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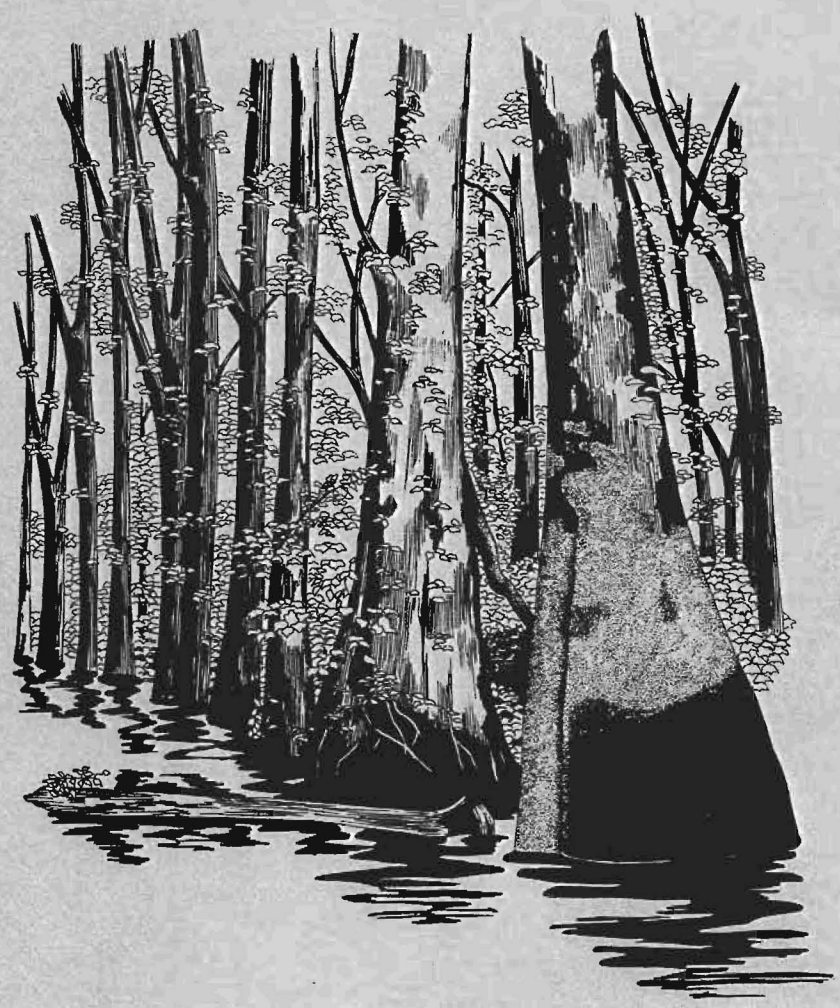
RESULTS OF A WORKSHOP CONCERNING ECOLOGICAL ZONATION IN BOTTOMLAND HARDWOODS



Fish and Wildlife Service

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August 1987

RESULTS OF A WORKSHOP CONCERNING ECOLOGICAL ZONATION IN BOTTOMLAND HARDWOODS

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INTRODUCTION

Under Section 404 of the Clean Water Act, the U.S. Environmental Protection Agency (EPA) has regulatory responsibilities concerning the discharge of dredged or fill material into the Nation's waters. In addition to its advisory role in the U.S. Army Corps of Engineers' permit program, EPA has a number of specific authorities, including formulation of the Section 404(b)(1) Guidelines, use of Section 404(c) to prohibit disposal at particular sites, and enforcement actions for unauthorized discharges. A number of recent court cases focus on the geographic scope of Section 404 jurisdiction in potential bottomland hardwood (BLH) wetlands and the nature of landclearing activities in these areas that require a permit under Section 404. Accordingly, EPA needs to establish the scientific basis for implementing its responsibilities under Section 404 in bottomland hardwoods.

EPA is approaching this task through a series of workshops designed to provide current scientific information on bottomland hardwoods and to organize that information in a manner pertinent to key questions, including the following. What are the characteristics of bottomland hardwoods (in terms of hydrology, soils, vegetation, fish, wildlife, agricultural potential, and the like) and how can the functions (e.g., flood storage, water quality maintenance, detrital export) that they perform best be quantified? How do perturbations like landclearing, levee construction, and drainage impact the functions that bottomland hardwoods perform and how can these effects best be quantified? And finally, how significant are the impacts and how is their significance likely to change under various management scenarios?

The first workshop in this series was held December 3-7, 1984, in St. Francisville, Louisiana. The workshop was attended by over 40 scientists and regulators (see ACKNOWLEDGMENTS section) and facilitated by the editors of this report under an Interagency Agreement between EPA and the U.S. Fish and Wildlife Service. The general objective of the workshop was to examine ways in which the structure and function of BLH ecosystems can be characterized and, in particular, to investigate the utility of a conceptual framework developed at a workshop held in Lake Lanier, Georgia, in 1980.[1] In this framework, the transition from aquatic habitats to upland habitats through a BLH ecosystem is divided into six zones based on concomitant variation in the soil moisture regime and associated vegetation (Table 1).[2] The zonation concept is of particular interest to EPA from at least two perspectives. The first is simply as a framework for organizing information. If the zones are discernible in the field, have recognizable characteristics, and perform identifiable functions, they might form a useful basis for tasks such as assessing the impacts of a particular site-specific activity. The second is the potential utility of the zonation concept in identifying the wetland portions of BLH communities. If the zones can be recognized in the field, and if one or more of them can be shown consistently to have wetland characteristics (i.e., perform functions, such as detrital export, often attributed to wetlands), while others do not, then the zones might have utility in identifying areas that fall under the jurisdiction of Section 404.

The workshop itself was divided into two parts. The first was a series of papers in which authors described current research and data-synthesis activities in the context of the zonation concept. The second was a series of

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[1]Clark, J.R., and J. Benforado, eds. 1981. Wetlands of bottomland hardwood forests. Elsevier Scientific, New York. 401 pp.

[2]Larson, J.S., M.S. Bedinger, C.F. Bryan, S. Brown, R.T. Huffman, E.L. Miller, D.G. Rhodes, and B.A. Touchet. 1981. Transition from wetlands to uplands in Southeastern bottomland hardwood forests. Pages 225-273 in J.R. Clark and J. Benforado, eds. Wetlands of bottomland hardwood forests. Elsevier Scientific, New York.

Table 1. General summary of major forest types found within the Gulf Coastal Plain of the United States in relation to soil moisture regime. Adapted from Huffman and Forsythe (1981)[1].

Soil moisture regime	Forest types[2]
I. Permanently inundated.	I. Aquatic vegetation
	Bottomland forest types
II. Intermittently exposed - soils are inundated or saturated by surface water or groundwater on a nearly permanent basis throughout the growing season of the prevalent vegetation,[3] except during extreme drought periods.	II. Atlantic White Cedar (97)[4] Bald Cypress (101) Bald Cypress - Tupelo (102) Mangrove (106) Pond Cypress (100) Pond Pine (98) Sweetbay - Swamp Tupelo - Red Bay (104) Water Tupelo - Swamp Tupelo (103)
III. Semipermanently inundated or saturated - soils are inundated or saturated by surface water or groundwater periodically[5] for a major portion of the growing season of the prevalent vegetation. Such conditions typically occur during the spring and summer months with a frequency ranging from 51 to 100 years per 100 years. The total duration of such seasonal events typically exceeds 25 percent of the growing season.	III. Black Willow (95) Cabbage Palmetto (74) Overcup Oak - Water Hickory (96)
IV. Seasonally inundated or saturated - soils are inundated or saturated by surface water or groundwater periodically for 1 to 2 months during the growing season of the prevalent vegetation. Such conditions typically occur up to the beginning of the summer season with a frequency ranging from 51 to 100 years per 100 years. The total duration of such seasonal events typically ranges from 12.5 to 25 percent of the growing season.	IV. Cottonwood (63) Live Oak (89 - wet site variants) Longleaf Pine (70 - wet site variants) Slash Pine (84 - wet site variants) Slash Pine - Hardwood (85) South Florida Slash Pine (111) Sugarberry - American Elm - Green Ash (93) Sweetgum - Willow Oak (92) Sycamore - Sweetgum - American Elm (94) Willow Oak - Water Oak - Diamondleaf (Laurel) Oak (99 - wet site variants)
V. Temporarily inundated or saturated - soils are inundated or saturated by surface water or groundwater periodically for short periods during the growing season but not totaling more than 1 month for the entire growing season of the prevalent vegetation. Such conditions typically occur with a frequency ranging from 1 to 50 years per 100 years. The total duration for such seasonal events typically ranges from 2 to 12.5 percent of the growing season.	V. Loblolly Pine (81 - wet site variants) Loblolly Pine - Hardwood (82 - wet site variants) Mesquite (68 - wet site variants) Southern Redcedar (73 - wet site variants) Swamp Chestnut Oak - Cherrybark Oak (91 - wet site variants)

Table 1. (Concluded)

Soil moisture regime	Forest types[2]
	Terrestrial or upland forest types
VI. Intermittently inundated or saturated - soils are rarely inundated or saturated by surface water or groundwater during the growing season of the prevalent vegetation, except during exceptionally high floods or extreme wet periods. Such conditions typically occur with a frequency ranging from 1 to 10 years per 100 years. The total duration of such seasonal events is typically less than 2 percent of the growing season.	VI. Cherrybark Oak (91 - dry site variants) Live Oak (89) Loblolly Pine (81 - dry site variants) Loblolly Pine - Hardwood (82 - dry site variants) Loblolly Pine - Shortleaf Pine (80 - dry site variants) Longleaf Pine (70 - dry site variants) Longleaf Pine - Scrub Oak (71) Longleaf Pine - Slash Pine (83 - dry site variants) Mesquite (68 - dry site variants) Sand Pine (69) Shortleaf Pine (75) Shortleaf Pine - Oak (76) Slash Pine (84 - dry site variants) Southern Redcedar (73 - dry site variants) Southern Scrub Oak (72) Swamp Chestnut Oak - Cherrybark Oak (91 - dry site variants) Sweetgum - Yellow Poplar (87 - dry site variants) Virginia Pine (79) Virginia Pine - Oak (78)

[1] Huffman, R.T., and S.W. Forsythe. 1981. Bottomland hardwood 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, New York.

[2] Placement of each forest type is based on maximum tolerance to soil moisture. Forest types may therefore be found associated with less frequently inundated sites; however, these associations are not shown. No attempt is made to order forest types within each soil moisture regime due to the high degree of within-group variability.

[3] Perennial plant species having an estimated areal coverage per hectare greater than or equal to 30 percent.

[4] Forest type number from: Society of American Foresters. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 pp.

[5] Periodically is used here to describe saturated soil conditions or inundation, resulting from ponding from groundwater, rainwater, overland flow, or stream flooding, that occurs on a detectable regular or irregular basis, with hours, days, weeks, months, or even years between events.

six workgroups in which participants discussed the zonation concept from the perspective of hydrology, soils, vegetation, fish, wildlife, and ecosystem processes. This report is a compilation of the written material from those workgroups, much of which was produced at the workshop. The formal papers presented in the first part of the workshop have been distributed to participants under separate cover, but are referenced in this report by citations such as: (Jones, workshop presentation).

Each of the workgroups was given the following set of tasks as a starting point for their discussions.

1. Comment on the oral presentations covering the subject matter of your workgroup (and other presentations if time permits), with particular reference to:

   A. Information from the presentation that supports the zonation concept in BLH communities and is useful in describing variations in functions across zones.

   B. Additional data or approaches that might be used in support of the ideas/conclusions expressed in the presentations.

   C. Data or approaches that might tend to contradict the ideas/conclusions expressed in the presentations.

   D. Topics that should be addressed in technical papers at subsequent workshops.

2. Identification of BLH zones and their boundaries in the field requires knowledge of specific indicators. For the discipline covered by your workgroup, please:

   A. Describe indicators that can be used to identify the zones.

   B. Describe and evaluate (e.g., strengths, weaknesses, exception areas, level of expertise required, time required) methods that might be used to measure these indicators.

   C. Describe important differences in the various zones in different geographic areas (e.g., the lower Mississippi River Valley versus the Atlantic Coastal Plain).

   D. Describe approaches other than ordination along a moisture (hydroperiod) gradient that might be useful in understanding structure and function of BLH ecosystems.

3. The following functions are often attributed to wetlands.

Hydrology

Flood control (storage and desynchronization)
Ground water recharge
Ground water discharge

Soils

Sediment trapping
Erosion control

Vegetation

Primary productivity
Timber harvest

Fish

Provision of food, cover, or other life requisites, both on and off site
Recreation associated with fish

Wildlife

Provision of food, cover, or other life requisites, both on and off site
Recreation associated with wildlife

Ecosystem Processes

Inputs, outputs, and processing of nutrients, energy/carbon, contaminants
Water quality maintenance

For this task, please:

A. Review and refine the set of functions to be considered by your workgroup.

B. Identify appropriate indicators or measures of the extent to which a particular BLH site performs these functions.

C. Describe quantitatively (where possible) as well as qualitatively how indicators of the functions vary by zone.

D. Document the rationale for your evaluation.

E. Identify, to the extent possible, the mechanisms or variables responsible for such variation across zones.

F. Describe important sources of variation other than zonation that influence performance of these functions (e.g., geographic location, adjacent land uses).

G. Describe quantitative as well as "quick and dirty" field evaluatior techniques for evaluating the functions identified for each zone. Also, describe nonfield evaluation techniques for more broad-scale applications (e.g., remote sensing, soils maps).

4. Prepare written and oral (20-minute) reports.

5. If time permits, critique the questions and answers from the Lake Lanier workshop with respect to:

   A. Completeness and accuracy given information acquired since that workshop.

   B. Additional questions that need to be addressed.

These tasks were suggested only as a potentially useful way of organizing discussions. As is evident from the following reports, the workgroups did not hesitate to adopt other approaches that were more relevant to their subject matter.

HYDROLOGY WORKGROUP REPORT

Johannes van Beek (Chairman), John Elder,
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INTRODUCTION

Bottomland hardwood (BLH) ecosystems exist in floodplains where the soils within the plant rooting zone are inundated or saturated for various periods during the growing season (Huffman and Forsythe 1981). The hydrologic regime of the adjacent river and the morphology of the floodplain are the primary factors affecting inundation at BLH sites. Secondary factors, such as ground water discharge, upland runoff, precipitation, soil characteristics, and evapotranspiration, interact with river hydrology and floodplain morphology to produce a soil saturation gradient from the river channel to the uplands. River hydrology also governs the sedimentation processes that, together with the moisture regime over very long time periods, determine soil types along the floodplain cross section. The interaction of the hydrologic regime and edaphic factors results in a complex environmental gradient influencing the plant associations found in BLH sites.

The Hydrology Workgroup considered two questions concerning the hydrologic regime in bottomland hardwoods. First, can the hydrologic regime be used to characterize zones within floodplain ecosystems and second, to what extent do hydrologic functions vary along a gradient from river channel to uplands? The following discussions focus on surface water hydrology, rather than ground water, because of its relative importance and because of the relative scarcity of studies concerning surface water/ground water interactions in BLH ecosystems.

CHARACTERIZATION OF ZONES

ZONAL INDICATORS

A number of indicators that reflect hydrologic conditions can be observed in the field. These include drift lines, water marks, crawfish burrows, height of cypress knees, sedimentation, and others. However, none of these is considered useful in the delineation of BLH zones because they indicate only that an area has been inundated in the past; they do not provide information concerning the frequency, timing, and duration of flood events. More informative indicators such as long-term water level or soil moisture data are not usually available.

METHODS

Hydrologic Indicators

The most useful, specific, hydrologic indicators for the delineation of BLH zones are believed to be those derived from the combination of gaging and topographic data and consideration of the hydrologic connection to the gaged water body. The U.S. Army Engineer Waterways Experiment Station (WES) has evaluated the relationship between distribution of BLH vegetation and the percent of the growing season during which a saturated soil condition occurs as a result of stream flooding (Jones, workshop presentation). As a hydrologic characteristic, this percent duration includes both the period of inundation and the period the soil remains saturated after flood recession.

The WES study adopted, with minor modifications, the percent duration limits (Table 2) defined for each zone at the 1980 Lake Lanier BLH workshop (Larson et al. 1981). Stream flow gaging data, topography, soil characteristics, and evapotranspiration information were then used to identify elevation bands corresponding to these soil saturation limits at 17 sites in the southeastern United States. Vegetation plots within each zone were sampled and

Table 2. Percent of the growing season during which saturated soil conditions occur.

Zone	% duration
I	100
II	>75-100
III	>25-75
IV	>12.5-25
V	>5-12.5
VI	0-5

analyzed to determine if the observed differences between zones were statistically significant. The study concluded that percent duration was a useful hydrologic indicator for explaining differences in floodplain vegetation communities. Other studies have also shown vegetation differences across hydrologic gradients, although the gradients do not always conform to the WES zonation scheme. Examples include two community mapping studies: (1) Sharitz (workshop presentation) in the Savannah River floodplain, South Carolina; and (2) Leitman et al. (1983) and Leitman (1984) in the Apalachicola floodplain, Florida.

Percent duration is most useful for describing BLH zones or comparing BLH zones in hydrologic systems with similar geomorphic and hydrologic characteristics. Under these conditions, the percent duration can also imply other characteristics of the hydrologic regime (e.g., depth, velocity, frequency, sediment load, timing). Depending on the desired resolution, these similar hydrologic systems may range from entire drainage basins of a given order to areas within a floodplain that function as a discrete part of the hydrologic

system. Percent duration is less useful for comparing BLH zones in systems with different geomorphic and hydrologic characteristics (e.g., East coast vs. Gulf coast) because the same percent duration value may result from very different conditions.

Although hydrologic indicators such as percent of the growing season with saturated soil conditions can be used to delineate BLH zones, the detailed gaging, topographic, soils, and evapotranspiration data required are not generally available and are time consuming and expensive to collect in the field. Therefore, alternative indicators will have to be used for most wetland determination surveys.

Other Indicators

The hydrologic data base described above for the WES study was used to define a flood tolerance index (FTI) for all vegetation species sampled (Theriot, workshop presentation). The numerical value of this index is related to the zone, or zones, in which the plant was found. An approach based on FTI values might be used in the following way to identify BLH zones at a particular site and to infer general hydrologic characteristics. Vegetation would first be sampled using presence/absence or more quantitative methods. Then, the five to ten most important species/size classes (based on numbers, canopy coverage, biomass, etc.) would be used to calculate an average or weighted average FTI for the site.

FTI values for a site would give a general idea of the zone in which that site is located and would facilitate comparison of that site with other sites in the same system. However, the precise position within the zonal continuum could not be read from the FTI value. For example, if the FTI for a site is 2.7, it would be reasonable to say that the site is in zone II but it would not be accurate to conclude that the site has saturated soil conditions about 40 percent of the time (seven-tenths of the difference between the extremes of zone II as shown in Table 2). The FTI value would also clearly indicate that the site has saturated soil conditions for a longer time than another site with an FTI of 4.1.

A further limitation of this approach is that the FTI values would not distinguish between the various ways that a particular hydrologic condition may have come about at any given site. The FTI value does not indicate the relative contributions of frequent flooding events, backwater flooding, ground water discharge, poor drainage, precipitation, evapotranspiration, and other factors that characterize the moisture regime and are major elements in determining the value of a given BLH system for vegetation, wildlife, and for providing certain ecological processes.

If a parameter such as the FTI value, based on increments of percent duration of inundation and saturation, is proven to be a reliable indicator within a given hydrologic system, then vegetation may be used to infer hydrologic conditions when the hydrologic regime has not been significantly modified and no gaging data are available. However, the latter approach only allows inferences concerning the moisture regime. Perhaps additional studies could be initiated to correlate vegetation information (e.g., FTI values, species composition) and soil information with particular hydrologic indicators such as flood frequency, duration, or timing.

GEOGRAPHICAL DIFFERENCES

Important differences in hydrology may exist between the various BLH zones in different geographic areas. These differences are the result of various physical characteristics of the drainage basins including climate, basin size, topography, and land use. These in turn produce significant differences in the annual stream hydrographs, the extent of backwater flooding, sediment load, surface water retention, and other important characteristics of the hydrologic regime at a given site. This may result in very similar or very different vegetation communities for areas whose hydrologic regimes differ greatly. Differences between geographic areas may be exemplified by comparing the wide floodplains and broad-crested hydrographs of the major streams within the Mississippi River Valley and the multiple peaks of streams occupying narrow valleys along the Atlantic Coast. Even within geographic

areas and vegetation zones, major differences may exist, as illustrated by areas along the lower Mississippi River that are subject to direct overflow versus backwater flooding.

EVALUATION APPROACHES

Structure and function of a BLH ecosystem are determined to a large extent by the manner in which the area functions hydrologically. For instance, the function of a BLH ecosystem relative to fisheries depends on its physical connection to the hydrologic system and on the extent and quality of associated permanent water bodies. Conversely, its function relative to terrestrial wildlife in part depends on the extent of annual flooding and the extent and quality of associated refuge areas during flood conditions. Functions with regard to flood control and water quality equally depend on the physical connection with stream systems and on characteristics of adjacent areas.

Accordingly, it is believed that any approach useful in understanding the function of a given bottomland hardwood community must focus on the manner in which the BLH ecosystem functions hydrologically and must consider the entire zonation in a holistic approach. By developing a set of criteria to assess the value of a BLH site with regard to a given function and by applying these criteria on a hydrologic unit basis, a unified approach can be developed that is applicable to estimation of total value, impact analysis, and management.

FUNCTIONS OF ZONES

Hydrologic functions commonly attributed to wetlands are flood control (including flood storage and desynchronization), ground water recharge, ground water discharge, and water quality protection and restoration. These functions have probably been studied more thoroughly in wetlands of other regions of the United States than in the Southeast. No technical information was presented

at this workshop concerning the hydrology functions. The following discussion represents only general observations on the subject based on general understanding of hydrologic processes in the Southeast. Additional information specific to these functions may be found in the literature.

For flood control, the position of the BLH site within the basin, the size of the basin relative to the BLH area, and the storage volume are very important in determining the degree of influence. The position of the wetland in relation to sub-basins is an important characteristic in flood timing (desynchronization or synchronization). The flood storage function, if any, would probably not be recognized without a loss, or partial loss, of the BLH area. Loss, in this sense, means removal of the area from the active floodplain (e.g., by levee construction) as opposed to merely changing the land use (e.g., conversion to agriculture). Resistance to water flow (roughness), evapotranspiration, soil saturation, and ground water exchange within the BLH system influence the degree to which the flood control function is performed. Parameters affecting the "roughness" of the flow area consist of size and density of vegetation, debris, and microtopography (depressions). These factors can be significant in the wide, heavily wooded floodplains unique to the Southeast.

Ground water functions are highly site specific relative to the local and regional geology. None of the workgroup participants had any special experience in this discipline or in the area of water quality.

ZONAL DIFFERENCES

Of the factors discussed above, only a few could be specifically related to the zonal concept. Concerning the flood control function, the lower zones provide more flood storage per unit area than higher zones. This deduction simply results from the fact that the lower zones have a greater depth at a given water level and thus more available vertical space for storage than do the higher, less frequently flooded zones. Also, the higher zones may tend to

have a greater "roughness" due to greater density of understory. The greater "roughness" causes an increase in friction loss in the flow area, decreasing velocities and increasing stages, therefore providing some measure of flood reduction. The stage increase provides additional storage area while the velocity reduction may provide changes in flood hydrograph timing. Variations in evapotranspiration and soil moisture probably could be related to zones. However, these factors may be relatively insignificant with respect to flood control. Variations in ground water discharge and recharge are probably relatively insignificant on a zonal basis. Other variations, such as regional geology, are probably more important.

SOURCES OF VARIABILITY

In general, for hydrologic functions, variation across zones is probably insignificant compared to other variations such as geographic location, position of the BLH in the basin, the annual number of flood peaks (flashiness), and basin topography. Some of these variations may be separated between the lower Mississippi Valley and streams along the Atlantic Coast.

EVALUATION METHODS

Basin and BLH positional relationships can be determined from available maps, photography, and LANDSAT imagery. Topographic data (such as quadrangle maps) provide information for determining storage volumes. Zone widths and average depth (elevational differences) can be obtained through a combined use of topographic maps, photographs, and field verification. Values for roughness characteristics can be obtained from flood study reports by the U.S. Army Corps of Engineers and U.S. Geological Survey. Various computer models (ground water models, flood routing models, backwater computations, floodplain transect analyses) exist to evaluate most aspects of these functions. The use of these models is quite complex and requires the expertise of experienced hydrologists.

CONCLUSIONS

There appears to be no argument among wetland ecologists that hydrologic processes and conditions constitute a key determinant of the structure and function of BLH systems. The variation in plant species and soils across different zones can indeed be explained largely on the basis of hydrologic differences, in particular, the duration of flooding. However, vegetation characteristics may differ for identical hydrologic conditions as a result of topography, soil conditions as related to sediment characteristics, and the source of flood waters. Therefore, hydrologic variables alone should not be used to define BLH zones and evaluate their functions and value. If a zonation concept is to be applied, zone boundaries must be carefully determined by use of combined information on vegetation, soils, and hydrology. The use of multiple parameters becomes particularly important in view of the many areas in which development has produced modification of the flooding regime that may not yet be reflected by soils and woody vegetation because of limited response time.

The general topic of hydrology in wetlands, important as it is in BLH investigations, was hardly addressed in this workshop. There is a need to provide more of this type of information in future workshops. In particular, it is suggested that one or more hydrologists with expertise in ground water-surface water interactions and/or evapotranspiration be invited. Participation of ground water and surface water modelers would also be helpful. Geographic differences are apparent and may constitute a major problem that must be addressed if the zonation concept is to be applied successfully. Further attention to differences among systems in the lower Mississippi Valley, Atlantic Coast, and Florida Gulf Coast is needed.

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SOILS WORKGROUP REPORT

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INTRODUCTION

Historically, the term bottomland hardwoods has been utilized to describe forests that occur on floodplains in the southern and central United States. Under natural conditions, there are definite, identifiable bottomland hardwood (BLH) plant communities within these floodplains. These transitional BLH plant communities and adjacent aquatic systems and upland forests were delineated into six zones (Table 1) by participants at the Bottomland Hardwood Wetlands Workshop held in Lake Lanier, Georgia, in June, 1980 (Clark and Benforado 1981). Soil scientists have long recognized that distinct soils occur in these different BLH communities and soil surveys consistently document these relationships. Even when the indicator plant communities are removed from an area, these sites retain their identity through their soil characteristics. Based on this information, the Soils Workgroup attempted to delineate soils in selected Southeastern floodplains into five of the six ecological zones described at Lake Lanier. This delineation was based on soil classification and on various physicochemical characteristics. Zone I was not treated because it represents permanently inundated aquatic habitat.

Efforts of the Soils Workgroup indicate that distinct correlations occur among soil hydrologic regimes, as evidenced by physicochemical properties, soil types, and vegetation for the five zones. The redox potential, oxygen content, and water table of hydric soils, for example, indicate their anaerobic

nature, and the vegetation on these sites is typically adapted to growing in standing water or in saturated soils. Nonhydric soils, on the other hand, are typically vegetated by species adapted to aerobic soil conditions.

Since soil surveys are recognized and used worldwide for transferring agrotechnology, the Soils Workgroup proposes that soil zonation, as determined by soil series name and supported by physicochemical characteristics as shown in this report, be used to delineate transition zones in bottomland hardwood floodplains. An added benefit of using soil series names and map units to delineate these zones is the vast amount of interpretive data, stored in the Soil Conservation Service's computers, that is accessible by soil series name.

PHYSICOCHEMICAL CHARACTERISTICS AND CLASSIFICATION OF SOUTHERN FLOODPLAIN SOILS

LOWER MISSISSIPPI RIVER FLOODPLAIN SOILS

Physicochemical characteristics and soil series classification information for a hypothetical cross section of the lower Mississippi River floodplain are described in Table 3 and illustrated in Figure 1. A description of these parameters is also presented in considerable detail by zones.

Zone II

Water is the overriding factor influencing the soil properties of this zone. Anaerobic conditions (i.e., the absence of oxygen) prevail throughout most of the year due to saturated soil conditions. These soils (clays) developed through sediment deposition in very low-energy environments. Their gleying is evidence of a strongly reduced condition. The soils commonly found in this zone include the Maurepas, Barbary, and Fausse series.

Soil oxygenation. Anaerobic conditions prevail throughout the year due to saturated soil conditions.

Table 3. Physicochemical characteristics of floodplain soils and soil series on the Mississippi River.

