derived from such monitoring. Because quality control of this monitoring is imperative, research scientists must play a principal role in the design, implementation, and interpretation of monitoring results.

RELATIONSHIP BETWEEN BMPs AND WATER QUALITY STANDARDS

As stated previously, State water quality standard regulations consist of the identified beneficial uses of water, criteria necessary to protect those uses, and the antidegradation policy. From a common use perspective, however, water quality protection has become synonymous with compliance with numeric criteria. Much emphasis has been placed on controlling nonpoint pollution through the use of BMPs. Many States have also formalized BMPs in State regulations. These regulations have required the use of BMPs for silvicultural activities: examples are the States of Washington and Oregon. At the same time, States require adherence to water quality criteria as part of State water quality regulations.

It would appear that the landowner could be in a double jeopardy situation. First, the land owner must apply certain practices (incurring costs and often reducing returns) required by the State. Once these practices are applied, the landowner is then subject to a second regulatory test—water quality standards.

It seems only reasonable that a land owner should be subjected to one set of regulatory performance standards; either BMPs or water quality standards. If a landowner properly implements State required BMPs, these should be sufficient to protect water quality. If not, the State should prescribe more sufficient BMPs. In such instances, the *performance standards* are applications of such BMPs. BMPs became the measure of accountability.

This does not mean that water standards are abandoned and replaced with BMPs. Water quality criteria become attainment *standards* rather than performance standards. The distinction being that attainment standards are an endeavor or objective to be reached. If BMPs are properly applied and water quality criteria are violated, regulatory action would not initially be brought against the landowner. Rather, the landowner and the State would share responsibility for not attaining the water quality standard. Both parties would enter into negotiation on what was required to protect water quality: the State sharing responsibility with the landowner. Water quality standards serve as the benchmark in evaluating performance as part of the feedback loopstandards would not, however, be used initially in a regulatory sense.

An alternative approach would be to abandon reliance on BMPs and use water quality numeric criteria as the performance standard. Such a policy has been advocated by some within the water quality field (Anderson 1987). Such a policy is, however, naive in recognizing the difficulties in demonstrating violations of numeric criteria for many natural constituents of water unless these violations are significant. In such significant violations, it is usually much easier to document misapplication or absence of BMPs. However, the use of numeric criteria for pollutants not found in natural waters is a reasonable approach in that the expected level of the pollutant is zero. For water quality constituents that are found naturally in water, such as sediment, it is difficult to define the natural levels of concentration. Natural concentrations change both spacially and temporarily, and for many constituents the natural variability is considerable. Substantiating a deviation from the "natural conditions" could involve intensive instream water quality monitoring. Even with such monitoring, deviations would be considerable, before cause-effect relationships could be developed. Substantial changes in water quality standards for nonpoint will be required before this approach is implementable in a regulatory program for many natural constituents of water.

In summary, BMPs and water quality criteria can both be "standards." BMPs are *performance standards* and water quality criteria *are attainment standards.* Performance standards can be used in a regulatory program where attainment standards are used to evaluate needed changes. If persistent exceedance of water quality standards continue, even after adjustments in BMPs and corrective measures, then these standards should serve a regulatory purpose. Such a use of water quality standards should be restricted to proven failure of the BMP approach.

MONITORING RESPONSIBILITIES

Since monitoring plays a prominent role ensuring the success of BMPs in protecting beneficial uses, something needs to be said about who monitors and what is monitored. As discussed previously, monitoring will attempt to answer four distinct questions (see figure 5). A problem remains, who will actually do the monitoring?

Using State BMPs

As discussed previously, a landowner choosing to use State BMPs as shown in Figure 4, has deferred to the State about technical design. We should not expect such a landowner to have the expertise to conduct quantitative water quality monitoring. However, the landowner can be expected to ensure that all the appropriate BMPs have been applied according to design requirements. Such assurance constitute implementation monitoring. Establishing how effective these BMPs are in meeting design objectives may be beyond the landowner's capabilities. The landowner, undoubtedly, will want to know if the applied BMPs were effective. To evaluate effectiveness, the State will have to take the lead and in the cooperative arrangement with the landowner, conduct effectiveness monitoring. The technical design, field procedures, lab analysis, and evaulation should be the responsibility of the State. The landowner may provide access, field support and, in some cases, may even do field sampling for the State. Under such a program, any validation or trend monitoring would clearly be the responsibility of the State. These responsibilities are displayed in Table 1.

