Forested Wetlands of the Southeast: Review of Major Characteristics and Role in Maintaining Water Quality

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE / *RESOURCE PUBLICATION* 163

RESOURCE PUBLICATIONS

This publication of the Fish and Wildlife Service is one of a series of semitechnical or instructional materials dealing with investigations related to wildlife and fish. Each is published as a separate paper. The Service distributes a limited number of these reports for the use of Federal and State agencies and cooperators. A list of recent issues appears on inside back cover.

Copies of this publication may be obtained from the Publications Unit, U.S. Fish and Wildlife Service, Matomic Building, Room 148, Washington, D.C. 20240, or may be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

Library of Congress Cataloging-in-Publication Data

Winger, Parley V.
Forested wetlands of the southeast.

(Resource publication ; 163)
Bibliography: p.
Supt. of Docs. no.: I 49.66:163
1. Water, Underground—Southern States—Quality. 2. Wetland ecology—Environmental aspects—Southern States. 3. Forest ecology—Environmental aspects—Southern States. I. Title. II. Series: Resource publication (U.S. Fish and Wildlife Service) ; 163. S914.A3 no. 163
[TD223.5] 333.95'4'0973 s 86-600256 [574.5'26325]

Forested Wetlands of the Southeast: Review of Major Characteristics and Role in Maintaining Water Quality

By Parley V. Winger

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Resource Publication 163
Washington, D.C. • 1986

Contents

Forested Wetlands of the Southeast: Review of Major Characteristics and Role in Maintaining Water Quality

by

Parley V. Winger

U.S. Fish and Wildlife Service
Columbia National Fisheries Research Laboratory
Athens Field Research Station
School of Forest Resources
University of Georgia
Athens, Georgia 30602

Abstract

Forested wetlands occupying floodplains of major rivers in the Southeast are highly productive and diverse ecological systems. The wetlands are produced and maintained by fluvial processes and unique hydrologic regimes consisting of periodic flooding and subsequent drydown. Fluctuations in soil chemistry and biology resulting from this flooding and drydown provide a broad range of environmental conditions that are important in determining the role of forested wetlands in maintaining and improving water quality. The periodic shift between aerobic and anaerobic conditions in floodplain soils in response to flooding facilitates the assimilation of nutrients and organic matter, hastens the degradation of persistent pesticides, and decreases the bioavailability of heavy metals.

The conservation and management of forested wetlands are critical concerns of State and Federal agencies responsible for the Nation's natural resources. Problems associated with the multiple use of forested wetlands and maintenance of environmental quality are complex, and the information needed to assist in solving them is often lacking or unavailable. The purpose of this report is to review the pertinent available literature, and to highlight the principal features of alluvial forested wetlands and the role of these systems in maintaining water quality.

Characteristics of Forested Wetlands

Bottomland hardwood forests, classified as forested wetlands by Cowardin et al. (1979), occupy floodplains of major river systems, particularly in the southeastern United States (Fig. 1). These highly productive and diverse systems (Conner and Day 1976; Brown et al. 1979) represent ecotonal zones between aquatic environments (i.e., rivers) and terrestrial uplands (Teskey and Hinckley 1977*a*). Continuous interactions among the bottomland hardwood forests, aquatic environments, and upland terrestrial areas occur through exchanges of energy, nutrients, and species; consequently these systems function as highly integrated units (Wharton 1980).

Hydroperiod

The hydroperiod essentially controls bottomland hardwood forests (Carter et al. 1979; Odum 1979*a*; Gosselink et al. 1981). Periodic inundation or overflow from rivers produces the functional characteristics (flora, fauna, soils) shown by these forested wetlands. Timing, frequency, intensity, and duration of flooding influence the abiotic factors such as sediment, soils, nutrients, and oxygen concentration; the abiotic factors in turn

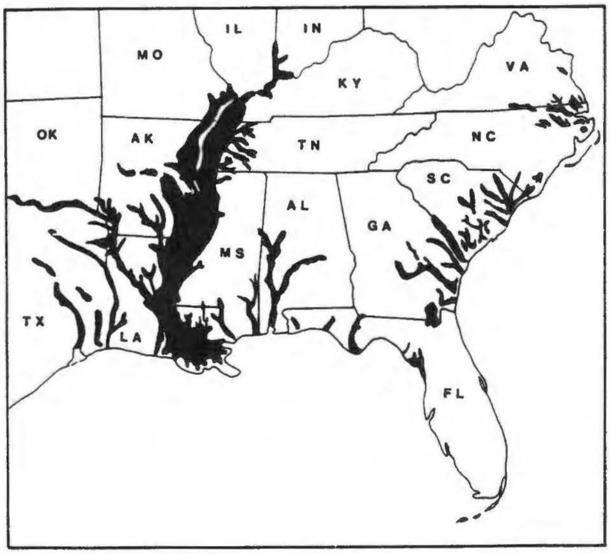


Fig. 1. Alluvial forested wetlands of the southeastern United States (adapted from Kuchler 1964).

determine the biotic responses such as species composition and diversity and primary production (Gosselink and Turner 1978; Wharton et al. 1982). Forested wetlands are considered open systems by virtue of the periodic inflow and outflow of sediments and organic matter (Klopatek 1975).

Fluvial Processes

Floodplains are formed as a result of fluvial processes associated with the erosional and depositional patterns of the associated rivers (Leopold et al. 1964; Bedinger 1981). Floodplains are actually part of the stream channel during periods of high flow (Wharton 1970). Lateral accretion or migration of the meandering channel is the primary means of floodplain formation, exceeding the contributions from overbank deposition (Wolman and Leopold 1957). Most channels are formed during high flow and modified at low flow (Keller 1977); major features of channel morphology are formed during bank-full stages or floods that occur at 1- to 2-year intervals (Wolman and Miller 1968). Most floods occur during late winter and early spring when floodplain forests are dormant. Floodplains are not uniformly flat, but are characterized by elevational changes from the river to the uplands that are correlated with flood frequency; the areas of lowest elevation are the sites most frequently flooded. Features of the floodplain formed during its development by the river are natural levees, oxbow lakes, sloughs, potholes, and low ridges (Wharton et al. 1977). The amount of overbank deposition of sediments on floodplains is highly variable and depends on the respective hydroperiod and suspended sediment load. Observed rates of vertical accretion range from a few millimeters per year to more than a meter during a single flood event (Brinson et al. 1981*b*). Coarse sediments are generally deposited near or on the natural levee bounding the channel and fine sediments are deposited in areas farther from the channel (Carlson and Runnels 1952; Harper 1938; Jahns 1947). Deposition of sediment is not uniform across the floodplain, but varies with differences in flow patterns associated with irregularities on the floodplain floor.

Flora and Fauna

The flora and fauna of bottomland hardwood forests are well adapted to the fluctuating hydrologic regime. The species composition, abundance, and distribution of the forest vegetation vary along a moisture gradient that is based on flood frequency and duration and the physiological response of each respective species to flooding and saturated soil (Teskey and Hinckley 1977*b*; Bedinger 1979*a*, 1979*b*; McKnight et al. 1981; Huffman and Forsythe 1981). The more water tolerant species, such as common baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*), are typical of areas having long hydroperiods; areas less frequently and less heavily flooded support mixed hardwood stands composed of maple, *Acer* spp.; elm, *Ulmus* spp.; ash, *Fraxinus* spp.; and oak, *Quercus* spp. (Cowardin et al. 1979). Many species of fish and wildlife, including endangered species (Williams and Dodd 1979), live in these wetland forests and depend on them for survival (Hubbard 1977; Fredrickson 1979; Clark 1979; Wharton 1980; Wharton et al. 1981; Brinson et al. 1981*b*).

Valuable Functions

Forested wetlands have many valuable functions, other than that of providing habitat for fish and wildlife. They are particularly important in the hydrologic relations of the watershed (Wharton 1970; Goodwin and Niering 1974; Mitsch et al. 1979*b*). Water is stored on the floodplain during high flow, thereby reducing the detrimental effects of floods, and later released during low-flow periods. Forested wetlands also contribute to groundwater recharge, particularly to the alluvial aquifers of the floodplain. Perhaps the greatest value of bottomland hardwood forests lies in their function as a buffer and filter system between man's urban and agricultural developments and the aquatic environment (Odum 1978). Concomitantly, forested wetlands serve as greenbelts that provide an effective hedge against overdevelopment (Odum 1979*b*). They also provide forest products (Johnson 1979; MacDonald et al. 1979; Palmisano 1979; Langdon et al. 1981); areas for recreation and education; and a unique environment for scientific research (Wharton 1970; Jahn 1979; Reimold and Hardisky 1979).