	Zone II	Zone III	Zone IV	Zone V	Zone VI
Soil series (name)	Maurepas, Barbary, Fausse	Sharkey, Alligator (flooded phases)	Commerce, Dundee, Tensas, Tunica	Askew, Bruin, Dubbs	Robinsonville, Crevasse
Soil oxygenation	Anaerobic	Anaerobic to aerobic	Aerobic to anaerobic	Aerobic	Aerobic
Soil drainage and wetness	Very poorly drained hydric	Poorly drained hydric	Somewhat poorly drained nonhydric	Moderately well drained nonhydric	Well to excessively drained nonhydric
Soil moisture regime (soil taxonomy)	Peraquic	Aquic (typic)	Aquic (aeric)	Udic (aquic)	Udic (typic)
Soil capability class	VI, VIIw, VIIIw	IIIw, IVw, Vw	IIw, IIIw	I	I, IIs
Hydrology (duration of saturation during growing season)	≈100%, except in extreme drought	>25 - 75%	>12.5 - <25%	>2 - <12.5%	<2%
Flooding	Continually, except in extreme drought	Freq. 11-100 yrs/ 100 yrs	Rarely 1-10 yrs/100 yrs	Very rarely 1 yr/100 yrs	Not flooded
Vegetation	Water tupelo, cypress, buttonbush, swamp privet, black willow	Water hickory, black willow, overcup oak	Sweetgum, sugarberry, willow oak	Cherrybark oak, swamp chestnut oak	Upland varieties, cherrybark oak, live oak, yellow poplar
Surface texture	Peats, mucks, clays (fluid)	Mucks, clays (firm)	Silty clay loam, loam, silt loam	Silt loam	Sandy loam
Subsoil texture	Peats, clays (fluid to firm)	Clays (firm)	Silty clay loam, loam, silt loam	Loams	Loams, sandy loam loamy sands
Soil pH	6.5 - 7.5	4.8 - 7.5	4.5 - 7.2	4.5 - 6.8	4.5 - 6.5
Soil classification (soil taxonomy)	Typic Medisaprist Typic Hydraquent Typic Fluvaquent	Vertic Haplaquept	Aeric Fluvaquent Aeric Ochraqualf Vertic Ochraqualf Vertic Haplaquept	Fluvaquentic Euthrochrapt Typic Hapludalf	Typic Udipsammant

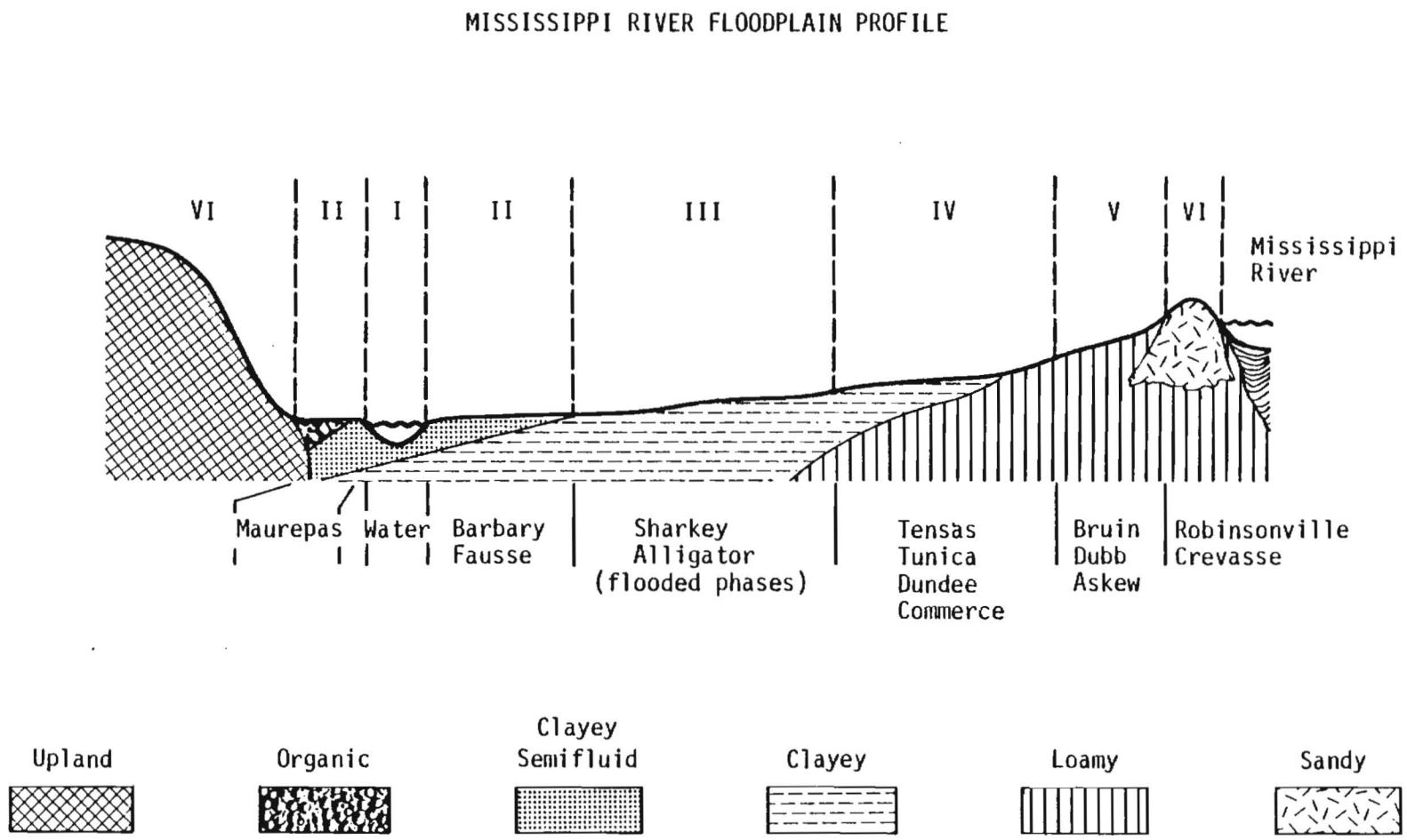


Figure 1. Idealized floodplain profile from the lower Mississippi River region showing soil series distribution by ecological zones.

Soil drainage and wetness. These soils are very poorly drained and are classed as hydric soils.

Soil moisture. The soil moisture regime is peraquic. Soils are intermittently exposed--soil saturation or inundation by ground or surface water typically occurs throughout the year.

Soil capability class. The soils are dominantly in Capability Classes VI, VIIw, and VIIIw.

Hydrology. Zone II soils are usually permanently ponded or flooded. During extended dry periods the soil surface is exposed; nevertheless, ground water (water table) or perched water extends to near the soil surface and maintains saturated conditions nearly 100% of the growing season. Zone II sites usually lie within the 1-year floodplain along streams and rivers but may include frequently or permanently ponded flats and basins outside of the 1-year floodplain.

Vegetation. Water tupelo (*Nyssa aquatica*), cypress (*Taxodium* sp.), buttonbush (*Cephalanthus occidentalis*), swamp privet (*Forestiera acuminata*), and black willow (*Salix nigra*) are characteristic of this zone.

Texture. Clays, mucks, and peat dominate the surface layer. Clayey material dominates the subsoil layer.

Soil pH. The pH of the soil series in this zone ranges from about 6.5 to 7.5.

Zone III

Zone III soils are intermittently flooded with alternating long anaerobic periods and short aerobic periods as reflected by brownish mottles. These soils developed in low-energy sediment depositional conditions (clays). The

soil-water-air relationship is such that vegetative root respiration is possible, although often sporadically, during the growing season. The soils commonly found in this zone include the flooded phases of the Sharkey and Alligator series.

Soil oxygenation. Anaerobic conditions predominate, but aerobic conditions occur sporadically during the growing season.

Soil drainage and wetness. These soils are poorly drained and are classed as hydric soils.

Soil moisture. The soil moisture regime is typic aquic with peraquic cycles. These soils are intermittently exposed during the growing season. Soils exhibit an aquic moisture regime and hydric soil conditions.

Soil capability class. The soils in zone III are dominantly in Capability Classes Vw, IVw, and IIIw.

Hydrology. Zone III soils are usually frequently flooded (51 to 100 years/100 years) to occasionally flooded (11 to 50 years/100 years). The fluctuating water table extends to the surface during most of the growing season (>25% to 75% of the time) but may recede to about 1 m below the surface during extended dry periods.

Vegetation. The predominant vegetation in this zone includes water hickory (*Carya aquatica*), black willow, overcup oak (*Quercus lyrata*), and persimmon (*Diospyros virginiana*).

Texture. Clays and mucks dominate the surface layers and clayey material dominates the subsoil.

Soil pH. The pH for the soils in this zone ranges from about 4.8 to 7.5.

Zone IV

Soils in zone IV exhibit a high range of oxidation-reduction conditions as depicted by a preponderance of brownish, yellowish, or reddish mottles. Soil texture and prolonged periods of nonsaturated conditions create an ideal soil-air-water relationship that is favorable to vegetative root respiration during the growing season. The soils developed in moderate-energy sediment depositional conditions (silty clay loam and silt loam). The soils commonly found in this zone include the Tensas, Tunica, Dundee, and Commerce series.

Soil oxygenation. Aerobic conditions predominate; nevertheless, anaerobic conditions do occur, but usually not during the growing season.

Soil drainage and wetness. These soils are somewhat poorly drained. They are typically nonhydric but have hydric characteristics.

Soil moisture. The soil moisture regime is dominantly aeric aquic; that is, the soils exhibit an aquic moisture regime but aeric conditions override. These soils exhibit hydric soil conditions.

Soil capability class. The soils in zone IV are dominantly in Capability Classes IIIw and IIw.

Hydrology. Zone IV soils have a fluctuating water table that may extend to the surface of the soil for more than 12.5% but less than 25% of the growing season. Generally, the water table is about 1 m below the soil surface. The soils are rarely flooded (1 to 10 years/100 years) during the growing season.

Vegetation. Sweetgum (*Liquidambar styraciflua*), sugarberry (*Celtis laevigata*), willow oak (*Q. phellos*), green ash (*Fraxinus pennsylvanica* var. *lanceolata*), and sycamore (*Platanus occidentalis*) are common species in this zone.

Texture. Silty clay loams, loams, and silt loams dominate both the surface layers and the subsoil.

Soil pH: The soil pH ranges from 4.5 to 7.2.

Zone V

Soils in zone V exhibit a high level of oxidation as depicted by a brown and yellow soil matrix with few gray mottles. Soil texture, structure, and natural drainage create an ideal soil-air-water relationship that is very favorable to vegetative root respiration and growth. The soils developed in moderately high-energy sediment depositional conditions (silt loam and very fine sandy loam). The soils commonly found in this zone are the Askew, Bruin, and Dubb series.

Soil oxygenation. Aerobic conditions predominate during the whole year.

Soil drainage and wetness. These soils are moderately well drained and are classed as nonhydric.

Soil moisture. The soil moisture regime is udic but on the aquic side (udic-aquic). These soils do not exhibit hydric soil conditions.

Soil capability class. The soils in zone V are dominantly in Capability Class I.

Hydrology. Zone V soils have a water table that is typically more than 1 m below the soil surface; nevertheless, the soil may be saturated from 2% to 12.5% of the growing season. The soils in zone V are very rarely flooded, less than 1 year/100 years during the growing season.

Vegetation. Cherrybark oak (*Q. falcata* var. *pagodifolia*), swamp chestnut oak (*Q. michauxii*), and sassafras (*Sassafras albidum*) are common in zone V.

Texture. Silt loams and very fine sandy loams dominate both the surface layers and the subsoil.

Soil pH. The soil pH ranges from 4.5 to 6.8.

Zone VI

Zone VI soils exhibit oxidized conditions, as depicted by matrix soil colors of reds, yellows, and browns. Soil texture and structure, and the natural soil drainage, result in conditions favorable to vegetative root respiration throughout the year. The soils developed in high-energy sediment depositional conditions (sandy loam and loamy sand). The soils commonly found in this zone are the Robinsonville and Crevasse series.

Soil oxygenation. Aerobic conditions predominate throughout the growing season and during the whole year.

Soil drainage and wetness. The soils are well drained to excessively drained and are classed as nonhydric soils.

Soil moisture. The soil moisture regime is udic (typic-udic). These soils do not exhibit hydric soil conditions.

Soil capability class. The soils in zone VI are in Capability Classes I and IIs (droughty).

Hydrology. The soils in zone VI are saturated less than 2% of the growing season. They do not flood.

Vegetation. Upland vegetation in zone VI includes cherrybark oak, live oak (*Q. virginiana*), yellow poplar (*Liriodendron tulipifera*), and white oak (*Q. alba*).

Texture. Very fine sandy loams, sandy loams, and loamy sands dominate both the surface layers and the subsoil.

Soil pH. Soil pH ranges from 4.5 to 6.5.

SAVANNAH RIVER FLOODPLAIN SOILS

Physicochemical characteristics and soil series classification information for a stylized cross section of the Savannah River in Aiken County, South Carolina, are described in Table 4 and illustrated in Figure 2. These parameters are also described in considerable detail for each zone.

Zone II

Water is the overriding factor influencing the soil properties in zone II. Anaerobic conditions prevail throughout the year due to saturated soil conditions as evidenced by dark grayish-brown surface and gray subsurface layers. The dominant soils found in this zone are the Chastain series.

Soil oxygenation. Anaerobic conditions prevail throughout the year due to saturated soil conditions.

Soil drainage and wetness. Soils are poorly drained and are classed as hydric.

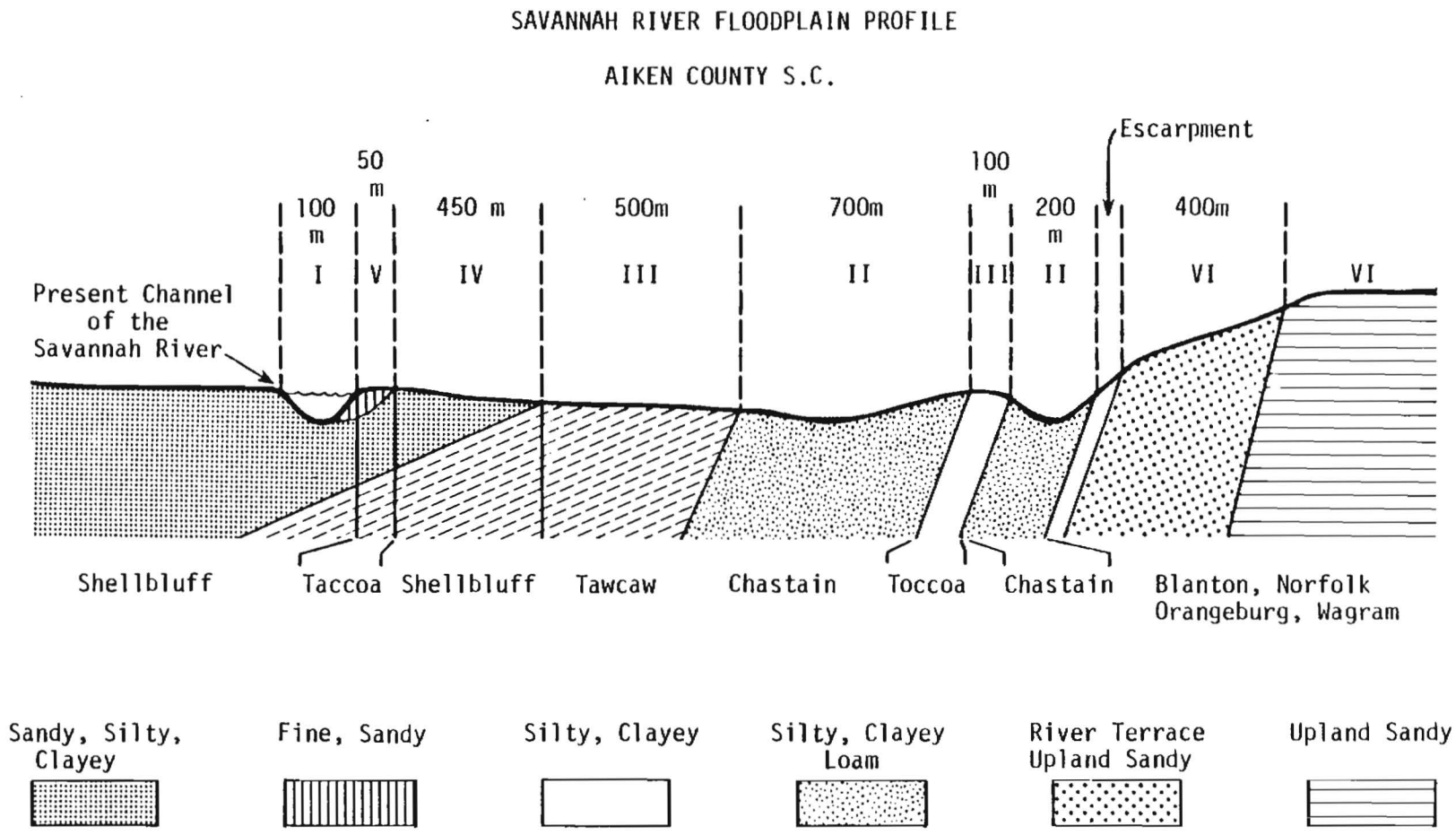
Soil moisture. Soils in this zone exhibit a peraquic moisture regime and hydric conditions. Soils are intermittently exposed--soil saturation or inundation by ground or surface water typically occurs throughout the growing season and throughout the year.

Soil capability class. The soils are dominantly in Capability Class VIw.

Hydrology. Zone II soils are permanently ponded or flooded. During extended dry periods the soil surface may be exposed; however, ground water (water table) or perched water extends to the soil surface and maintains saturated conditions. Zone II soils usually lie within the 1-year floodplain along streams and rivers but may include flats and basins, outside of the 1-year floodplain, that are permanently ponded from ground water and rainfall sources.

Table 4. Physicochemical characteristics of floodplain soils and soil series on the Savannah River, Aiken County, South Carolina.

	Zone II	Zone III	Zone IV	Zone V	Zone VI
Soil Series	Chastain	Tawcaw	Shellbluff	Toccoa	Blanton, Norfolk, Orangeburg, Wagram
Soil Oxygenation	Anaerobic	Anaerobic to aerobic	Dominantly aerobic to anaerobic	Aerobic	Aerobic
Soil drainage and wetness	Poorly drained, hydric	Somewhat poorly drained, hydric	Moderately well to well drained, nonhydric	Moderately well to well drained, nonhydric	Moderately well to well drained, nonhydric
Soil moisture regime (soil taxonomy)	Aquic to Peraquic	Aquic	Udic	Udic	Udic
Soil capability class	VIw	VIw	IIIw	IIIw	I, IIe, IIIe
Hydrology (duration of saturation during growing season)	≈100% except in extreme drought	>25% - 75%	>12.5% - <25%	>2% - <12.5%	<2%
Flooding	Continually except in extreme drought	Freq. 11-100 yrs/ 100 yrs	Rarely 1-10 yrs/ 100 yrs	Very rarely 1 yr/100 yrs	Not flooded
Vegetation	Bald cypress, water tupelo, laurel oak	Water tupelo, laurel oak	Cherrybark oak, Shumard oak, sweetgum, yellow poplar	Yellow poplar, southern red oak	Pine, mixed hardwoods
Surface texture	Silty clay loam	Silty clay loam	Silty clay loam	Fine sands	Sandy loams
Subsoil texture	Silty clay	Silty clay	Silty clay loam	Loamy	Sandy clay loams
Soil pH	4.5 - 6.0	4.5 - 6.5	4.5 - 6.5	5.1 - 6.5	4.5 - 6.0
Soil classification (soil taxonomy)	Typic Fluvaquents	Fluvaquentic Dystochrepts	Fluventic Dystrochrepts	Typic Udifluvents	Grossarenic Paleudults Typic Paleudults Arenic Paleudults



* Information taken from V. Rogers (in prep.) Soil Survey of the Savannah River Plant Area, U.S. Soil Conservation Service

Figure 2. Idealized floodplain profile from the Savannah River in Aiken County, South Carolina, showing soil series distribution by ecological zones.

Vegetation. Bald cypress (*T. distichum*), water tupelo, and laurel oak (*Q. laurifolia*) are the most common tree species in this zone.

Texture. Surface layers are dominated by silty clay loams. Silty clays dominate subsurface layers.

Soil pH. Soil pH ranges from 4.5 to 6.0.

Zone III

These are intermittently flooded soils with alternating long anaerobic periods and short aerobic periods as reflected by brownish soil mottles. These soils form on old floodplains subject to occasional flooding but receive little fresh sediment. The soil-water-air relationship is such that vegetative root respiration is possible, although often sporadic, during the growing season. The dominant soils in this zone are the Tawcaw series.

Soil oxygenation. Conditions are dominantly anaerobic with brief aerobic periods during the growing season.

Soil drainage and wetness. These soils are somewhat poorly drained, but are hydric soils.

Soil moisture. The soil moisture regime is aquic. Soils are periodically flooded by runoff and ground water. Flooding may be of long duration during the growing season.

Soil capability class. The soils are dominantly in Capability Class VIw.

Hydrology. Zone III sites are frequently flooded (51 to 100 years/100 years) to occasionally flooded (11 to 50 years/100 years) and flooding or inundation occurs for an extended period in the growing season. The fluctuating water table extends to the surface during most of the growing season (>25% to 75% of the time), but may recede to about 1 m below the surface during extended dry periods.

Vegetation. Water tupelo and laurel oak are major components of the natural forest stand.

Texture. Silty clay loam dominates the surface layers. Silty clay dominates the subsoil.

Soil pH. Soil pH ranges from 4.5 to 6.5.

Zone IV

Zone IV soils undergo alternating periods of aerobic to anaerobic conditions. However, aerobic conditions dominate the surface layers as evidenced by dark red mottles. Soil texture and prolonged periods of nonsaturation create an ideal soil-water-air relationship that is favorable to vegetative root respiration during the growing season. The soils developed in fluvial sediments on floodplains along streams that drain from the Piedmont. Soils are dominantly of the Shellbluff series.

Soil oxygenation. Soils are dominantly aerobic; however, anaerobic conditions may occur, but usually not during the growing season.

Soil drainage and wetness. Soils are moderately well to well drained and are classed as nonhydric.

Soil moisture. Soils exhibit a udic moisture regime. Aerobic conditions prevail for most of the year. These soils do not exhibit hydric conditions.

Soil capability class. The soils are dominantly in Capability Class IIIw.

Hydrology. Zone IV soils have a fluctuating water table that may extend to the surface of the soil for more than 12.5% but less than 25% of the time during the growing season. Generally, the water table is 1 m below the soil surface. The soils are rarely flooded (1 to 10 years/100 years) during the growing season.

Vegetation. Major tree species in this zone include sweetgum, yellow poplar, cherrybark oak, and Shumard oak (Q. shumardii).

Texture. Surface layers are silty clay loam. The subsoil is dominated by silty clay loam.

Soil pH. Soil pH ranges from 4.5 to 6.5.

Zone V

Soils exhibit a high level of oxidation as depicted by a brown or yellow soil matrix with few gray mottles. These soils form in alluvium on floodplains. Soil texture, structure, and natural drainage create an ideal soil-air-water relationship that is very favorable to vegetative root respiration and growth. These soils are dominantly aerobic. The dominant soils in this zone are the Toccoa series.

Soil oxygenation. Aerobic conditions predominate during the whole year.

Soil drainage and wetness. Soils are moderately well drained to well drained and are nonhydric.

Soil moisture. The soil moisture regime is udic. Brief flooding is common throughout the year. These soils do not exhibit hydric soil conditions.

Soil capability class. The soils are dominantly in Capability Class IIIw.

Hydrology. Zone V soils have a water table that is typically more than 1 m below the soil surface; nevertheless, the soil may be saturated from 2% to 12.5% of the growing season. The soils in this zone are very rarely flooded, less than 1 year/100 years during the growing season.

Vegetation. Yellow poplar, southern red oak (Q. falcata), and sweetgum are major components of the forest in zone V.

Texture. Surface layers are dominated by fine sands and loams. The subsoil is dominated by loams.

Soil pH. Soil pH ranges from 5.1 to 6.5.

Zone VI

Soils exhibit oxidized conditions as evidenced by matrix soil colors of reds, yellows, and browns. Soil texture and structure, and the natural soil drainage, result in conditions favorable to vegetative root respiration throughout the year. These upland soils are dominated by the Blanton, Norfolk, Orangeburg, and Wagram series.

Soil oxygenation. Aerobic conditions prevail throughout the growing season and during the whole year.

Soil drainage and wetness. Soils are moderately well drained to well drained and are nonhydric.

Soil moisture. Soils exhibit a udic moisture regime. Soils are flooded or saturated only during exceptionally wet periods. These soils do not exhibit hydric soil conditions.

Soil capability class. The soils are dominantly in Capability Classes I, IIe, and IIIe.

Hydrology. Soils in zone VI are saturated less than 2% of the growing season. These soils do not flood.

Vegetation. Upland vegetation, including pine and mixed hardwoods, dominates this zone.

Texture. Surface layers are dominated by sandy loams. Sandy clay loams dominate the subsoil.

Soil pH. Soil pH ranges from 4.5 to 6.0.

MEYER'S BRANCH FLOODPLAIN SOILS

Physicochemical characteristics and soil series information for a typical cross section of Meyer's Branch, Aiken County, South Carolina, are shown in Table 5 and illustrated in Figure 3. Individual parameters for each zone are also described in more detail in the following discussions.

Zone II

Water is the overriding factor influencing the soil properties in this zone. Anaerobic conditions prevail throughout the year due to saturated soil conditions. An accumulation of silt, woody material, muck, and peat is evidence of the anaerobic conditions. Soils commonly found in this zone are the Johnston and Dorovan series.

Soil oxygenation. Anaerobic conditions prevail throughout the year due to saturated soil conditions.

Soil drainage and wetness. The soils are very poorly drained and are hydric.

Soil moisture. The soil moisture regime is peraquic. Soils are intermittently exposed--soil saturation or inundation by ground water is typical during the growing season. Soils exhibit hydric conditions.

Soil capability class. The soils are dominantly in Capability Class VIIw.

Table 5. Physicochemical characteristics of floodplain soils and soil series on Meyer's Branch, Aiken County, South Carolina.

	Zone II	Zone III	Zone IV	Zone V	Zone VI
Soil series	Johnston, Dorovan	Bibb, Osier	Albany, Ogeechee	Alley	Blanton
Soil oxygenation	Anaerobic	Dominantly anaerobic to aerobic	Dominantly aerobic to anaerobic	Aerobic	Aerobic
Soil drainage and wetness	Very poorly drained, hydric	Poorly drained, hydric	Somewhat poorly to poorly drained, nonhydric	Moderately well to well drained, nonhydric	Moderately well to well drained, nonhydric
Soil moisture regime (soil taxonomy)	Peraquic	Aquic	Udic, Aquic	Udic	Udic
Soil capability class	VIIw	Vw	IIIw, IVw	IIs, IIIs, IIIa, IVs	IIIs
Hydrology (duration of saturation during growing season)	≈100% except in extremo drought	>25% - 75%	>12.5% - <25%	>2% - <12.5%	<2%
Flooding	Continually except in extreme drought	Freq. 11-100 yrs/ 100 yrs	Rarely 1-10 yrs/ 100 yrs	Very rarely 1 yr/100 yrs	Not flooded
Vegetation	Swamp tupelo, sweet bay, water tupelo, cypress	Swamp tupelo, laurel oak, pond pine	Pond pine, sweetgum	Slash pine, longleaf pine, southern red oak, sweetgum	Slash pine, longleaf pine, southern red oak
Surface texture	Silty, loamy, mucky (fluid)	Silty, loamy (firm)	Sandy	Sandy	Sandy
Subsoil texture	Loamy, sandy (fluid to firm)	Loamy, sandy	Sandy, loamy	Sandy, loamy	Sandy, loamy
Soil pH	4.5 - 5.5 3.6 - 4.4	4.5 - 5.5	3.6 - 6.5 4.5 - 5.5	4.5 - 6.5	4.5 - 6.0
Soil classification (soil taxonomy)	Cumulic Humaquepts Typic Medisaprists	Typic Fluvaquents	Grossarenic Paleudults Typic Paleudults	Arenic Paleudults	Grossarenic Paleudults

MEYER'S BRANCH FLOODPLAIN PROFILE

AIKEN COUNTY S.C.

