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INTEGRATING ECOLOGICAL CONCEPTS WITH NATURAL RESOURCE MANAGEMENT OF SOUTHERN FORESTS[1, 2]

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Abstract. Natural resource management must integrate commercial development and use of forest resources with the maintenance of ecological values. The "New Perspectives" program of the U.S. Forest Service is responding to increased public environmental awareness and legislative mandates in placing a greater emphasis on ecosystem sustainability and non-traditional utilization of national forestlands. The forest of the southern United States is a complexity of associations developed along topographic and environmental gradients and shaped by natural disturbances and anthropogenic perturbations. It is highly fragmented as a result of past clearing for agriculture and timber harvesting and patterns of land ownership. Southern forests, in contrast to those in other regions, are mostly privately owned. This fragmentation is being maintained by current urbanization and industrialization as the population of the South increases.

Our purpose is to identify ecological themes and concepts compatible with the stewardship philosophy of the Forest Service's New Perspectives that can be applied to the management of sustainable southern forest resources. Of special concern are the maintenance of biological diversity, watershed and water quality protection, and the assessment of regional land-use effects on the integrity of forest ecosystems and on continued forest productivity. Ecological principles must be integrated with natural resource management on landscape and regional scales to achieve sustainability of the southern forest ecosystem.

Key words: biological diversity; ecological values; forest management; forest sustainability; fragmentation; functional diversity; landscape diversity; landscape ecology; riparian forests; southern forests.

INTRODUCTION

For the past two centuries and through the early decades of this century the over-exploitation of forest resources in the southern United States culminated in severe resource-management problems. Forests were indiscriminately logged, burned, and grazed without concern for regeneration or watershed protection. The deforestation and poor agricultural practices, especially on marginal lands, resulted in soil erosion and a loss of soil fertility. Early reports documented widespread damage to the region's forests, as well as associated large-scale erosion and flooding. Initially there were no resource management agencies to encourage or to enforce stewardship, and technical knowledge for resolution of these burgeoning problems did not exist. In the early 1900s some leaders and organizations attempted to promote conservation of the forest resources, and their efforts laid the basis for later programs, as well as for the transfer of forest reserves to the Department of Agriculture's Forest Service in 1905.

Public concern over forest conditions, as well as recommendations from a 1908 conference of governors on conservation of natural resources, resulted in the passage of the Weeks Law in 1911 and the Clarke-McNary Act in 1924. This legislation mandated federal funds for (1) acquisition of lands associated with significant watersheds, and (2) forest management assistance to farmers. Further programs of reforestation were begun by the Roosevelt administration during the 1930s. The development of these and other government and civic programs reflected increasing public concern over conservation—concern that was due, in part, to the writings of Aldo Leopold, Robert Marshall, and others (USDA 1988).

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[2] For reprints of this group of papers on forest management, see footnote 1, page 219.

For much of the first half of this century the natural resource management community worked to correct earlier abuses. The effective combination of conservation policy, education, and research over several decades resulted in significant regional reforestation, improved wildlife management, and greater erosion control and watershed protection (Douglass and Goodwin 1980). The notable results of these programs constitute perhaps the best recent example of a highly successful regional conservation program. Some of this success stems from the goals of soil and water conservation being linked to the viable economic base of lumber, fiber, and other forest products.

During the latter half of this century public interest in the directives of the U.S. Forest Service has changed. Increased environmental awareness has resulted in the passage of additional legislation, such as the Endangered Species Act and the Clean Air and Water Acts, and the establishment of the Environmental Protection Agency. In the South, population increases and demographic shifts have created new large urban centers. The increased southern population has placed additional demands on natural resources and revised the priorities for their utilization. On publicly owned lands, demand is increasing for watershed protection and non-product amenities such as recreation and preservation of biological diversity (U.S. Senate Committee on Agriculture, Nutrition and Forestry 1991). On private lands, parallel shifts have occurred in ownership priorities, and timber may no longer be the major management objective for many private non-industrial forest land owners (Oliver 1986).

The U.S. Forest Service has acknowledged these changes in public perspectives and legislation in its "New Perspectives" program, and is placing greater emphasis on ecosystem sustainability and non-traditional utilization of national forestlands (Kessler et al. 1992). These new perspectives represent a new stewardship philosophy, where forests are managed as sustainable ecosystems within their broader landscapes rather than as independent-stand units whose economic production is maximized. There is now greater emphasis on procedures that continue product output by functioning in accord with, rather than in conflict with, those processes that ensure ecosystem sustainability.

Our objective is to identify ecological themes and concepts compatible with the stewardship philosophy of the Forest Service's New Perspectives that can be applied to the management of sustainable southern forest resources. Central to the concept of ecosystem sustainability are (1) maintenance of biological diversity, (2) watershed and water-quality protection, (3) assessment of effects of regional land-use and global change on forest ecosystems, and (4) continued forest productivity. These concerns should be of great importance on both public and private forest lands. We discuss the following themes and identify related ecological concepts that are central to management of southern forests:

(1) *Maintenance of biological diversity.*—Diversity across temporal and spatial dimensions is a natural and essential feature of the forest landscape.