Loss of Bottomland Hardwoods

Unfortunately, much bottomland hardwood forest has been lost as a result of man's activities, and the little that remains is being lost at an alarming rate (Turner et al. 1981; Table 1). Of the originally estimated 127 million acres of wetlands (including both inland and coastal systems) in the United States (Shaw and Fredine 1956), only 70 million acres remained in the early 1970's (Goodwin and Niering 1974). The Mississippi Alluvial Valley, which represents the largest acreage of bottomland hardwood forests in the United States, originally contained 24 million acres of forested wetlands; however, only 11.8 million acres remained in 1937 and only 5.2 million acres in 1978 (MacDonald et al. 1979). Other surveys conducted on different portions of the Mississippi Alluvial Valley have shown similar losses (Holder 1971; Yancy 1969; Frey and Dill 1971; Korte and Fredrickson 1977; Sternitzke 1976; Forsythe and Gard 1980). Only 3.9 million acres of bottomland hardwood forests will remain in the Mississippi Alluvial Valley in 1995 if land-use patterns remain unchanged (MacDonald et al. 1979). Although other forested wetland systems in the Southeast have not been subjected to such intensive development, habitat has nevertheless been lost (Wharton 1970, 1977; Bayless and Smith 1964; Barstow 1971). Many of the remaining unaltered forested wetlands have the potential for development, but major land-use changes in the future will be more difficult and expensive because the most desirable land has already been converted (Klopatek et al. 1979; Clawson 1979).

Table 1. *Area (in thousands of acres) of bottomland hardwood forest (oak-gum-cypress and elm-ash-cottonwood categories) in southeastern United States. Information determined from U.S. Forest Service forest statistics (mostly incomplete) from each State, 1940–1983.*

	Years				
State	1940	1950	1960	1970	1980
Va.	968	936		713	
N. C.	2,573	3,199		2,678	
S. C.	2,279		2,104	2,668	2,233
Ga.		4,421		3,200	3,500
Fla.	6,515	5,461		4,055	3,900
Ala.	2,691	2,374		2,539	
Miss.	3,388	3,756	3,636	3,512	
La.		6,602	6,507	5,498	
Tex.		3,598	2,352	2,574	
Ark.		4,455		3,053	2,835
Mo.	1,363			838	
Tenn.		922		698	778
Ky.	503			1,038	

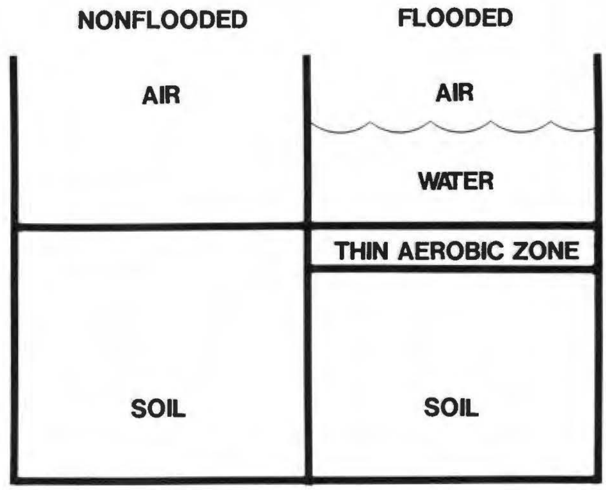
Most land lost from the bottomland hardwood forests in the Southeast has been diverted to agricultural use, particularly for soybean production (Holder 1971; Korte and Fredrickson 1977; MacDonald et al. 1979); other activities that have been responsible for substantial losses are channel alteration (dredging, canalization, and channelization), mining, bank and shore construction, and water impoundment (Darnell et al. 1976; Brinson et al. 1981*b*). Conversion of forested wetlands to agricultural and other uses has been primarily the result of federally funded channel and drainage programs that have reduced the threat of flooding and allowed encroachment onto the floodplains (Wharton 1970; Holder 1971; Choate 1972; Mattson 1975; Bragg and Tatschl 1977; Best et al. 1978; Fredrickson 1979; Shabman 1980).

Forested Wetlands and Water Quality

Appurtenant to the direct loss of forested wetlands through conversion to agricultural lands is the problem of maintaining water quality of adjacent aquatic systems. Agricultural lands are major contributors of nonpoint source pollutants such as sediments, fertilizers (nutrients), pesticides, salts, organic and inorganic materials, and pathogens (Thronson 1978). The climatological and soil conditions in the Southeast, particularly in the Mississippi Alluvial Valley, are conducive to extensive transport of sediments and agricultural chemicals into the aquatic environment (Schmitt and Winger 1980). This susceptibility to sediment transport, the large amounts of floodplain area in cultivation, the additional clearing of bottomland hardwoods for agricultural purposes, and the proliferation of newly registered pesticides tend to indicate that degradation of water quality by agricultural chemicals may become more pronounced in the Southeast in the future.

The environmental fates of agricultural chemicals depend on land-use practices, climate, geographic area, and chemical properties of the compounds. These factors in turn influence the interrelated processes of application, transport, attenuation, and accumulation of pesticides (Schmitt and Winger 1980). Purification processes or sink mechanisms in aquatic systems involve pathways that are common to all systems and generally consist of chemical transformations such as oxidation, hydrolysis, and photochemical conversion; biological transformations by microbes, plants, and animals; and physical processes such as solubilization, agglomeration, and sedimentation (Kearney et al. 1969; Benoit 1971; Schlesinger 1979). These same purification processes can be expected to function in forested wetland ecosystems; however, the unique characteristics of fluctuating hydroperiod and periodic drydown, coupled with the accompanying changes in oxygen content in the soil, add dimensions to nutrient cycling and pollutant removal and degradation in floodplain swamps that are not present in upland soils (Yoshida 1975; Leonard et al. 1976).

Wetland soils and sediments degrade or inactivate, or reduce adverse impacts from contaminants such as plant nutrients, toxic metals, and pesticides that drain into aquatic environments (Gambrell and Patrick 1978). The soil characteristics of forested wetlands depend on the hydrologic regime and inputs of organic and inorganic material from upstream and within the floodplain (Brown et al. 1979). Floodplain soils typically



Aerobic Zone	Anaerobic Zone
Oxidized Conditions	Reduced Conditions
Eh = 400 to 700 mV	Eh = 250 to 350 mV
Aerobic Microbes	Anaerobic Microbes
Nitrification	Denitrification
Organic Matter Demcomposed	Decomposition of Organic Matter Retarded
Soluble $SO_4^{=}$	H_2S—Insoluble Sulfides
Insoluble Fe^{+++} Mn^{+++}	Soluble Fe^{+++} Mn^{+++}
Soluble CO_2 HCO_3^- $CO_3^{=}$	Soluble CH_4

Fig. 2. Characteristics of flooded and nonflooded soils of alluvial forested wetlands (Eh = redox potential).

have high silt and clay concentrations, which are contributed through overbank deposition of fine materials (Patrick 1981). The organic content of the soil is high, 10–20%, as a result of extensive leaf and litter contributed by the vegetation and slow decomposition rates, particularly during flood periods (Brown et al. 1979). During these inundations, only a thin layer of soil contains oxygen, the underlying areas being devoid of it; during periods of drydown, however, the upper strata of the soil are aerated and organic materials are oxidized (Fig. 2). The switching from anaerobic to aerobic conditions in the soil during the sequence of flooding and drydown plays an important role in processing and assimilating nutrients, organic matter, and pollutants in forested wetlands (Wharton and Brinson 1979).

Flooding also alters the microbial components of the soil; aerobes are replaced by facultative anaerobes, which in turn are superseded by anaerobes. These successive changes follow or are accompanied by reductions in oxygen concentration and oxidation-reduction (redox) potential, and general convergence of both acid and alkaline soils toward pH 7 (Ponnamperuma 1972; Yoshida 1975; Gambrell and Patrick 1978). Redox potential is generally in the range of 400 to 700 mV in aerobic soils, and −250 to 300 mV in waterlogged soils (Patrick 1978).

Nutrient Uptake in Forested Wetlands

One of the most important values of forested wetlands lies in their ability to improve water quality by filtering or removing nutrients and pollutants from the water (Goodwin and Niering 1974; Wharton 1970; Karr and Schlosser 1978; Carter et al. 1979; Kadlec and Kadlec 1979; Kibby 1979; Odum 1979*a*; Lowrance et al. 1984). The broad floodplains, protracted periods of inundation, and large capacity for water storage provide coastal plain streams of the southeastern United States and lower Mississippi Valley with high nutrient exchange potentials (Brinson et al. 1983). Wetland systems are complex, having many storage compartments with different uptake and release mechanisms (Howard-Williams 1985). Forested wetlands, like wetlands in general, tend to be nutrient sinks (Kitchens et al. 1975), storing nutrients during spring and early summer and releasing them in late summer and fall (Kibby 1979). Most of the nutrients deposited on the floodplain during inundation are inorganic, and those released are in the form of organic matter such as leaf litter. Nitrogen and phosphorus concentrations are significantly reduced in water flowing through forested wetlands during periods of overflow (Kitchens et al. 1975; Mitsch et al. 1979*a*; van der Valk et al. 1979; Brinson et al. 1981*a*), thereby reducing the total amounts of these nutrients available to downstream areas. Deposited sediments in seasonally flooded wetlands provide a more permanent nutrient storage than vegetative uptake because most annual vegetative uptake is returned in the form of easily leached and decomposable litter (Johnston et al. 1984).