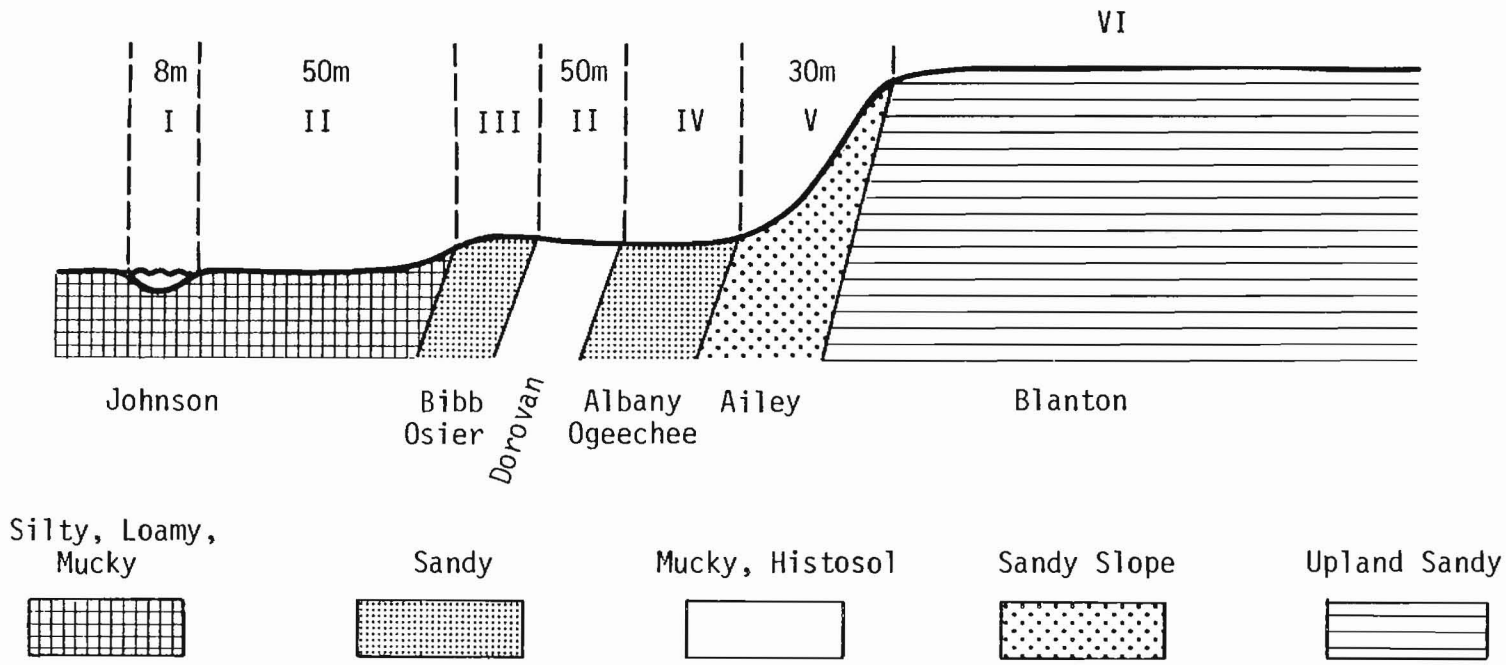


Figure 3. Idealized floodplain profile from Meyer's Branch in Aiken County, South Carolina, showing soil series distribution by ecological zones.

Hydrology. Zone II sites are permanently ponded or flooded. During extended dry periods the soil surface may be exposed; however, ground water (water table) or perched water extends to the soil surface and maintains saturated conditions nearly 100% of the growing season. Zone II sites usually lie within the 1-year floodplain along streams and rivers but may include flats and basins, outside of the 1-year floodplain, that are permanently ponded from ground water and rainfall sources.

Vegetation. Swamp tupelo (*Nyssa sylvatica* var. *biflora*), sweet bay (*Magnolia virginiana*), water tupelo, and cypress are the dominant species in zone II.

Texture. Silts, mucks, and loams dominate the surface layers. Loams and sands dominate the subsurface layers.

Soil pH. Soil pH ranges from 4.5 to 5.5 in Johnston mineral soils and from 3.6 to 4.4 in Dorovan organic soils.

Zone III

These soils are intermittently flooded or ponded with alternating long anaerobic periods and short aerobic periods as evidenced by brownish soil mottles. The soil-air-water relationship is such that vegetative root respiration is possible, although often sporadically, during the growing season. Soils commonly found in the zone are the Bibb and Osier series.

Soil oxygenation. Conditions are dominantly anaerobic, but become aerobic during periods of low rainfall.

Soil drainage and wetness. The soils are poorly drained and are classed as hydric.

Soil moisture. The soil moisture regime is aquic. Soils are periodically saturated by runoff and ground water and may dry out during periods of drought. Soils exhibit hydric soil conditions.

Soil capability class. The soils are dominantly in Capability Class Vw.

Hydrology. Zone III sites are frequently flooded (11 to 100 years/ 100 years) and high water table, ponding, flooding, or inundation occurs for an extended period in the growing season (at least >25% to 75% of the time). Zone III sites usually lie within the 1-year floodplain along streams and rivers but may include flats and basins, outside the 1-year floodplain, that are frequently ponded from ground water and rainfall sources.

Vegetation. Major tree species in this zone include swamp tupelo, laurel oak, and pond pine (*Pinus rigida* var. *serotina*).

Texture. Sands and loams dominate the surface and subsoils.

Soil pH. Soil pH ranges from 4.5 to 5.5.

Zone IV

Soils exhibit a high range of oxidation-reduction conditions as depicted by a preponderance of brownish, yellowish, and reddish mottles. Soil texture and prolonged periods of nonsaturated conditions create an ideal soil-air-water relationship that is favorable to root respiration during the growing season. Soils formed on nearly level, elevated areas of the floodplain. Dominant soils are the Albany and Ogeechee series.

Soil oxygenation. Aerobic conditions predominate; however, anaerobic conditions do occur during flooding and ponding of soils, but usually not during the growing season.

Soil drainage and wetness. These nonhydric soils are somewhat poorly drained to poorly drained.

Soil moisture. The soil moisture regime is dominantly udic and aquic. Aerobic conditions prevail for most of the year. These soils have nonhydric characteristics.

Soil capability class. Soils are dominantly in Capability Classes IIIw and IVw.

Hydrology. Zone IV sites are rarely flooded (1 to 10 years/100 years). They have a fluctuating water table that may extend to the surface for more than 12.5% but less than 25% of the growing season. Zone IV sites lie within the 1- or 2-year floodplain along streams and rivers. Zone IV sites also include flats and basins, outside the 2-year floodplain, that are frequently ponded from ground water and rainfall sources, but where ponding does not persist into the summer season.

Vegetation. Pond pine and sweetgum are two of the major tree species found in this zone.

Texture. Sands dominate the surface layers. Sands and loams dominate the subsoils.

Soil pH. Soil pH ranges from 3.6 to 6.5 for Albany soils and from 4.5 to 5.5 for Ogeechee soils.

Zone V

Soils exhibit brownish, yellowish, or reddish mottles that indicate a wide range of oxidation-reduction conditions. These soils are found on nearly level to steep uplands. Upland sites are well drained while toe slopes are often ponded. Ailey is the dominant soil series in this zone.

Soil oxygenation. The soils are normally well drained and aerobic; however, ponding may occur on toe slopes resulting in brief anaerobic conditions.

Soil drainage and wetness. Soils are moderately well drained to well drained and are nonhydric.

Soil moisture. The moisture regime is udic. Ponding following rainfall is common on toe slopes. These soils do not exhibit hydric soil conditions.

Soil capability class. The soils are dominantly in Capability Classes IIs, IIIs, IIIa, and IVs.

Hydrology. Zone V soils have a water table that is typically more than 1 m below the soil surface; however, the soils may be saturated from 2% to 12.5% of the growing season. Zone V sites occur between the 100-year and the 2-year floodplain and are very rarely flooded (<1 year/100 years).

Fluctuating water tables that extend to the soil surface during wet seasons and recede to depths well below the solum during the growing season are common. Surface water from intensive rainfall may cause overland flow (short-term flooding) on soils that have low infiltration and percolation rates. This may occur during wet periods or during previously dry periods when soil moisture is below field capacity.

Vegetation. Slash pine (*Pinus caribaea*), longleaf pine (*Pinus palustris*), southern red oak, and sweetgum dominate this zone.

Texture. Surface layers are dominated by sands. Sands and loams dominate the subsoils.

Soil pH. Soil pH ranges from 4.5 to 6.5.

Zone VI

Soils exhibit oxidized conditions as evidenced by matrix soil colors of reds, yellows, and browns. Soil texture and structure, and the natural soil drainage, result in conditions favorable to vegetative root respiration throughout the year. These soils are almost never flooded. Soils are dominated by the Blanton series.

Soil oxygenation. Aerobic conditions prevail throughout the year as a result of well drained soils.

Soil drainage and wetness. Soils are moderately well drained to well drained and are nonhydric.

Soil moisture. Soils exhibit a udic moisture regime. Soils are never saturated except during exceptionally wet periods. These soils do not exhibit hydric soil conditions.

Soil capability class. The soils are dominantly in Capability Class IIIs.

Hydrology. The soils in zone VI are saturated less than 2% of the time during the growing season. They do not flood.

Vegetation. Slash pine, longleaf pine, and southern red oak predominate in this zone.

Texture. Surface layers are dominantly sands. Sands and loams dominate the subsoils.

Soil pH. Soil pH ranges from 4.5 to 6.0.

MEASUREMENT OF SOIL AERATION

As a result of field data collected from research plots in the lower Mississippi River Valley, generalized diagrams of soil redox potential, soil oxygen content, and water-table cycles have been developed for each of three different sites: dry, intermediate, and wet. These preliminary observations are based on incomplete field research. Final analysis of all the data may

lead to modifications of results. However, these initial findings give us a better understanding of the nature of the oxidation-reduction processes in bottomland hardwood soils.

DRY SITES

Dry sites are located on high ridges with typical overstory vegetation of sassafras, eastern hophornbeam (Ostrya virginiana), and American beech. The soils are well to excessively drained and the water table on these sites stays low throughout the year (Fig. 4). The oxygen content generally fluctuates between 15% and 21%, rarely falling below 13%. Redox potential always remains above +300 mv. These sites are not flooded. This is a typical profile for ecological zone VI.

INTERMEDIATE SITES

Intermediate sites are generally found between the ridge sites and the true swamps. Dominant overstory vegetation ranges from the sweetgum-yellow poplar forest type on the higher elevations to the overcup oak-water hickory type on the lower, wetter sites. Soil drainage ranges from well drained to somewhat poorly drained. The poorly drained soils with lingering high water and low oxygen and redox values reflect zone III (Fig. 5). The better drained sites, distinguished by lower water tables and higher oxygen and redox values, are indicative of zone V. Zone IV is somewhere between the two extremes. Oxygen content on the drier sites stays above 10%, rising as high as 21% during periods of drought. Soil redox potential stays above +300 mv. The oxidation-reduction cycle on the wetter sites is quite distinct. The water table rises in late winter and early spring with resulting decreases in oxygen content and redox potential. Oxygen content falls below 5% and occasionally to zero. Redox potential remains below +300 mv for a large portion of the year. Oxygen and redox can remain quite low well into the growing season depending on the hydroperiod.

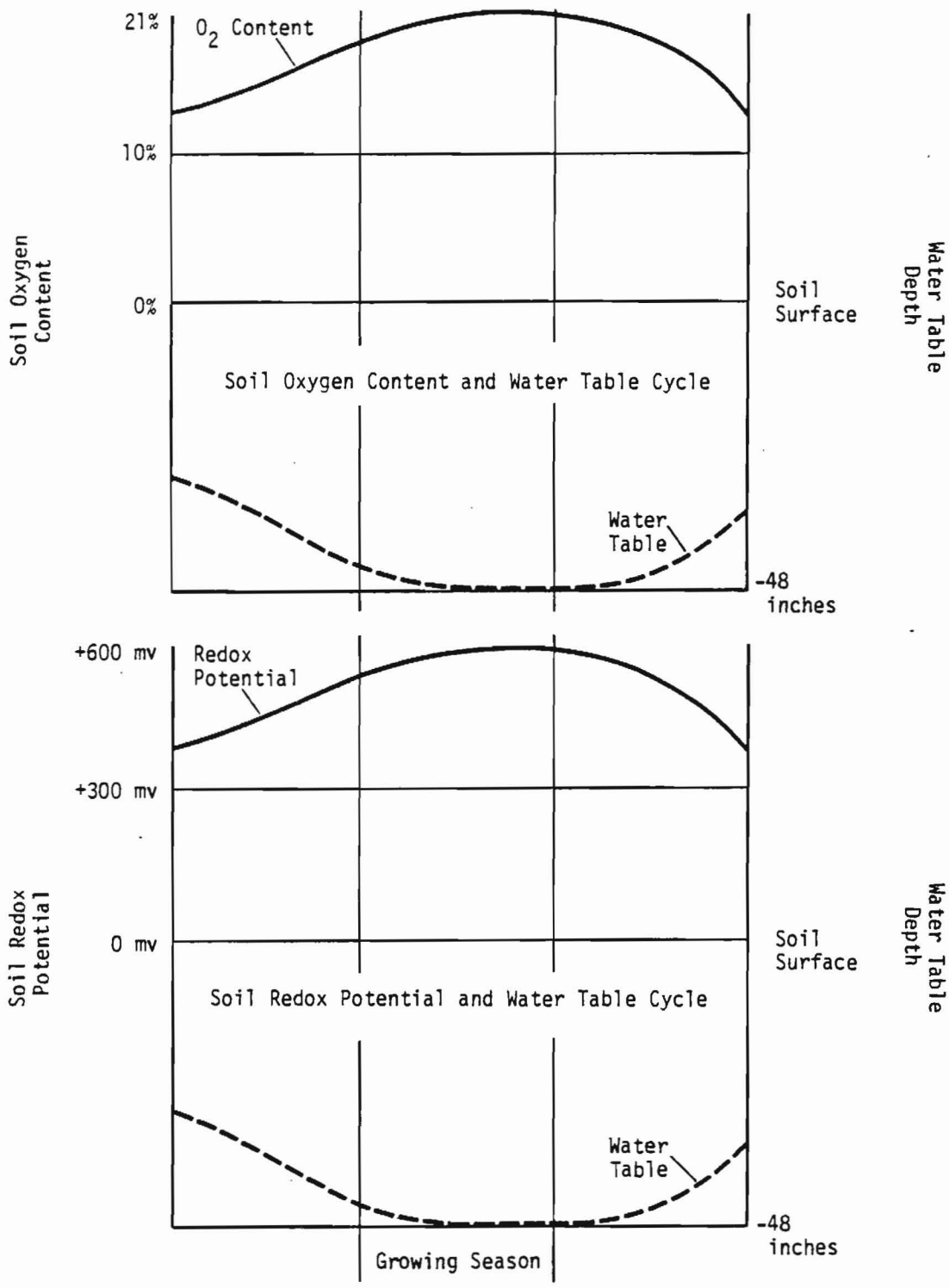


Figure 4. Soil oxygen content, redox potential, and water table cycle for dry sites in the lower Mississippi River Valley.

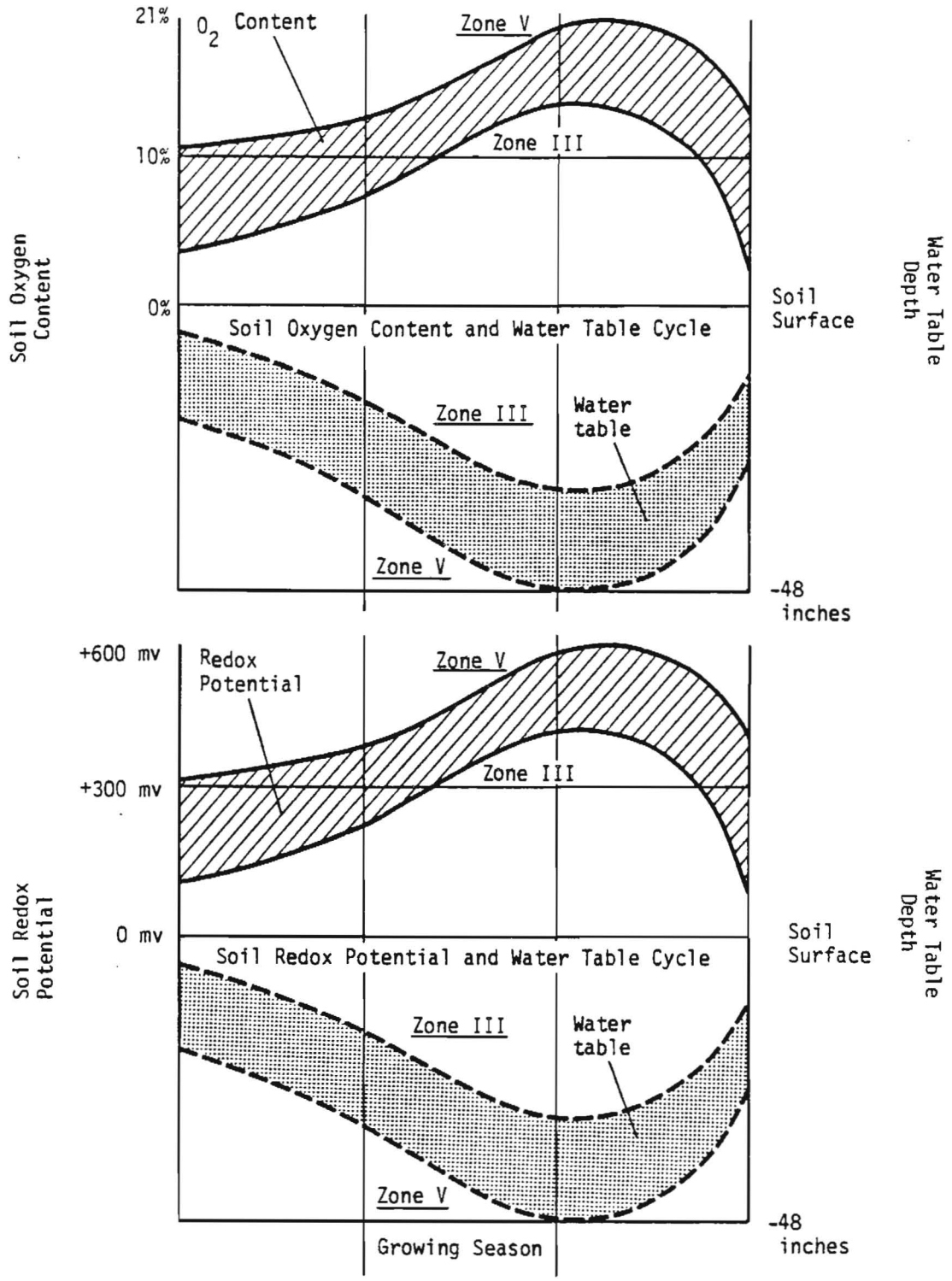


Figure 5. Soil oxygen content, redox potential, and water table cycle for sites with intermediate moisture regimes in the lower Mississippi River Valley.

WET SITES

Wet sites are found in low landscape elevations and are dominated by saturated soil conditions. Species associations are limited to flood-tolerant, obligate wetland plants such as bald cypress, water tupelo, swamp privet, black willow, and buttonbush. The soils are very poorly drained with peraquic moisture regimes. The water table remains at or near the surface for most of the year. Soil oxygen contents are very low (less than 5%) with strong reducing conditions of less than +100 mv (Fig. 6). These sites are in zone II.

CONCLUSIONS

The consensus of the Soils Workgroup, based on the preceding analyses, is that there is a direct correlation between soil series mapping units, hydrology, and BLH plant communities. The soils are identified by their physicochemical makeup plus vegetative data, when available, but are recognizable even without the vegetative data. The group believes that soils provide a more permanent identification tool for delineating bottomland hardwood sites than vegetation or hydrology. The Soils Workgroup strongly recommends that zonation of bottomland hardwoods be based on soil series information available through soil surveys and validated by multidisciplinary teams of soil scientists, hydrologists, and biologists.

This approach works very well in the lower Mississippi River Valley bottomland hardwood area, but additional on-site research, such as that done in the lower Mississippi River Valley, needs to be conducted for other bottomland systems throughout the Southeast to reinforce, refine, and improve soil zonations (soil survey delineation) throughout the Southeast.

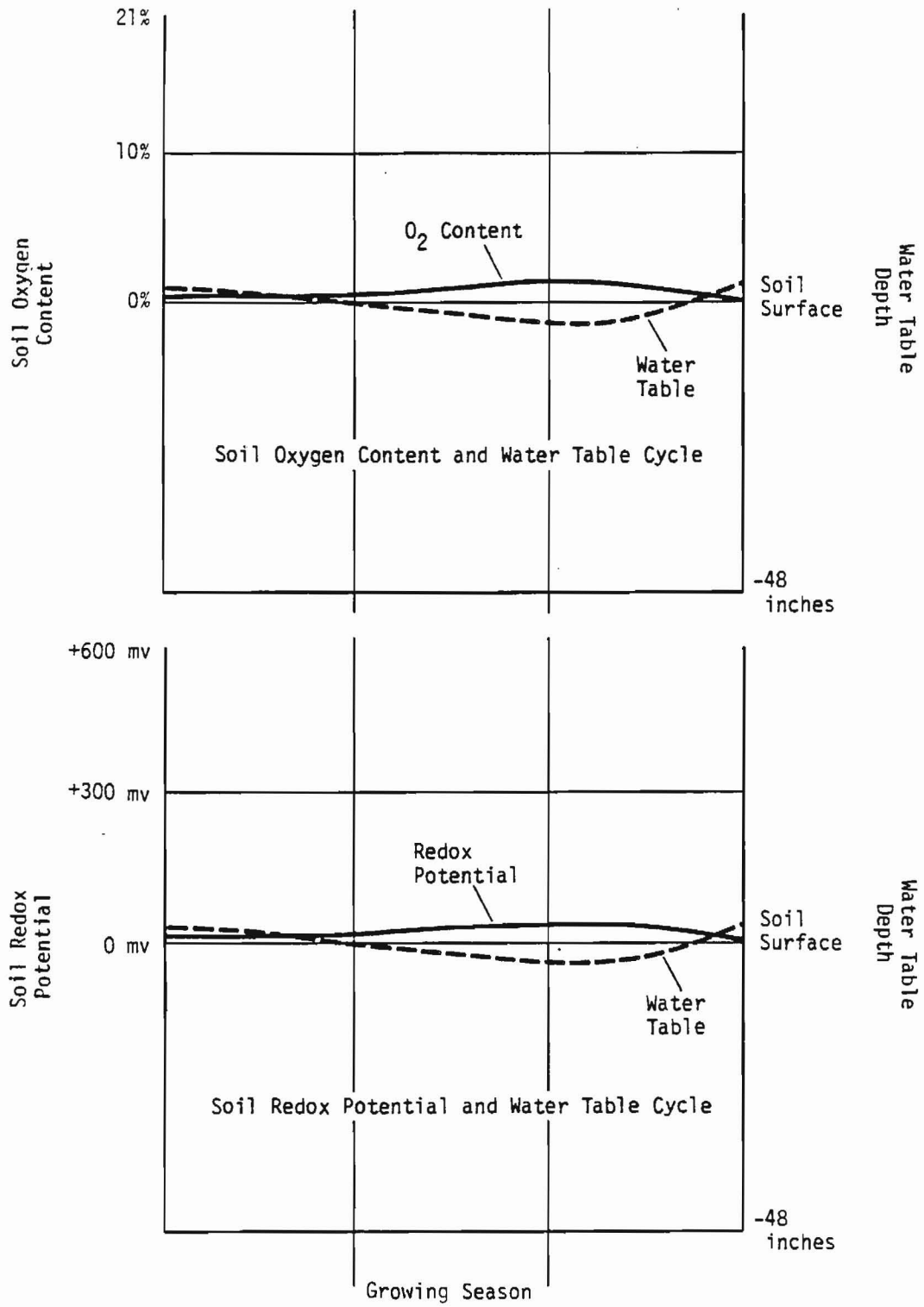


Figure 6. Soil oxygen content, redox potential, and water table cycle for wet sites in the lower Mississippi River Valley.

It is also recommended that other BLH functions, such as water quality improvement, utilization by fish, utilization by wildlife, and lastly, utilization by humans, be more carefully evaluated through field research and synthesized and integrated into the six zones (corresponding to the five soil zones and the water zone) of bottomland hardwoods.

REFERENCES

Clark, J.R., and J. Benforado, eds. 1981. Wetlands of bottomland hardwood forests. Elsevier Scientific, New York. 401 pp.

VEGETATION WORKGROUP REPORT

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INTRODUCTION

Bottomland hardwood (BLH) communities have been defined as floodplain ecosystems dominated by woody vegetation that has demonstrated ability, because of morphological and/or physiological adaptations, to survive, achieve maturity, and reproduce in an environment where the soils within the root zone may be inundated or saturated for various periods during the growing season (Huffman and Forsythe 1981). The distribution of plant species within a BLH ecosystem is dependent on each species' response to complex environmental gradients that exist in transitional habitats from river channels to nonflooded sites. Hydrologic and soil moisture regimes are recognized as the principal factors influencing the distribution of plant species along this gradient, and these factors have been generalized for management purposes into six zones (Table 1). Zone I represents permanently flooded, aquatic habitat, and zone VI represents nonflooded, upland habitat. Zones II through V represent the portion of the gradient where BLH communities occur. Although the same plant species can often be found in more than one zone, all species are limited at some point by anaerobic soil conditions, and all find some combination of conditions optimal for growth and reproduction.

Although five tasks were suggested for the Vegetation Workgroup (see INTRODUCTION), time permitted addressing only the first four. In approaching these tasks, the workgroup considered two key questions concerning the distribution of vegetation in bottomland hardwoods. First, can attributes of the vegetation be used to characterize zones within a BLH wetland? Second, do vegetation functions or processes vary along floodplain gradients? With respect to the first question, there was significant disagreement concerning assignment of plant species to particular zones. In some cases, however, it appears that various plant communities are distributed in zones such as those identified at the Lake Lanier workshop. In other cases, zones and communities are intermingled and practically inseparable without a considerable expenditure of time and effort. Other environmental factors must be considered in these cases in order to show a distinct relationship between plant communities and the soil moisture regime. With respect to the second question, discernible differences exist between plant communities, functions, and BLH zones, but these may be difficult to detect except in cases where the plant communities are very distinct.

CHARACTERIZATION OF ZONES USING VEGETATION

INDIVIDUAL SPECIES AS INDICATORS OF BLH ZONES

Abrupt changes in the distribution of plant species rarely occur in natural, undisturbed environments of the southeastern United States. Plant species distributions are a response to a complex of environmental factors, including rainfall, temperature, nutrients, disease, insects, flooding, soil type and condition, and many others. Species that occupy bottomland hardwood sites are no exception. They often occur in several, if not all, of the zones as defined in Table 1. Furthermore, BLH species may exist as dominants in more than one zone. Therefore, individual plant species usually have relatively little value in defining or identifying zones within a BLH community.

PLANT COMMUNITIES AS INDICATORS OF BLH ZONES

As noted above, the distribution of individual plant species in a BLH community is a response to a complex environmental gradient, with hydrology and soil moisture as dominant factors. While each species is distributed somewhat differently along this gradient, groups of species that respond similarly to the gradient can often be identified as distinct plant communities. The extent to which these communities intergrade with each other depends on the abruptness of changes in the environmental gradient. Where man's activities or natural disturbances have perturbed BLH ecosystems, species typical of several communities may intermingle and coexist for several decades.

Although communities generally intergrade continuously along environmental gradients, rather than forming distinct, clearly separated zones, classification of common community or forest types is often used as a means of description (Whittaker 1975). Community or forest types are the preferred basis for characterization of BLH zones by most plant scientists. Nevertheless, some BLH forest or community types may occur in more than one soil moisture or hydrologic zone, reflecting the fact that some dominant species have a wide range of tolerance to changes in soil moisture and other environmental conditions. The occurrence of the same community type across several zones is particularly common in areas that have been significantly altered by flood control or timber management activities. For example, if the hydrology of zone II has been altered such that the soil moisture regime is more similar to that of zone IV, the species composition may change gradually, favoring those species that are adapted to drier conditions. In such cases, other factors, including soil type, flooding history, current flood control practices, timber management, and agricultural practices, must be considered in management and regulatory decisions that seek to define meaningful limits to the distribution of wetlands in BLH ecosystems.

METHODS FOR CHARACTERIZING BLH PLANT COMMUNITIES

A number of techniques have been used for the characterization of bottomland hardwoods by communities. The following discussions are based on the field experience of workgroup members and their familiarity with available, accepted resource measurement techniques.

Field reconnaissance. Field reconnaissance surveys can provide a general description of plant communities, stand complexity, and history of the area. They can help to identify areas requiring additional, more detailed characterization efforts. However, reconnaissance surveys employ only subjective information and, by themselves, are of limited utility in large or very diverse areas. Application of reconnaissance methods requires an ability to identify bottomland hardwood species (trees, shrubs, and vines), recognition of morphological changes, and field experience with community complexes in the geographic area. Acceptable reconnaissance surveys can be accomplished fairly quickly.

Transect. Two types of transect surveys can be used to characterize vegetation in bottomland hardwood areas. Line transects are used to sample all individual plants that "touch" the transect line. Belt transects are used to sample individuals within a certain distance of the transect line. Belt transects allow a number of vegetation parameters to be quantified. Transects can be continuous or interrupted, are usually oriented perpendicular to a water course, and are used to define general changes in community distributions. Transects are usually not necessary in order to characterize relatively homogeneous areas. Unless the placement of transects is random, the data obtained can be biased by location. Also, unless species-area curves are employed, the initial number of belt transects is subjective and statistical analysis can be difficult (Mueller-Dombois and Ellenberg 1974). In addition to the level of expertise required for reconnaissance studies, the use of transects requires an understanding of sample design, data analysis procedures, and management practices in the region. If the area to be sampled is not too

complex, line transects can be conducted fairly rapidly; belt transects may be very time consuming if several parameters are estimated (Mueller-Dombois and Ellenberg 1974).

Complete inventory. A complete inventory of an area is the most objective characterization technique. Since all individual plants are sampled, complete inventories allow reorganization of data for many desired analyses. However, these inventories are very costly and therefore rarely used. They require extensive time and effort, and may be destructive. Complete inventories are therefore not feasible in large areas. Expertise required to conduct and utilize complete inventories is generally the same as that for transects.