Using Site Specific Design Options

A landowner who chooses the option of designing a mix of site specific practices (BMPs) to control nonpoint pollution is provided a great deal of flexibility. This flexibility and authority must be coupled with increased responsibilities. One area of responsibility is monitoring.

The landowner should have all the resources to evaluate effectiveness of the BMPs in meeting management objectives, as well as protecting water quality. Therefore, the landowner has an obligation to not only ensure proper application of BMPs but to monitor effectiveness. If BMPs are not effective in meeting objectives, then through the feedback loop (Figure 3), the BMPs should be modified. The State also has an interest in the effectiveness of new or different practices since these techniques may be more cost effective than State BMPs. Coordination with the State is necessary so that results of monitoring can be used, not only by the landowner but by the State, in modification of State specified BMPs.

Table l.-Monitoring responsibilities

Type of monitoring	Use of State BMPs	Using site specific design
	Responsible Party	
Implementation	Owner	Owner
Effectiveness	State/Owner	Owner (Coor./State)
Validation	State	Owner/State
Trend	State	State

Models of one type or another are generally used to design site specific BMPs. Such models require validation. Validation monitoring also involves evaluation of water quality criteria to ensure these criteria protect the beneficial uses of water. Both the landowner and the State have a vested interest in validation monitoring. To be cost effective in such monitoring, a cooperative venture between the State and landowner would appear most appropriate. This cooperation might involve the State in monitoring design, lab analyses, and interpretation of results. The landowner might appropriately be involved with monitoring design, collection of data, and interpretation of results.

SUMMARY

A nonpoint management strategy has been presented that builds upon the direction established by the EPA (EPA 1987). This strategy uses an iterative process of (1) design and selection of BMPs, (2) application of practices, (3) monitoring to ensure practices are properly applied and effective, and (4) evaluation of monitoring results to feedback for adjustment of practices and/or water quality criteria and objectives. This strategy emphasizes the prevention of pollution through the use of preventive BMPs rather than strict compliance with water quality standards. BMPs can be used as a landowners performance requirement while water quality standards are used as attainment objectives. Both BMPs and State water quality criteria serve as “standards”.

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THE EFFECTIVENESS OF SILVICULTURAL NONPOINT SOURCE CONTROL PROGRAMS FOR SEVERAL SOUTHERN STATES

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Abstract.-Concerns about the impact of nonpoint source activities (including forest management operations) on water quality led to the development of state nonpoint source control programs. Most Southern states have adopted nonpoint source control programs for forest operations baaed on state approved Best Management Practices (BMPs). Based on ongoing program assessments, those states which have promoted their nonpoint source control programs have been successful in protecting water quality. Of the program assessment methods utilized, qualitative surveys of BMP use and effectiveness and focused watershed studies have proven most useful. The success of BMP-based nonpoint source control programs provides an example for future wetlands management control programs.

INTRODUCTION

In 1980 Boschung and O'Neil presented the results of a study in Alabama on the effects of clearcutting on macroinvertebrates and fish. They found that ". . . forest clearcutting did not significantly affect . . . fish and macroinvertebrates . . ." Based on the results of this study and a review of literature they concluded that ". . . if the clearcut is properly conducted, the adverse effects on forest streams and their fauna can be minimized or practically eliminated." This demonstrates one of the important concepts behind Best Management Practices. There are reasonable (proper) management controls which can be used to minimize adverse effects on forest streams and their fauna.

This same concept holds for forest wetlands. Wetland functions can be protected if management utilizes those practices which have been demonstrated to minimize impacts.