The fate of nitrogen in wetland soil varies with the hydrologic regime. Nitrate deposited during inundation or formed through nitrification processes is removed from the soil by vegetation for growth during periods of drydown. In flooded soils, nitrate nitrogen diffuses downward from the water column and the thin aerobic (oxidized) layer into the anaerobic layer (reduced), where facultative anaerobes denitrify it to nitrous oxide and molecular nitrogen. Ammonium nitrogen in the water phase or oxidized layer of soil undergoes nitrification to nitrate. Ammonia derived from organic nitrogen in the anaerobic layer diffuses upward to the oxidized layer, where it is nitrified. The denitrification of nitrogen in flooded soils is an important means of removing excess nitrogen and improving water quality (Engler and Patrick 1974; Engler et al. 1976; Patrick and Reddy 1976; Gambrell and Patrick 1978; Terry and Tate 1980; Reddy and Patrick 1984).

Forested wetlands tend to be sinks for phosphorus because no mechanisms are available for release except to downstream areas, and little particulate matter containing phosphorus is exported from a swamp during flooding (Brinson 1977; Mitsch et al. 1979*a*; Yarbro 1983). Phosphorus entering the floodplain by way of overflow rapidly enters the sediments, where it becomes available for plant uptake. Most of the phosphorus is tied up in the sediment and vegetation. Cycling from vegetation occurs primarily when litter falls back to the sediments, decomposes, and is taken up by roots (Brinson et al. 1980). Phosphorus and nitrogen in litter deposited in the fall are not released until after the trees begin growing in the spring; thus wetlands tend to conserve nutrients even during flooding and while trees are dormant (Brinson 1977).

Sewage Assimilation

Assimilation by wetlands of organic wastes and nutrients typical of sewage effluents has been evaluated primarily in nonalluvial wetlands, such as hardwood swamps in Florida (Boyt et al. 1976), cypress wetlands in Florida (Odum et al. 1977), and freshwater marshes in Louisiana (Turner et al. 1976), Wisconsin (Spangler et al. 1976), and Florida (Steward and Ornes 1975). One exception was the assessment of the nutrient-assimilation capacity of an alluvial swamp in North Carolina by Brinson et al. (1981*a*). Evaluation of weekly additions of nitrate, ammonium, phosphate, and secondarily treated sewage effluent to separate chambers installed on the floodplain floor showed that nitrate disappeared rapidly (probably through denitrification pathways) and did not accumulate in the subsurface water. On the other hand, ammonium accumulated in the surface water and, after a lag, also in the sediment; however, these accumulations were depleted during summer drydown, probably through nitrification-denitrification pathways. Nitrogen and ammonium are readily converted to N_2 gas through these pathways (Engler and Patrick 1974; Gambrell et al. 1975). Bartlett et al. (1979) found that biological denitrification in wetland soil reduced 90% of supplemental nitrate to nitrous oxide and nitrogen gas. Phosphorus has no similar escape mechanism (Prentki et al. 1978), and Brinson et al. (1981*a*) found that phosphate accumulated in the sediments and leaf litter. The only permanent removal of phosphorus may be through plant harvest or periodic flushing (Sloey et al. 1978); however, Hill and Sawhney (1981) showed that the mobility of phosphorus and its transport to the groundwater increased under anaerobic conditions.

The potential for forested wetlands to assimilate nutrients seems high, largely because of their cyclic inundation and drydown periods; however, management options for any specific wetland depend on its hydrologic regime (Sloey et al. 1978). In addition, the effects of long-term application of wastewaters to wetlands are unknown; possibly wetlands are degraded as a result of the accumulation of toxic metals and excessive nutrient loading.

Pesticides in Forested Wetlands

Pesticides entering aquatic environments from farms are particularly important to water quality, since they may be acutely toxic to aquatic organisms (Bingham 1969; Ferguson 1967; Young and Nicholson 1951) or may persist for extended periods in sublethal concentrations and elicit chronic response or bioaccumulate in the biota (Ferguson et al. 1967; Willis et al. 1976; Cotton and Herring 1974). Recognition that toxic substances can enter ecological cycles (Woodwell 1967) and produce undesirable environmental consequences (Keith 1966; Nicholson 1969) has increased concern and interest in the environmental fate of toxic materials such as pesticides (Paris et al. 1975). The roles of forested wetlands in the distribution, degradation, and cycling of toxic material are largely unknown, but wetlands may have significant potential for decreasing toxic materials transported through a river system, due to the unique features attributable to their periodic inundation and drydown.

Pesticides are transported from agricultural land to aquatic environments through overland flow in solution, either as particulated pesticide crystals or as amorphous material bound to eroded soil particles or solubilized in humic material (Leonard et al. 1976). Pesticides in solution may also be adsorbed to associated suspended sediment during runoff (Pionke and Chesters 1973). Most contaminants in water are adsorbed to particulate matter, which tends to sink and accumulate in the bottom material (Edwards 1977). The association of pesticides with sediment is related to particle size and organic content of the sediment (Richardson and Epstein 1971; Sharom et al. 1980). Consequently, the amount of pesticide passing over or settling on the floodplain during overflow is directly correlated with the amount and type of suspended organic and inorganic material in the water, topographic relief, and water velocity (Ragsdale and Shure 1973; Brisbin et al. 1974). During periods of flooding, large quantities of sediment are sometimes deposited on the floodplain (Brinson et al. 1981*b*), thereby improving water quality by reducing the loads of sediment and associated contaminants in streams (Wharton 1970; Richardson and Epstein 1971). For example, Asmussen et al. (1977) found that 70% of the pesticide and 94% of the sediment in runoff were removed during overflow through a vegetated waterway.

The effectiveness of sediments as sorbents is influenced by the amount of organic material present; organic sediments tend to adsorb many pesticides more strongly than mineral sediments (Pionke and Chesters 1973). Humic and fulvic acids in soil and water are important carriers of some pesticides and have the potential for promoting biological and nonbiological degradation of many pesticides (Khan 1980; Liu et al. 1983). Silt and clays are generally better sorbents than are sand fractions (Karickhoff et al. 1979). In general, cationic pesticides are adsorbed onto clay and organic colloids by ion exchange, acidic pesticides are weakly adsorbed to particulate matter, and basic pesticides are physically adsorbed to neutral soil; nonionic pesticide attachments depend on the physical chemistry of the respective compounds

Table 2. *Percent degradation of organochlorine insecticides in soils under aerobic and anaerobic conditions and anaerobic conditions amended with organic matter.*

Compound and time (weeks)	Condition: Aerobic	Anaerobic	Anaerobic plus organic matter	Reference
DDT				
520	95			Edwards 1964
72	20			Edwards 1966
7		65	90	Farmer et al. 1974
5	23	50	97	Ko and Lockwood 1968
7		71	95	Spencer et al. 1974
12	15	83	99	Guenzi and Beard 1968
22	30	75	86	Guenzi et al. 1971
Aldrin				
156	95			Edwards 964
52	74			Edwards 1966
6		95		Hill and McCarty 1967
Dieldrin				
416	95			Edwards 1964
52	25			Edwards 1966
7		6		Hill and McCarty 1967
20	20	30	18	Guenzi et al. 1971
Endrin				
22	23	42	56	Guenzi et al. 1971
Lindane				
338	95			Edwards 1964
52	40			Edwards 1966
22	46	70	72	Guenzi et al. 1971
9		95		Raghu and McCrae 1966
2	0	63		Yoshida and Castro 1970
2			80	Hill and McCarty 1967
Heptachlor				
182	95			Edwards 1964
52	55			Edwards 1966
22	56	88	95	Guenzi et al. 1971
38				Hill and McCarty 1967
Toxaphene				
6	0		98	Parr and Smith 1976

(Weber 1972). Desorption of pesticides from sediment is slow or does not occur, and adsorption of pesticides by sediment can reduce concentrations in aquatic biota (through competition for the pesticide), enhance degradation rates, and reduce bioactivity (Pionke and Chesters 1973).