Remote sensing. Remote sensing is the most feasible method for characterizing vegetation types over large areas. In addition, low altitude imagery can be utilized for detailed characterization of vegetation communities in small areas. Remote sensing also provides a basis for repeat characterizations and, therefore, detection of changes through time. Several types of imagery at various scales are typically available from a number of sources. In the context of regulatory activities, the drawback to all remote sensing techniques is that they have limited value for accurately drawing geographic jurisdictional lines. The workgroup concluded that remote sensing is a tool with broad application, particularly for the evaluation of temporal changes in vegetation. However, its utility is highly dependent on availability of imagery and the proficiency of personnel interpreting that imagery. Data acquisition can be quite costly and, in most cases, reliable results require field verification. In addition, utility of the data for particular purposes is strongly influenced by factors such as season of the year, cloud cover, and snow cover. One of the major weaknesses of remote sensing is that only the canopy layer of the plant community is sampled. In areas that have changed hydrologically, the canopy may not represent plant community types that are developing in response to changes in the physical environment.

The Vegetation Workgroup concluded that an evaluation of data collection methodologies should be conducted prior to or during the next workshop. Such

a task would entail: (1) a literature review of appropriate evaluation methodologies; and (2) a survey of research programs that have applied such methodologies to determine which are the most useful (e.g., Waterways Experiment Station flood tolerance index research, Savannah River Ecology Laboratory research, Atchfalaya River research, Lower Ouachita River Basin research, and Mississippi River research).

GEOGRAPHICAL DIFFERENCES AMONG BLH COMMUNITIES

The group found that there may well be important differences in the various zones in different regions where different bottomland hardwood communities are found. For example, the following issues were raised regarding regional differences:

1. Is there significant replacement of plant species with ecological equivalents within zones from one geographical area to another?

2. Do individual species exist in different zones in different geographical areas?

3. Do hydrologic parameters (e.g., flood duration and flood frequency) vary in their importance in limiting the distribution of BLH types in different geographical areas? For example, in watersheds that have frequent floods of short duration (e.g., watersheds characteristic of portions of the Atlantic Coastal Plain), flood frequency may be relatively unimportant as a determinant of the distribution of modal plant community types.

An attempt to evaluate the regional floristic variation in model BLH community types will be made by Dr. Lyndon C. Lee in conjunction with other workshop participants prior to or during the next workshop. Current field and literature data are now being submitted to Dr. Lee in a prescribed format. These data will be examined to determine if logical subgroupings of BLH communities can be identified on the basis of their floristic similarities.

OTHER APPROACHES USEFUL IN UNDERSTANDING STRUCTURE AND FUNCTION OF PLANT COMMUNITIES

The workgroup agreed that, in addition to floristic ordination analyses, there are other approaches that may aid in understanding the structure and function of bottomland hardwood communities. It was also recognized, however, that soil moisture and hydrology are the principal driving forces within the ecosystem, and that water sets the basic evaluation framework. The workgroup agreed that many relevant vegetation data presently exist. A reexamination of those data would be useful to determine their applicability to the problems at hand. Other approaches may include:

1. Long-term study of physiological and morphological adaptations of bottomland hardwood species (this could be an important EPA research initiative).

2. Survey of life-history research, including seed and fruit production and age (size) class structure of stands.

3. Observation of morphological variability, which may give some indication of geographic variation and distribution along the hydrologic gradient.

4. Analysis along other gradients, such as edaphic gradients (e.g., soils, nutrients, eH, and pH), water logging stress (e.g., long-term physiological studies), or productivity gradients (e.g., net primary productivity).

5. Characterization of plant succession and community development in bottomland hardwood types.

6. Consideration of hydrologic variation and its relationship to the distribution of zones and vegetation communities (e.g., back swamp versus headwater swamp communities).

PLANT COMMUNITY FUNCTIONS IN RELATIONSHIP TO BLH ZONES

PRODUCTIVITY DIFFERENCES AMONG PLANT COMMUNITIES

Net primary productivity (NPP) is the major ecosystem process that can be attributed to the vegetation of BLH forests. Accumulation of organic carbon as biomass on BLH sites provides: (1) the basis for food chains that exist in adjacent aquatic, floodplain, and upland sites (ECOSYSTEM PROCESSES WORKGROUP REPORT, this volume); (2) stem biomass (yield), which is important to the forest products industry; and (3) plant community structural diversity, which provides habitat for associated biota.

The major components of NPP include stem production, leaf litter production, and seed and fruit production. The relative distribution of NPP and its components along a generalized floodplain cross section is presented in Figure 7. This partitioning of production is based on existing data and the assumption that maximum productivity generally occurs on sites that are seasonally, rather than constantly or rarely, flooded (Brinson et al. 1981) (Fig. 8). There was significant disagreement on assigning plant communities to particular BLH zones on disturbed sites; therefore, productivity estimates are based on data and knowledge about homogeneous plant communities studied along hydrologic gradients at selected, relatively undisturbed floodplain sites. The dominant or prevalent species in the five hydrologic/plant community types used are presented in Table 6. These community types are given the designations A1 through A5 to distinguish them from zones, because it was felt that the same community can be found in more than one of the zones as defined by soil moisture regime in Table 1. Zone VI was not discussed, as it is a nonflooded area typically located above the floodplain.

NPP relationships are summarized across the generalized floodplain gradient following the approach of Gosselink et al. (1981). Productivity is lowest in A1 and increases gradually over the hydrologic gradient to a peak in A4. Observed trends are generally related to the hydrologic regime as suggested by Odum (1978) (Fig. 8). Estimates for total productivity in A1 were not available, but A1 productivity may be very important, depending on the amount

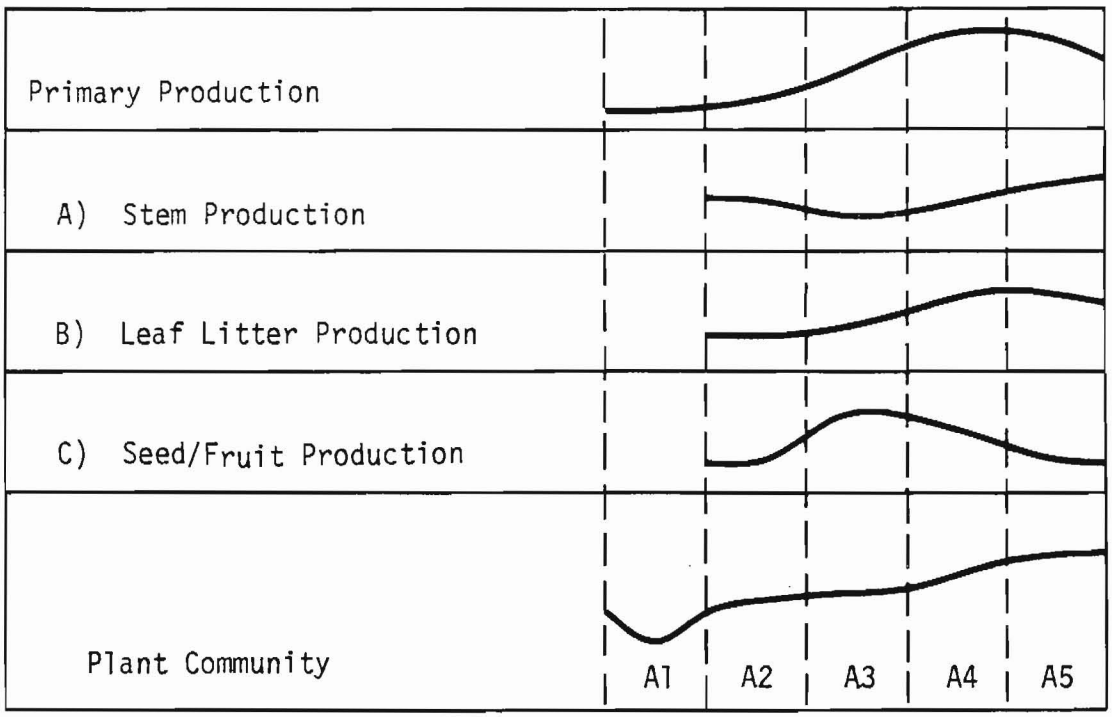

Figure 7. Relative distribution of net primary productivity and its components across a generalized floodplain cross section.

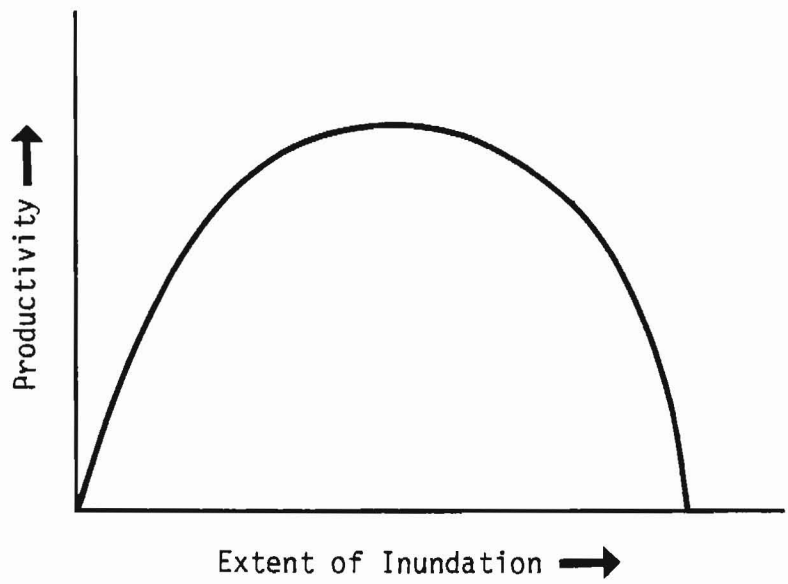

Figure 8. Assumed relationship between inundation and productivity (after Odum 1978).

Table 6. Dominant species considered in estimating the productivity of various plant communities.[1]

Plant community	Dominant species
A1	Floating aquatics Rooted vascular macrophytes Phytoplankton
A2	Bald cypress (*Taxodium distichum*) Tupelo (*Nyssa aquatica* and *N. sylvatica* var. *biflora*)
A3	Overcup oak (*Quercus lyrata*) Water hickory (*Carya aquatica*)
A4	Nuttal oak (*Quercus nuttallii*) Willow oak (*Quercus phellos*) Sweetgum (*Liquidambar styraciflua*) Green ash (*Fraxinus pennsylvanica*) American elm (*Ulmus americana*)
A5	Water oak (*Quercus nigra*) Cow oak (*Quercus michauxii*) Cherrybark oak (*Quercus falcata* var. *pagodifolia*) Pecan (*Carya illinoensis*) Shumard oak (*Quercus shumardii*)

[1]After Huffman and Forsythe (1981).

and type of vegetative cover. For example, Mitsch et al. (1979) found that floating aquatics contributed over 50% of the NPP in A1. Some evidence exists to indicate that NPP in some A2 communities can be considerably higher than that shown in Figure 7 (R.L. Johnson, pers. comm.). For example, NPP in a relatively undisturbed stand of bald cypress (Taxodium distichum) and tupelo (Nyssa aquatica) was equivalent to that in A4; however, such sites are rare. Standing crops in community A2 can be considerably higher than for any other community because of increased stem density. Additionally, bald cypress is longer lived and continues to grow and accumulate biomass longer than other BLH species.

Stem production. Stem production is lowest in A3. Plant community types A4 and A5 exhibit two and three times the productivity of A3 communities, respectively. Stem production in A2 is approximately equivalent to production in A4. Production in A3 and A4 is dependent on site water balance regimes, which are predominantly controlled by flooding frequency, duration, and soil texture (R.L. Johnson, pers. comm.; Broadfoot and Williston 1973; Robertson et al. 1978). This has implications for timber harvest potential (yield) in these plant community types.

Leaf litter. Leaf litter production in A2 is approximately 50% of the production in any of the other plant communities. The variation in production on a yearly basis is higher in A2 than in any of the other communities. On the basis of data provided by W.H. Conner (pers. comm.), apparent accumulation of leaf litter is most rapid in A2. This trend is probably due to lower rates of decomposition in A2 compared with sites in A3, A4, and A5 occupied by other plant communities. Rates of microbial decomposition of leaf litter are regulated principally by the availability of oxygen (Adamus and Stockwell 1983), which is a function of flooding regime and water temperature (Brinson 1977).

Seed/fruit production. Seed/fruit production on floodplain sites is a cyclic phenomenon. Extremely high production occurs every two to five years, depending on the particular plant community type and climatic conditions.

White oak species, which commonly form major components of the A3 plant community, are very consistent producers. On the other hand, red oaks (e.g., willow and nuttall oaks), which occur in A4 and A5, are less consistent in their production of mast. Other species produce varying amounts of mast and their value to wildlife varies from species to species (Martin et al. 1961).

SOURCES OF VARIABILITY

Hydroperiod is apparently the major factor affecting productivity in BLH communities. However, there are secondary factors that can influence productivity and regenerative capacity across communities in a floodplain, within a river basin, and across large geographic areas. These factors include:

1. Community species composition, development, and response to disturbance.
2. Latitudinal differences in the length of the growing season and annual precipitation.
3. Edaphic variation among zones and between BLH sites (e.g., available nutrients, pH, soil texture).
4. Light intensity and quality at different stages of community development.
5. Past history of sites, including logging, fire, agricultural activities, drainage, and management practices.
6. Perturbations to stands by pests and disease.
7. Backwater/headwater flooding effects.
8. Changes in groundwater, such as salinity and level.
9. Duration, timing, and frequency of catastrophic flood events.
10. Natural and artificially induced changes in river courses.
11. Location of a site within the watershed.
12. Changes in sea level.
13. Variability in species responses.

14. Genetic variability within species.

15. Beaver impoundments.

METHODS FOR ESTIMATING PRODUCTIVITY

Applicability of field techniques for quickly estimating aboveground biomass depends on the level of experience of the person involved in the evaluation as well as reliable comparative data. Both the woody and herbaceous components can be roughly estimated using known areas, establishing an arbitrary ground cover scale, and relating this to one plot treated quantitatively (Mueller-Dombois and Ellenberg 1974). An assessment can be made by measuring basal areas by woody species. A count of the woody plants and estimates of basal area or of tree heights by species can provide rough estimates of tree biomass for a given area. The herbaceous component can be estimated using a scale for guide estimation technique, separating the cover percentages by species (Mueller-Dombois and Ellenberg 1974). Data from plots and/or transects along gradients can be used to estimate biomass. Strengths and weaknesses of these techniques are discussed above and are described in detail in Mueller-Dombois and Ellenberg (1974). Woody plant growth can be estimated within and/or between species along a gradient using tree bands and increment borings. Growth is commonly projected using rates reflected in boring data or from current biomass, which can be expected to increase by 3% to 5% per year in many BLH communities.

Allometric relationships between foliage biomass and DBH are available for some BLH species. Estimates of potential yearly leaf litter production can be obtained from this information for some communities.

Seed/fruit production of oaks by diameter class can be estimated fairly accurately. Applying these data to diameter and density data for species within a given community can provide estimates of seed/fruit production per unit area.

Nonfield evaluation techniques include communication with people familiar with the area, aerial photography and remote sensing, wetland maps, forest type maps, topographic maps, soil maps, USGS and U.S. Army Corps of Engineers stage/discharge data, Corps of Engineers projects maps, community profiles, and personal knowledge.

CONCLUSIONS

The Vegetation Workgroup concluded that individual plant species can often exist and achieve dominance in more than one of the zones defined by soil moisture and hydrology (Table 1). Individual species are thus not particularly useful in identifying or delineating those zones. Groups of species that respond in similar ways to complex environmental gradients often form distinct plant communities. However, such communities can also exist in more than one zone. Additional knowledge of hydrology and soil moisture is thus necessary before site-specific decisions can be made concerning whether or not a particular plant community is indicative of a particular soil moisture regime. Furthermore, disturbance and complex topography often lead to situations where various communities are intermingled and practically inseparable. It is imperative that such factors be considered when attempting to use plant communities and zones for descriptive or regulatory purposes.

The workgroup also concluded that BLH plant communities vary in their ability to carry out certain functions. Although data are scarce, BLH communities appear to differ with respect to functions such as net primary production, stem production, leaf litter production, and seed/fruit production.

Each workshop participant should provide recommendations for:

1. further study of relationships between plant communities and hydrologic regime;

2. further study of vegetation functions in relationship to plant communities; and

3. suggested topics and questions for the next BLH workshop, which will deal with impacts and predicting loss or gain of wetland functions and associated values.

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FISHERIES WORKGROUP REPORT

Dale Hall (Chairman), C. Fred Bryan, Ellis Clairain,
Joseph Jacob, Victor Lambou, and Richard Johnson (Recorder)

INTRODUCTION

Bottomland hardwood (BLH) ecosystems provide a wide variety of natural resource benefits. Uses such as timber production, water quality enhancement, flood storage, nutrient recharge, and waterfowl habitat are well established values. Of particular concern to this workgroup, however, are the high quality benefits provided to fishery resources for reproduction, protection from predation, food availability, and harvest for human consumption and recreation. Sport and commercial fishes dependent upon bottomland hardwoods support a large economic base that is one of the most prolific in the United States (Lambou, workshop presentation). Overall fish harvests of 9,000 kg/km^2/year have been documented.

Harvest of the fisheries resources is accomplished by both commercial and sport interests. The bulk of the commercial catch in BLH systems consists of buffalofish, catfish, carp, drum, suckers, and crawfish; bass, crappie, sunfish, catfish, and crawfish predominate in the sport catch. All these species spend at least a portion of their life cycle in flooded bottomland hardwoods or derive benefits in nutrition from the flood cycle.

In June 1980, a workshop was held at Lake Lanier, Georgia, to assess the status of knowledge regarding bottomland hardwood ecosystems and their functional values. The results of that workshop were published in 1981 (Clark and Benforado 1981) and were used as a base of departure for our analyses. At

that workshop, Larson et al. (1981) divided the forested portion of bottomland hardwood ecosystems into "ecological zones" based on "soil-moisture/hydrologic habitat conditions" and described the forest types associated with the various zones (Fig. 9).

The question was raised by the U.S. Environmental Protection Agency as to the validity of this concept from an ecological standpoint. Our workgroup was asked to review these zones with particular regard to intrinsic fishery resource values. Specifically, we were asked to evaluate the value of each zone relative to the life requisites of indigenous sport and commercial fishes.

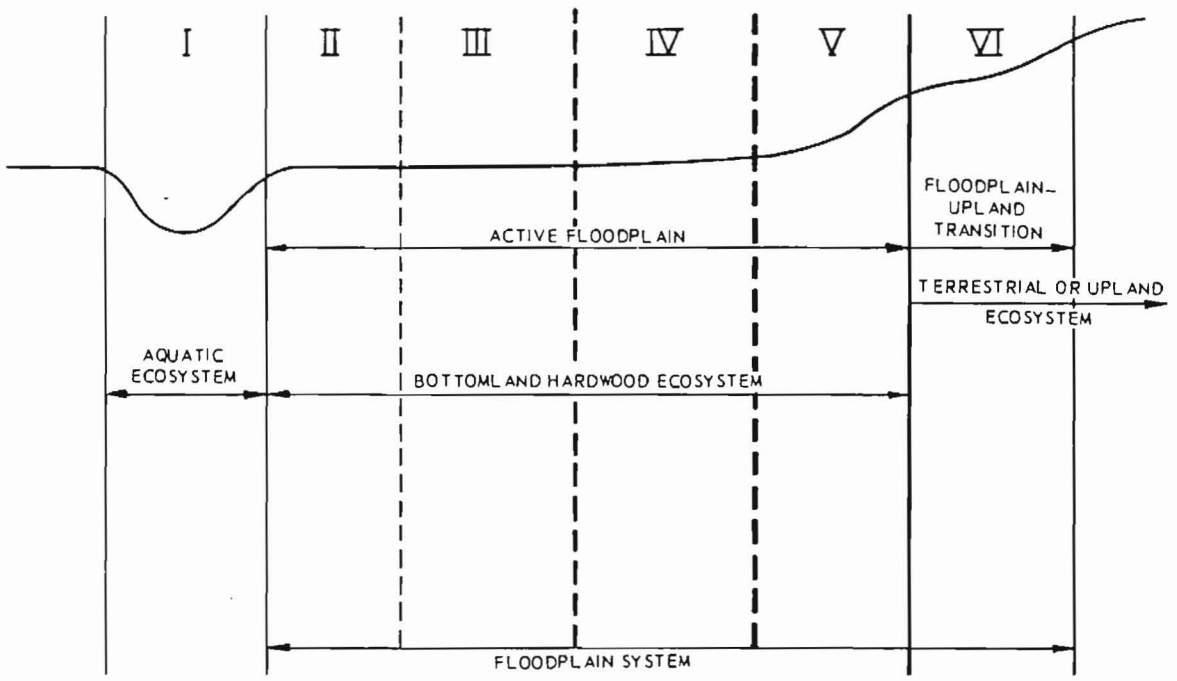

Figure 9. Generalized profile of ecosystems and transitions associated with floodplains of the southeastern United States (after Larson et al. 1981).

We accepted this charge with the understanding that the literature does not contain a wealth of information directly assessing functional fisheries values, but does contain associated findings that can be applied through extrapolation. To facilitate our analyses, we established basic assumptions that guided our discussion of relative values of the various zones. First, it was assumed that all areas inundated by a given frequency flood are connected by hydrologic avenues for finfish movement. This assumption alleviated the need for differentiation of flooded bottomland hardwoods relative to stream overflow or ponded rainfall origin.

Second, we realized that variation in flooding events could cause a shift in the importance of the zones due to timing, duration, and/or absence of inundation. To alleviate this variable, the 10-year frequency event was selected for geographic extent of inundation. Aerial extent of inundation across the zones and predicted duration were then taken from Larson et al. (1981) for this flood event. For purposes of comparison, however, Figure 10 illustrates the relative value of the zones averaged over many years. Zone I

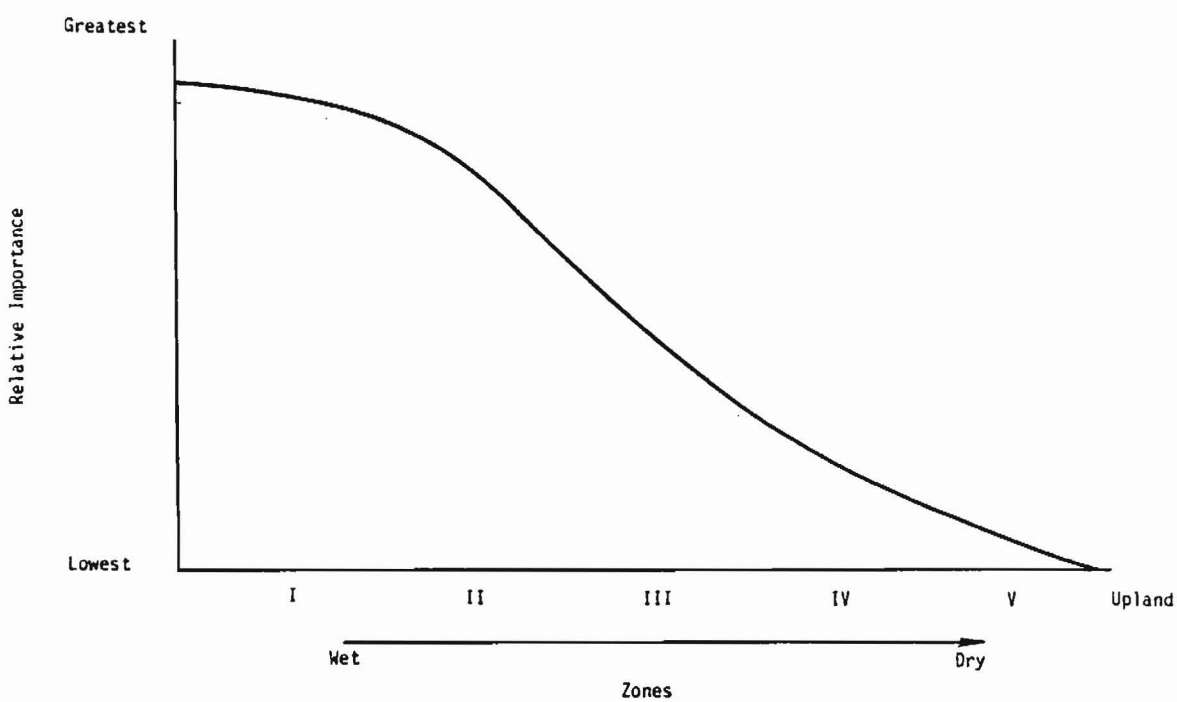

Figure 10. Relative importance of bottomland hardwood zones to fisheries resources averaged over many years.

would be permanently inundated and would, therefore, have the highest value to the fishery resource. The value of the zones would gradually decrease in an upslope direction because the frequency and duration of inundation, and consequently the available habitat, would decrease. However, Figure 10 does not reflect the relative importance of the higher zones for a single flood event that crosses all zones in the floodplain. Analyses of the importance of zones during such a single event would elevate the importance of the higher, more shallowly flooded zones for particular life requisites of aquatic species (see RESULTS AND DISCUSSION).

Finally, we assumed sufficient quantities of phytoplankton, micro- and macrozooplankton, aufwuchs, detritus, and terrestrial insects to be available as food organisms during the early life stages of finfishes.

In our analyses, the interdependency of Southern rivers and their floodplains became a constant reminder that one cannot realistically separate the "adjacent permanent waterbody" from the "bottomland hardwood ecosystem" when discussing the viability of fishery resources. However, we made a concerted effort to explore the functional interrelationships between bottomland hardwood zones for fishery populations. The remainder of this report elucidates this effort and our conclusions.

APPROACH

Bottomland hardwood ecosystems are extremely diverse and dynamic. Hydrologic conditions vary dramatically from permanently flooded (zone I) to infrequently flooded (zone V). These ecosystems support a wide diversity of aquatic biota during all life stages, as was amply demonstrated in the Lake Lanier workshop (Wharton et al. 1981, 1982) and in this workgroup (Lambou, workshop presentation). A brief description of the dynamics of this system is presented in the RESULTS AND DISCUSSION section.

However; a detailed evaluation of the utilization of all zones by all life stages for all species was beyond the scope of our effort. Therefore, we identified target organisms and evaluation criteria for analyses. This approach was not intended to ignore the importance of flooding to the life cycles of other aquatic biota (e.g. macroinvertebrates, phytoplankton, or zooplankton) or other life requisites, but rather to permit a manageable scope for this report. A brief description of the life forms and evaluation criteria is presented below.

A. Life Forms Examined - Two broad categories of organisms were examined: finfishes and crawfishes. Finfishes were further subdivided into adults and young-of-the-year because of substantial differences in the life requirements of these groups. Young-of-the-year were considered to be all eggs, larvae, and juvenile fishes that have not completed their first year of life nor reached marketable status while, for our purposes, adults were considered to be all finfishes that have completed their first year of life. The value of the zones to each of these groups of organisms is amplified in the discussion below.

B. Evaluation Criteria - The basic life requisites of food availability, living space/protective and predatory cover, and reproductive substrate were examined for each life form (crawfishes, adult finfishes, and young-of-the-year finfishes) by zone.

RESULTS AND DISCUSSION

The yield of fish to man from bottomland hardwood floodplains is largely dependent upon the maximum area flooded (Lambou, workshop presentation; Welcomme 1979). In the case of a mixed fishery (finfishes and crawfishes) in the Atchafalaya Basin, Louisiana, a harvest of 8,797 kg/km^2/year per maximum area flooded has been documented (Lambou, workshop presentation), while in the case of tropical finfish it has been estimated that the yield varies from 4,000 to 6,000 kg/km^2/year per maximum area flooded for normally exploited systems (Welcomme 1979).

However, the relationship of yield to area flooded is complex and depends upon present and past flooding cycles, timing and duration of flooding, amount of permanent water during the low-water season, the kind and types of finfishes found, and the characteristics of the fishery harvest. The maximum amount of fishes in the standing stock is greatest during the flood event and least just prior to onset of flooding, because reproductive strategies of most riverine species are cued to spring floods. Thus, the excess produced during a flood must be lost during the low-water period to bring the population within the carrying capacity of the habitat.

Simulation models of floodplain finfish populations by Welcomme and Hagborg (1977) indicate that differences in high water, or flood regime, from year to year generate great differences in fish biomass produced. However, the carryover success of the community is largely dependent upon the amount of water remaining during the dry seasons of the year (zone I). These simulations showed that the more water remaining during the low-water period, the more efficient the transmittal of population increases during the high-water years is to succeeding years. Production and biomass were maximized during high flood years and production ranged from 24,100 to 56,400 kg/km^2/year of the mean area flooded. Alternate exposure and flooding of the land is of great importance in maintaining the viability and productivity of fishery populations occurring in streams that drain bottomland hardwood ecosystems. The effects depend more upon the timing, area, and duration of flooding than on the degree of fluctuation as measured in vertical feet. This alternating wet/dry cycle has important effects on fish population dynamics and controls the amount of forage available. Food availability, in turn, sets upper bounds on the population size any species of finfish may attain. Thus, one can begin to understand the complex interdependence that exists between the permanent aquatic water bodies and their associated floodplains. The effects of fluctuating water levels on fish populations are discussed by Wood (1951), Wood and Pfitzer (1958), and Lambou (workshop presentation).