This paper will discuss the effectiveness of Best Management Practices and nonpoint source (NPS) control programs for several Southern states. The paper will first describe a Best Management Practice (BMP). The special role of BMPs for forest operations will then be discussed. BMPs are important tools for implementing water quality protection under Sections 208, 319, and 404 of the Clean Water Act. Some examples which demonstrate the effectiveness of individual BMPs will be presented. Finally, the effectiveness of state nonpoint source control programs and methods of assessing program effectiveness will be discussed. The use of BMPs in NPS control programs provides an example for future wetlands management control programs.

WHAT IS A BEST MANAGEMENT PRACTICE?

Forest management activities and their effects on stream and water quality are referred to in regulatory jargon as nonpoint source activities. Nonpoint sources of pollution are distinguished from point sources because they are: (a) not traceable to any discreet facility, (b) are induced by natural processes including precipitation, and (c) are best controlled using Best Management Practices. A Best Management Practice (BMP) is a practical and effective practice which can reduce the amount of pollution generated to a level compatible with water quality goals. A more complete definition is provided later. An example of a BMP is "do not operate or skid in the stream channel."

Most Southern states have had BMP guidelines for forest operations for nearly a decade. Figure la shows state nonpoint source control programs in the South. Louisiana has just recently adopted BMP guidelines. However, even though most Southern states have BMP guidelines and most of us have become familiar with BMPs, we tend to forget just how recently BMPs were accepted as a water quality management tool. It was 1975 before EPA created the concept BMPs as part of regulations to implement Section 208 of the Federal Water Pollution Control Act Amendments.

The Federal Water Pollution Control Act And Development Of BMPs

Section 208 and BMPs

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) began the process which has led to development of the BMP concept as we know it today. Under the provisions of Section 208 of that Act, states were required to develop area-wide water quality management plans. One step in developing these plans was to ". . . identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution . . ." and the development of ". . . procedures and methods (including land use requirements) to control to the extent feasible such sources" (Senate Committee on Environment and Public Works 1978). Originally, this area-wide planning was focused largely on urban areas designated to have water quality problems. Area-wide management was designed to coordinate construction of suitable point source treatment facilities. This approach was successfully challenged in court by the National Resource Defense Council (NRDC vs Train).

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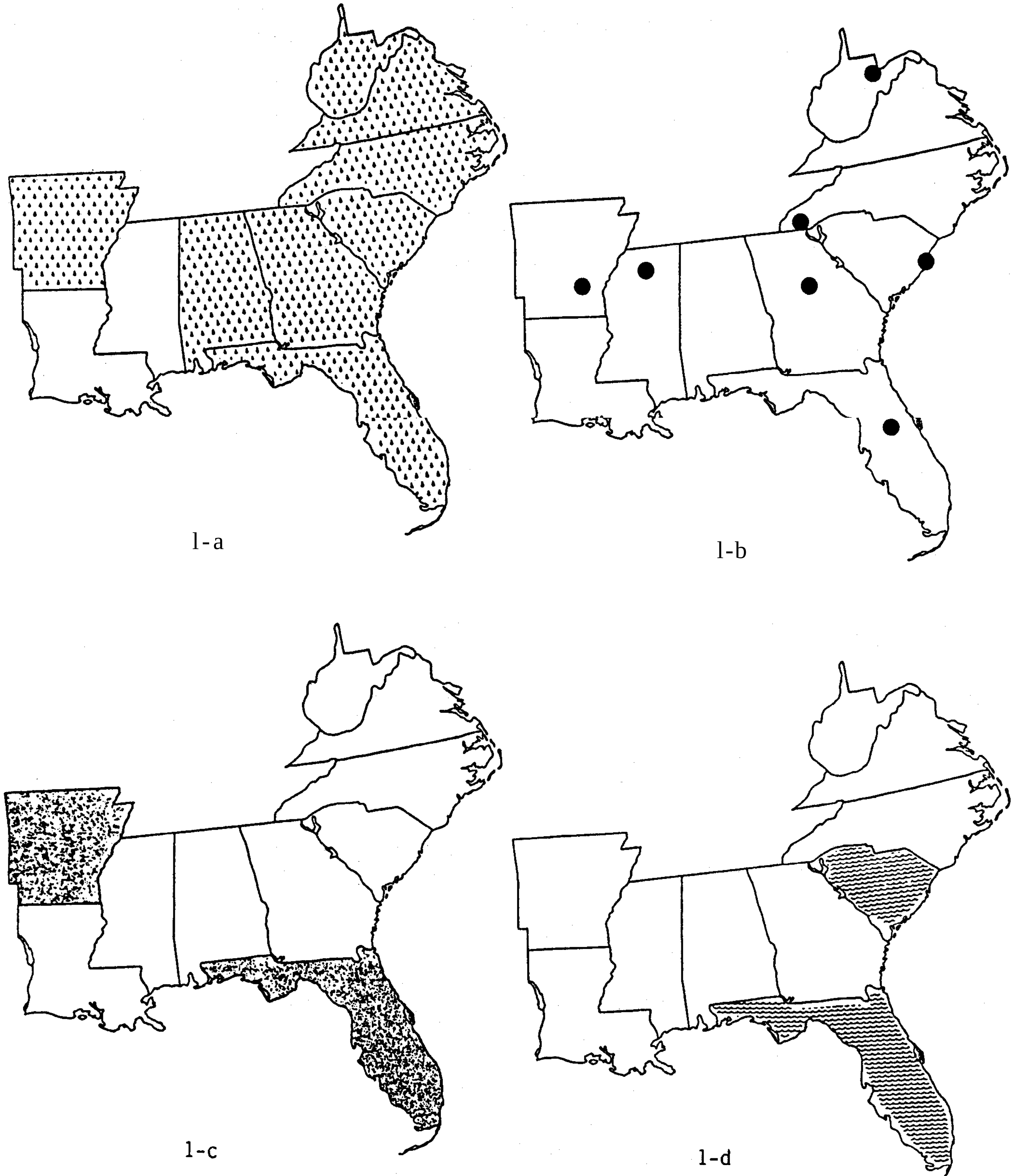