Organochlorines are persistent in the environment and present more serious residue problems than do other pesticides, because they are nonpolar (immobile) and resist chemical and biological degradation under normal conditions (Fries 1972; Pionke and Chesters 1973). However, Hill and McCarty (1967) have shown that many pesticides degrade more quickly under biologically active anaerobic conditions than under aerobic conditions. Persistence of organochlorines is generally considered to be longer under aerobic than under anaerobic soil conditions (Table 2). Flooding soils may be an effective means of reducing certain organochlorines such as DDT (Kearney et al. 1969; Fries 1972; Farmer et al. 1974). In aerobic soils, DDT is relatively stable and only slowly converted to the less toxic metabolite DDD (Guenzi and Beard 1967, 1968; Castro and Yoshida 1971;

Spencer et al. 1974). The conversion of DDT to DDD appears to be a reductive dechlorination process that is inhibited by oxygen (Fries 1972).

Not all organochlorine pesticides are degraded faster under anaerobic than under aerobic conditions. For example, Guenzi et al. (1971) reported that degradation of DDD and dieldrin was slower under anaerobic conditions, and Castro and Yoshida (1971) found that aldrin was more persistent in flooded (anaerobic) soil than in upland soil (chlordane and dieldrin were persistent under both soil conditions).

Organophosphate insecticides, although generally less persistent than the organochlorines (Pionke and Chesters 1973), also degrade rapidly under anaerobic conditions (Lichtenstein and Schulz 1964). Siddaramappa et al. (1973) showed that microbes degrade parathion in flooded soils, and Wahid et al. (1980) demonstrated that 56% of the parathion applied to flooded soil was degraded after only 5 s and 88% after 30 min. Diazinon persisted for 15 days in flooded soil that had been previously exposed to it (Sethunathan 1972).

Most herbicides are relatively short-lived and generally do not present long-lasting environmental problems (Frank 1972). Helling (1976) showed that many denitroaniline herbicides were lost more quickly from reduced soils (flooded) than from more oxidized soils, but Camper et al. (1980) reported that compounds such as profluralin and trifluralin were degraded at about equal rates under all conditions; and Thomas and Holt (1980) found that molinate (carbamate herbicide) was degraded faster under aerobic than under flooded (anaerobic) conditions. They noted also that, once the flooded soil dried, molinate degraded at the same rate as in nonflooded soil.

Under anaerobic conditions, persistent pesticides are believed to be degraded by facultative and obligate anaerobes inhabiting the soil (Fries 1972; Leonard et al. 1976). Evidence that microbes are important in the degradation of the organochlorine insecticides stems from the general lag period between the time of application and the time when significant rates of degradation occur (Hague and Freed 1974), and from the absence of degradation in sterilized soils (MacRae et al. 1967). The lag is considered to be the time required for the microbial populations to increase in abundance or for suitable enzymes to be inducted. In addition, the need for organic matter as an energy source in the degradation of pesticides supports the other evidence that microbes play an important role (Ko and Lockwood 1968; Guenzi and Beard 1968; Guenzi et al. 1971; Farmer et al. 1974).

Microbes seemingly degrade many chemicals without depending on them for energy or nutrients. The microorganisms can grow on another substrate such as organic matter while performing the transformation enzymatically by cometabolism (Alexander 1981). Soil microorganisms use many classes of pesticides as a sole or partial source of energy (Leonard et al. 1976). Microbes, for example, effectively degrade herbicides by using the carbon of the compounds for an energy source (Audus 1960); however, many of the organochlorine insecticides are cometabolized (and thus are not used as an energy source).

Factors other than the absence of oxygen may be involved in anaerobic degradation. Wahid and Sethunathan (1979) indicated that the reduced components from flooded soil (such as H_2S) may be partly responsible for the breakdown of some pesticides. In addition, Fe^{++} and Mn^{++} formed under anaerobic conditions may complex and stabilize negatively charged and acidic organic pesticides (Pionke and Chesters 1973). Lowering of the redox potential may also be an important consideration. For example, Willis et al. (1974) found that trifluralin did not begin to degrade until the redox potential was between 150 and 50 mV, and Guenzi et al. (1971) wrote that the amount of some pesticides was reduced substantially when the redox potential was reduced to about 250 mV. Similarly, Parr and Smith (1976) detected no degradation of toxaphene in an aerobic environment, whereas under anaerobic conditions it was degraded microbially when the redox potential ranged between 0 and −100 mV. However, the influence of oxidation-reduction conditions on degradation rates of pesticides is compound specific (Gambrell et al. 1984*a*, 1984*b*).

Fluctuations between aerobic and anaerobic conditions typically shown by alluvial forested wetlands provide a broad range of physical, chemical, and biological conditions conducive to pesticide degradation. Degradation that is inhibited or retarded under either aerobic or anaerobic conditions may resume when the opposite condition occurs. Diazinon, for example, is hydrolized microbially in both aerobic and anaerobic environments, but at a faster rate anaerobically, and hydrolysis products accumulated under flooded conditions are readily mineralized in unflooded soil (Sethunathan 1972). Similarly, dechlorination of toxaphene begins under anaerobic conditions, and the less chlorinated products are further degraded when the environment becomes aerobic (Clark and Matsumura 1979).

Metals in Forested Wetlands

Wetland sediments—reduced sediments in particular—are effective sinks for most metal contaminants. Most metals in soil solution are weakly adsorbed to mineral or organic colloids through ion exchange. The availability of some metals, as influenced by oxidation intensity, depends on several factors—e.g., metal precipitation in the form of insoluble sulfides in the reducing environment, metal coprecipitation or adsorption with hydrous oxides of iron and manganese in the oxidizing environment, and complexation with insoluble humic material (Gambrell and Patrick 1978). Radionuclides seemingly follow the same mechanisms and pathways followed by metals (Boto and Patrick 1979; McHenry and Ritchie 1975). The formation of H_2S under reducing (anaerobic) conditions results in the formation of insoluble metal sulfide precipitates, and thus limits the mobility and bioavailability of certain metals (Engler and Patrick 1975; Gambrell and Patrick 1978; Jackson 1978). During drydown and a shift to oxidizing (nonflooded) conditions, however, metal sulfides become considerably less stable and may become more soluble (Engler and Patrick 1975; Gambrell and Patrick 1978). For example, Reddy and Patrick (1977) found that cadmium uptake by rice increased when the redox potential increased from a strongly reduced condition (−200 mV) to a moderately oxidized condition (400 mV).

The ferrous (Fe^{++}) and manganous (Mn^{++}) forms that predominate in reduced soils are soluble and available to certain biota (e.g., some Oligochaeta and Chironomidae); however, the ferric (Fe^{+++}) and manganic (Mn^{+++}) forms that predominate under oxidized conditions are more stable and therefore less available for uptake. The stability of hydrous oxides of iron and manganese decreases under reduced conditions, and adsorbed or coprecipitated metals are released. However, complexation with insoluble organics or formation of sulfide precipitates tends to immobilize metals released by the dissolution of the hydrous oxides under flooded conditions (Gambrell and Patrick 1978).

Large amounts of organic matter in floodplain soils can complex with metals and essentially immobilize them. Hunt and Lee (1976) found that 98% of the heavy metals were removed during overland flow, primarily by the surface organic layer; however, the oxidation of organic matter tends to decrease the stability of associated metals, and thus increases their bioavailability (Gambrell and Patrick 1978). Miller et al. (1975) found that sediments with highly organic materials—particularly humic acids—complex with mercury and release little elemental mercury.

Water passing through swamps tends to take up high concentrations of organic material (on the order of 100 ppm). Organic matter from the floodplain soil and leaf leachates complexes with metals and thus contributes to their mobilization and transport. Beck et al. (1974) found that metals and organic matter are flushed out of swamp systems in high concentrations; however, the fate of the metals associated with the organic matter in river systems is essentially unknown. They probably are deposited downstream or taken up by algae and vascular plants. Rodgers et al. (1978) found that metals discharged from a fossil fuel power plant into an ash basin system were removed from water by adsorption to the sediments and through uptake by the duckweed *Lemna perpusilla;* concentrations of metals were about 10 times higher in the duckweed and sediments than in the water. Miller et al. (1975) determined that mercury in water was rapidly and strongly adsorbed to sediments, and Jackson (1978) found that algal blooms were effective in concentrating heavy metals that were later released to the sediments when the algae died and sank to the bottom. Although metals removed from the water or sediment by plants may become available for transfer along food chains (Kadlec and Kadlec 1979; Kibby 1979), they tend to be accumulated less by plants than by consumer organisms (Guthrie and Cherry 1976).