(2) *Fragmentation of the southern landscape.*—Modern shifts in land-use patterns have fragmented regional landscapes and altered critical ecological processes that regulate productivity, environmental quality, and biological diversity.

(3) *Maintenance of environmental quality.*—Maintaining the functional integrity and sustainability of ecosystems is critical to environmental quality, and hence to resource productivity.

(4) *Balancing economic commodities and ecological values.*—The output of economic commodities and conservation of ecological values must be balanced to ensure the long-term sustainability and biological integrity of southern forests.

To consider these themes in the proper perspective, it is first necessary to understand the history and complexity of the southern forests.

Ecology of Southern Forests

Throughout its history the Southern landscape of the United States has been influenced by periodic natural disturbances and, in more recent millennia, by anthropogenic perturbations. Gradual climatic shifts, disturbances in the form of fire, wind, disease, and insects, and anthropogenic perturbations from agriculture and other human activities have constantly altered the natural progression of forest succession.

Role of natural disturbances

The gradual vegetative changes associated with climatic cycles occurred over a broad temporal scale. Although the South was not glaciated, its climate has been periodically altered by glacial advance and retreat, with corresponding changes in the character and ranges of plant associations. For example, the higher elevations of the Southern Appalachians were largely unforested tundra during the late Wisconsin Period (22 000–13 500 B.P.), with boreal forests persisting at lower elevations (Watts 1980, Delcourt and Delcourt 1987).

In contrast to gradual climatic change, natural catastrophic perturbations, such as hurricanes or tornadoes, may devastate millions of hectares in a matter of hours. These disturbances also may vary on a spatial scale, and be frequent to rare on a temporal scale. Hurricanes as large as Hugo, which damaged $>10^6$ ha of forest in South Carolina in 1989, may be expected only about once in 100 yr, but smaller hurricanes occur much more frequently (Hooper et al. 1990). Tornadoes are also common throughout much of the South. The cyclonic winds of hurricanes and tornadoes create openings in the canopy, and they contribute to heavy fuel loadings on the ground, which may promote natural fires. These and other types of large-scale perturbations are consistent with the natural history of the South and helped to maintain the forest and landscape diversity essential to support the variety of flora and fauna of the region. In the absence of disturbance the number of potential vegetation types would be small, because plant succession throughout the region strongly favors a few hardwood associations (Kuchler 1964).

Anthropogenic effects

With the arrival of hunter-gatherer cultures in the Southeast ≈12 000 yr ago, fire assumed a more important role in determining forest composition and structure. The Southeast supported Native American population densities that were among the highest on the continent. They used fire to concentrate game species, to open the forest and improve forage for game, and to clear the land for agriculture and settlement (Komarek 1974). Because of periodic natural disturbances and the land management activities of these early Americans, the concept of an unbroken forest stretching without end across the South at the time of European settlement is a myth (Hudson 1976, Buckner 1989). Pre-Columbian forests of the South were open in the understory, and contained large treeless prairies, meadows, and savannas as well as extensive tracts of timber (Williams 1989).

Fires ignited by Native Americans were not confined to the Coastal Plain but were ubiquitous throughout the South. They spread until climatic, topographic, or fuel conditions extinguished them. Even in the Piedmont and southern Appalachians, burning was common (Van Lear and Waldrop 1989). This burning, along with agricultural clearing and firewood gathering, affected most of the land below 1000 m elevation in the southern Appalachians (DeVivo 1991).

European settlements, especially the agriculture-based English colonies, continued frequent burning and cleared land of forests for agricultural fields. In the 250 yr between the English settlement at Jamestown and the Civil War, southern agriculture gradually expanded. In the late 1800s cotton production increased markedly, and by 1935 $>26 \times 10^6$ ha in the South were under cultivation or in pasture (Healy 1985). Timber harvesting for lumber also became an important industry after the Civil War (USDA 1988). Between 1880 and 1920 most of the remaining original southern forests were cut. During this period, the South led the nation in timber production, and most of the cutover land was left to regenerate naturally. Deforestation and farming resulted in extensive soil erosion. In Georgia, for example, almost all of the topsoil was lost from 47% of the uplands (Hartman and Wooten 1935).

The acreage of cleared land peaked in the mid-1930s, and in much of the South the forest occurred as isolated patches in a matrix of cropland. Over the past 50 yr, however, there has been a conversion of agricultural lands back to forest and a coalescence of individual tracts of forest (Odum 1989). In Georgia, croplands have declined by 50% and forestlands have increased to 65% of total land use in the state (Odum 1989). The greatest conversion to forests has occurred in the Piedmont, where agricultural acreage has declined by 60% since the 1930s. The upper Coastal Plain has shown less change and has about the same amount of farmland today as in the 1930s (Turner and Ruscher 1988).

Forest development in the 1900s was assisted by (1) fire prevention and suppression efforts by the U.S. Forest Service and state forestry commissions and (2) forest replanting. This "second forest" of the South was harvested after World War II to feed the expanding pulp and paper industry of the region. The South's "third forest" is the source of most of the wood being harvested today (USDA 1988). This is generally a dense and highly productive forest of mid-size trees, whose principal use is wood and fiber production. Although the present southern forest is not as fragmented by croplands as the forest of the 1930s, it may become more fragmented in the future due to urban and industrial development.