Figure 1.—Southern states with: (a) approved silvicultural nonpoint source control programs; (b) forest water quality research programs; (c) continuing assessments of nonpoint source control program effectiveness; and (d) special BMPs for wetlands.

As a result, all state lands (not just designated areas) were subject to planning under section 208. In 1975, as required by this court case, EPA developed revised regulation to implement Section 208. Rey (1980) found that:

> "the salient feature of the new regulations was the creation of the concept of "best management practices" (BMPs) as an appropriate tool for nonpoint source control. EPA defined BMPs as "a practice, or combination of practices, that are determined by a state, or designated area-wide planning agency, after problem assessment, examination of alternative practices, and appropriate public participation, to be the most effective, practicable (including technological, economic and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals."

Another important development was the issuance by EPA of the SAM-31 guidelines which determined that voluntary nonpoint source control programs were acceptable if they were adequate to achieve water quality goals (EPA Water Planning Division 1977).

Section 404 and BMP's

Another significant portion of PL 92-500 for forest management was Section 404 which concerned dredge and fill activities. Originally, the Corp of Engineers, which has primary responsibility for regulation of dredge and fill activities, narrowly defined the Waters of the United States. This limited the scope of activities which were subject to regulation to those traditional dredge and fill activities associated with maintaining navigable waterways. However, a law suit (NRDC vs Callaway) successfully extended this authority to wetlands and ephemeral streams (Haines and other 1988). This expanded jurisdiction might have severely impaired forest management, but in the 1977 Clean Water Act (PL 95217) Congress provided an exemption for normal forestry including harvesting, minor drainage, and road construction. The need to use BMPs in forest road construction for operations otherwise subject to Section 404 permits was specifically noted in PL 95-217. Thus, BMPs were considered once again to be an appropriate method of controlling impacts to water resources.

Section 319 and BMPs

Amendments in 1987 (PL 100-4) added Section 319 to the Federal Water Pollution Control Act. Section 319 shows the complete change in attitude about nonpoint sources from the first efforts of area-wide water quality management under Section 208. While Section 208 planning, at first, largely avoided area-wide planning for nonpoint sources, Section 319 requires that states determine those navigable waters ". . . which, without additional action to control nonpoint sources of pollution, cannot reasonably be expected to attain or maintain applicable water quality standards or the goals and requirements of [the FWPCA]." States must determine the nonpoint source categories (i.e., silviculture, agriculture, construction etc.) causing state waters to not meet water quality goals and then develop a management plan to control those categories. It appears that many states with effective silvicultural nonpoint source control programs developed under Section 208 will utilize and revitalize those programs to comply with Section 319 requirements.