Importance of the Relation of Forested Wetlands to Water Quality

The role of forested wetlands in improving water quality through deposition of sediments, assimilation of nutrients and organic matter, degradation of pesticides, and storing of heavy metals should surely be considered when evaluating the functional values and benefits attributed to these important resources. Management should strive to maintain and retain the physical, chemical, and biological characteristics of these systems that are integral to their viable functioning. Many of these characteristics would be protected if normal hydrologic regimes that allow periodic overflow of the floodplain were preserved and maintained.

References

Alexander, M. 1981. Biodegradation of chemicals of environmental concern. Science 211:132–138.

Asmussen, L. E., A. W. White, Jr., E. W. Hauser, and J. M. Sheridan. 1977. Reduction of 2,4-D load in surface runoff down a grassed waterway. J. Environ. Qual. 6:159–162.

Audus, L. J. 1960. Microbiological breakdown of herbicides in soils. Pages 1–19 *in* E. K. Woodford and G. R. Sagra, eds. Herbicides in the soils. Blackwell Scientific Publications, Oxford, England.

Barstow, C. J. 1971. Impact on channelization of wetland habitat in the Obion-Forked Deer Basin, Tennessee. Trans. N. Am. Wildl. Nat. Resour. Conf. 36:362–376.

Bartlett, M. S., L. C. Brown, N. B. Hanes, and N. H. Nickerson. 1979. Denitrification in freshwater wetland soil. J. Environ. Qual. 8:460–464.

Bayless, J., and W. B. Smith. 1964. The effects of channelization upon the fish populations of lotic waters in eastern North Carolina. Proc. N. C. Wildl. Resour. Comm. 15 pp.

Beck, K. C., J. H. Reuter, and E. M. Perdue. 1974. Organic and inorganic geochemistry of some coastal plain rivers of the southeastern United States. Geochim. Cosmochim. Acta 38:341–364.

Bedinger, M. S. 1979*a*. Forests and flooding with special references to the White River and Ouachita River Basins, Arkansas. U.S. Geol. Surv., Water Resour. Invest., Open-file Rep. 79-68.

Bedinger, M. S. 1979*b*. Relation between forest species and flooding. Pages 427–435 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Bedinger, M. S. 1981. Hydrology of bottomland hardwood forests of the Mississippi embayment. Pages 161–176 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Benoit, R. J. 1971. Self-purification in natural waters. Pages 223–261 *in* L. L. Ciacciao, ed. Water and water pollution handbook, Vol. 1. Marcel Dekker, New York.

Best, L. B., K. L. Varland, and R. B. Dahlgren. 1978. Effects of stream channelization on land-use practices in Iowa. Iowa State J. Res. 52(4):411–423.

Bingham, C. R. 1969. Comparison of insecticide residues from two Mississippi oxbow lakes. Proc. Annu. Conf. Southeast. Assoc. Game Fish. Comm. 23:275–280.

Boto, K. G., and W. H. Patrick, Jr. 1979. Role of wetlands in the removal of suspended sediments. Pages 479–489 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Boyt, F. L., S. E. Bayley, and J. Zoltek, Jr. 1976. Removal of nutrients from treated municipal wastewater by wetland vegetation. J. Water Pollut. Control Fed. 48:789–799.

Bragg, T. B., and A. K. Tatschl. 1977. Changes in floodplain vegetation and land use along the Missouri River from 1826–1972. Environ. Manage. 1(4):343–348.

Brinson, M. M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology 58(3):601–609.

Brinson, M. M., H. D. Bradshaw, and R. N. Holmes. 1983. Significance of floodplain sediments in nutrient exchange between a stream and its floodplain. Pages 199–221 *in* T.D. Fontaine III and S.M. Bartell, eds. Dynamics of lotic ecosystems. Ann Arbor Science Publishers, Ann Arbor, Mich.

Brinson, M. M., H. D. Bradshaw, R. N. Holmes, and J. B. Elkins, Jr. 1980. Litterfall, stemflow, and throughfall nutrient fluxes in an alluvial swamp forest. Ecology 61(4):827–835.

Brinson, M. M., H. D. Bradshaw, and E. S. Kane. 1981*a*. Nitrogen cycling and assimilative capacity of nitrogen and phosphorus by riverine wetland forests. Univ. N. C., Water Resour. Res. Inst., UNC-WRRI-167.

Brinson, M. M., B. L. Swift, R. C. Plantico, and J. S. Barclay. 1981*b*. Riparian ecosystems: Their ecology and status. U.S. Fish Wildl. Serv., FWS/OBS-81/17.

Brisbin, I. L., Jr., R. J. Beyers, R. W. Dapson, R. A. Geiger, J. Gentry, J. W. Gibbons, M. J. Smith, and S. K. Woods. 1974. Patterns of radiocesium in the sediments of a stream channel contaminated by production reactor effluents. Health Phys. 27:19–27.

Brown, S., M. M. Brinson, and A. E. Lugo. 1979. Structure and function of riparian wetlands. Pages 17–31 *in* R. R Johnson and J. F. McCormick, tech. coords. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. U.S. For. Serv., Gen. Tech. Rep. WO-12.

Camper, N. D., K. Stralka, and H. D. Skipper. 1980. Aerobic and anaerobic degradation of profluralin and trifluralin. J. Environ. Sci. Health 15(5):457–474.

Carlson, W. A., and R. T. Runnels. 1952. A study of silt deposited by the July 1951 flood, central Kansas River Valley. Trans. Kans. Acad. Sci. 55:209–213.

Carter, V., M. S. Bedinger, R. P. Novitzki, and W. O. Wilen. 1979. Water resources and wetlands. Pages 344–375 *in* P. E. Greeson, J. R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Castro, R. F., and T. Yoshido. 1971. Degradation of organochlorine insecticides in flooded soils in the Philippines. J. Agric. Food Chem. 19(6):1168–1170.

Choate, J. S. 1972. Effects of stream channeling on wetlands in a Minnesota watershed. J. Wildl. Manage. 36:940–943.

Clark, J. 1979. Fresh water wetlands: Habitats for aquatic invertebrates, amphibians, reptiles, and fish. Pages 330–343 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Clark, J. M., and F. Matsumura. 1979. Metabolism of toxaphene by aquatic sediment and a camphor-degrading pseudomonad. Arch. Environ. Contam. Toxicol. 8:285–298.

Clawson, M. 1979. Forests in the long sweep of American history. Science 204:1168–1174.

Conner, W. H., and J. W. Day. 1976. Productivity and composition of a baldcypress-water tupelo site and bottomland hardwood site in a Louisiana swamp. Am. J. Bot. 63:1354–1364.

Cotton, D., and J. Herring. 1974. A survey of mercury and pesticide residues in fish from locations outside the Delta region in Mississippi. Miss. Game Fish Comm., Fish. Div. F-30-1.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv., FWS/OBS-79/31.

Darnell, R. M., W. E. Pequegnat, B. M. James, F.J. Benson, and R. A. Defenbaugh. 1976. Impacts of construction activities in wetlands of the United States. Pollution of water, soils, and aquatic environments. U.S. Environ. Prot. Agency, Ecol. Res. Ser. EPA-600/3-76-045.

Edwards, C. A. 1964. Effects of pesticide residues on soil invertebrates and plants. Pages 239–261 *in* G. T. Goodman, R. W. Edwards, and J. M. Lambert, eds. Ecology and the industrial society. John Wiley & Sons, New York.

Edwards, C. A. 1966. Insecticide residues in soils. Residue Rev. 13:83–132.

Edwards, C. A. 1977. Nature and origins of pollution of aquatic systems by pesticides. Pages 11–38 *in* M. A. Q. Khan, ed. Pesticides in the aquatic environment. Plenum Press, New York.

Engler, R. M., D. A. Antie, and W. H. Patrick, Jr. 1976. Effect of dissolved oxygen and redox potential and nitrate removal in flooded swamp and marsh soils. J. Environ. Qual. 5:230–235.

Engler, R. M., and W. H. Patrick, Jr. 1974. Nitrate removal from floodwater overlying flooded soils and sediments. J. Environ. Qual. 3:409–413.

Engler, R. M., and W. H. Patrick, Jr. 1975. Stability of sulfides of manganese, iron, zinc, copper, and mercury in flooded and nonflooded soil. Soil Sci. 119(3):217–221.

Farmer, W. J., W. F. Spencer, R. A. Shepherd, and M. M. Cliath. 1974. Effect of flooding and organic matter application on DDT residues in soil. J. Environ. Qual. 3:343–346.

Ferguson, D. E. 1967. The ecological consequences of pesticide resistance in fishes. Trans. N. Am. Wildl. Conf. 32:103–107.

Ferguson, D. E., J. L. Ludke, M. T. Finley, and G. C. Murphy. 1967. Insecticide-resistant fishes: A potential hazard to consumers. J. Miss. Acad. Sci. 13:138–140.