The current forest landscape

The forests of the South currently occupy $\approx 74 \times 10^6$ ha, which is slightly less than this century's peak in 1962 of 80×10^6 ha (USDA 1988). About one third of the forests are dominated by pine species, both naturally regenerated and planted, and ≈15% are also classified as mixed pine–hardwood. The remainder, $>36 \times 10^6$ ha, is dominated by hardwood species, two thirds of which are classified as upland hardwoods and one third as bottomland hardwoods (Fig. 1).

About 66.5×10^6 ha (i.e., 90%) of the forest land in the South is privately owned (USDA 1988). Forest industries own 17×10^6 ha in this category, while "other private" owners own the remaining 49.5×10^6 ha. Many of the private lands are small holdings; according to a 1978 survey, 92% of the ownership units were <40 ha (USDA 1988). Of the 7×10^6 ha of publicly owned forest, $\approx 4 \times 10^6$ ha is in National Forests. The remainder is in state forests, wildlife refuges, and other federal and state ownerships.

Recent descriptions of the vegetation and environmental gradients of the southeastern landscape suggest several major forest associations (Christensen 1988, Greller 1988, Gholz and Boring 1991; Fig. 2). The Southeastern Evergreen Forest that extends along the Atlantic and Gulf Coastal Plains and south into central Florida is a pine-dominated association, with hardwood forests developing in wetlands or where fire and other disturbances are excluded (Monk 1968, Christensen 1988). Successional communities such as sand pine scrub, oak sandhill, pine flatwoods, and cypress

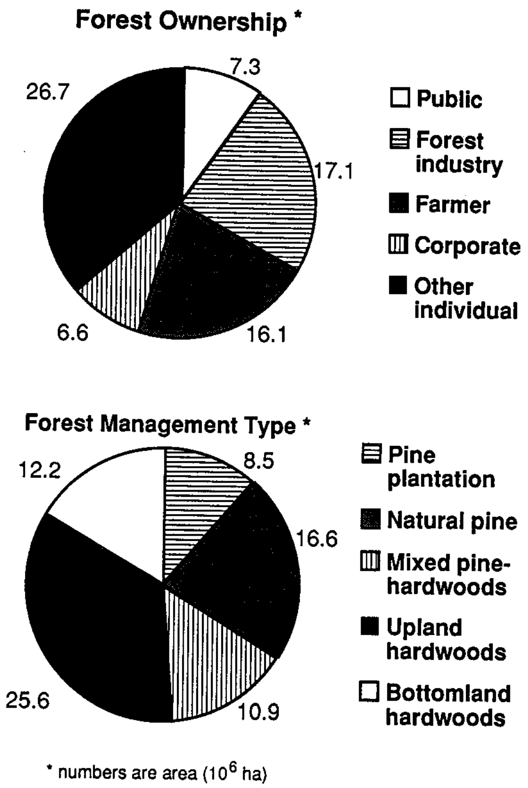

FIG. 1. Current patterns of forest ownership and management in the southern United States. Data from the Southeast and South Central regions of the USDA Forest Service are combined. (Based upon USDA 1988.) Numbers are multiples of 10^6 ha.

swamp communities are maintained within this association by fire or flooding (Monk 1968). Alluvial forests of mixed hardwoods and cypress extend northward along the Mississippi drainage and also occur on the floodplains of major rivers.

The Oak–Pine Forest occurs on the Piedmont and contains a range of forest types, from swamp hardwoods on alluvial hydric sites to oak-dominated communities on xeric sites. Fire suppression efforts since the turn of the century have gradually shifted the composition of these forests from pine to oak dominance, especially on private, non-industrially owned lands (Brender 1974, Gholz and Boring 1991).

The Appalachian Oak and Mesophytic Forests occupy the broad central region of the Eastern Deciduous Forest. Mixed-oak forests dominate the slopes of the southern Appalachian Mountains and the Valley and Ridge provinces, whereas mesophytic forests containing a diverse group of species occur on rich cove sites in the Appalachians (Day et al. 1988). Pine forests exist on ridges and on exposed, droughty sites with a history of intense fires, but these are becoming scarce due to fire suppression. The Oak–Pine–Hickory and Oak–Hickory Forests west of the Mississippi River are distinguished from the Oak–Pine Forest to the east by having a drier climate and fewer hardwood and pine species (Braun 1950).

Within all of these associations the distribution and relative abundance of individual species in response to geomorphic factors (i.e., topography, moisture, soils) and to the frequency of natural disturbances have been modified by human land use. Historic and current land-use patterns have resulted in a highly fragmented landscape throughout the South. Although individual forest tracts have coalesced as agricultural lands have declined, urbanization and development (including construction of highways, and homes in rural areas) have continued to subdivide the landscape. This fractionation of landscapes has altered critical ecological processes related to biodiversity and sustainability. Maintenance of diversity and sustainability in the southern forest requires management strategies that consider regional biogeography and landscape pattern in addition to local landowner concerns (Noss 1983).