The vast majority of Southern freshwater finfishes are oviparous (egg-laying) with advanced embryological development taking place post-hatching.

For the first few days after emerging from the egg, the larva receives nutrition from a yolk sac while primitive organs of digestion are developing. Within 3 to 7 days the yolk material may be exhausted and the larva makes the transition from endogenous to exogenous nutrition. The main factors involved in the success of this transition are: (1) the density of food organisms available, and (2) the capability of the larva to capture its food (Hempel 1965; Schumann 1965).

Some fishes, such as bass and sunfish, build nests and guard the eggs and young while fanning the nest to keep the eggs free from sediment. Many others, such as shad, buffalo, and carp, merely broadcast or spray their eggs over vegetation. In the latter, the eggs possess an adhesive coating that causes them to cling to vegetation or bottom detritus. This spawning behavior enhances survival; the eggs are kept free from siltation and aerated by water movement. After hatching, the vegetation becomes cover for protection against predation (Hall 1979).

The dimension of water that larvae can search for food is measured in liters or less for the first few days of life. In the search for food and "avoidance" (albeit more or less passive) of predators, the larval fish is dependent on the whims of currents to position it near food and away from enemies. The larval fish's centers of olfaction and sight are such that, from their dietary items, one can only conclude that they are opportunistic feeders. They will apparently swallow almost any suspensoid material and will survive to the next mouthful only if the first one proved nutritious. In view of the fact that the gape (mouth) of most new hatchlings is measured in fractions of millimeters, those suspensoids [e.g., algae, detritus, protozoans, rotifers, copepod nauplii (not adults), small cladocerans] must be smaller than the gape in order for the larva to swallow.

While fish populations can exist in the area of permanent inundation, recruitment is fostered during the flood cycle. The end result is a continuum of fisheries production that expands with the migrating water's edge.

Concomitantly, limitations in access to floodplain habitat may limit fishery productivity. In essence, therefore, the productivity of permanent water bodies cannot be isolated from the productivity of adjacent floodplains.

As flood waters rise and recede, an edge of shallow water migrates across the floodplain. It is this shallow zone of the shifting water's edge that houses the highest fishery production at any given time (Lambou, workshop presentation). Therefore, the values assessed in our analysis must be considered transient between zones as the water crests and recedes and can vary from year to year with different flood events. As will be seen, however, we believe the productivity of shallow water areas increases with inundation of zones IV and V.

ADULT FINFISHES

The values attributed to space/cover, food availability, and reproduction habitat were assessed for each zone during the 10-year flood event (Table 7). During this flood, zones I through V are expected to be inundated for 30 days or more during the growing season (Larson et al. 1981).

Cover/Living Space

The amount of cover in each zone varies with the amount of water present (flood event). Cover is an impediment to feeding by predator species and important as protection for prey species. A weighted value to reflect the overall considerations of cover was assigned to each zone (Table 7). Cover in zone I was considered of medium value to adults before the flood, low value during a flood, and medium to high value afterwards. This was based upon the difference in location of fishes in the floodplain and the increase in depth of zone I during a flood, as well as the concentration of fishes following recession of floodwaters.

Table 7. Relative importance of bottomland hardwood zones in meeting certain life requisites for adult finfishes, young-of-the-year finfishes, and crawfishes (L = low, M = medium, H = high).

Life requisites	Zone I Before flood	Zone I During flood	Zone I After flood	Zone II	Zone III	Zone IV	Zone V
Adult finfishes							
cover	M	L	M/H	L	M/H	H	H
food	L	M	H	L	M/H	H	H
spawning substrate	L	L	M	L	M	H	H
Young-of-the-year finfishes							
cover	H	L	H	M	M/H	H	H
food	M	L	H	L	M/H	H	H
spawning substrate	L	M/H	H				
Crawfishes							
food				M	H	H	H
burrow utilization				H	M	L	L

The values of functions for zones II through V were considered, by definition, to be present only when the water exceeds bank full. Cover was considered to have low to no value (importance) during the 10-year event in zone II, due to concentrations of fishes at the shallower depths of the floodplain. Zone III was assigned high to medium values for cover based upon an increase in ground cover vegetation and the increased use by finfishes. Zones IV and V were considered to provide the greatest amount of cover due to a great increase in annual, perennial, and shrub vegetation. These zones were assigned high values for cover and utilization due to concentrations of finfishes in the shallow edge area.

Food Availability

Food was considered to be of low value to adult finfishes in zone I prior to flooding due to reduced metabolism in response to low water temperatures. Adult fishes feed only infrequently during the colder winter months. During the flood, which typically occurs in spring, the water temperature rises and metabolic processes increase, thus elevating to medium the value of food in zone I. Following recession of flood waters, a concentration of new life forms is washed into zone I at a time when metabolic processes are rapidly increasing. Therefore, food attains a high value to adult finfishes following the flood. Zone II was considered to have low value as a food area during our flood of analysis. However, this could change for less frequent events. For zone III, food concentrations increase due to shallower depth and heavier organic material (detritus). The value for food in zone III was therefore considered to be medium to high. Zones IV and V provide the highest concentrations of food organisms, both invertebrate and vertebrate, and were considered to be of high value.

Reproduction Substrate

Spawning substrate is of low importance prior to the flood. Late winter and early spring spawners use either mainstem floodplain bayous, bending cutoffs, or meander lakes in which there are usually sufficient substrates for spawning sites. After the flood, late spawners (June, July, August, and even September) may find suitable substrates only in zone I; these substrates are extremely important to those species (high).

Spawning substrates in zone II are less important during our assumed flood than sites near the water's edge in zones III, IV, and V, but perhaps of similar importance to those substrates in zone I for the same reasons listed above (low during the flood).

As the floodwaters rise to the levels of zones III, IV, and V, the availability (or proximity) of spawning substrates become increasingly

important, because we envision that it is at these levels that the water has arrived in a timely fashion for the bulk of the spawning populations of riverine fishes. Therefore, we assigned values of medium for zone III and high for zones IV and V.

YOUNG-OF-THE-YEAR FINFISHES

Cover/Living Space

Cover in zone I (permanent water) is of low importance to larval and juvenile finfishes during a flood, but has high value before (for carryover of juveniles) and after (for concentration of current hatchlings) the flood (Table 7). Zone II provides medium value due to importance for young as the waters recede down to zone I. Medium to high values are found for cover in zone III due to increased vegetation, with zones IV and V providing high values.

Food Availability

As previously discussed, food is of paramount importance to larval and juvenile finfish survival. Zone I provides some food for young-of-the-year before the flood (medium) in the form of microbial and invertebrate colonization of plant stems and clay banks. If the cover is of suitable surface, bacterial flora, protozoans, algae, rotifers, and other small organisms are available. Therefore, the overall value for food of zone I to young-of-the-year finfishes was considered high during flood recession. Zone III was rated medium to high due to increased vegetative (organic) material. Zones IV and V were considered the optimum habitat for production of needed food organisms (high).

CRAWFISHES

It was the opinion of the group that zone I receives insignificant use by crawfish populations. Therefore, for the most part, our analyses were limited to zones II through V.

Most floodplain crawfishes (e.g., red swamp crawfish) spend their whole life cycle in the forested area of the floodplain. Their life cycle strategy is flexible, which allows them to take advantage of the timing and duration of the flood event. When floodwaters overtop the burrow, overwintering crawfishes and their young are released from the protected depths of the ground water table. The crawfishes, vegetative detritus feeders, concentrate in the shallow water edge of the flood, moving with the water as stages rise and fall.

Because of extensive detrital material available on the forest floor, densities as high as $42.1/m^2$, with biomass as high as $127.5\ g/m^2$ have been estimated in shallow flood waters of the Atchafalaya River, Louisiana (Lambou, workshop presentation). In the whole flooded forested study area, a mean number of $3.4/m^2$ and a biomass of $303.3\ g/m^2$ were estimated, with total production of $69{,}717\ kg/km^2$.

In the Atchafalaya Basin Floodway, crawfishes normally burrow from late June through July. The bottomland hardwood zones in which this occurs depend upon the frequency flood present; however, in one area studied, the majority of the burrows were in zones II and III while most of the production occurred in zones IV and V (Lambou, workshop presentation).

The abundance of burrows at a particular location in the overflow area appears to be dependent upon the water level at the time of burrowing, which can vary from year to year. The higher numbers of burrows in zones II and III may, however, reflect evolutionary adaptations for the higher frequency floods. Because of the massive number of individuals that usually occur in flooded hardwood wetlands, predation does not appear to be a significant factor for survival and was not considered for analysis of crawfishes.

Food Availability

The amount of food present in zone II was assessed to have medium value to crawfish populations (Table 7). This value was assumed due to the marginal ability of crawfishes to digest cellulose, including the needle leaves of cypress. Zones III, IV, and V were assigned high values for food due to increased organic production.

Burrow Utilization

Because crawfishes carry the eggs and young attached to their ventrum until release in the spring, burrow utilization was examined here to replace spawning substrate. Zone II has very high burrow activity and is an important area for this life requisite. Zone III was rated as medium value based on numbers observed in field analyses. Zones IV and V were considered to have low values for burrow utilization due to less frequent flooding.

CONCLUSIONS

There are trends in the importance of "ecological zones" in bottomland hardwoods when evaluation criteria are applied to life requisites of fishes. Adult finfishes have fluctuating values in zone I, depending upon stages in the flood cycle (Fig. 11), but zone I certainly provides a place for carryover until the next flood. Zones II and III reflect gradual increases in values further in the floodplain, with optimum values in zones IV and V. Young-of-the-year finfishes nearly mirror value increases across the zones (Fig. 12) that are seen for adult finfishes. Zones IV and V provide optimum values to larval and juvenile finfish species. Crawfish populations reflect a marked increase from zone II to III and optimum values for food in zones IV and V (Fig. 13). Burrow utilization is inversely related to values for food production in the zones. Zones II and III function for crawfishes as zone I functions for finfishes.

Therefore, when one examines the overall findings of the fishery workgroup (Fig. 14), a trend of increasing values is seen across the zones for all fishery aspects considered except for crawfish burrow utilization. Zones II and III appear to provide lesser overall value to the fish communities while zones IV and V appear to be optimal for spawning, rearing, and growth.

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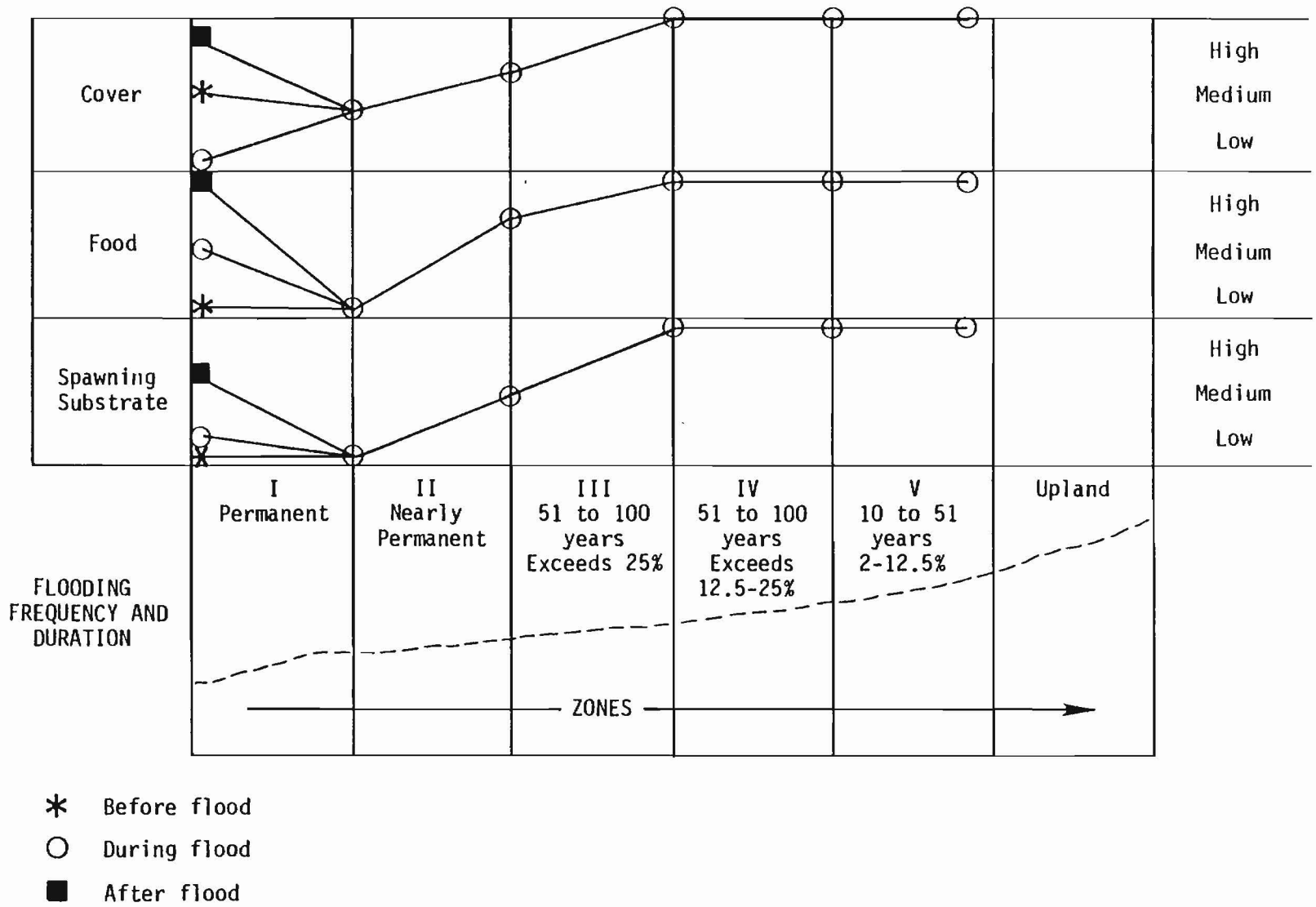


Figure 11. Relative value of bottomland hardwood zones in meeting the life requirements of adult finfishes in a 10-year flood event.

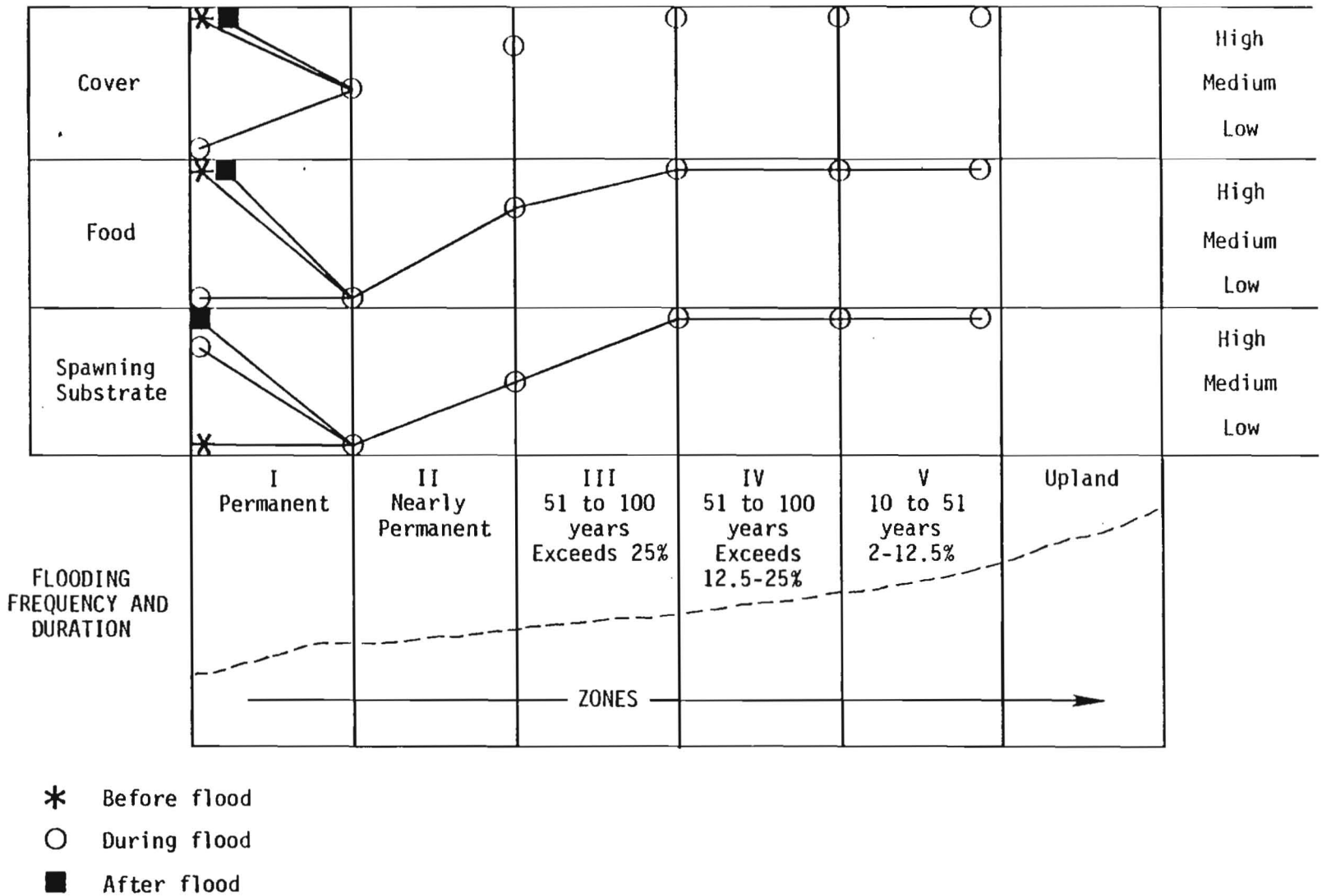


Figure 12. Relative value of bottomland hardwood zones in meeting the life requirements of young-of-the-year finfishes in a 10-year flood event.

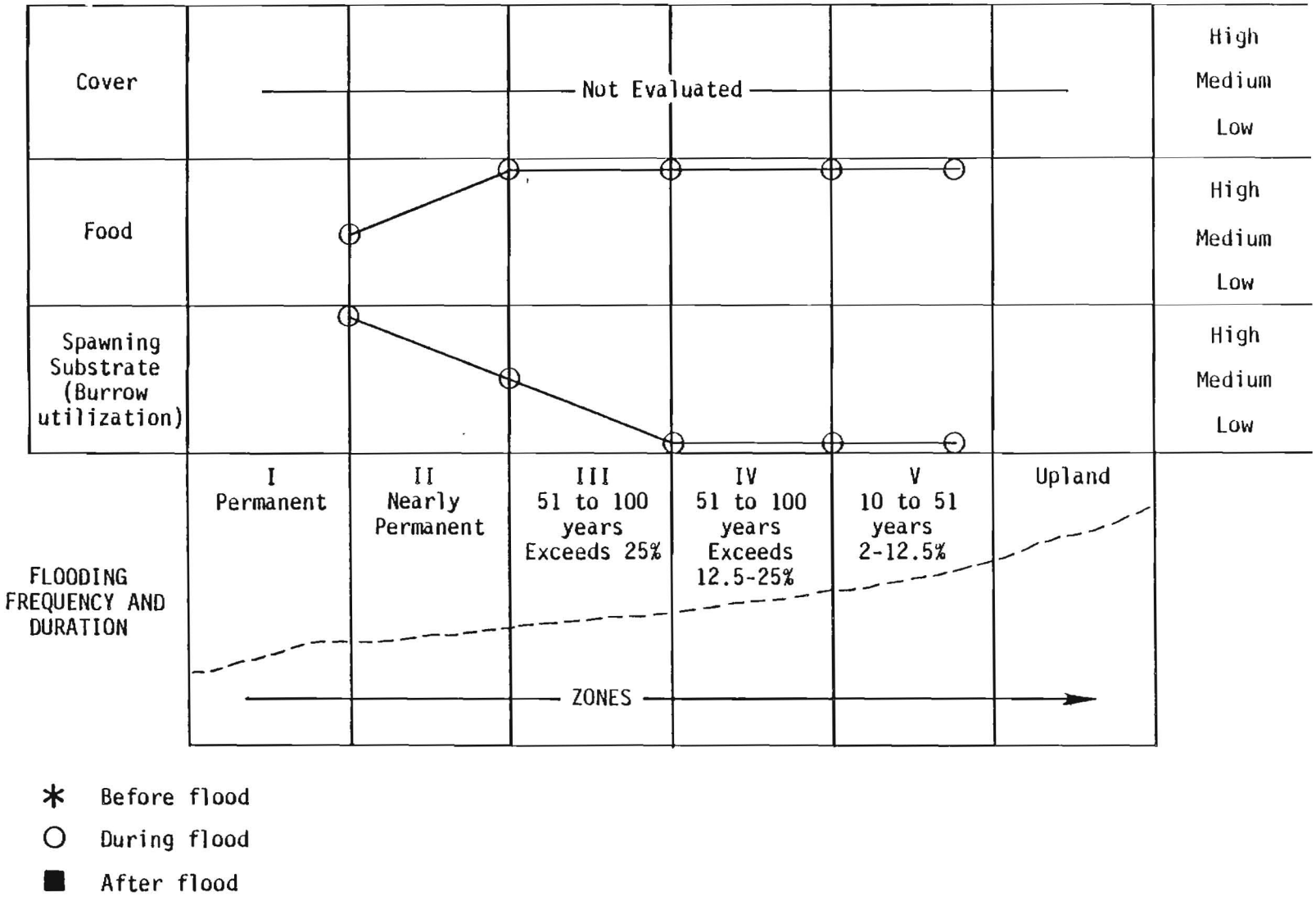
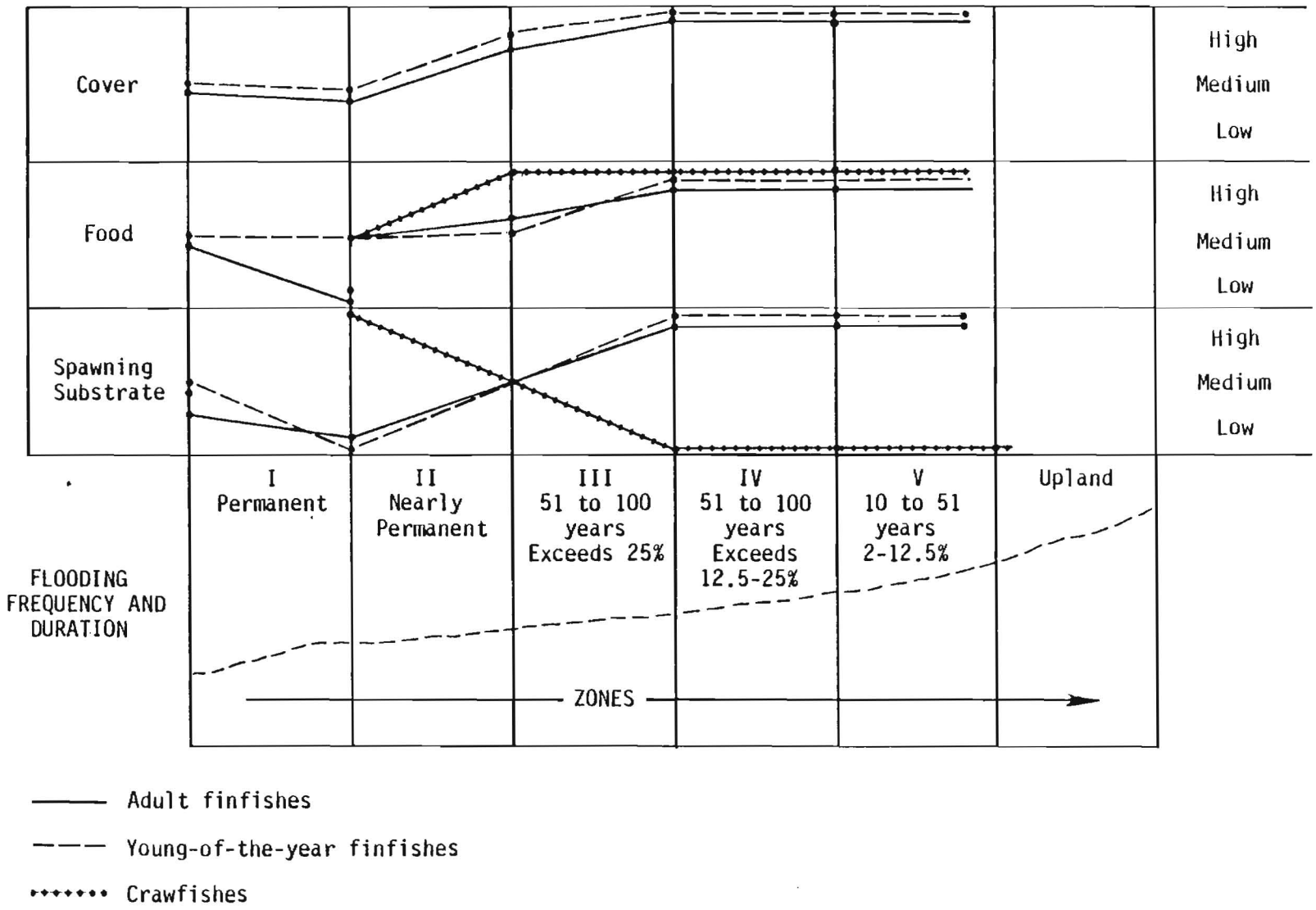


Figure 13. Relative value of bottomland hardwood zones in meeting the life requirements of crawfishes in a 10-year flood event.



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WILDLIFE WORKGROUP REPORT

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INTRODUCTION

Bottomland hardwood forests are generally recognized as highly productive and important habitats for wildlife. Inputs from the river, in the form of water, organic matter, sediment, and nutrients, interact with environmental gradients, such as hydroperiod and elevation, to support a diverse and highly productive flora, which in turn supports a complex wildlife community (Wharton et al. 1982). Larson et al. (1981) suggested that hydroperiod, soils, and individual plant species tolerances to inundation result in recognizable vegetative communities, or zones, along a gradient from river to uplands (Table 1). The question considered by the Wildlife Workgroup was the extent to which these zones, assuming that they are represented by recognizable plant communities, are useful in describing how bottomland hardwoods function to support the diverse wildlife populations that are present. For purposes of discussion at the workshop, the question was divided into two parts: characterization of the zones and the functions of the zones. Characterization refers to using individual wildlife species or species assemblages in defining or identifying zones, as well as whether the zones support recognizably different wildlife communities. Functions, on the other hand, refer to the ways the zones provide for the needs of wildlife. Both of these aspects of the relationship between wildlife and the zonation concept are discussed below and the report concludes with an assessment of the utility of the zonation concept from a wildlife perspective. Throughout, the zones are assumed to be as defined by Larson et al. (1981).

CHARACTERIZATION OF ZONES

WILDLIFE SPECIES AS INDICATORS OF ZONES

Frederickson (1979) and Wharton et al. (1981) showed that many wildlife species use more than one bottomland hardwood zone in meeting their life requirements. In some cases, this is simply a reflection of mobility and an opportunistic nature, which allow species to take advantage of seasonal availability of resources (e.g., mast) in different zones or to escape floods by moving to higher zones. In other cases, the relationship is more obligatory, with two or more zones being necessary for a species to satisfy all of its needs. The combination of these factors makes it unlikely that many wildlife species would be useful for identifying or defining zones. Some species of small stature and limited mobility may, however, be restricted to a single zone. For example, Wharton et al. (1982) indicated that the marbled salamander (*Ambystoma opacum*) and the mud salamander (*Pseudotriton montanus*) seldom occur outside of zone IV. To the extent that they occur, such species might provide useful corroboration of zonal boundaries established in other ways. However, the difficulty of finding and identifying such species in the field makes it unlikely that they would ever be useful as the primary means of delineating zones.

ZONES AS A MEANS OF CHARACTERIZING WILDLIFE COMMUNITIES

While most large, mobile wildlife species are not restricted to a single zone, the zones do tend to support recognizably different species assemblages. Fredrickson (1979) and Wharton et al. (1981, 1982) provided detailed information concerning the kinds of wildlife communities found in the various zones. On a subjective basis, it appears that the species assemblages in zones I and II are quite different from those in zones III, IV, and V. Zones IV and V are particularly difficult to separate on the basis of their wildlife communities,

while zone III is somewhat easier. If sufficient data are available, coefficients of community (Whittaker 1975:118) or other indices of similarity of species assemblages could be used to verify these generalizations.

The wildlife communities associated with the various zones can thus be characterized in a general way. However, presence or absence of particular species at any single bottomland hardwood site will also depend on a variety of other factors, including geographic location (e.g., lower Mississippi Valley vs. Atlantic Coastal Plain), order of the stream, width of the various zones, size of the entire bottomland hardwood tract, interspersion of the various zones, openings created by natural perturbations (e.g., wind, fire, beaver activity) or management (e.g., logging), and contiguity with upland habitats. The effects of such factors are discussed in more detail in a subsequent section (IMPORTANCE OF FACTORS OTHER THAN ZONES).