Forsythe, S. W., and S. W. Gard. 1980. Status of bottomland hardwoods along the lower Mississippi River. Trans. N. Am. Wildl. Nat. Resour. Conf. 45:333–340.

Frank, P. A. 1972. Herbicidal residues in aquatic environments. Pages 135–148 *in* R. G. Gould, ed. Fate of organic pesticides in the aquatic environment. Am. Chem. Soc., Adv. Chem. Ser. 111.

Fredrickson, L. H. 1979. Floral and faunal changes in lowland hardwood forests resulting from channelization, draining, and impoundment. U.S. Fish Wildl. Serv., FWS/OBS-79.

Frey, H. T., and H. W. Dill, Jr. 1971. Land use changes in the southern Mississippi Alluvial Valley, 1950–69. U.S. Econ. Res. Serv., Agric. Econ. Rep. 215.

Fries, G. G. 1972. Degradation of chlorinated hydrocarbons under anaerobic conditions. Pages 256–270 *in* R. G. Gould, ed. Fate of organic pesticides in the aquatic environment. Am. Chem. Soc., Adv. Chem. Ser. 111.

Gambrell, R. P., J. W. Gilliam, and S. B. Weed. 1975. Denitrification in subsoils of the North Carolina Coastal Plain as affected by soil drainage. J. Environ. Qual. 4:311–316.

Gambrell, R. P., and W. H. Patrick, Jr. 1978. Chemical and microbiological properties of anaerobic soils and sediments. Pages 375–423 *in* D. D. Hook and R. M. M. Crawford, eds. Plant life in anaerobic environments. Ann Arbor Science Publishers, Ann Arbor, Mich.

Gambrell, R. P., B. A. Taylor, K. S. Reddy, and W. H. Patrick, Jr. 1984*a*. Fate of selected toxic compounds under controlled redox potential and pH conditions in soil and sediment-water systems. U.S. Environ. Prot. Agency, EPA-600/S3-84-018.

Gambrell, R. P., C. N. Reddy, V. Collard, G. Green, and W. H. Patrick, Jr. 1984*b*. The recovery of DDT, kepone, and permethrin added to soil and sediment suspensions incubated under controlled redox potential and pH conditions. J. Water Pollut. Control Fed. 56(2):174–182.

Goodwin, R. H., and W. A. Niering. 1974. Inland wetlands: Their ecological role and environmental status. Bull. Ecol. Soc. Am. 55(2):2–6.

Gosselink, J. G., S. E. Bayley, W. H. Conner, and R. E. Turner. 1981. Ecological factors in the determination of riparian wetland boundaries. Pages 197–219 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Gosselink, J. G., and R. E. Turner. 1978. The role of hydrology in freshwater wetland ecosystems. Pages 63–78 *in* R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Freshwater wetlands: Ecological processes and management potential. Academic Press, New York.

Guenzi, W. D., and W. E. Beard. 1967. Anaerobic biodegradation of DDT to DDD in soil. Science 156:1116–1117.

Guenzi, W. D., and W. E. Beard. 1968. Anaerobic conversion of DDT to DDD and aerobic stability of DDT in soil. Proc. Soil Sci. Soc. Am. 32:522–524.

Guenzi, W. D., W. E. Beard, and F. G. Viets, Jr. 1971. Influence of soil treatment on persistence of six chlorinated hydrocarbon insecticides in the field. Proc. Soil Sci. Soc. Am. 35:910-913.

Guthrie, R. K., and D. S. Cherry. 1976. Pollutant removal from coal-ash basin effluent. Water Resour. Bull. 12(5):889–902.

Hague, R., and V. H. Freed. 1974. Behavior of pesticides in the environment: "Environmental chemodynamics." Residue Rev. 52:89–116.

Harper, H. J. 1938. Effect of silting on tree development in the flood plain of Deep Fork of the North Canadian River in Creek County. Proc. Okla. Acad. Sci. 18:46–49.

Helling, C. S. 1976. Dinitroaniline herbicides in soils. J. Environ. Qual. 5:1–15.

Hill, D. E., and B. L. Sawhney. 1981. Removal of phosphorus from waste water by soil under aerobic and anaerobic conditions. J. Environ. Qual. 10:401–405.

Hill, D. W., and P. C. McCarty. 1967. Anaerobic degradation of selected chlorinated hydrocarbon pesticides. J. Water Pollut. Control Fed. 39(8):1259–1277.

Holder, T. H. 1971. Disappearing wetlands in eastern Arkansas. Arkansas Planning Commission, Little Rock.

Howard-Williams, C. 1985. Cycling and retention of nitrogen and phosphorus in wetlands: A theoretical and applied perspective. Freshwater Biol. 15:391–431.

Hubbard, J. P. 1977. Importance of riparian ecosystems: Biotic considerations. Pages 14–18 *in* R. R. Johnson and D.A. Jones, eds. Importance, preservation and management of riparian habitat: A symposium. U.S. For. Serv., Gen. Tech. Rep. RM-43.

Huffman, R. R., and S. W. Forsythe. 1981. Bottomland hardwood forest communities and their relation to anaerobic soil conditions. Pages 187–196 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Hunt, P. G., and C. R. Lee. 1976. Land treatment of wastewater by overland flow for improved water quality. Pages 151–160 *in* J. Toubier and R. W. Pierson, Jr., eds. The biological control of water pollution. University of Pennsylvania Press, Philadelphia.

Jackson, T. A. 1978. The biogeochemistry of heavy metals in polluted lakes and streams at Flin Flon, Canada, and a proposed method for limiting heavy-metal pollution of natural waters. Environ. Geol. 2(3):173–189.

Jahn, L. R. 1979. Values of riparian habitats to natural ecosystems. Pages 157–160 *in* R. R. Johnson and J. F. McCormick, tech. coords. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. U.S. For. Serv., Gen. Tech. Rep. WO-12.

Jahns, R. H. 1947. Geologic features of the Connecticut Valley, Mass., as related to recent floods. U.S. Geol. Surv., Water-Supply Pap. 996.

Johnson, R. L. 1979. Timber harvests from wetlands. Pages 598–605 *in* P. E. Greeson, J. R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Johnston, C. A., G. D. Bubenzer, G. B. Lee, F. W. Madison, and J. R. McHenry. 1984. Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland. J. Environ. Qual. 13:283–290.

Kadlec, R. H., and J. A. Kadlec. 1979. Wetlands and water quality. Pages 436–456 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Karickhoff, W. W., D. S. Brown, and T. A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res. 13:241–248.

Karr, J. R., and I. J. Schlosser. 1978. Water resources and the land-water interface. Science 201:229–234.

Kearney, P. C., E. A. Wooson, and J. R. Plimmer. 1969. Decontamination of pesticides in soil. Residue Rev. 29:137-149.

Keith, J. O. 1966. Insecticide contamination in wetland habitats and their effects on fish-eating birds. J. Appl. Ecol. Suppl. 3:71-86.

Keller, E. A. 1977. The fluvial system: Selected observations. Pages 39-46 *in* A. Sands, ed. Riparian forests in California: Their ecology and conservation. Institute of Ecology, University of California, Davis.

Khan, S. U. 1980. Determining the role of humic substances in the fate of pesticides in the environment. J. Environ. Sci. Health B15(6):1071-1091.

Kibby, H. V. 1979. Effects of wetlands on water quality. Pages 289-298 *in* R. R. Johnson and J. F. McCormick, tech. coords. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. U.S. For. Serv., Gen. Tech. Rep. WO-12.

Kitchens, W. M., Jr., J. M. Dean, L. H. Stevenson, and J. H. Cooper. 1975. The Santee Swamp as a nutrient sink. Pages 349-366 *in* F. G. Howell, J. P. Gentry, and M. H. Smith, eds. Mineral cycling in southeastern ecosystems. Energ. Res. Dev. Admin., ERDA CONF-740513.

Klopatek, J. M. 1975. The role of emergent macrophytes in mineral cycling in freshwater marsh. Pages 367-392 *in* F. G. Howell, J. B. Gentry, and M. H. Smith, eds. Mineral cycling in southeastern ecosystems. Energ. Res. Dev. Admin., ERDA CONF-740513.

Klopatek, J. M., R. J. Olson, C. J. Emerson, and J. L. Jones. 1979. Land-use conflicts with natural vegetation in the United States. Environ. Conserv. 6(3):191-200.

Ko, W. H., and J. L. Lockwood. 1968. Conversion of DDT to DDD in soil and the effect of these compounds on soil microorganisms. Can. J. Microbiol. 14:1069-1073.

Korte, P. A., and L. H. Fredrickson. 1977. Loss of Missouri's lowland hardwood ecosystem. Trans. N. Am. Wildl. Nat. Resour. Conf. 42:31-41.

Kuchler, A. W. 1964. Potential natural vegetation of the conterminous United States. Am. Geogr. Soc. Spec. Publ. 36.