MAINTENANCE OF BIOLOGICAL DIVERSITY

Diversity across temporal and spatial dimensions is a natural and essential feature of the forest landscape. There is general agreement among scientists that the current rate of loss of biological diversity is without precedent in human history, and constitutes a significant problem relating to human welfare (OTA 1987, Wilson and Peter 1988). Three types of diversity must be considered in the management of forest ecosystems: compositional, structural, and functional (Crow 1989). Considerable effort has been directed toward compositional diversity, especially maintaining species numbers, population sizes, and genetic diversity. Structural diversity, as expressed by the variety and arrangement of habitats, is critical to the maintenance of many species. Functional diversity represents variation in ecological processes or interactions, such as nutrient recycling. All these aspects of diversity must be considered, maintained, and balanced, to ensure ecosystem sustainability. Although laudable, efforts to manage forests for the critical habitats of endangered species can be carried to extremes and be as potentially damaging to ecosystems as management for maximum product production.

In managing forests to maintain diversity and to ensure sustainability of forest resources, a *landscape perspective* is needed that coordinates the habitat requirements of various species (including threatened species) and functional attributes of ecosystems (Probst and Crow 1991). Certain fundamental ecological concepts should provide a general framework to define and determine optimum biodiversity compatible with continued commodity output. Although these concepts should be a framework for coordinating alternative uses, there may be problems and situations where com-

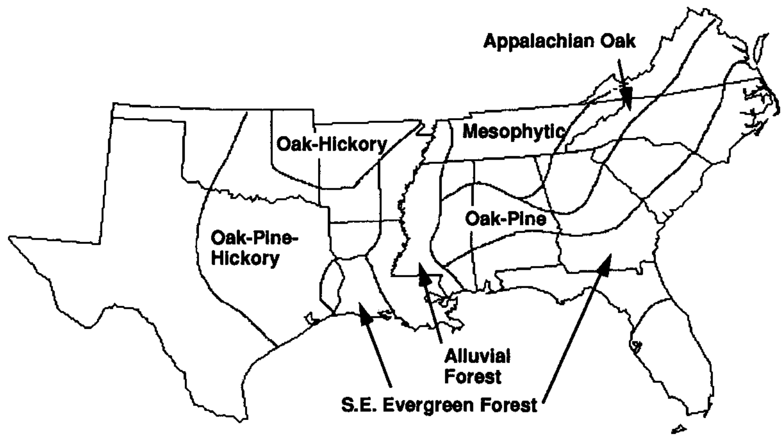

FIG. 2. Major forest associations in the southern United States (modified from Gholz and Boring 1991).

peting uses and management objectives cannot be resolved.

Achieving high local habitat diversity may not perpetuate high diversity of the landscape

Forest management to maintain compositional and structural attributes of biological diversity may be hampered by different perspectives of the scale at which diversity is measured. Noss (1983) describes three basic scales of diversity: (1) the number of species within a single habitat or community, (2) the change in species composition along an environmental gradient or between habitats, and (3) the total species diversity of a large geographic region or landscape. These concepts reflect the *alpha, beta,* and *gamma* diversity of Whittaker (1972). Many factors will affect the responses of organisms to these aspects of scale, including their size, mobility, foraging patterns, and life histories.

Forest management techniques for achieving maximum diversity differ according to scale (see Noss 1983). Achieving the maximum local habitat diversity may not be the best plan for sustaining high regional diversity. For example, management for within-habitat diversity should be directed toward attaining optimum levels of limiting resources to ameliorate interspecific competition and increasing structural complexity to provide more physical niche space.

Management for between-habitat diversity includes maintaining a variety of successional forest stages, and interspersing different types of managed and natural forests. The size of these forest units is critical (Hunter 1990). Too many small patches of differing habitat may appear visually diverse but may not be large enough for the requirements of many organisms. This fragmentation, which has been noted for "islands" of forest in open habitat, applies as well to mixes of forest types where the units of management are too small.

Managing for landscape diversity requires maintaining sufficiently large areas of different habitats on a regional scale so that population levels and genetic variation of species that live entirely in one habitat are preserved. However, too many large units may present problems for species that depend on boundary areas or "edges" between habitats. The management of an area should be optimized in respect to surrounding and neighboring areas to prevent undue duplication of habitats and to ensure that the landscape arrangement does not produce barriers to dispersal and gene flow across the area.

Traditional management goals have been directed toward maintaining maximum habitat diversity within local units (such as parks, wildlife areas, and other public-use lands). This approach to conservation has developed primarily through extension of island biogeographic theory (MacArthur and Wilson 1967) to land-use planning and the design of nature preserves. However, almost all ecosystems are "open," exchanging energy, mineral nutrients, and species. Thus, the landscape mosaic, comprising local ecosystems and usually containing people and their activities, may be more appropriate in managing for the goal of a sustainable environment (Noss 1983, Forman 1988). The landscape paradigm identifies patterns that might otherwise go unnoticed, including regional trends in extinction and colonization, relative abundances of species and habitat types, and the interdispersal of "source areas" (where reproduction of a species is high) and "sink areas" (where reproduction may be low and populations are continually recolonized by dispersal from source areas) (Pulliam 1988).