BMPs, Forest Management and Water Quality

Best Management Practices offer several advantages for controlling water quality impacts from nonpoint source activities. BMPs utilize practical and reasonable methods for achieving water quality goals. BMPs address the causes of water quality impacts before they occur. Retroactive correction of silvicultural nonpoint source problems is almost always more costly and less effective than prevention. BMP compliance can be monitored more easily and at less cost than can water quality or other stream parameters.

At least one state has attempted to not hold landowners in double jeopardy for water quality standards and BMPs. In Washington, compliance with state forest practice rules is considered compliance with state water quality standards. A recent national EPA guidance for nonpoint source control programs states that ". . . once BMPs have been approved by the state, the BMPs become the primary mechanism for meeting water quality standards" (Jensen 1987). This guidance document goes on to find that "proper installation, operation, and maintenance of state approved BMPs are presumed to meet a landowner's or manager's obligation for compliance with applicable water quality standards".

Through an interactive process, BMPs have achieved acceptance as an effective and important tool in protecting waters associated with nonpoint source activities. The new EPA guidance documents provide an added incentive for states to develop approved BMPs and for forest operators to apply those BMPs.

EFFECTIVENESS OF BMPS

The forestry profession has always had a "show me" attitude which demands that carefully conducted research back up assessments about management options. This has resulted in much research about specific management practices and their effectiveness in controlling water quality impacts. State BMPs were not created in a vacuum. It is the programs shown in figure lb which have provided information on harvesting, mechanical. and chemical site preparation, prescribed fire, drainage, road construction and the impact of these practices on discharge, water quality and in some cases stream biology (Ice 1982). Several projects have been carried out by the USDA Forest Service at Coweeta, NC; Parsons, WV; and the Santee Watershed, SC. The University of Arkansas at Monticello, Texas A & M University, States of Arkansas and Oklahoma, and Weyerhaeuser Co. have demonstrated the relative water quality impacts of different management options for forest roads and harvesting in Texas, Arkansas and Oklahoma. Clemson University has had a long-standing research project at the Bella Baruch Forest Science Institute in South Carolina which has shown how drainage operations affect water quality. The University of Georgia has conducted assessments of different silvicultural practices for the Piedmont. The IMPACT project provided baseline information on the relative impacts of forest operations in the Florida flatwoods (Riekerk 1983).

Wetland BMPs

An example of the practical outcome of these types of research efforts is the recent "Best Management Practices for South Carolina's Forest Wetlands." (South Carolina Forestry Commission 1988). Some examples of BMPs provided in this document include: (a) the use of broad-based road dips for sites with noticeable topography changes, (b) the use of site preparation techniques that do not significantly disturb surface soil in secondary SMZs, and (c) felling controls to avoid stream courses or removal of entire trees from streams as soon as practical.

Roads

The use of broad-based dips to provide adequate drainage from forest roads has been investigated for a number of years. Research at Parson, WV and Coweeta, NC demonstrated that even 'minimum-standard' roads can have substantially improved erosion performance with proper spacing and location of dips and with appropriate road surfacing (rock or grass) (Kochenderfer and others 1984; swift 1985).

Site Preparation

For site preparation, intensity of disturbance, proximity of disturbance to the receiving water and use of erosion controls are some of the factors influencing water quality impacts. In one study, Beasley and Granillo (1985) found that chemical site preparation caused no significant change in sediment loss from a harvested site while mechanical site preparation increased sediment loss. Sediment losses were low even for the mechanically site prepared watersheds (less than one-half ton/acre) and within 3 years sediment losses were not significantly different than the control watersheds. Similarly, Chang and others (1982) measured short-term sediment losses 20 times greater for clearcut and site-prepared plots where soil was severely disturbed (about 1.4 tons/acre) as compared to a clearcut plot without site preparation (about 0.06 tons/acre).