FUNCTIONS OF ZONES

From a wildlife perspective, the basic functions of bottomland hardwoods are to provide food, cover, reproductive sites, movement corridors, and other life requisites for both resident and migrant species. In addition, bottomland hardwoods provide significant opportunities for recreation associated with wildlife.

INDICATORS OF FUNCTIONS

Several variables, or indicators, might be used to evaluate the extent to which the different zones perform a wildlife support function. Various measures of species diversity, for example, compared across zones, would give an idea of the richness of the community associated with each. Population densities would provide a measure of the use of each zone by individual species. For example, Wharton et al. (1981:158) presented information on breeding bird densities in the zones of bottomland hardwoods of the Atlantic

Coastal Plain. These kinds of performance measures have at least two drawbacks, however. First, they require data that can only be obtained through intensive field investigations. Second, they are not particularly useful for assessing the effects of various perturbations, because they do not allow effective consideration of the mechanisms through which perturbations impact wildlife species.

Another approach to evaluating how the bottomland hardwood zones function to support wildlife is to consider more specific categories of resources that they provide (e.g., mast, cavities, other types of cover). The zones can be ranked, at least qualitatively, according to the extent to which they supply such resources. In principle, it should then be possible to begin to analyze impacts of perturbations by considering, first, which functions (resources) will be affected by a particular perturbation, and, second, which species utilize those resources and thus are likely to be impacted. Wharton et al. (1981:159-160) presented some preliminary information in this format. Below we expand and refine that information, as well as discuss some other functions that do not seem to be easily related to zones.

RELATIONSHIP OF FUNCTIONS TO ZONES

Food, Cover, and Reproductive Sites

The quality and quantity of specific types of food, cover, and reproductive sites provided seem to be the wildlife functions that can most easily be ranked according to zones (Table 8). Rankings in Table 8 are based on the best judgement and experience of workgroup participants. In developing this information, we attempted to describe typical, mature, relatively undisturbed (at least recently) sites in the Lower Mississippi Valley and Atlantic Coastal Plain where all zones are present. The exception to this general rule is that most sites in zone II have not experienced good regeneration following logging, so there is some question as to whether they can be considered mature. Important geographic variations are noted where they were recognized. The

Table 8. Relative importance of the bottomland hardwood zones (Larson et al. 1981) in producing specific types of food, cover, and reproductive sites for wildlife (0 = none or negligible, 1 = low, 2 = moderate, 3 = high).

Function	Zone I	II	III	IV	V
1. Production of acorns	0	0	1	3	3
2. Production of nuts other than acorns	0	0	1	2	3
3. Production of berries and soft fruits in the high canopy	0	1	1	2	3
4. Production of berries and soft fruits in the subcanopy and shrub zones	0	1	1	3	3
5. Production of soft fruits by vines	0	1	1	3	3
6. Production of herbs (grasses, weeds, and sedges) and browse for birds and mammals	0	1	1	2	3
7. Availability of terrestrial invertebrates for food	0	1	1	2	3
8. Availability of aquatic macroinvertebrates (including crayfish) for food	3	3	3	2	1
9. Availability of small mammals as prey	0	1	1	2	3
10. Availability of reptiles and amphibians as prey	1	3	3	2	1
11. Availability of small birds as prey	0-1	3	3	3	3

Table 8. (concluded).

Function	Zone I	II	III	IV	V
12. Availability of flying insects as food	3	2	2	2	2
13. Diversity of forest strata	0	2	1	2-3	3
14. Availability of ground-level cover (stumps, logs, bottom cavities, etc.)	0	1	1	3	3
15. Availability of arboreal cavities	0	3	2	3	2
16. Refuge from high water for terrestrial species	0	0	0	1	3
17. Availability of cover to escape from predators	2	3	2	2	2
18. Availability of intermittent pools for amphibians	1	3	3	3	1
19. Availability of cover for wintering waterfowl	1	3	3	3	1

following numbered list corresponds to the entries in Table 8 and provides the rationale for the assigned rankings.

1. Acorns represent an important food resource for many wildlife species. Zones IV and V were judged to be the most important acorn producers because of the number and diversity (both red and white oaks) of species that produce acorns preferred by wildlife.

2. Nut-bearing trees such as shagbark hickory (Carya ovata), pecan (Carya illinoensis), and American beech (Fagus grandifolia) were judged to increase in abundance and productivity along the moisture gradient through zones III, IV, and V.

3. Production of berries and soft fruits by species such as sugarberry (Celtis laevigata) and persimmon (Diospyros virginiana) was judged to increase along the moisture gradient. Zones II and III may at times be more important than indicated depending on the productivity of tupelo (Nyssa aquatica) and persimmon, respectively.

4. Shrubs producing soft mast [e.g., deciduous holly (Ilex decidua) and green hawthorn (Crataegus viridis)] are less abundant in the more frequently flooded zones (II and III). The importance of zone II is much greater in areas where Drummond's red maple (Acer rubrum var. drummondii) is abundant.

5. Abundance and diversity of vines producing fruit [e.g., snailseed (Cocculus carolinus), Alabama supplejack (Berchemia scandens), poison ivy (Rhus radicans), lady's eardrops (Brunnichia cirrhosa), and peppervine (Ampelopsis arborea)] are greater in the less frequently flooded zones (IV and V). Zones II and III can be more important than indicated in situations where there is an open canopy that allows more vines to exist.

6. Herbs and browse are more abundant in the less frequently flooded zones (IV and V). Again, zones II and III can be more important than indicated in open-canopy situations.

7. Availability of terrestrial invertebrates may be limited by flooding. However, even though zone II is flooded much of the year, some terrestrial invertebrates would occur on emergent logs, cypress knees, detrital mats, and around the bases of trees.

8. Aquatic macroinvertebrates would tend to be less abundant at higher, less frequently flooded elevations. It should be noted, however, that zone IV has been shown to be very important for waterfowl when it is flooded.

9. Many small mammals are not tolerant of flooding of high frequency or long duration, or are dependent on food organisms (e.g., terrestrial invertebrates) that do not tolerate flooding well.

10. Reptiles and amphibians are generally more abundant at wetter sites. This function may vary greatly with latitude, however, with numbers and diversity of reptiles and amphibians increasing from northwest to southeast.

11. Small birds occur in large numbers at some time of the year in all zones with adequate vegetation structure. Therefore, the importance of zones may vary seasonally, but on an annual basis, all zones except zone I tend to be similar.

12. Flying insects can be captured more easily in open areas. Zone I is thus the most important for this function. All other zones appear to be equally important above the canopy.

13. Greater plant species diversity in forest strata provides more food, cover, and reproductive sites for birds. Diversity tends to increase as sites become drier. However, the management history of an area can also significantly influence diversity, especially in zones II and III.

14. The value of ground-level cover, such as stumps, logs, and bottom cavities, is higher in zones that are less frequently flooded.

15. Zones II and IV are most important because of the presence of cypress (*Taxodium distichum*) and sugarberry, respectively, both of which are prone to cavity formation.

16. Higher ground provides greater opportunity for terrestrial species to escape high water. Interspersion of zones, such as found in ridge and swale topography, is also very important for species of limited mobility.

17. Escape cover was broadly interpreted to include any place that birds, mammals, reptiles, and amphibians might escape from predators; therefore, little difference exists between zones. Interspersion may be particularly important in some cases; for example, deer, bear, and swamp rabbits can make use of alternating ridge and swale topography with standing water to elude hunting dogs or natural predators.

18. Intermittent pools are important breeding places for amphibians. Such pools were judged to be most abundant and useful in zones II, III, and IV, because these zones are intermittently flooded.

19. Winter waterfowl habitat was considered from the point of view of cover, primarily for escape, loafing, and roosting. The utility of the zones in this respect is, of course, highly dependent on the flooding regime.

As mentioned above, the rankings in Table 8 are subjective in nature, based on the collective experience and observations of workgroup members. If it seems desirable, some of these functions could be quantified using data available in the literature. Despite their subjectivity, however, we believe that these rankings reflect fairly accurately the differences in function that would be encountered on sites meeting the criteria outlined (i.e., mature, relatively undisturbed sites in the lower Mississippi Valley and Atlantic Coastal Plain with all zones present). In addition, we feel that the approach represented by these rankings may have merit in attempting to assess the kinds of impacts on wildlife that might be expected from different kinds of perturbations. However, it is extremely important to note that these rankings are not intended to represent values to society of the zones or the wildlife they support. It would be particularly inappropriate, for example, to sum the rankings across all functions to obtain an overall "value" of a zone to wildlife. This should become even more obvious in the following sections, where we discuss two functions (movement and recreation) that are largely unrelated to zones and a number of factors other than zones that interact to determine the extent to which bottomland hardwoods support wildlife populations.

Movement

In addition to providing food, cover, and reproductive sites, bottomland hardwoods serve an important function in providing corridors through which wildlife species move. Several different types of movement can be distinguished, including: seasonal movements between bottomland hardwood zones, as well as between uplands and the floodplain, which allow species to satisfy all of their life requirements; movements between blocks of habitat, which allow species to repopulate vacant areas and maintain genetic diversity; and long-distance movements of migratory species.

For all of these kinds of movements, the spatial pattern of bottomland hardwood forests, both on a local and regional basis, may be more important than the specific zones that are present in determining the utility of the

forests to wildlife. Harris (workshop presentation) described several examples of the importance of the juxtaposition of bottomland hardwoods and uplands for species such as squirrels and turkeys. At the regional or continental scale, the location of blocks of habitat relative to movement patterns and needs of migratory birds is an important determinant of the extent to which bottomland hardwoods function to support those species.

Recreation

Recreation associated with wildlife is another important function served by bottomland hardwoods. Furthermore, it is likely that recreation will become an even more important function in the future, as human populations increase and the resource base decreases. It is the judgement of the group that the utility of bottomland hardwood sites in providing recreation is determined more by ease of access and proximity to population centers than by factors such as what zones are present. Many of the species of interest to recreationists, particularly hunters, are broadly distributed within the zones and/or move between zones in satisfying their needs. Therefore, it seems likely that recreationists would be similarly distributed, provided that access is available.

IMPORTANCE OF FACTORS OTHER THAN ZONES

We have argued above that the bottomland hardwood zones differ in their ability to provide some resources for wildlife (e.g., specific types of food, cover, and reproductive sites) and that these differences can be estimated, at least qualitatively. However, a number of other factors are also important in determining the utility of these resources to wildlife at any particular site.

Geographic Location

Geographic location is important in several ways in determining the usefulness of a bottomland hardwood site to wildlife. First, there are broad-scale differences (e.g., central Mississippi Valley vs. lower Mississippi

Valley vs. Atlantic Coastal Plain) in the species assemblages that use bottomland hardwoods. For example, Harris (workshop presentation) discussed changes in the number of species of reptiles and amphibians on a continental scale from Northwest to Southeast. Second, location within a given system (e.g., the Lower Mississippi Valley) may be important. For example, some migratory birds may make greater use of the sites close to the Gulf Coast than they do sites farther north. Finally, the pattern of habitat blocks along migration routes will be an important determinant not only of usage of particular sites, but utility of the system as a whole to migratory species.

Size of Tract

Many species with large body size require large blocks of habitat for satisfying their life requirements. For such species, the size of the habitat block, which may include uplands and agricultural lands as well as bottomland hardwoods, is an important determinant of utility.

Diversity, Interspersion, and Juxtaposition

Many wildlife species utilize multiple habitats (zones) during an annual cycle. Usefulness of a site for these species depends on factors such as diversity (the number of zones or habitats present), interspersion (the degree to which the habitats are mixed together, as opposed to ordered along a continuous gradient), and juxtaposition (which habitats are located adjacent to which).

Edge

It is a well known principle in ecology that borders between distinctly different communities (edges) often contain not only higher densities of the species from each community, but also a set of species found only along the edge itself. In bottomland hardwoods, openings created by natural perturbations (e.g., wind, fire, beaver activity) and management activities (e.g., logging) provide such edge and are thus important factors in determining the usefulness of a site to wildlife.

Contiguity with Other Habitats

As mentioned earlier, contiguity with other habitats may be an important determinant of the utility of a site to wildlife. Sites that link other habitats together may be especially important in allowing movement of individuals, thus contributing to repopulation of vacant areas following major flood events and preservation of genetic diversity throughout the range of a species.

CONCLUSIONS

Based on the above discussion, the following conclusions can be drawn concerning the zonation concept and the wildlife-support functions of bottomland hardwoods.

1. To the extent that they are comprised of different vegetative communities, the zones tend to support recognizably different wildlife species assemblages. In particular, zones I and II tend to support different species than do zones III, IV, and V. The species assemblages in zones IV and V are difficult to distinguish; zone III is somewhat easier.

2. Many wildlife species utilize more than one zone. It is therefore unlikely that presence or absence of particular wildlife species can be used as the primary means of delineating zone boundaries. However, presence of some small species of limited mobility may provide useful corroboration of zone boundaries established in other ways.

3. The vegetation communities implied by the zones differ in their ability to provide certain specific resources for wildlife and these differences can be ranked, at least qualitatively, for typical sites. To the extent that specific perturbations can be described in terms of their effect on these resources, this approach may be useful in assessing the kinds of wildlife species likely to be impacted by a given action.

4. It would be inappropriate, however, to use these qualitative rankings to determine the overall value of a particular zone to wildlife, or to compare the values of two or more zones.

5. Similarly, the zonation concept by itself is not sufficient to determine the extent to which a particular site supports wildlife. Other factors, including geographic location; size of the tract; diversity, interspersion, and juxtaposition; edge; and contiguity with other habitats, must also be taken into consideration.

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ECOSYSTEM PROCESSES WORKGROUP REPORT

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INTRODUCTION

The Ecosystem Processes Workgroup organized its discussions around development of the following set of ecological principles concerning bottomland hardwood (BLH) ecosystems:

TIME SCALES

- Components of the BLH ecosystem respond in different ways and at different rates to temporal variations in the major driving variables of sun, hydrology, and soils.

HYDROLOGY

- Hydroperiod, or the timing and duration of inundation, is the principal driving force of ecological function and composition of vegetation in BLH ecosystems.

- At the landscape level, BLH ecosystems receive, absorb, and dissipate kinetic energy generated elsewhere in the watershed. The pattern of this dissipation within the BLH ecosystem determines patterns of ecosystem structure and function.

SPATIAL PATTERNS

- BLH ecosystems are composed of a mosaic of site conditions. The pattern of this mosaic (i.e., complexity and interspersion) has significant effects on the functioning of a BLH ecosystem.

PRODUCTIVITY

- Net primary production (NPP) in BLH ecosystems is generally higher than that of mesic upland ecosystems in the same geographic region.

- BLH ecosystems support a multifaceted assemblage of consumers because the ecosystems alternate between terrestrial and aquatic conditions.

TRANSFORMATION AND TRANSPORT OF MATERIALS

- BLH ecosystems are open systems that transform energy and materials derived from inflows. Hence, outflows from BLH ecosystems differ quantitatively and qualitatively from inflows.

- Episodic flooding events serve to transport accumulated NPP from BLH sites to aquatic consumers and food webs in other sites.

- Mineral cycling in BLH ecosystems has both recycling and throughput (import-export) components. The ratio of these components, called the cycling index (CI = recycling/throughput), increases along a gradient of increasing elevation.

CONCLUSION

- The BLH ecosystem (floodplain and river) acts as a functional unit within the landscape.

Each of these principles is followed, first, by an explanation that more fully develops the principle and, second, by examples that document information and observations that support the principle or were responsible for its development. It is our consensus that these principles are sound, but they are also very general. As a result, new information from a larger number and wider geographical distribution of BLH ecosystems will allow the principles to be refined and modified. This iterative process of reexamination and refinement will serve to strengthen, in our opinion, our concluding principle that the functioning of whole BLH ecosystems cannot be adequately separated into the functions of independent subsystems or zones.

ECOSYSTEM PROCESSES

TIME SCALES

Principle

Components of the BLH ecosystem respond in different ways and at different rates to temporal variations in the major driving variables of sun, hydrology, and soils.

Explanation. Three major driving variables that act on BLH systems are sun, hydrology, and soils. These are related to the length of time required to develop various structural features.

- SUN - Solar radiation has some geographic variation in the Southeast, but is not significantly different between BLH ecosystems and neighboring ecosystems.
- HYDROLOGY - Long-term phenomena during the ice age were responsible for the large-scale features of floodplains that support BLH ecosystems. Recognizable topographic features (e.g., Deweyville Terrace) are associated with this time scale. On a shorter time scale, there is year-to-year variation in rainfall and river flow, with an apparent 5- to 7-year cycle superimposed on the dominant annual cycle.
- SOILS - Soils, in addition to hydroperiod, have a strong influence on surface drainage, infaunal populations, and biogeochemical processes. All of these processes and components affect soils, but soils are basically a reflection of long-term sedimentation and diagenic processes.

Examples. Over a time scale of 100's to 1000's of years, weathering and sedimentation interact to produce the major geomorphic features of a BLH system. These include such features as soil type, ridge and swale topography, point bars, and natural levees. There are areas where changes in these features can be very rapid, such as in the Atchafalaya Basin and Delta (Gagliano and van Beek 1975), but generally these changes are much slower than biotic changes.

Over a scale of 10's to 100's of years, distinctive vegetative communities develop as a function of soils and the hydrologic regime. During very wet or dry years, a forest community may be functioning under suboptimal conditions. However, it generally takes one or two rotations for dominant vegetation to adjust to a permanent change in hydrology.

On the scale of a few years to 10's of years, riverflow and precipitation go through characteristic wet and dry cycles. The life cycles of larger animals, understory shrubs, and seedlings respond to cycles within this time frame. These organisms (considering seedlings to be different ecologically than adults) are inherently more mobile as populations than overstory trees. Seedlings may become established in different zones than trees of the same species during abnormally wet or dry years. Animals such as long-lived fishes, amphibians, reptiles, birds, and mammals become more or less abundant in response to year class dominance, habitat changes, and variability in environmental parameters. These organisms move through much of the BLH ecosystem and into neighboring ecosystems.

The annual cycle is one of the most dominant time scales, reflecting the temperate climate and the seasonality of the hydrologic regime. Lambou (workshop presentation) illustrated how young-of-the-year crayfish move into and out of BLH areas during a flood. During years of larger floods, more of the area is used and the important "zone" seems to be the moving water edge. Harris (workshop presentation) discussed the complimentary temporal distribution of fruit and seed sources over the year in the BLH ecosystem. Wildlife use these food sources as they become available. Lambou (workshop presentation) showed that when parts of the BLH system were removed, composition of the nekton community was simpler, productivity was decreased, and the diversity of diet items declined. Harris (workshop presentation) indicated that many amphibians from flatwoods move into BLH forests to reproduce. He also showed that migratory birds use BLH areas to lay down migratory fat both coming from and going to their breeding grounds, and that the northward front of migration is often tied to insect emergence in the spring. Litterfall and herb production are annual events that make food available to consumers.

A number of processes operate on time scales of less than one year. The generation time for many small animals (and some herbaceous plants) is considerably less than one year. Thus, there may be several generations of insects, microarthropods, and small soil organisms occurring within a single annual cycle. The generation time of progressively smaller organisms is shorter. Bacteria may have generation times of less than a day. Some chemical processes are even faster. The timing of these processes and the activities of organisms may be tied to temperature, a particular stage in the hydrologic cycle, rainfall, daylength, or other physical-chemical factors.

In general, the generation time (turnover time) of processes is related to the size of the structure of which they are a part (Fig. 15). The larger a component is, the more it contributes to overall or gross ecosystem structure. Small components are much more mobile and tend to couple processes and parts of the system. The ecosystem needs to be defined both by its structure and processes. A concept analogous to the River Continuum Hypothesis (Vannote et al. 1980) is appropriate temporally as well as spatially for understanding and managing BLH ecosystems. Therefore, we propose a BLH Continuum Hypothesis: both structure and processes at different spatial scales have ecological significance over different time scales. Thus, the pattern of vegetation, when arranged by tree community zones, provides an understanding of BLH functioning at approximately the 100-year time scale. However, the pattern of vegetation provides only partial insight into processes that occur on shorter time scales (e.g., activities of smaller consumers) and is itself a response to processes that occur over longer time scales (e.g., large, infrequent flood events that modify geomorphic features).

HYDROLOGY

Principle

Hydroperiod, or the timing and duration of inundation, is the principal driving force of ecological function and composition of vegetation in BLH ecosystems.

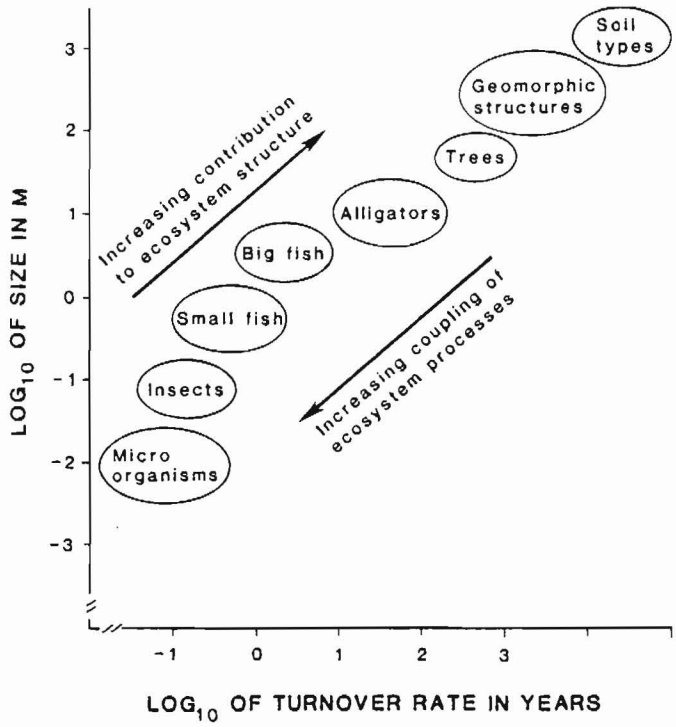

Figure 15. The BLH Continuum Hypothesis: generalized relationship between spatial scale of structure and temporal scale of associated processes.

Explanation. BLH ecosystems are associated with the floodplain of most major and minor rivers in the southeastern United States. It is generally accepted that hydrology strongly influences the functions of these systems. Primary production, nutrient transformation and cycling, wildlife habitat, and aesthetics are directly linked with the presence, movement, and quality and quantity of water in these systems (Clark and Clark 1979).

BLH forests are diverse and productive systems that are adapted to the fluctuating water regime of the floodplain. The alternating wet-dry hydrologic cycle represents an energy subsidy that maintains high productivity. Because the length of periodic inundation changes with elevation within the system (i.e., from permanent water to uplands), BLH ecosystems contain a mosaic of microenvironments and species assemblages able to withstand varying lengths of soil saturation. Recognition of these species assemblages has led to attempts to divide the system into discrete zones. However, the entire floodplain, to

some point of maximum flooding (e.g., 100-year floodplain), is an integral part of the river system. Species assemblages in the bottomlands are controlled by the river, and they in turn contribute to riverine processes and populations. Water shapes and maintains floodplains by transporting and redistributing sediments and nutrients within the system (Wharton et al. 1982). Sources of water to bottomlands and rivers include precipitation and runoff, groundwater, and tidal flow. The hydrologic regime can be partitioned into temporal and directional components that are distributed across elevational gradients from stream channel (aquatic) to the upland.

Examples: duration of inundation. Flooding duration corresponds most directly to drainage area. Small watersheds with steep slopes, particularly in areas with dense clay soils, are characterized by fast runoff and infrequent flooding for short durations (Wharton et al. 1982). Southeastern rivers can have flooded bottomlands that are inundated from 18% to 40% of the year (Bedinger 1981). Such rivers have broad vegetated floodplains. Water movement through these systems is slowed, which allows for increased infiltration and sediment deposition, increased aquatic use of flooded bottomlands, and protection of downstream areas from flooding.

Examples: upslope processes. Upslope processes are dependent on the presence of extensive inundation in the floodplain as a transport medium. Examples include: (1) migrations and movements of fish into the floodplain; (2) dispersal of populations, such as redistribution of seeds, by water movement; and (3) transport of sediments and nutrients.

Examples: downslope processes. When flood waters recede, particulate organic matter and dissolved nutrients are transported downslope. The timing and amount of this output from BLH ecosystems are critical to the life histories of many aquatic species.

Water not only enters the BLH ecosystem upslope from the rivers, but also by overland runoff from uplands, groundwater seepage, and by direct precipitation. Water is retained by bottomland soils, or if soils are saturated, runs off to the river. These sources of water may maintain aquatic species in channels and other depressions within the floodplain during nonflooded periods.

Examples: vertical processes. Saturated floodplains may be in direct communication with surficial aquifers. It is probable that more discharges occur in BLH areas than recharges. Discharges may occur at low-water periods from seeps of groundwater. Seeps generally occur along the steeper slopes of the floodplain. Seeps may maintain soil in a saturated condition in many areas within floodplains. Seeps and localized rainfall are very important in maintaining soil moisture during summer months when the river flow is low and evapotranspiration is high. Vertical sources of water are, thus, very important in maintaining populations of terrestrial and amphibious species in swamps during these periods.

Principle

At the landscape level, BLH ecosystems receive, absorb, and dissipate kinetic energy generated elsewhere in the watershed. The pattern of inundation associated with this dissipation within the BLH ecosystem determines patterns of ecosystem structure and function.

Explanation. BLH floodplains function as units to absorb the kinetic energy of a wide variety of flood events, ranging from relatively high-frequency, low-energy events to low-frequency, high-energy events (e.g., 100-year flood). For a given elevation within a floodplain, the total kinetic energy received over time will be the cumulative effect of low-energy, high-frequency floods and high-energy, low-frequency floods (Fig. 16). The whole spectrum of flooding events contributes to overall kinetic energy at low elevations. At high elevations (especially those areas remote from the stream channel) only high-energy, low-frequency events transmit kinetic energy. However, much of the energy is dissipated at lower elevations by the time the

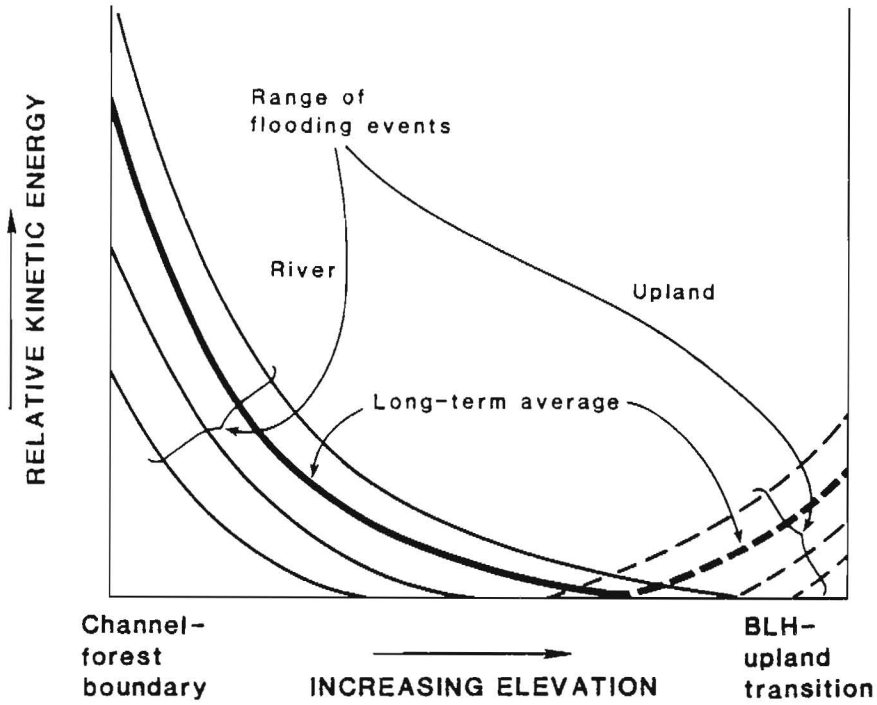

Figure 16. Distribution of kinetic energy associated with different riverine flooding and upland runoff events along a generalized BLH elevation gradient.

flood waters reach higher elevations. Although the exact shape of the curve is not known, and may vary from one BLH ecosystem to another, we propose exponentially decreasing kinetic energy with increasing elevation. However, at the BLH-upland transition at highest elevations, runoff from uplands represents an additional vector of kinetic energy, thus giving an overall concave shape to the curve (Fig. 16).

Examples. All wetland functions may not be occurring at all elevations in a given flooding event. For example, during dry years, flooding is restricted to lower elevations within the floodplain and fish habitat, erosion protection, sedimentation, and detrital export may be restricted to this flooded zone. Drier, higher portions of the floodplain may serve different functions during this period, such as providing wildlife movement corridors. Years of low flood amplitude and duration are also very important for repopulation of communities because seed germination and seedling establishment of many

wetland species, such as cypress (Taxodium distichum) and water tupelo (Nyssa aquatica), occur when flooding is absent.