Conservation of biological diversity requires maintenance of all successional stages of forests as well as of all representative forest types

According to the classic view of southern forest succession, spatial and structural complexity build over time and thus are maximized in old-growth stages. Old-growth forests and the organisms and processes they represent are an essential aspect of global biodiversity that is at risk (Franklin 1988). Unfortunately, only a few remnant old-growth forests remain in the South. The old-growth forest ecosystem encompasses all phases of forest development, from young trees growing in gaps created by windthrow or natural mortality to an uneven canopy dominated by mature trees (Crow 1989). Recent studies of natural forest stands in the Pacific Northwest (Hansen et al. 1991) concluded that the canopy structures, snag densities, and levels of fallen trees in unmanaged young, mature, and old-growth stands make all three of these seral stages suitable habitat for many species of forest plants and vertebrate animals, and suggest that conservation should focus on natural forests of all ages. Much less is known about habitat availability in natural forests of the South.

Managed plantations typically lack the multilayered canopy, diverse tree sizes, and abundant snags and fallen trees that exist in natural forests (Hansen et al. 1991). Where maintenance of diversity is a goal, silviculture to enrich forest structure within managed stands must be practiced. This may involve longer rotations, less intensive harvesting and site-preparation practices, retention of mature trees in harvested stands, or retention of snags and of large woody debris on the forest floor. These practices may result in short-term reduction of the quantity of traditional forest products, but they will enhance non-timber values and promote the sustainability of both commodity and non-commodity values over a longer time (Crow 1989).

Both structural and functional diversity are critical to ecosystem stability

In our concern for the maintenance of species variety or endangered populations, functional aspects of diversity are often overlooked. Certain key species or structural attributes may be especially important in maintaining some forest ecosystem functions or processes. For example, longleaf pine (*Pinus palustris*) and wiregrass (*Aristida stricta*) function to direct local lightning strikes into ground rather than crown fires. The dense cover of wiregrass and pine needles is highly flammable. The frequency of ground fires maintains the composition of the longleaf pine–wiregrass forest ecosystem (Platt et al. 1988) and results in one of the most diverse herbaceous groundcovers in the world. This diverse flora supports a fauna unique to the region (Noss 1989). Understanding the complex interactions of such key species and preserving their functional roles is as important to biodiversity as maintaining compositional diversity, genetic diversity, and endangered organisms.

Nitrogen-fixing plant species are also examples of important functional components of forest ecosystems. Many of these species, such as black locust (*Robinia pseudoacacia*) or red alder (*Alnus rubra*) colonize disturbed, early-successional forest sites where nitrogen availability is low, and facilitate rapid forest regeneration (Boring and Swank 1984). The nitrogen fixed by these early successional species contributes to the long-term productivity of the forest. The understory of fire-maintained pine forests commonly contains herbaceous legumes (especially *Lespedeza* and *Desmodium* spp.) that fix nitrogen at rates of 1–10 $kg \cdot ha^{-1} \cdot yr^{-1}$ (Hendricks and Boring 1989). These species may be important in replacing nitrogen lost in combustion.

Standing dead trees and downed logs serve many ecological functions in forests, as well as in aquatic systems (Harmon et al. 1986, Maser et al. 1988). The importance of snags for wildlife has long been recognized, and fallen logs and decaying trees provide habitat for many faunal species. In riparian forests and streams, logs provide structures for retaining food and sediments for an array of organisms. In unmanaged forests of prehistoric times, substantial amounts of coarse woody debris were likely present (Spies et al. 1988). However, in managed stands it remains a major challenge to maintain this important structural component while producing timber commodities. In southern forests with moderate climatic conditions or frequent fires, woody debris may be short-lived and require continual replacement. Few baseline data are available concerning quantities and functional role of woody debris in southeastern forest ecosystems.

Fragmentation of the Southern Landscape

Modern shifts in land-use patterns have fragmented regional landscapes and altered critical ecological processes that regulate productivity, environmental quality, and biological diversity. Although the southern forest occupies more area than it did 50 years ago, human influence on the forest land base is continually increasing (Healy 1985). While the impacts of this forest fragmentation on specific plant and animal species are not fully understood, it is clear that fragmentation affects species directly by loss of habitat and indirectly through the isolation of populations remaining in residual patches (Crow 1989).

Native species diversity is influenced by the size, distribution, edge characteristics, and dispersion of stands across landscapes

Dividing large and continuous tracts of natural habitat into smaller habitats surrounded by altered or disturbed areas—such as has occurred in the southern landscape—is a major concern relating to biological diversity (Harris 1984). Habitat fragments may be patches of old-growth surrounded by second-growth forests, woodlots surrounded by agricultural lands, urban forests, and other areas separated by less suitable habitat. Although natural disturbances result in fragmentation and the formation of forest patches, the negative effects of habitat fragmentation are aggravated in human-dominated landscapes.

Such fragmentation can adversely affect species requiring interior forest conditions or those requiring several habitats in close proximity. It is perhaps axiomatic that several endangered species in the Southeast require either wetlands or large tracts (i.e., Red-cockaded Woodpeckers). Those species that require large tracts of wetland forest are especially threatened or extinct (e.g., Ivory-billed Woodpeckers). Declines in migratory bird populations in the eastern deciduous forest may be related to forest fragmentation; certain long-distance migratory species are usually found only in fairly large forests (Whitcomb et al. 1981). Furthermore, through habitat fragmentation populations may become isolated and the chances of local extinction and inbreeding increase.