Langdon, D. G., J. P. McClure, D. D. Hook, J. M. Crockett, and R. Hunt. 1981. Extent, condition, management, and research needs of bottomland hardwood-cypress forests in the southeastern United States. Pages 71-85 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Leonard, R. A., G. W. Bailey, and R. R. Swank, Jr. 1976. Transport, detoxification, fate, and effects of pesticides in soil and water environments. Pages 48-78 *in* Land applications of waste materials. Soil Conservation Society of America, Ankeney, Iowa.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman & Co., San Francisco.

Lichtenstein, E. P., and K. R. Schulz. 1964. The effects of moisture and microorganisms on the persistence and metabolism of some organophosphorus insecticides in soils with special emphasis on parathion. J. Econ. Entomol. 57(5):618-627.

Liu, D., J. Carey, and K. Thomson. 1983. Fulvic-acid-enhanced biodegradation of aquatic contaminants. Bull. Environ. Contam. Toxicol. 31(2):203-207.

Lowrance, R., R. Todd, J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34(6):374-377.

MacDonald, P. O., W. E. Frayer, and J. K. Clauser. 1979. Documentation, chronology, and future projections of bottomland hardwood habitat loss in the Mississippi Alluvial Plain. U.S. Fish Wildl. Serv., Div. Ecol. Serv., Vicksburg, Miss. Vols. 1 and 2.

MacRae, I. C., K. Raghu, and T. F. Castro. 1967. Persistence and biodegradation of four common isomers of benzene hexachloride in submerged soils. J. Agric. Food Chem. 15(5):911-914.

Mattson, C. D. 1975. Effect of small watershed program on major uses of land: Examination of 60 projects in the southeast Mississippi Delta and Missouri River tributaries regions. U.S. Econ. Res. Serv., Agric. Econ. Rep. 279.

McHenry, J. R., and J. C. Ritchie. 1975. Redistribution of Cesium-137 in southeastern watersheds. Pages 452-461 *in* F. G. Howell, J. B. Gentry, and M. H. Smith, eds. Mineral cycling in southeastern ecosystems. Energ. Res. Dev. Admin., ERDA-CONF-740513.

McKnight, J. S., D. D. Hook, O. G. Langdon, and R. L. Johnson. 1981. Flood tolerance and related characteristics of trees of the bottomland forests of the southern United States. Pages 29-69 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Miller, R. W., J. E. Schindler, and J. J. Alberts. 1975. mobilization of mercury from freshwater sediments by humic acid. Pages 445-451 *in* F. G. Howell, J. B. Gentry, and M. H. Smith, eds. Mineral cycling in southeastern ecosystems. Energ. Res. Dev. Admin., ERDA-CONF-740513.

Mitsch, W. J., C. L. Dorge, and J. R. Wiemhoff. 1979*a*. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois. Ecology 60(6):1116-1124.

Mitsch, W. J., W. Rush, A. Behnke, and L. Lai. 1979*b*. Environmental observations of a riparian ecosystem during flood season. Univ. Ill., Water Resour. Cent., Res. Rep. 142.

Nicholson, H. P. 1969. Occurrence and significance of pesticide residues in water. J. Wash. Acad. Sci. 59:77–85.

Odum, E. P. 1979*a*. The value of wetlands: A hierarchial approach. Pages 16–25 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland function and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Odum, E. P. 1979*b*. Opening address: Ecological importance of the riparian zone. Pages 2–4 *in* R. R. Johnson and J. F. McCormick, tech. coords. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. U.S. For. Serv., Gen. Tech. Rep. WO-12.

Odum, H. T. 1978. Value of wetlands as domestic ecosystems. Pages 9–18 *in* J. H. Montanari and J. A. Kusler, chairmen. Proceedings of the National Wetland Protection Symposium. U.S. Fish Wildl. Serv., FWS/OBS-78/97.

Odum, H. T., K. C. Ewel, W. J. Mitsch, and J. W. Ordway. 1977. Recycling treated sewage through cypress wetlands in Florida. Pages 35–67 *in* F. M. D'Itri, ed. Wastewater renovation and reuse. Marcel Dekker, New York.

Palmisano, A. W. 1979. Harvest from wetlands. Pages 589–597 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Paris, D. F., D. L. Lewis, J. T. Barnett, Jr., and G. L. Baughman. 1975. Microbial degradation and accumulation of pesticides in aquatic systems. U.S. Environ. Prot. Agency, EPA-660/3-75-007.

Parr, J. F., and S. Smith. 1976. Degradation of toxaphene in selected anaerobic soil environments. Soil Sci. 121(1):52–57.

Patrick, W. H., Jr. 1978. Chemistry of flooded soil and effects on mineral nutrition. Pages 40–48 *in* W. E. Balmer, ed. Proceedings soil moisture-site productivity symposium. U.S. For. Serv., Div. State Priv. For., Southeast Reg. Rep.

Patrick, W. H., Jr. 1981. Bottomland soils. Pages 177–185 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Patrick, W. H., Jr., and K. R. Reddy. 1976. Nitrification-denitrification reactions in flooded soils and water bottoms: Dependence on oxygen supply and ammonium diffusion. J. Environ. Qual. 5:469–472.

Pionke, H. B., and G. Chesters. 1973. Pesticide-sediment-water interactions. J. Environ. Qual. 2:29–45.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29–96.

Prentki, R. T., T. D. Gustafson, and M. S. Adams. 1978. Nutrient movements in lakeshore marshes. Pages 169–194 *in* R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Freshwater wetlands: Ecological processes and management potential. Academic Press, New York.

Raghu, K., and I. C. MacRae. 1966. Biodegradation of the gamma isomer of benzene hexachloride in submerged soils. Science 154:263–264.

Ragsdale, H. L., and D. J. Shure. 1973. Flood plain transfer and accumulation of ^{137}Cs from a reactor effluent stream. Pages 243–253 *in* Environmental behavior of radionuclides released in the nuclear industry. Int. At. Energ. Agency, IAEA-SM-172-33.

Reddy, C. N., and W. H. Patrick, Jr. 1977. Effects of redox potential and pH on the uptake of Cd and Pb by rice plants. J. Environ. Qual. 6:259–262.

Reddy, K. R., and W.H. Patrick. 1984. Nitrogen transformations and loss in flooded soils and sediments. CRC Critical Rev. Environ. Control 13:273–309.

Reimold, R. J., and M. A. Hardisky. 1979. Nonconsumptive use values of wetlands. Pages 558–564 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Richardson, E. M., and E. Epstein. 1971. Retention of three insecticides on different size soil particles suspended in water. Soil Sci. Soc. Am. Proc. 35:884–887.

Rodgers, J. H., Jr., D. S. Cherry, and R. K. Guthrie. 1978. Cycling of elements in duckweed (*Lemna perpusilla*) in a stream and swamp drainage system. Water Res. 12:765–770.

Schlesinger, R. B. 1979. Natural removal mechanisms for chemical pollutants in the environment. BioScience 29(2):95–101.

Schmitt, C. J., and P. V. Winger. 1980. Factors controlling the fate of pesticides in rural watersheds of the lower Mississippi River Alluvial Valley. Trans. N. Am. Wildl. Nat. Resour. Conf. 45:354–375.

Sethunathan, N. 1972. Diazinon degradation in submerged soil and rice-paddy water. Pages 244–255 *in* R. G. Gould, ed. Fate of organic pesticides in the aquatic environment. Am. Chem. Soc., Adv. Chem. Ser. 111.

Shabman, L. 1980. Economic incentives for bottomland conversion: The role of public policy and programs. Trans. N. Am. Wildl. Nat. Resour. Conf. 45:402–412.

Sharom, M. S., J. R. W. Miles, C. R. Harris, and F. L. McEwen. 1980. Behavior of 12 insecticides in soil and aqueous suspensions of soil and sediment. Water Res. 14(8):1095–1100.

Shaw, S. P., and C. G. Fredine. 1956. Wetlands of the United States. U.S. Fish Wildl. Serv. Circ. 39.

Siddaramappa, R., K. P. Rajaram, and N. Sethunathan. 1973. Degradation of parathion by bacteria isolated from flooded soil. Appl. Microbiol. 26(6):846–849.

Sloey, W. E., F. L. Spangler, and C. W. Fetter, Jr. 1978. Management of freshwater wetlands for nutrient assimilation. Pages 321–340 *in* R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Freshwater wetlands: Ecological processes and management potential. Academic Press, New York.

Spangler, F. L., W. E. Sloey, and C. W. Fetter, Jr. 1976. Wastewater treatment. by natural and artificial marshes. U.S. Environ. Prot. Agency, EPA-600/2-76-207.