Felling Controls

Directional felling is a practical approach to avoid loading streams with fresh organic material. Fresh slash can leach and cause high biochemical oxygen demand (BOD) and low dissolved oxygen or the slash can create flow problems (Hall and others 1987). Management of organic debris in streams is a complex subject. While there are concerns about immediate water quality impacts from too much fresh organic debris in streams, there are similar concerns about the need for long-term inputs of organic material from the land to the stream. Large woody material provides stream stability, structure and fish habitat. Fine organics can provide important food sources for aquatic stream systems. How much wood and fine organic material is appropriate for stream or wetland systems is not well defined. Some states outside the South now require that minimum basal area and number of trees be left to recruit wood debris for streams (Ice and others 1988).

Although considerable refinement is needed, and we obviously need to study wetlands more, the BMPs used in nonpoint source control programs and now being developed for wetland protection programs are based on a strong foundation of forest water quality research.

ASSESSING PROGRAM EFFECTIVENESS

Monitoring of program effectiveness has been a key element of nonpoint source control programs since their early development. Monitoring and program evaluation allows management agencies to assess the effectiveness of BMPs and their implementation and to make necessary adjustments to the program. However, state agencies have struggled to identify appropriate methods to assess program effectiveness. States have employed several different methods to assess the effectiveness of their silvicultural nonpoint source control programs. Indirect methods have involved modeling, measures of resources allocated, attitude and awareness surveys, and records of public complaints. Direct techniques can be categorized into three types: (a) broad-scale water quality monitoring to assess changes related to forest management; (b) focused watershed studies to evaluate the effectiveness of state BMPs; and (c) qualitative surveys to determine whether BMPs are being implemented and whether they are effective.

Assessing Nonpoint Source Impacts in Georgia

An example of an attempt to use broad-scale water quality monitoring is an assessment of nonpoint source impacts in Georgia. In 1981 the Georgia Environmental Protection Division conducted a three-year monitoring study of several nonpoint source activities including commercial forest operations. Clusters of streams located in major physiographic regions were identified for monitoring. For each stream, data were collected on the basin characteristics and land-use activities, stream biology and water quality. Stream reaches were mapped for stream morphology, habitat distribution, and aquatic and riparian vegetation. Water quality samples were collected on a semi-monthly basis and macroinvertebrate samples were collected quarterly. The infrequently collected water quality samples proved to be ineffective in indicating impacts to the forest streams. Sediment loads for these systems are too dependent on discharge and others factors. Sedimentation of stream channels, which modified habitat and filled in stream pools, was the most important impact associated with forest management. These stream habitat modifications were confirmed by changes in periphyton, macroinvertebrate and fish populations. Stream recovery was rapid compared to other nonpoint source activities and it was judged that even these impacts could have been avoided if state BMPs had been used (Georgia Environmental Protection Division 1985). Water quality did not adequately reflect response because it did not account for natural variability.

Assessing the Effectiveness of Silvicultural BMPs in Kentucky

An example of a focused watershed study is found in Kentucky. The University of Kentucky contracted with the State of Kentucky to conduct two studies in controlled watersheds. The primary objective of these studies is to determine the impact of harvesting on water quality with and without BMPs. At each site one watershed serves as a control, a second watershed was logged using "logger choice", and a third watershed was logged using state BMPs. Watersheds were instrumented for automatic sampling and were calibrated for hydrologic and water quality response using paired-watershed methods. Preliminary results show that sediment discharge is increased by both harvesting practices but that the increases are small (compared to other land-use activities) and the State BMPs reduce water quality impacts (Coltharp 1984).

Carefully conducted, controlled watershed studies provide a valuable test of state BMPs. These types of projects are needed for other sites and conditions but they can't be applied universally to all forest operations. For Caspar Creek, a small research watershed in California, it costs $30,000 per year to sample discharge and suspended sediment at each stream monitoring station. It could easily cost $100,000 to install and monitor for discharge and sediment for one management operation (upstream - downstream). In Oregon there are 10,000 notifications of silvicultural operations each year. If just one percent were monitored it would still cost $10,000,000. Another example is the Bull Run watershed which supplies water for the city of Portland, OR. Federal Law (PL 95-200) requires the Forest Service to achieve water quality standards specifically developed for this basin. Cost for monitoring in this single drainage is estimated to be $500,000 per year.