Fragmentation favors species common to ecotones and edges between communities because forest edges commonly have high densities of herbaceous and woody-cover species and high food availability. Game animals are often edge-adapted (Hunter 1990). For this reason, traditional wildlife management has often stressed maximizing edge, such as plantations alternating rows of pines and grass or crops to improve quail habitat. Animals of suburban and many urban and agricultural landscapes are also edge-adapted species.

Because human manipulation has left forests reduced and isolated, a management goal should be to avoid further fragmentation of large tracts. In areas where forests substantially dominate the land, a management program that optimizes spatial heterogeneity by managing stands at a variety of scales can produce both edge habitat and large stands (Hunter 1990). It may be necessary to accept that private land holdings will generally promote edges because of their inherent fragmentation. Thus, large public lands should be considered for management for interior species.

Interconnections among patches in a landscape may be significant to maintenance of diversity (Noss 1983), and it may therefore be useful to promote the development of forest corridors or "stepping-stones" of small forest tracts to encourage dispersal between forest islands on private lands (Diamond 1975). Because corridors may need to be >100 m wide for the migration of some interior species (Ranney et al. 1981), one of the best ways to provide corridors is to maintain forest cover along waterways (Recher et al. 1987).

Alteration of large-scale disturbance regimes results in shifts in regional vegetation

In addition to fragmenting the southern forest landscape, land-use practices have modified characteristic natural disturbance regimes that affect forest composition and structure. Fires and floods are disturbances that humans have learned to employ or modify, but activities that alter or restrict the effects of natural environmental events may severely modify the forest structure.

The U.S. Forest Service and state forestry commissions have policies to control large, catastrophic forest fires, but use controlled fires as management tools. However, current prescriptions for using fire fail to simulate the historical role of fire in Southern ecosystems. Most prescribed burns are low-intensity winter fires, whereas most lightning fires and those set by Native Americans occurred during the growing season and were of higher intensity.

As a result of fire suppression, dramatic shifts in species composition and structure of Southern forests are occurring. In the Southern Appalachians, fire-intolerant species are now more prevalent than in the past. Rhododendron (*Rhododendron maximum*) and mountain laurel (*Kalmia latifolia*) now form dense canopies that alter forest structure by inhibiting the regeneration of pine and oak species (Clinton 1989). The longleaf pine (*Pinus palustris*)—wiregrass (*Aristida stricta*) community that once was the dominant vegetation type on roughly 30 × 10^6 ha of southeastern Coastal Plain has been reduced to ≈2 × 10^6 ha by fire exclusion and species conversions (Noss 1989).

Restoration of some forest communities will be impossible without the reintroduction of summer fires. It is no longer possible to permit high-intensity summer fires to extend across broad southern landscapes; however, it may be possible to restore burning regimes on intermediate scales that more closely resemble historic fire regimes (Frost et al. 1986). Even though dormant-season burns do not necessarily simulate the historical role of fire, they do enable land managers to accomplish certain objectives, such as reducing wildfire hazard, improving habitat for numerous wildlife species, and controlling plant succession. However, fires, even controlled burns, may be affected by the urbanization of the South. Conflicts caused by spatial proximity of forest lands to developed areas may limit the ability to use fire as a management tool. Many traditional forestry practices prove objectionable when applied in a mixed urban–rural setting (Healy 1985).

Altering the natural flood patterns of rivers and streams affects the recruitment and growth of floodplain species and the structure of these riparian forests. Most of the major southern rivers have been controlled through the construction of dams and reservoirs or through channelization (Schneider and Sharitz 1988). Changes in the natural hydrologic regime that do not allow adequate flood-free periods for germination and establishment of bottomland hardwood seedlings may have long-term effects on forest composition (Sharitz et al. 1990). In addition, prolonged floods during the growing season may result in high seedling mortality and reduced growth. Dams and impoundments also

TABLE 1. Values of riparian ecosystems.*

Hydrologic values
Store flood waters and ameliorate downstream flooding
Serve as areas of aquifer recharge or discharge
Provide continuous source of water
Organic productivity values
Have high primary productivity
Have high secondary productivity, which supports fisheries, trapping, and hunting
Export organic matter to downstream ecosystems, such as lakes and estuaries
Produce high yields of quality lumber
Biotic values
Provide required habitat for many plant and animal species
Provide corridors for animal movement and to connect habitat patches
Provide spawning areas for some anadromous and other fish species
Produce organic matter from riparian vegetation for aquatic food chains
Biogeochemical values
Have high capacity to recycle nutrients
Provide buffer zones for maintaining water quality
Sequester heavy metals and some toxic chemicals
Accumulate organic matter and thus provide sink for some chemical compounds
Other values
Contribute to landscape diversity
Provide areas of sedimentation for building soils
Serve as locations for recreation and relaxation

* Modified from Brinson et al. 1981.

contribute to the fragmentation of riparian forest habitats.