Spencer, W. F., M. M. Cliath, W. J. Farmer, and R. A. Sheperd. 1974. Volatility of DDT residues in soil as affected by flooding and organic matter applications. J. Environ. Qual. 3:126–129.

Sternitzke, H. S. 1976. Impact of changing land use on delta hardwood forests. J. For. 74(1):25–27.

Steward, K. K., and W. H. Ornes. 1975. Assessing a marsh environment for wastewater renovation. J. Water Pollut. Control Fed. 47(7):1880–1891.

Terry, R. E., and R. L. Tate III. 1980. Effect of flooding on microbial activities in organic soils: Nitrogen transformations. Soil Sci. 129(2):88–91.

Teskey, R. O., and T. M. Hinckley. 1977*a*. Impact of water level changes on woody riparian and wetland communities. Vol. 1. Plant and soil responses. U.S. Fish Wildl. Serv., FWS/OBS-77/58.

Teskey, R. O., and T. M. Hinckley. 1977*b*. Impact of water level changes on woody riparian and wetland communities. Vol. 2. The southern forest region. U.S. Fish Wildl. Serv., FWS/OBS-77/59.

Thomas, V. M., and C. L. Holt. 1980. The degradation of (C-14) molinate in soil under flooded and nonflooded conditions. J. Environ. Sci. Health 15(5):475–484.

Thronson, R. E. 1978. Nonpoint source control guidance, agricultural activities. U.S. Environ. Prot. Agency, EPA/440/3-78/001.

Turner,R. E., J. W. Day, Jr., M. Meo, P.M. Payonk, T. B. Ford, and W. G. Smith. 1976. Aspects of land-treated waste application in Louisiana wetlands. Pages 145–167 *in* D. L. Tilton, R. H. Kadlec, and C. J. Richardson, eds. Freshwater wetlands and sewage effluent disposal. University of Michigan, Ann Arbor.

Turner, R. E., S. W. Forsythe, and J. J. Craig. 1981. Bottomland hardwood forests land resources of the southeastern United States. Pages 13–28 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

U.S. Forest Service. 1930-1983. Forest statistics (respective states). U.S. Dep. Agric., Resour. Bull.

van der Valk, A. G., D. B. Davis, J. L. Baker, and C. E. Beer. 1979. Natural freshwater wetlands as nitrogen and phosphorus traps for land runoff. Pages 457–467 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Wahid, P. A., C. Ramakrishna, and N. Sethunathan. 1980. Instantaneous degradation of parathion in anaerobic soils. J. Environ. Qual. 9:127–130.

Wahid, P. A., and N. Sethunathan. 1979. Involvement of hydrogen sulphide in the degradation of parathion in flooded acid sulphate soil. Nature (Lond.) 282(5737):401–402.

Weber, J. B. 1972. Interaction of organic pesticides with particulate matter in aquatic and soil systems. Pages 55–120 *in* R. G. Gould, ed. Fate of organic pesticides in the aquatic environment. Am. Chem. Soc., Adv. Chem. Ser. 111.

Wharton, C. H. 1970. The southern river swamp—a multiple-use environment. Bureau of Business and Economic Research, School of Business Administration, Georgia State University, Atlanta.

Wharton, C. H. 1977. Why save swamps? Nat. Conserv. News 27(3):5–9.

Wharton, C. H. 1980. Values and functions of bottomland hardwoods. Trans. N. Am. Wildl. Nat. Resour. Conf. 45:341–353.

Wharton, C. H., and M. M. Brinson. 1979. Characteristics of southeastern river systems. Pages 32–40 *in* R. R. Johnson and J.F. McCormick, tech. coords. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. U.S For. Serv., Gen. Tech. Rep. WO-12.

Wharton, C. H., W. M. Kitchens, and T. W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: A community profile. U.S. Fish Wildl. Serv., FWS/OBS-81/37.

Wharton, C. H., V. W. Lambou, J. Newsom, P. V. Winger, L. L. Gaddy, and R. Mancke. 1981. The fauna of bottomland hardwoods in southeastern United States. Pages 87–160 *in* J. R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific Publishing Co., New York.

Wharton, C. H., H. T. Odum, K. Ewel, M. Duever, A. Lugo, R. Boyt, J. Bartholomew, E. DeBellevue, S. Brown, and L. Duever. 1977. Forested wetlands of Florida—their management and use. Florida Division of State Planning, Tallahassee.

Williams, J. D., and C. K. Dodd, Jr. 1979. Importance of wetlands to endangered and threatened species. Pages 565–575 *in* P. E. Greeson, J. R. Clark and J. E. Clark, eds. Wetland functions and values: The state of our understanding. Am. Water Resour. Assoc., Tech. Publ. 79-2.

Willis, G. H., L. L. McDowell, J. F. Parr, and C. E. Murphree. 1976. Pesticide concentrations and yields in runoff and sediment from a Mississippi Delta watershed. Proceedings of the Federal Inter-Agency Sedimentation Conference, Sedimentation Committee. Water Resour. Counc. 3:53–64.

Willis, G. H., R. C. Wander, and L. M. Southwick. 1974. Degradation of trifluralin in soil suspensions as related to redox potential. J. Environ. Qual. 3:262-265.

Wolman, M. G., and L. B. Leopold. 1957. River flood-plains: Some observations on their formation. U.S. Geol. Surv. Prof. Pap. 282-C:87-109.

Wolman, M. G., and J. P. Miller. 1968. Magnitude and frequency of force in geometric processes. J. Geol. 69(1):54-74.

Woodwell, G. M. 1967. Toxic substances and ecological cycles. Sci. Am. 216(3):24-31.

Yancey, R. K. 1969. The vanishing Delta hardwoods and their wildlife resources. Louisiana Wildlife and Fisheries Commission, Governor's Seminar, Mississippi Delta Hardwoods, Little Rock, Ark., 1 December 1969.

Yarbro, L. A. 1983. The influence of hydrologic variations on phosphorus cycling and retention in a swamp stream ecosystem. Pages 223-245 *in* T. D. Fontaine III and S. M. Bartell, eds. Dynamics of lotic ecosystems. Ann Arbor Science Publishers, Ann Arbor, Mich.

Yoshida, T. 1975. Microbial metabolism of flooded soils. Pages 83-122 *in* E. A. Paul and A. D. McLaren, eds. Soil biochemistry. Vol. 3. Marcel Dekker, New York.

Yoshida, T., and T. F. Castro. 1970. Degradation of gamma-BHC in rice soils. Soil Sci. Am. Proc. 34:440-442.

Young, L. A., and H. P. Nicholson. 1951. Stream pollution resulting from the use of organic insecticides. Prog. Fish-Cult. 13:193-198.

A list of current *Resource Publications* follows.

153. Handbook of Toxicity of Pesticides to Wildlife, by Rick H. Hudson, Richard K. Tucker and M. A. Haegele. 1984. 97 pp.
154. Nonconsumptive Use of Wildlife in the United States, by William W. Shaw and William R. Mangun. 1984. 20 pp.
155. Ecology and Management of the Bullfrog, by R. Bruce Bury and Jill A. Whelan 1984. 23 pp.
156. Statistical Inference From Band Recovery Data—A Handbook, by Cavell Brownie, David R. Anderson, Kenneth P. Burnham, and Douglas S. Robson. 1985.
157. The Breeding Bird Survey: Its First Fifteen Years, 1965-1979, by Chandler S. Robbins, Danny Bystrak and Paul H. Giessler. 1986. 196 pp.
158. Techniques for Studying Nest Success of Dicks in upland Habitats in the Prairie Pothole Region, by Albert T. Klett, Harold F. Duebbert, Craig A. Faanes, and Kenneth F. Higgins. 1986. 24 pp.
159. Research and Development Series: An Annotated Bibliography, 1889-1985, by Thomas J. Cortese and Barbara J. Grosheck. 1986. In Press.
160. Manual of Acute Toxicity: Interpretation of Data Base for 410 Chemicals and 66 Species of Freshwater Animals, by Foster L. Mayer and Mark R. Ellersieck. 1986. 579 pp.
161. Interpretation adn Compendium of Historical Fire Accounts in the Northern Great Plains, by Kenneth F. Higgins. 1986. 39 pp.
162. Population Ecology of the Mallard VIII: Winter Distribution Patters and Survival Rates of Winter-Banded Mallards, by James D. Nichols and James E. Hines. 1986. In Press.

As the Nation's principal conservation agency, the Department of the Interior has responsibilty for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
OFFICE OF INFORMATION TRANSFER
1025 PENNOCK PLACE, SUITE 212
FORT COLLINS, COLORADO 80524

THIRD-CLASS MAIL

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF THE INTERIOR

PERMIT No. G-77

NOTE: Mailing lists are computerized. Please return address label with change of address.