High water produces a shift of wetland functions within the BLH floodplain. As water rises, energy input into the system is greater and more plant communities provide erosion control and water filtration. Also, the increasing areal extent of flooding provides habitat and food for moving populations of fish and aquatic invertebrates and transports detritus to depressions such as oxbow lakes and ponds that support aquatic food webs. While the zonation concept may describe certain aspects of vegetation and soils (i.e., longer time scales), kinetic energy of flood waters represents a more continuous variable on which ecosystem processes are functionally dependent.

SPATIAL PATTERNS

Principle

BLH ecosystems are composed of a mosaic of site conditions. The pattern of this mosaic (i.e., its complexity and interspersion) has significant effects on the functioning of a BLH ecosystem.

Explanation. Geomorphic processes operating on long time scales have produced highly varied patterns of physical surfaces within many BLH floodplains. Local variation in topography and soil texture generally results in a mosaic of soil moisture and hydroperiod and thus a mosaic of plant assemblages. A zonal classification of BLH forests can be misleading to the extent that it ignores this spatial pattern. Actual spatial patterns range from a simple gradient of generally monotonically increasing elevation away from the river (or base of the primary natural levee) that is most characteristic of 1st, 2nd, and some 3rd order streams (Fig. 17a), to much more heterogeneous cross sections composed of backswamp, channel fill, oxbow lake, ridge, swale, point bar, hummock, and "mini-basin" features (Fig. 17b).

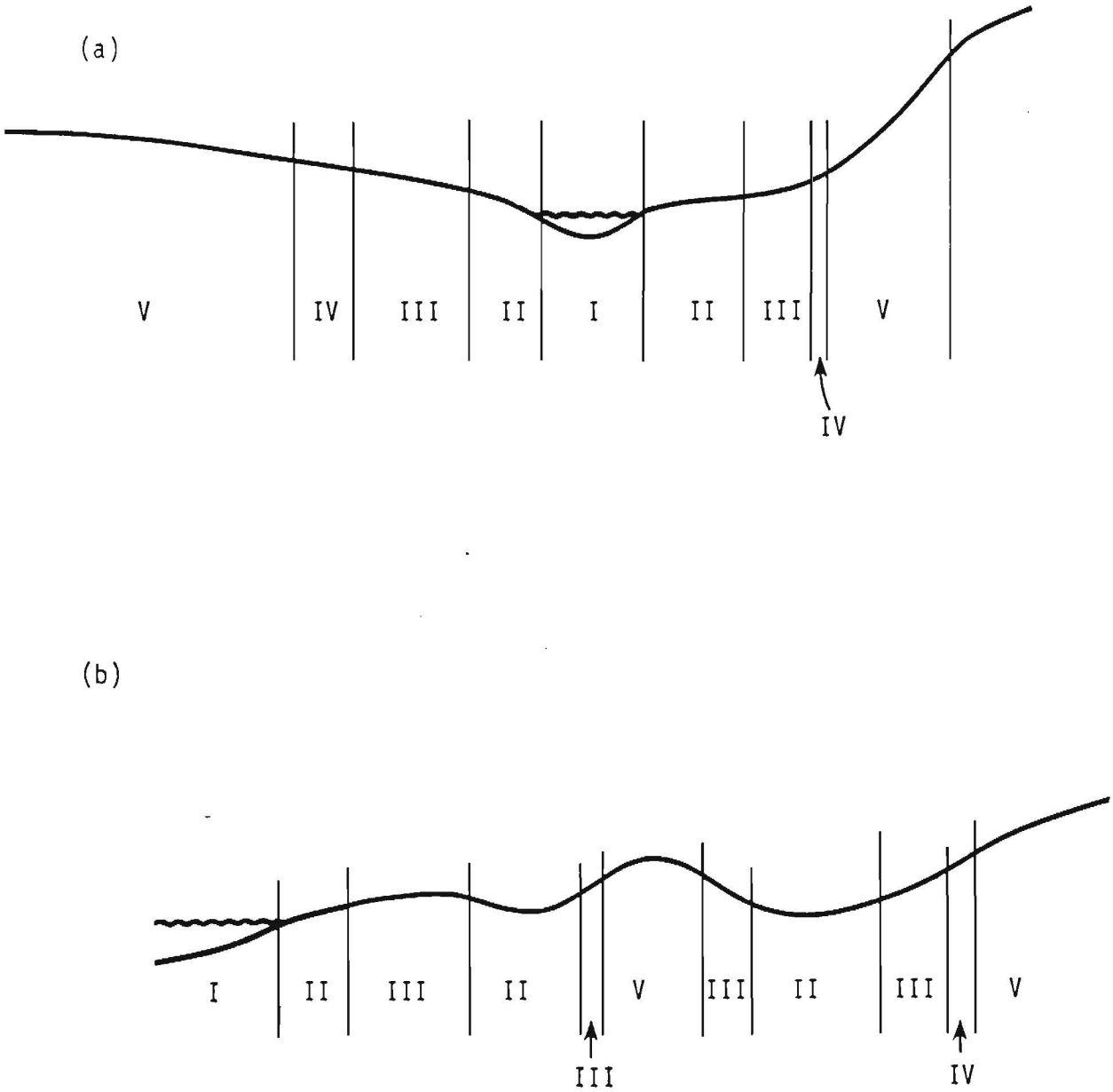

Figure 17. Cross section of BLH with (a) simple spatial patterns of monotonically increasing elevation and monotonically decreasing hydroperiod, and (b) more complex spatial pattern of elevation and hydroperiod.

Examples. Hydroperiod is a primary determinant of plant community composition. The pattern of vegetation, therefore, reflects the topographic pattern as it influences flooding and drainage. Silt-bearing rivers tend to have the most diverse patterns, while low-gradient blackwater streams originating in the coastal plain tend to be more topographically uniform. Ecosystem variability is generally greater in riverine systems than in the low-gradient streams. Sites that are inundated almost constantly support open stands of water tupelo and bald cypress with considerable algae and aquatic macrophytes. Drier sites with different species compositions may be found throughout the floodplain and often have relatively abrupt ecotones with wetter communities. Because of this interspersion, activities of animals in drier sites may be more directly coupled to those in the wet sites than is generally assumed.

The importance of spatial pattern to species depends upon their mobility and territorial requirements. For small, less mobile animals, high diversity and interspersion tend to reduce the size of the effective habitat to small, sometimes isolated areas. Spatial pattern may become critical for rare plant and animal species because of lack of contiguous habitat. For larger, more mobile fauna (e.g., deer, bear, squirrels), the effective functional ecosystem is larger and is not affected as greatly by small-scale interspersion.

Spatial pattern within the BLH ecosystem would seem to have important effects on a number of ecosystem functions. The relationships of many of these functions to spatial patterns have not been explicitly studied. However, the following characteristics and functions might be hypothesized to change as a function of increased spatial complexity and interspersion:

- Ecotones (habitat edge) will increase.

    1. Linear edge per unit area increases thereby providing more suitable habitat for birds and larger mammals.

- Refugia and "island" biogeographic processes will increase in importance.

  1. Sloughs and oxbow lakes may serve as refugia for aquatic species between large flood events.

  2. Isolated fish and amphibian populations in sloughs and oxbow lakes at considerable distances from the mainstream will exhibit smaller variation among individuals of the same species due to small gene pool size and infrequent recruitment when recruitment is dependent upon flood events.

  3. Drier sites within the ecosystem will support isolated populations of small mammals that are likely to be extirpated in the largest floods.

  4. Recolonization potential of aquatic and terrestrial "islands" will be a function of the frequency of access to the river (for aquatic systems) or to the upland (for terrestrial islands during drought or low-water periods).

- Flooding, drainage, and soil formation will be more complex.

  1. The pattern of inundation for any specific flooding stage will reflect the complexity of relief in the ecosystem.

  2. Deposition of sediment and subsequent soil formation will reflect the complexity of inundation.

  3. A topographically complex landscape may trap a higher fraction of water in semi-isolated depressions and thus retain flood waters longer (Fisk 1972).

- Transport of waterborne materials will be altered.

  1. Complex flooding and drainage patterns will create incomplete flushing patterns of waterborne materials upslope and, in turn, downslope to the stream when floodwaters recede.

  2. Certain interspersed subsystems will tend to have tighter upslope and downslope nutrient and energy couplings.

  3. Flora (e.g., seeds) and fauna (e.g., fish) dependent on water for access to sites within the BLH ecosystem may have less complete access (in space and time). Fish may spawn, at high water, in areas that later become isolated from permanent water and then dry out completely.

These hypotheses illustrate that spatial variation and its effects on the functions of BLH ecosystems constitute landscape values of the BLH system and deserve further study.

PRODUCTIVITY

Principle

Net primary production of BLH ecosystems is generally higher than that of mesic upland ecosystems in the same geographic region.

Explanation. Net primary productivity (NPP) tends to be greatest at sites with intermediate hydroperiods. Extended hydroperiods (e.g., at low floodplain elevations) limit NPP due to the physical and chemical properties of anaerobic sediments. Transpiration and photosynthesis rates are slowed when root systems suffer the cumulative effects of oxygen depletion, eventually impeding water and nutrient uptake and plant growth. Water tupelo and cypress, which have adapted to extended hydroperiods, are two of the species in BLH ecosystems that have overcome metabolic restrictions. NPP at well-drained sites (e.g., at higher elevations in the floodplain) may be limited at times by low soil moisture or nutrient availability.

Respiration and photosynthesis rates are related to ambient temperature and oxygen availability in the soil. Because unflooded conditions and high temperatures coincide during the growing season, sites with a fluctuating water table provide optimum conditions for reducing moisture stress, while providing root systems with sufficient oxygen and nutrients. However, NPP may vary considerably across specific BLH sites as a function of stand age and composition, as well as fluctuations of environmental conditions.

Examples. Cole and Rapp (1981), in a review of 22 worldwide temperate coniferous and deciduous forest stands, found mean annual biomass and N accumulations to be 2.7 megagrams/ha and 5.19 kg/ha, respectively. Messina et al. (1983) found biomass and N to accumulate at an annual rate of 4.6 megagrams/ha and 6.93 kg/ha, respectively, for southeastern bottomland hardwood ecosystems.

This high productivity can be attributed to the moderate climate of the region and the rich growing conditions offered by the alluvial soil.

During ecological succession in forested ecosystems, large amounts of energy are initally allocated to increase the photosynthetic surface. The adaptive strategies to accomplish this across a gradient of soil moisture and oxygen are not well documented. Species that require rapid establishment due to deep or frequent flooding (e.g., T. distichum, N. aquatica, and Salix nigra) accumulate aboveground biomass more rapidly than species of adjacent floodplain forest communities during the first 10 years of succession. Specific biomass components (e.g., fruits) may not have the same relative distributions over elevational gradients within the BLH system as that observed for NPP. This could have particular importance to biota that may utilize very specific fractions of the NPP at different times of the year (WILDLIFE WORKGROUP REPORT, this volume).

Principle

BLH ecosystems support a multifaceted assemblage of consumers because the ecosystem alternates between terrestrial and aquatic conditions.

Explanation. BLH ecosystems provide an important interface between aquatic and terrestrial habitats. Use of BLH ecosystems by both aquatic and terrestrial consumers at different stages in the wet-dry cycle results in a consumer community that is more structurally and temporally complex than communities in adjacent upland and aquatic sites. As a result, food webs are likely to be far more complex than would be expected in purely aquatic or terrestrial environments. The significance of this complexity is not known. However, we hypothesize that the presence of consumers from both environments at different times of the year may result in a more complete transfer of energy to higher trophic levels in both grazing and detrital food webs.

Examples. Periods of wetting and drying in BLH ecosystems provide peaks in habitat availability and consumer production. Flooding increases the surface area available to fish for migration, feeding, and spawning (Brinson

et al. 1981). In contrast, dry-downs serve to concentrate food sources for various bird species such as the wood stork (Kahl 1964). Still other species, such as fingernail clams, tree frogs, and some salamanders, appear to benefit most during periods of partial inundation (Wharton et al. 1981). According to Wharton et al. (1981), destruction of BLH habitat may have an inordinately large effect on river and upland fauna, as well as on temporary inhabitants of BLH ecosystems.

TRANSFORMATION AND TRANSPORT OF MATERIALS

Principle

BLH ecosystems are open systems that transform energy and materials derived from inflows. Hence, outflows from BLH ecosystems differ quantitatively and qualitatively from inflows.

Explanation. Because of the high primary productivity associated with BLH ecosystems, energy is available for many transformations of elements to more reduced forms. Studies have variously demonstrated that BLH ecosystems are net sources for some elements, sinks for others, or merely transformers among forms of the same element. Generally, the BLH floodplain is a depositional ecosystem that is accumulating materials and elements (SOILS WORKGROUP REPORT, this volume). These functions are of primary importance to water quality of adjacent and downstream aquatic ecosystems.

This discussion of elemental cycling in BLH ecosystems is restricted, for convenience, to those elements that are essential nutrients, and, further, to nitrogen and phosphorus, which are often considered to be limiting to plant growth. These nutrients are also the ones that are generally responsible for degradation of water quality in aquatic ecosystems when they are available in large quantities.

Some of the confusion that exists in interpreting results of input-output studies on BLH ecosystems is due to definition of boundary conditions. Transformations that occur in water moving as sheet flow across the forest floor

within a BLH ecosystem may be more readily detected than those that occur over an upstream-downstream transect along a river that is bordered by floodplain forest. A similar confusion occurs in interpreting results of nutrient budgets from saltmarsh-estuarine ecosystems (Nixon 1980).

For BLH ecosystems, studies can be divided into:

A. Comparative ecosystem studies (natural vs. channelized streams where the BLH has been wholly or partially eliminated).

B. Input-output studies that include the river and adjacent BLH floodplain (essentially measuring upstream-downstream changes by sampling in the stream channel).

C. Studies that focus on processes within the BLH system, such as nutrient uptake, recycling, decomposition, and other physical, chemical, and biochemical transformations.

These approaches are illustrated and described in Figure 18.

Examples. In comparing channelized and natural (unchannelized) streams in North Carolina (Study Category A), Kuenzler et al. (1977) demonstrated that channelized streams export more nitrogen and phosphorus than natural streams. Percentages of land in forest and agriculture were similar in both cases. These results are commonly interpreted to indicate that the drainage and elimination of floodplain ecosystems along channelized streams eliminate stream-floodplain exchanges, remove a forested buffer ecosystem between uplands and the stream channel, and provide a more direct conduit for upland runoff (usually from agricultural fields) to flow into the stream. The presence of the BLH ecosystem provides the mechanisms for biogeochemical processes, such as sorption of soluble phosphorus and ammonium to inorganic soil particles, removal of nitrate and ammonium through the nitrification-denitrification pathway, and uptake of soluble forms of N and P by immobilization in decomposition and algal growth (short-term removal) and through uptake and recycling by vascular plants, especially trees (longer-term removal).

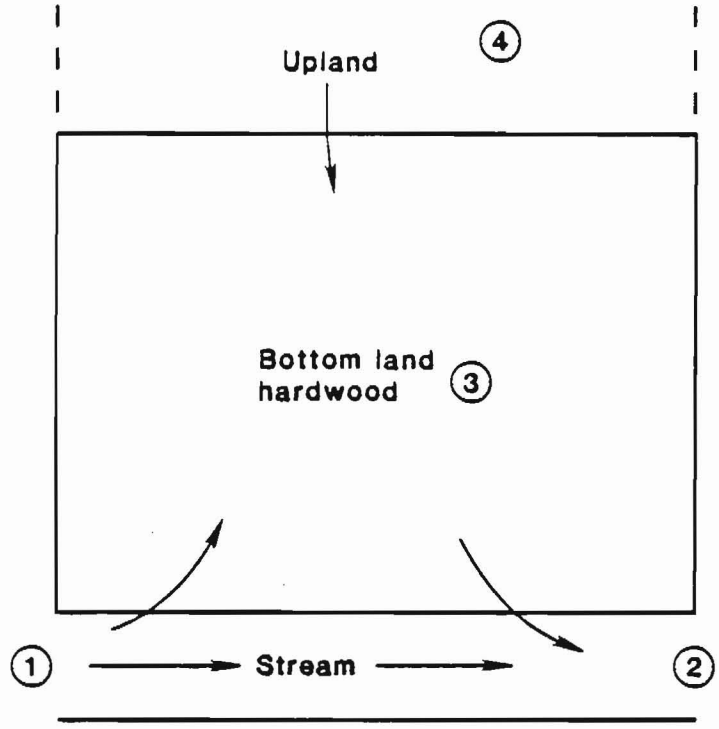

Figure 18. Conceptualization of three approaches to determining nutrient processes in BLH ecosystems. Comparative ecosystem studies measure "2" with and without the presence of the BLH area. Input-output studies measure fluxes at "1" and "2". Within-BLH studies measure recycling processes at "3" or, occasionally, as runoff from the upland, "4," and transformation along a downslope gradient within "3".

In an input-output study of the Apalachicola River in Florida (Study Category B), Elder (workshop presentation) showed only small differences in total amounts of incoming and outgoing total N and P. However, the river and BLH system, together, resulted in transformations among chemical species. For nitrogen, predominantly inorganic forms were more abundant as inputs, while particulate organic forms were more abundant as outputs. Inputs of soluble reactive phosphorus also appeared to become transformed to organic forms. The findings of net import of nitrate, ammonium, and soluble reactive phosphorus can be related to biogeochemical processes discussed above. Other examples are summarized in Table 4 of Taylor et al. (workshop presentation).

Finally, studies that examine within-BLH transformations (Study Category C) generally show a high potential for processing nutrients by microbial transformations and root uptake. This is demonstrated by studies both on sediment-water exchange in flooded portions of the BLH (Yarbro 1979; Brinson et al. 1983, 1984) and on return rate of nutrients in litterfall (Brinson et al. 1980). Leaf litter acts as a site for strong, short-term immobilization of nitrogen (Qualls 1984). Little can be said from these studies in relation to long-term inputs and outputs or retention by BLH systems. However, they clearly demonstrate the mechanisms that are responsible for nutrient transformation. They also illustrate the stabilizing effect of recycling in the face of hydrologic forces that otherwise would favor downstream movement of nutrients and consequent effects on water quality. Furthermore, sequestering and immobilization of heavy metals and organic toxins and the metabolic breakdown of organic toxins, such as pesticides, are functions that have been demonstrated in wetland and aquatic sediments (Pionke and Chesters 1973; Schlesinger 1979).

Principle

Episodic flooding events serve to transport accumulated NPP from BLH sites to aquatic consumers and food webs in other sites.

Explanation. Processes of organic matter export are an important part of the food chain support function of BLH ecosystems. Determinants of organic matter export from BLH sites include:

- Timing and duration of flooding and the velocity of flood waters.
- NPP and its distribution in various components (e.g., roots, stem wood, leaf litter, and mast).
- Decomposition processes as they influence the net accumulation and form (e.g., particle size) of detritus at a site.

Examples. Comparative watershed analyses by Mulholland and Kuenzler (1979) suggest that watersheds with wetlands export more organic matter than those without extensive wetlands (Fig. 19). Patterns of organic material

output are related to flooding events. Feeding and spawning of fish populations in Barataria Bay, Louisiana, are correlated to annual pulses of organic export from an alluvial swamp (Day et al. 1977). Large amounts of organic matter may also enter the food chain with less frequent flood events. Major flushes of organic matter in 5- to 7-year intervals were coincident with peaks in commercial fishing harvests in Apalachicola Bay, Florida (Livingston et al. 1976). Rarely flooded portions of BLH forests may serve as sources for organic carbon. Accumulations of organic materials in these areas would provide infrequent but important long-term inputs to downslope systems, on the scale of 50 to 100 years.

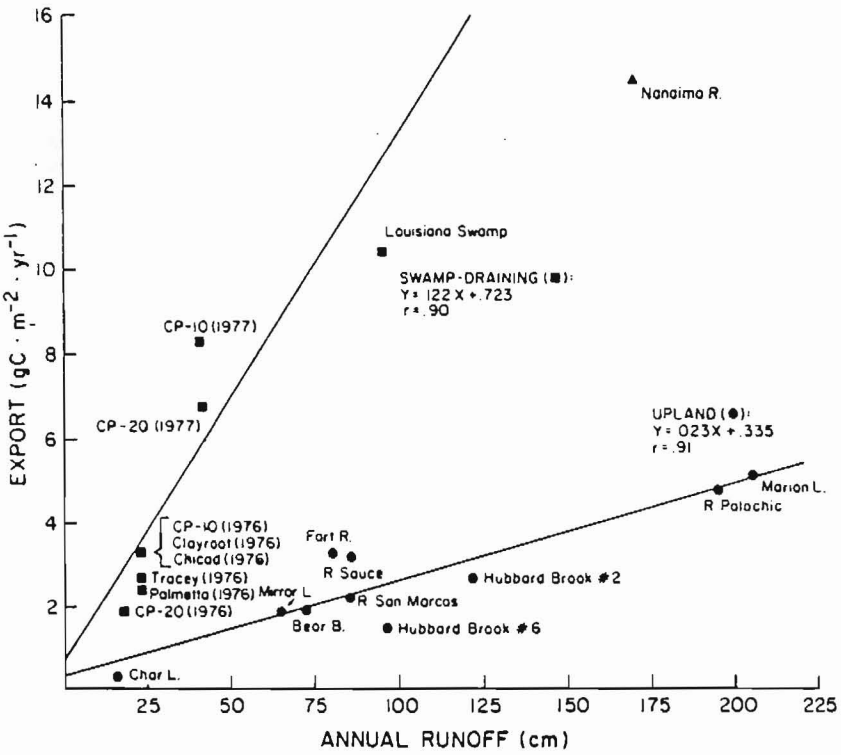

Figure 19. Organic export from wetland (squares) and upland (circles) dominated watersheds (from Mulholland and Kuenzler 1979).

Principle

Mineral cycling in BLH ecosystems has both a recycling component and an import-export (throughflow) component. The ratio of these two, called the cycling index (CI = recycling/throughflow), increases along the gradient of increasing elevation.

Explanation. The cycling index is defined as the ratio of recycled flow to total system throughflow (Finn 1976). Because mineral recycling probably differs little across the elevational gradient, the cycling index is affected principally by the system throughflow factor, which roughly corresponds to hydroperiod. This is not to suggest that recycling is the same at all elevations. At elevations where the water level fluctuates above and below the soil level, alternating wetting and drying may contribute to more rapid decomposition and release of nutrients for recycling. In addition, breakdown of leaf litter and release of nutrients from some species (e.g., *N. aquatica* and *Liquidambar styraciflua*) occur more rapidly than from other species (e.g., *Quercus laurifolia* and *T. distichum*) (Elder and Cairns 1982). Furthermore, differences in litterfall of different plant assemblages imply unequal rates of recycling through nutrient uptake. However, it is doubtful if recycling changes by as much as a factor of two across the elevational gradient in BLH floodplains.

In contrast to recycling, throughflow changes much more rapidly along an elevational gradient due to (a) lateral, bidirectional transport between stream and floodplain, (b) downslope transport from uplands to floodplain, and (c) transport from higher to lower elevations within the floodplain. Because of the geomorphic configuration of many floodplains, the upland-floodplain transition may have more rapid throughflow than expected, which modifies the relationship with hydroperiod (Fig. 20). With increasing elevation, the cycling index increases asymptotically because of an expected exponential decrease in kinetic energy and flow rate (Fig. 16) and, consequently, reduced capacity to transport particulate matter and dissolved nutrients.

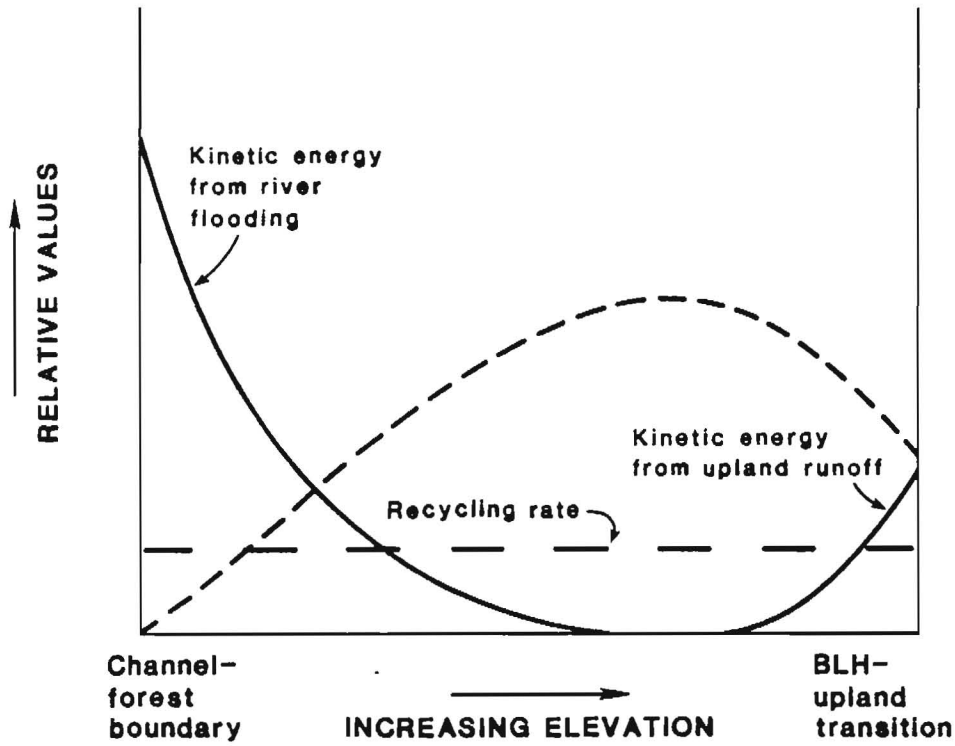

Figure 20. Cycling index as a function of generalized elevational gradient from stream channel to upland in a BLH ecosystem.

Examples. Annual leaf fall for five BLH communities on the Apalachicola River floodplain was between 471 and 530 g/m² (Elder and Cairns 1982). Leaf decomposition rates ranged between 0.19% and 0.56% weight loss per day at six locations. Both would serve as indices of recycling although they do not represent the total amount of nutrients or carbon recycled. Assuming that the remaining amount recycled is proportional to that measured in leaf decomposition, total recycling by decomposition would vary by no more than 3-fold between lowest and highest values. Similar assumptions for leaf fall indicate that recycling over an annual cycle actually varies much less than decomposition rates would suggest. Thus, a factor of 3 may represent an upper limit to the amount of variation of recycling within BLH communities.

Throughflow by floodwaters, however, would be a function of lateral "discharge" times frequency of flooding for a given elevation in the floodplain. Assuming flooding frequencies that vary between once per year and once

per 100 years, a factor of 100 would represent a lower limit to the amount of throughflow within BLH communities.

The downward inflection of the cycling index at higher elevations (Fig. 20) is a result of steep relief and hydrologic gradients normally found at the floodplain-upland boundary. Studies of this boundary area have demonstrated high rates of lateral movement of water and nutrients (Lowrance et al. 1984; Peterjohn and Correll 1984).

CONCLUSIONS

PRINCIPLE

The BLH system (floodplain and river) acts as a functional unit within the landscape.

Explanation

The BLH forest with its river is a complete unit, with gradients of water, soil types, and vegetation as simply parts of a unified whole. Zones or areas within the BLH ecosystem do not function independently. A number of ecosystem processes (e.g., movements of water and water-borne materials and movement and migration of fish and wildlife species) provide important connections among zones. Modification of one zone may thus change the behavior in a second zone by modifying the input the second zone receives. Furthermore, some overall properties of BLH ecosystems are determined by the spatial and temporal configuration of specific contributions from multiple zones. A simple example is that a BLH ecosystem composed of multiple zones provides an area of newly-wetted edge under a wide variety of flooding intensities. One zone provides the edge at the exact times when another zone does not provide it. Thus, it is misleading to assume that certain zones in the floodplain can function naturally when other zones are removed or altered, or when river flow

is modified. Within the larger landscape, the river-floodplain is an open system, responding to events upstream and in the adjacent upland and influencing downstream ecosystems. The following examples elaborate some of the important processes integrating zones.

Examples

River-floodplain functions. The floodplain and the river are part of a single geological and ecological unit. The river course and its overflow area were formed by geomorphic processes, whereby the floodplain reflects the historical meandering of the river; the present channel is scoured and maintained by river flow; and the intricate mosaic of natural levees, sloughs, point bars, and backswamp deposits results from deposition and erosion on the floodplain (Fig. 21). The intimate relationship between the stream and its floodplain is clearly shown by Figure 22. This figure shows that for a large number of rivers across the nation, regardless of size, bankfull depth is exceeded once every 1.5 years, on the average. The size and characteristics of both the stream channel and the floodplain are clearly functions of both streamflow volume and velocity.