MAINTENANCE OF ENVIRONMENTAL QUALITY

Maintaining the functional integrity and sustainability of ecosystems is critical to environmental quality, and hence to resource productivity. Reforestation of the southern landscape and the use of improved forestry practices have resulted in major improvements in water quality, soil erosion and watershed protection (Swank and Crossley 1988, Williams 1989). Although these represent significant achievements, more can be done to relate continued sustained productivity on forested lands to improved environmental quality.

Soil and water are sustainable natural resources whose quality must be protected to maintain ecosystem integrity

Logging and site preparation operations can degrade forest sites through changes in physical and nutritional properties and through soil displacement (Burger 1983). Raking residual debris following clearcutting into windrows displaces tons of topsoil and exposes the soil surface to erosion. This practice can significantly degrade soil resources and sustained productivity. Morris et al. (1983) showed that nutrient displacement into windrows amounted to >10% of the site's nutrient reserves. Loblolly pine production over a 31-yr period on a windrowed site was 23% less than on a broadcast-burned site (Fox et al. 1988). Neary et al. (1984) projected yield declines for southern pines on a variety of sites after high-intensity site preparation, even when fertilizer was applied.

Such high-intensity activities not only decrease site productivity and sustainability but also produce sediment, which is the primary pollutant degrading water quality during forestry operations. Less-intensive methods of site preparation, such as prescribed fire, generally cause less erosion than mechanical methods in the steep terrain of the Piedmont and southern Appalachians (Van Lear et al. 1985, Van Lear and Danielovich 1988). Some timber-harvesting practices in steep terrain increase the potential for erosion, although guidelines exist to limit impacts (Swift 1984). Roads and skid trails are the sources of ≈90% of the eroded sediment (Anderson et al. 1976); thus they must be minimized to prevent degradation of water quality.

Research has shown that forest management operations can be planned and conducted so that impacts on soil and water resources are relatively minor (Stone et al. 1978). However, the gap between results from research and operational forestry must be narrowed if the quality of soil and water resources is to be improved or protected in the future. Progress could be achieved by wider adoption of Best Management Practices (BMPs), voluntary state guidelines based on research and experience that are designed to minimize effects of forest land use on the environment (Georgia Forestry Commission 1988, Georgia Forestry Association 1990). These guidelines contain information concerning the effects of various practices on soil and water quality, and how these practices may be modified to protect these critical resources. These voluntary guidelines are preferred by landowners over rigid government regulation because they allow more operational flexibility, but they must be updated periodically and be implemented more widely and correctly to establish better public confidence in forest management.

Riparian zones and wetland forests are critical in maintaining aquatic productivity and water quality

Among the many values of wetlands and riparian zones (Table 1) is the improvement of surface water quality. Undesirable materials, including particulates and solubles, organics and inorganics, and nutrients and toxins, are removed or retained in the wetland. The processes that affect removal from water include sedimentation of suspended matter, adsorption and fixation onto soil particles, metabolism of organics, and microbial conversion to gases, which escape to the atmosphere. Forested wetlands and riparian zones have been reported to remove 20–90% of the N and 20–80% of the P from runoff or streamflow (Kuenzler 1989).

The presence of riparian forests also improves habitat quality and biodiversity of the stream system by contributing large woody debris to the channel. Large woody debris provides habitat structure, stability, and food resources. In Coastal Plain streams, debris dams are the predominant retentive devices that trap organic matter and increase habitat diversity for invertebrates and vertebrates (McArthur 1989). Most invertebrate production is associated with the wood, either on the floodplain or in the channel. Even in relatively large systems, such as the Ogeechee, the biomass of invertebrates on coarse woody debris was 20 to 50 times greater than in sandy benthic areas of the main channel and 5 to 10 times that in the muddy, benthic backwater areas (Benke et al. 1984).

In addition, riparian forests are important habitats in their own right. As a result of ecological features, such as availability of water, edges, successional patterns, special microhabitats defined by their physical features, and their fertility and productivity, riparian zones commonly support a high diversity of species (Brinson et al. 1981). Furthermore, their linear nature and vegetation coverage allow them to serve as corridors connecting habitat islands in an otherwise fragmented landscape.

Controversy abounds regarding management of forested wetlands in the South, including peat-based pocosin areas and pine savannas as well as riparian zones. At issue is preservation of the functions of natural wetlands and the effects of silvicultural practices that typically include such site preparation operations as draining, removal of logging debris, bedding, and the use of herbicides and fertilizers. Silviculture that simulates those natural processes that normally occur in wetlands will tend to preserve the ecological functioning of these areas.

Balance of Economic Commodities and Ecological Values

The output of economic commodities and conservation of ecological values must be balanced to ensure long-term sustainability and biological integrity of southern forests. Well-planned and properly applied silvicultural practices can promote biodiversity and functionality by simulating the disturbance regimes of pre-Columbian forests while providing for the continued production of commodities. Mixtures of even-aged and uneven-aged management systems can be used to simulate the perturbations common to the environments in which southern ecosystems evolved (Hunter 1990). To ensure a balanced landscape, we also should protect remaining old-growth forests in the South whenever possible because these areas are now quite rare. It may be desirable to allow succession to proceed to an old-growth condition in those areas such as steep bluffs and wetland corridors where the benefits of old-growth forest exceed income lost from timber revenues. Moreover, the absence of disturbance in these areas protects against site degradation.