Assessing Program Effectiveness in Florida

Figure lc shows the two states with compliance and BMP effectiveness surveys ongoing in the South.

In Florida, forest operations near streams or lakes are randomly sampled for BMP utilization and water quality protection. On-the-ground inspections are carried out to determine compliance with state BMPs. The field assessment involves an 85 point questionnaire which covers roads, streamside management zones and site preparation. An overall pass/fail rating is given to the site. Statewide the compliance rate for forestry BMPs has ranged from 84 to 91 percent. These surveys have helped to identify persistent problems and target control activities. The 1987 survey identified specific management practices related to roads that needed additional protection (Conner and others 1988). Assessment in other states have found that when guidelines are complied with most water quality problems are avoided (Sachet and others 1980).

Assessing Program Effectiveness in Arkansas

The Arkansas Forestry Commission has combined direct surveys with an erosion model. At each site a trained field forester makes a visual rating of stream crossings, Stream Management Zones (SMZs), the road system and harvested area. Information is collected about visual signs of erosion and their location, the implementation of BMPs, skidding in the SMZ, and other indicators of water quality impact or stream protection. The forester also selects representative sites within units for analysis according to the Modified Universal Soil Loss Equation. This provides quantitative estimates of performance over time. BMP compliance levels are determined and a direct assessment is made of whether BMPs are working (Arkansas Forestry Commission 1985).

EFFECTIVENESS OF SOUTHERN SILVICULTURAL NONPOINT SOURCE CONTROL PROGRAMS

The relative success of voluntary nonpoint source control programs, such as those employed by most Southern states, has surprised a number of observers. The voluntary approach was generally favored by the forestry community in the South because it avoided regulatory requirements and could be incorporated as part of an existing extension effort of state forestry agencies. It is remarkable to see a compliance rating of 90 percent and greater in Florida for a voluntary program when California, with an extensive regulatory program, has found best practices applied in less than 60 percent of operations surveyed (California Water Resources Control Board 1987).

SUMMARY AND CONCLUSIONS

BMPs developed as a response to concerns about nonpoint source control techniques, largely spawned by the evolution of the Federal Water Pollution Control Act and its various amendments. Although perhaps cautiously adopted at first, BMPs have now been accepted as an effective method of controlling nonpoint source impacts. States have effectively utilized BMPs in the development of nonpoint source control programs. Various methods have been utilized in order to assess the effectiveness of these programs, Special watershed studies which compare "logger choice" with "BMP controlled" operations and qualitative surveys such as those utilized by Florida and Arkansas, have proven to be the most useful and practical. Those Southern states which have adopted and promoted their silvicultural nonpoint source control programs have been remarkably successful in protecting water quality.

The BMP approach, which has proven so effective for upland sites, holds promise for application to wetland sites. Two states, South Carolina and Florida, (figure 1d) have developed guidelines for wetland forest operations using BMPs. However, we also need to recognize special wetlands considerations as we attempt to develop BMP-based wetland protection programs. Limited research-has been conducted in wetlands for both on-site and off-site impacts. Hydrologic and water quality monitoring programs will be difficult to conduct. Processes can differ between well-drained upland sites with relief and flat wetlands site. These differences may require adjustments in traditional BMPs. In considering effects of forest management activities on wetland functions the following could be important: (a) limited opportunities for sediment transport off-site; (b) management impact on site productivity; (c) leaching of organics; and (d) changes in runoff patterns (including freshwater intrusion into estuaries). Just like BMPs for well drained sites, BMPs for wetlands need to be flexible to account for the specific wetland types and conditions encountered.

BMPs provide an opportunity to maintain wetland functions while still managing and harvesting forest products. The use of BMPs in nonpoint source control programs for forest operations provides an example of the types of opportunities available for managing wetlands impacts.

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