In addition to functioning as a geologic unit, river and floodplain are also an ecological unit. The ecological characteristics of the floodplain result from the periodic flooding by the adjacent stream. Conversely, water quality and biota of the stream are both strongly influenced by processes occurring on the floodplain. Sediments and nutrients carried by the river nourish the floodplain. Typically, river-borne, inorganic nutrients are transformed and released again to the river as organic detritus. Fish and shellfish move from the river into the floodplain to feed and breed during overflow periods (Lambou, workshop presentation). For many species both the stream and floodplain are obligate habitats for completion of their life cycles. Flood waters are stored on the floodplain, buffering the stage and flow rate of the stream. Any processes that modify streamflow also modify the physical (Belt 1975), and hence ecological, characteristics of the downstream river and its floodplain. For example, it has been reported that peak flows

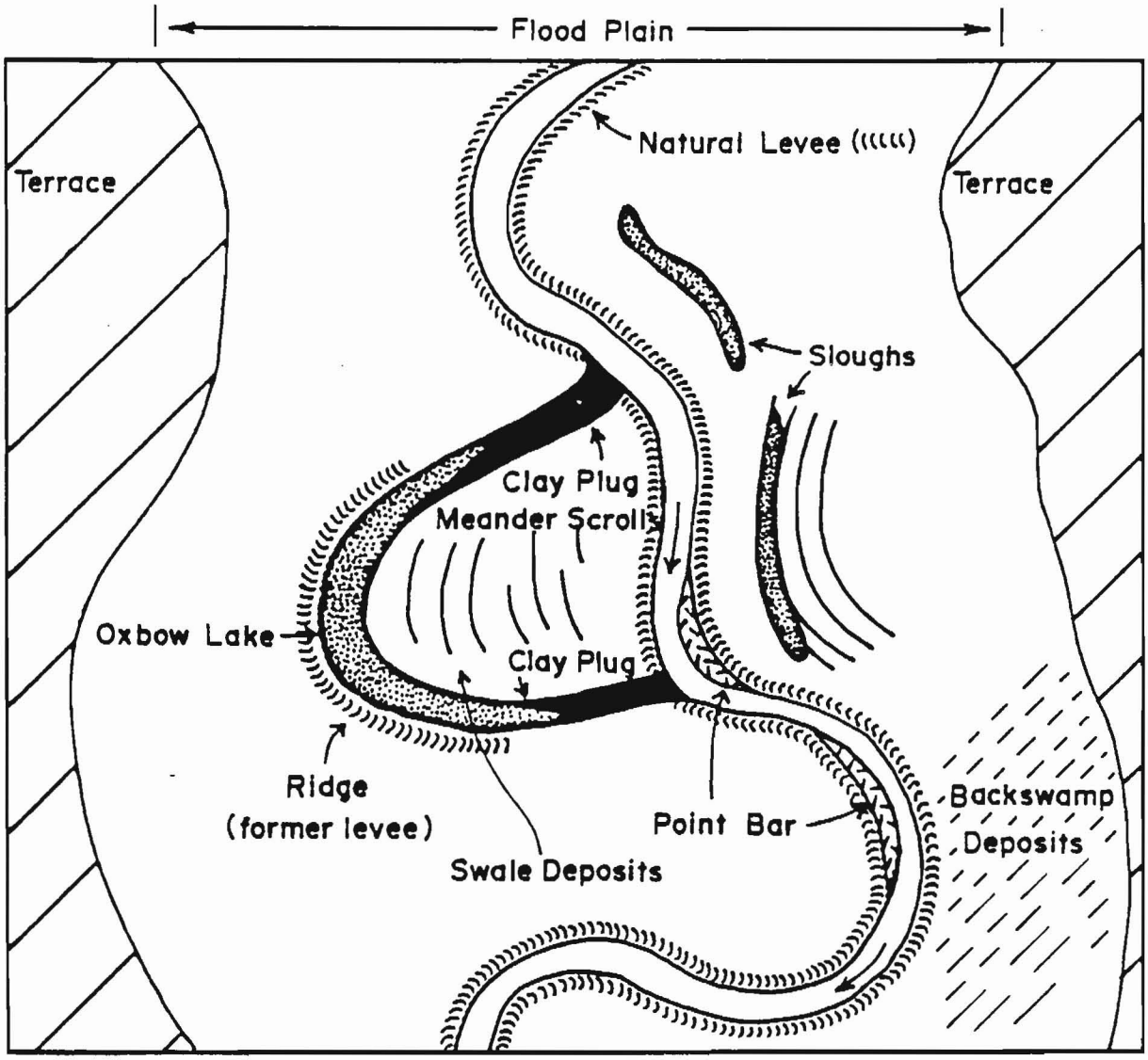

Figure 21. Major geomorphic features of a floodplain (from Taylor et al., workshop presentation).

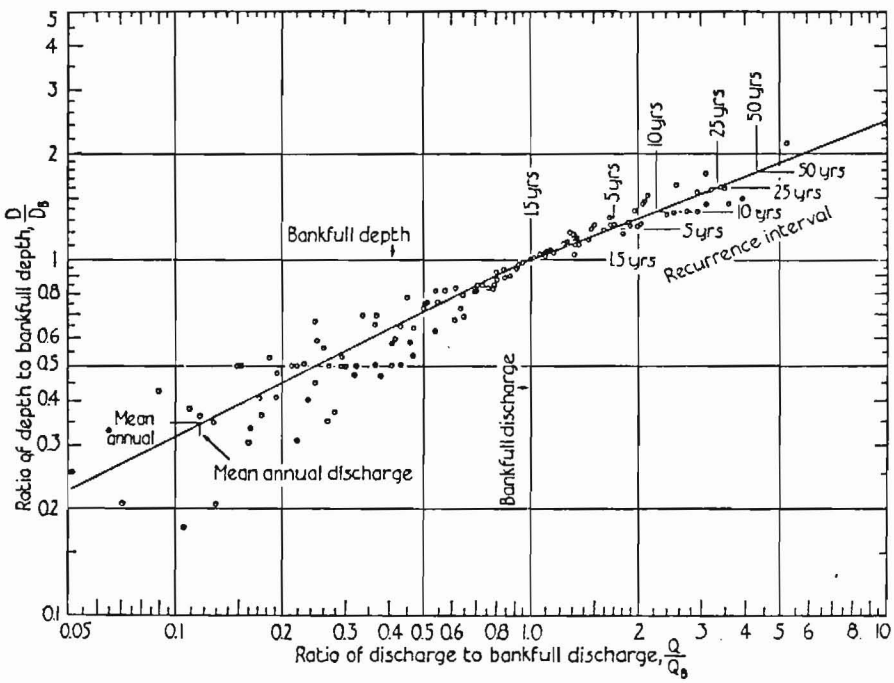

Figure 22. Characteristics of BLH flooding (from Taylor et al., workshop presentation): (a) recurrence interval for bankfull flooding (Leopold et al. 1964) and (b) relationship between flood duration and recurrence interval (Bedinger 1981).

will be 60% to 65% lower if a watershed has 15% of its area in wetlands or lakes than if no wetlands or lakes are present (Zinn and Copeland 1982). For this reason the U.S. Army Corps of Engineers purchased the Charles River floodplain upstream from Boston rather than build expensive flood control structures for the city (U.S. Army Corps of Engineers 1971).

Floodplain interzonal functions. The functional aspects of every "zone" in the BLH forest are tied together through hydrologic, geomorphic, and biotic interconnections. It is difficult to look at one zone in isolation from another because of these connections.

The BLH zones are connected by surface water during flooding and by groundwater during dry periods. Water flow is a major means of transport of materials, energy, and biota. If one or more zones are absent, then adjacent zones may suffer from a lack of hydrologic connections. For example, if a zone of bottomlands is converted to agriculture, the hydroperiod of adjacent zones, the chemicals transported to those zones, and wildlife use of the zones may change. Groundwater connections between zones are generally unidirectional during nonflooding conditions, going from uplands to the river. Nevertheless, the continual input of essential groundwater to the lower zones, and ultimately to the river, can be interrupted if the upper zones are drained and/or converted to agricultural use.

Consumers migrate from one zone to another, depending on hydrologic conditions and other seasonal pulses. Mobile consumers, both aquatic and terrestrial, feed and forage at the moving boundary between flooded and unflooded parts of the floodplain. From the aquatic side, fish migrate into the wetland opportunistically during flooding, for both feeding and spawning (Bryan et al. 1975; Lambou, workshop presentation). For example, few fish species would survive in the lower Mississippi River Basin without the overflow to floodplains that provides nurseries during spring floods. Depth of water dictates the extent of fish movement and use of the bottomland, but as water level changes, fish use several floodplain zones. Terrestrial animals also migrate across bottomland zones, often concentrating their activities at the

land-water interface. Raccoons, otter, mink, and other fur-bearing mammals often find optimum feeding at the water's edge, regardless of whether it appears in lower zones or in the upland transition zone (Wharton et al. 1982).

Genetic pools, which may dominate one zone, can contribute to the productivity and species diversity of adjacent zones. Tree species are distributed across several zones in the BLH forest. However, they are generally dominant in one or two zones that provide competitive advantages for those species. These species provide potential seed sources for adjacent zones, should ecological niches become open. If certain zones are eliminated from the bottomland hardwood forest, then adjacent zones will suffer in tree species diversity. This could lead to reduced productivities and possibly reductions in the diversity of consumers that inhabit the remaining zones.

Upland-floodplain interactions. The floodplain is a buffer between the stream on one side and the adjacent upland on the other. Surface and groundwater moving downslope from upland to stream are modified while passing through the floodplain. Generally, the effect is to reduce the water volume and the quantity of pollutants in the water that reaches the stream (Lowrance et al. 1984). When the upland ecosystem is forested, runoff is minimal. But, when the upland area is in agricultural production, water, eroded sediments, inorganic fertilizer nutrients, and pesticides may run off in quantity. The upper zones of the floodplain are particularly effective in reducing water runoff volume through infiltration and evapotranspiration. At the same time, sediments, dissolved nutrients, and pesticides are removed by biochemical and physical processes.

The movement of animals across the upland boundary also may be significant. Upland species such as deer move into the floodplain to feed on the high quality food produced there and retreat to uplands when flooding occurs. When the upland is in pasture or row crops the floodplain/field edge may be an area of high utilization, supporting songbirds, turkeys, deer, and other animals that feed in the fields and seek cover in the forest.

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WORKSHOP SUMMARY

James Roelle and Gregor Auble

This section is an attempt on the part of the authors to synthesize and interpret the information presented in the preceding workgroup reports and discussions held at the workshop. As such, the information contained in the summary should not be attributed to any of the workshop participants nor to the agencies and institutions they represent.

Section 404 of the Clean Water Act of 1977 (CWA) (33 USC Section 1344) regulates the discharge of dredged or fill material from point sources into waters of the United States. While permits for such activities are issued by the U.S. Army Corps of Engineers (COE), the U.S. Environmental Protection Agency (EPA) is intimately involved in the administration of the CWA in general and Section 404 in particular. With respect to Section 404, EPA responsibilities include issuance (in conjunction with COE) of the Section 404(b)(1) guidelines, which establish criteria to be used in evaluating permit applications; designation, under Section 404(c), of areas where discharge of dredged or fill material will not be permitted due to unacceptable impacts on municipal water supplies, shellfish beds, fishery areas, wildlife, or recreation areas; and enforcement actions for unauthorized discharges. Under current Federal regulations, the term "waters of the United States" includes many wetlands. Wetland delineation, which is complimentary to environmental evaluation methodologies applied during enforcement actions, Section 404(c) decisions, and oversight of compliance with the Section 404(b)(1) guidelines, is an additional part of EPA responsibilities. Although authority for delineation is frequently delegated to COE, EPA has retained this authority in the case of bottomland hardwood (BLH) ecosystems.

For Section 404 purposes, wetlands are defined as "...those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" [33 CFR 323.2(c)]. While this definition provides a useful, general description of wetlands, recent court cases attest to the fact that terms such as "normal circumstances," "prevalence," and "typically adapted" are subject to differing interpretations. Delineation of wetlands on a site-specific basis has therefore involved considerable judgment and the evaluation of a variety of factors, including hydrology, soils, and vegetation. Delineation of the wetland portions of BLH ecosystems has been particularly troublesome, because such ecosystems occupy a continuum of sites ranging from nearly permanently flooded to very rarely flooded.

These circumstances have led EPA to seek a synthesis of the best current scientific information concerning BLH ecosystems, with particular reference to:

(1) Characteristics. BLH communities are complex and diverse. Information concerning the best ways that they can be described or characterized is important from the perspective of understanding the resource and for making rational, objective determinations of wetland boundaries.

(2) Functions. Wetlands are regulated under the CWA because of the functions (e.g., water quality enhancement) they perform and the value of those functions to society. Information about those functions is therefore critical for regulatory decisions concerning BLH ecosystems. In addition, to the extent that such functions differ quantitatively or qualitatively between various types of BLH communities, they may provide useful corroborative information for delineating wetland boundaries.

(3) Impacts. BLH ecosystems are impacted by a variety of man's activities. An understanding of those activities and their impacts is essential for determining which activities fall under the jurisdiction of Section 404 (i.e., constitute a point-source deposition of dredged or fill material) and for assessing how those activities affect the functions that the CWA is intended to protect.

The workshop described in this report was the first step in this process of information synthesis, addressing the topics of characterization and function. The general approach to the workshop was motivated by the perception that bottomland hardwoods are diverse, complex ecosystems and that, for regulatory purposes, it would be highly desirable to have some convenient framework for categorizing and understanding that complexity. The zonation concept elaborated at a previous workshop at Lake Lanier, Georgia (Clark and Benforado 1981), seemed to hold some promise for providing such an organizational framework. The specific purpose of the workshop was therefore to elicit information concerning how well the structure and functions of bottomland hardwood ecosystems can be represented by a series of reasonably discrete types (zones) along a soil moisture gradient. An ancillary purpose was to assess the utility of the zonation concept from a regulatory perspective. Finally, the workshop was useful in updating the participants and EPA personnel about the state of the art in bottomland hardwood ecological research.

CHARACTERIZATION OF BLH ZONES

There is general agreement that the distribution of vegetation is a result of the responses of individual species to a complex of environmental factors and that the soil moisture regime is the most important of these factors in BLH ecosystems. Furthermore, there is agreement that species with similar tolerances to soil saturation tend to be distributed similarly and that these groups of species can often be described, for convenience, as separate communities. The extent to which these communities are distinct functional entities has been a topic of discussion among plant ecologists for many years. One question addressed by this workshop was whether or not hydrology, soil properties, and vegetation are sufficiently well correlated that their concomitant variation can be adequately described by a series of reasonably distinct, discrete zones.

The report from the Vegetation Workgroup seems to indicate that they may not be. Three factors contribute to this conclusion. First, in many cases

changes along the soil moisture gradient are so gradual that the plant "communities" intergrade with one another. Sharply defined community boundaries are hard to identify and are frequently absent. Second, there are many other cases in which the complexity of factors determining vegetation distribution (e.g., variations in microtopography) results in a mix of species with quite different tolerances to soil saturation. The resultant mosaic of vegetation is frequently difficult to describe or separate into constituent spatial units. And finally, even in those cases where fairly distinct plant communities can be recognized, they may be associated with more than one of the soil moisture categories defined at Lake Lanier (Table 1) (i.e., soil and vegetation boundaries are not always coincident).

The Soils Workgroup Report, on the other hand, indicates a considerably more positive view of the zonation concept. Basically, the workgroup members appear to have accepted the idea of zonation and devoted their time to refining the relationships between soils, hydrology, and vegetation. A comparison of the results of this effort with results from the Lake Lanier workshop is presented in Table 9. Soil hydrologic regime (as indicated by physicochemical properties), soil type, and vegetation are described in the Soils Workgroup Report as being distinctly correlated. Typical cross sections illustrating the relationships between these parameters are presented for three floodplains in the southeastern United States. Vegetation at sites with hydric soils is described as typically adapted to growth in standing water or saturated soils, while sites with nonhydric soils are described as supporting plant species adapted to aerobic soil conditions. Finally, the Soils Workgroup proposes that soil series be used as the means for delineating zones within BLH communities, principally because of the vast amount of data already available from Soil Conservation Service surveys, and because soil properties change much more slowly over time, even in the presence of rather severe physical disturbance, than do vegetation and hydrologic parameters.

Table 9. Comparison of the relationships between soil saturation, frequency of flooding, and vegetation developed at the Lake Lanier and St. Francisville workshops.

		Lake Lanier[1] (Gulf Coastal Plain Sites)		St. Francisville[2] (Lower Mississippi River Sites)	
Zone	Common species	Soil saturation (% of growing season)	Frequency of inundation (years/100 years)	Soil saturation (% of growing season)	Frequency of inundation (years/100 years)
II	Water tupelo Buttonbush Swamp privet Black willow	~100	100	~100	100
III	Water hickory Black willow Overcup oak	>25	51-100	25-75	11-100
IV	Sweetgum Sugarberry Willow oak	12.5-25	51-100	12.5-25	1-10
V	Cherrybark oak Swamp chestnut oak	2-12.5	1-50	2-12.5	<1
VI	Cherrybark oak Live oak Yellow poplar	<2	1-10	<2	-

[1]After Huffman and Forsythe (1981).

[2]SOILS WORKGROUP REPORT (this volume).

There are several aspects of the apparent discrepancy between the Vegetation and Soils Workgroup reports in terms of how strongly they support the zonation concept. One aspect is that the distribution of soil properties may actually fit a zonal classification better than the distribution of vegetation does because the relevant soil properties are a slowly changing integration of conditions over a long time period. However, it is difficult to separate this aspect from a possible difference between the workgroups in their respective judgements about what is an acceptable level of precision. There are certainly comparable problems in defining the exact boundary line between soil series as those the Vegetation Workgroup identifies in defining the exact boundary line between plant communities. Furthermore, not all important soil properties are stable, long-term indicators. For example, oxygen concentrations can fluctuate widely, on short time scales, as an individual site (regardless of zone) fluctuates between dry and saturated conditions.

A difference between the workgroups in their perspectives on acceptable precision seems the only way of understanding their disagreement about how well the distribution of vegetation fits a zonal classification. Neither workgroup presented data or arguments concerning the distribution of vegetation which the other workgroup was not considering. However, the Soils Workgroup judged that a zonal classification was an acceptable fit to the distribution of vegetation, whereas the Vegetation Workgroup judged that the lack of fit was a serious problem.

Hydrology Workgroup members also dealt with the characterization issue in some detail, but from a slightly different perspective. They appear to have started with the assumption that there are no fundamental discontinuities in hydrologic processes that would suggest boundaries for zones. They then focused on ways in which elevations corresponding to specific durations of soil saturation might be estimated from hydrologic information (e.g., gaging data). They further considered ways in which other parameters (e.g., vegetation composition) might be used as surrogates in cases where the necessary hydrologic data do not exist. They are also careful to point out, however, that the same river flooding regime can lead to different vegetation types

depending on factors such as soil characteristics and topography. They therefore conclude that, if a zonation concept is to be applied, information on vegetation, soils, and hydrology must be considered in establishing zone boundaries.

The Wildlife Workgroup members directly addressed the characterization issue. They concluded that wildlife species are a relatively poor way to define or identify zones because most of the wildlife species found in BLH ecosystems tend to be mobile and utilize more than one BLH zone either opportunistically or because two or more zones are necessary to satisfy habitat requirements.

FUNCTIONS OF BLH ZONES

Five of the workgroups (Hydrology, Vegetation, Fisheries, Wildlife, and Ecosystem Processes) considered the question of the relationship between BLH functions and zones in some detail. Without exception, members of these workgroups were able to identify some variation, either qualitative or quantitative, in functions for various parts of the BLH ecosystem. In most cases, however, it appears that they were able to do so only by considering a zone to be equivalent to a particular vegetation community. This is not surprising in view of the fact that results of studies concerning functions (e.g., net primary productivity) are often reported in terms of a particular vegetation community. In at least one case (the Vegetation Workgroup), however, there was a reluctance to equate communities and zones. This is consistent with the conclusion of the Vegetation Workgroup that a given plant community may often be found in more than one of the zones defined on the basis of soil moisture regime, reflecting an imperfect correlation between soils and vegetation.

Perhaps more importantly, these workgroup reports indicate that three other conclusions can be drawn concerning the functions of BLH zones. First, factors other than the zone (e.g., topography, regional and local community diversity, interspersion, source of flooding) are often, perhaps usually, more important in explaining variations in function. Second, at some times sites

toward the drier end of the soil moisture regime perform functions attributed to wetlands and, furthermore, these tend to be the times when wetter sites are unable to perform those functions. And third, there are no obvious discontinuities in functions that would tend to support delineation of wetland boundaries at any particular point along the soil moisture gradient.

Despite these similarities, there are considerable differences in the depth to which variations in function across zones are discussed in the workgroup reports. These differences appear to be related to two slightly different ways of asking the basic question: "Are there variations in function across BLH zones?" versus "How much of the variation in functions can be explained by the zones?" The Hydrology Workgroup, for example, apparently focused on the second question, and therefore their report concludes that variation in hydrologic functions due to zone is likely to be insignificant compared to other sources of variability. The Vegetation Workgroup Report considers the first version of the question in some detail, but also lists a number of other sources of variability. The Wildlife Workgroup Report takes a similar approach and also points out the potential utility of that approach for impact analysis. The Fishery Workgroup Report takes a somewhat different tack, focusing on the first version of the question after making a series of strongly limiting assumptions (e.g., considering only the 1 in 10-year flood, considering only sites with a direct hydrologic connection to the river, and considering only certain life stages of certain organisms) to eliminate other sources of variability. And finally, the Ecosystem Processes Workgroup Report focuses almost entirely on the second version of the question, discussing in some detail a variety of factors other than zone that have significant effects on the functions of BLH communities and concluding on that basis that such functions cannot be adequately described in the context of a series of independent zones.

DISCUSSION

The overall goal of the workshop was to bring scientific information to bear on some policy issues concerning BLH ecosystems. To this end, progress was made at the workshop in several areas.

1. Workshop participants were apprised of the state of knowledge concerning bottomland hardwoods.

2. It was agreed that factors other than zone are important in determining BLH functions.

3. It was recognized that vegetation, soils, and hydrology are all important components in a multi-parameter approach to BLH characterization.

More specifically, the workshop was designed to examine the utility of the zonation concept as a framework for characterizing the structure and function of BLH ecosystems. We feel that there were several problems that limited the discussions on this topic at the workshop. We discuss these in the following sections, not because we feel that we have a clear and correct resolution of them, but rather in the hope that their future clarification will lead to more fruitful discussions.

CHARACTERIZATION OF HYDROLOGY

Hydrologic characteristics were a central factor in many discussions. Ambiguity in the variables used to describe the hydrologic characteristics (e.g., hydroperiod) occasionally led to miscommunication. More specifically, frequency and duration of inundation were both considered, but the relationship between the two was poorly defined. This situation was apparently futher complicated by the fact that some people tended to equate frequency of inundation with frequency of overbank flooding from the adjacent river, while others interpreted frequency of inundation to mean the frequency with which saturated soils occur, regardless of the source of water. The result of such failures to distinguish among variables that are similar and related, but not equivalent, is hypotheses that are difficult to test, or even discuss, in any rigorous scientific way.

PRECISION

Much of the disagreement concerning the utility of the zonation concept seemed to stem from differing opinions concerning acceptable levels of precision in classifying the landscape. A particularly difficult point was the appropriateness of approximating relatively continuous distributions with a series of discrete classes (i.e., zones). To some extent, this reflects fundamental differences in perspectives among various disciplines and long-standing debates in community ecology over the nature of vegetation assemblages. Most of the disagreement at the workshop appeared to focus on the acceptability of a discrete approximation and not on the basic nature of the distributions being approximated. To the extent that this is true, the disagreement is likely to remain a matter of perspective and will be difficult to reconcile by additional discussion or analysis.

TIME SCALES

The Ecosystem Processes Workgroup Report points out that the processes connecting various structural and functional characteristics of BLH ecosystems operate on a wide range of time scales (e.g., from nearly instantaneous changes in soil chemistry and microorganisms in response to an individual flooding event, to the geologic time scale of soil formation). These multiple time scales complicated the attempts to relate functions to a single structural model (i.e., zonal classification). The Fisheries Workgroup approached this issue by focusing on a single, well-defined type of event. Clearly, this approach is limited in addressing the larger question of how different areas of the landscape perform some function over time; however, it illustrates the importance of being specific about which of the many possible time scales is being considered in defining a particular relationship.

DESCRIPTIONS; DEFINITIONS, AND INDICATORS

We believe that there are important conceptual distinctions between the use of variables in a general description, in a prescriptive definition, and as surrogate indicators. Furthermore, we feel that confusion among these uses has led to confusion in discussions and has limited the extent to which science can contribute to the resolution of important questions.

As elaborated at the Lake Lanier workshop, the zonation concept involved concomitant variation in hydrology, soils, and vegetation. Zones were described based on ranges of values for parameters in these three related areas. However, the zones were not prescriptively defined in terms of dependent and independent variables. While there seems to be consensus that hydrology, soils, and vegetation are strongly (but not perfectly) related, use of all three parameters as descriptors has created problems in evaluating the zonation concept, especially at sites that do not have all three characteristics of a single zone. The reasons for this lack of fit may even be well understood (e.g., the site is changing and vegetation and soils have not yet adjusted to an altered hydrologic regime). However, a zonal classification that uses three parameters as descriptive characteristics, without regard to causal connections among them, cannot make use of this understanding. Thus, such sites appear as "errors" in application of the concept to the landscape.

This situation could be improved by clearly defining the zones in terms of a single independent variable. Hypotheses concerning the relationship of any number of dependent variables to this independent variable could then be stated and tested scientifically. In cases where the independent variable might be difficult to measure, other parameters could be used as indicators, once their relationship to the independent variable was known. Lack of correlation would then be an error term in our ability to estimate the defining parameter (potentially correctable by gathering additional information), rather than a conceptual problem.

To date; those who have examined the zonation concept experimentally have adopted just such an approach. For example, studies currently in progress at the U.S. Army Engineer Waterways Experiment Station (Jones, workshop presentation; Theriot, workshop presentation) have clearly defined duration of soil saturation in the growing season as the sole independent variable and vegetation composition as the dependent variable. Similarly, the Soil Workgroup members argue in their report that soil series can be used to define zones within BLH communities. This conclusion is based on their judgment of a high degree of correlation between certain hydrologic regimes, soil properties, and vegetation, in combination with the pragmatic consideration of the existence of a large geographic data base on soils.

We feel that much of the difficulty concerning distinctions between a general descriptive concept, a prescriptive definition, and surrogate indicator variables applies to the issue of wetland delineation as well as zonal classification. The regulatory wetland definition is really a descriptive (and perhaps somewhat circular) concept, rather than a prescriptive criterion for classifying the landscape. This is consistent with general use of the term wetlands by scientists. It represents a shared concept, but not an operational or prescriptive definition. This implies that judgment will be required to interpret the regulatory definition, including terms such as normally, typically adapted, and prevalent. We believe that there are no clear scientific criteria for making that judgment in a way that is unequivocally correct and, in fact, that several alternatives may be scientifically defensible.

CONCLUSIONS

1. All workgroups that dealt with functions of BLH ecosystems identified qualitative or quantitative variation in functions associated with zones or, at least, with one or more of the gradients represented by the zonal classification. In many cases, this was accomplished by concentrating on the variation in function associated with particular

vegetation communities (e.g., the Wildlife Workgroup's evaluation of habitat quality) or with hydrologic characteristics (e.g., the Ecosystem Processes Workgroup's assessment of mineral cycling indices).

2. No obvious and striking discontinuities in functions were identified that would provide significant help in delineating or defining zonal or wetland boundaries.

3. There was general agreement that higher (less frequently inundated) zones perform functions attributed to wetlands at some times, and that these are often the same times that the lower zones are less able to perform these functions. Although no workgroup dealt very effectively with integration across time scales, a number of objections were raised to the simple notion that a site that is inundated 1 in 10 years performs 1/10 the function of an annually inundated site.

4. For many functions, other sources of variability were identified as being more important than zone in determining those functions. Furthermore, many functions (e.g., habitat for mobile organisms and flux of water-borne materials) were viewed as integrating across zones and thus not well considered by treating zones as independent entities.

5. There was mixed response to the question of how well the zonation concept characterizes the BLH landscape for regulatory purposes. Some participants felt that a modified zonal classification would represent a significant amount of the variation in structural and functional characteristics of BLH sites and thus might serve as a framework for a regulatory program. Other participants stressed the variations in both structural and functional characteristics that were not well represented by a zonal classification and the resultant difficulties in partitioning the BLH landscape into a series of discrete zones, each with unique ranges of values for various structural and functional attributes.

6. Despite the aforementioned disagreement, there was consensus that characteristics of hydrology, soils, and vegetation clearly vary from unequivocally wetland sites within a BLH landscape to unequivocally upland sites and, furthermore, that these characteristics are generally related both by correlation and by known causal mechanisms. This consensus, to the extent that it was ever in question, certainly provides general support for a multi-parameter approach to wetlands characterization. Although it was not a workshop conclusion, we believe that there is an important distinction between a multi-parameter identification procedure using some parameters as surrogate measures, and the conceptual confusion in applying a multi-parameter definition. From this perspective two of the most promising results of the workshop were:

- The general recognition of soil saturation as a critical causal variable relating many wetland characteristics; and

- The conclusion of the Soils Workgroup that soil series are relatively stable and pragmatic indicators of the past history of soil saturation in BLH sites.

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