From an ecological view, even-aged stands are expected to result naturally in southern forests as a result of fire or severe storms. They may not, however, have occurred in the patch sizes, shapes, and periods of rotation currently involved in contemporary forest management. Nor did they historically exhibit the degree of soil disturbance and reduction of structural diversity that commonly occurs during harvest and mechanical site preparation operations in use today. Practices such as windrowing coarse woody debris and preparing planting beds have no natural analogs.

Even-aged forest management using clearcutting, seed-tree, or shelterwood regeneration methods can produce conditions similar to those that result from medium- to large-scale natural disturbance events. Silvicultural systems that mimic these disturbances should leave snags and a significant component of large woody debris on the ground following harvest to ensure the continuation of the structural legacy from the previous stand (Hansen et al. 1991). Less-traditional regeneration methods, such as reserve seed-tree and irregular shelterwood methods (Smith 1986), in which large trees from the previously harvested stand are maintained as new individuals regenerate, may produce structurally more diverse stands. Future research should focus upon both ecological and economic studies of such nontraditional silvicultural systems.

Uneven-aged forest management, in which only individual trees or small groups of trees are harvested at any time, simulates conditions where disturbance is more localized, such as canopy gaps created from the deaths of individual trees. The small openings are regenerated naturally, usually by shade-tolerant species. Valuable shade-intolerant species will become less prevalent as this type of management continues. Such management may maintain more of the structural and functional attributes of older-growth forests, including several age classes of overstory trees, but it requires a greater road density and visitation rate than even-aged management. Increased road density and use may affect soil and water resources. Thus, soils and topography that are sensitive to these impacts should be managed in other ways.

Although forests traditionally have been managed by the alternatives of even or uneven-aged regeneration systems, they can be combined, or other alternatives may be designed. The choice of silvicultural method is determined by ecological characteristics of the species (e.g., shade tolerance, susceptibility to windthrow, adaptability to flooding, seed dispersal), ecological values (species diversity, protection of rare and endangered species, and consideration of environmental quality), economic efficiency, and the land-management objectives. The techniques are available to balance concerns for biological diversity, environmental

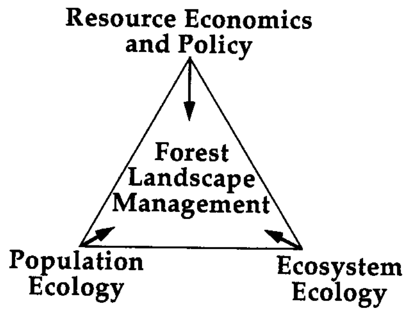

FIG. 3. The relationship between forest management, ecology, and resource management.

quality, and commodity production. The developing capacities of geographic information systems and their increasingly frequent implementation on modest, desktop computers will provide easy planning of effective management practices. Data on soil types, topography, wetlands, stream channels, and stand age may be easily combined to suggest the best management practices. Any proposed management plan can then be readily evaluated for its suitability for wildlife and endangered species management objectives.

Agency decisions on public land-use policy, congressional mandates, or changing economic goals may drive the implementation of non-traditional forest management on southern National Forest lands. However, these lands are relatively small holdings in comparison to the private, non-industrial forest lands which dominate the southern United States. To be implemented on private lands, initiatives are needed that integrate the ecological goals of management with an acceptable level of financial return. Although many private landowners may be willing to accept some reduced profit to sustain ecological values, it is unrealistic to expect large-scale implementation of new management procedures without sustained income or tax benefits or other personal rewards.

FUTURE PERSPECTIVES

Productivity of a single resource, such as timber, need not be maximized on all forest lands. Nor can there be total emphasis on biodiversity and other noncommodity values in a region where the majority of land is in private ownership. Instead, the principles of forestry and ecology must be combined in a balance that ensures continued production of forest goods, continued ability of the land to produce, and continued quality of the forest for all its users. This is the basis of stewardship and the conservation ethic as established by Leopold (1949) and others. It also is the ecological rationale for multiple-use forest management.

Such ambitious and complex management requires better understandings of how forest production, biological diversity, ecosystem function, and landscape diversity interact. This must arise from a better integration of multidisciplinary approaches than we have achieved in the past (Fig. 3). It will also require new cooperative efforts among groups that have not yet worked together effectively (NRC 1990, Lubchenco et al. 1991).

With the growing awareness that local practices are related to global and regional problems through atmospheric linkages, we are beginning an exciting and critical era for both the ecological sciences and the practice of natural resource management and conservation. It is a time of opportunity, when both theory and practice are undergoing scientific maturation and major technological progress, and the former delineations between "basic" and "applied" science are being replaced by new models of co-directed research. The needs for cooperative contributions, more sustainable forms of management, and long-term strategies have never been so great (NRC 1990, Lubchenco et al. 1991). Our challenge is for bold landscape-scale, regional-scale and global-scale integration of population and ecosystem ecology with natural resource management (Fig. 3). Our global problems of diminishing natural resources and reduced environmental quality cannot be solved with provincial attitudes and specialist approaches. The problems require that the diverse community of conservation scientists adopt an increasingly cooperative approach oriented at pragmatic and innovative problem-solving using ecological principles.

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