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36. Effects of Global Climate Change on Biodiversity in Forests of the Southern United States

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Climate has not been stable in the past. Fluctuations of pine (*Pinus*) pollen in a 50,000-year sequence from Lake Tulane in Florida indicate that major vegetation shifts occurred during the last glacial cycle. Phases of pollen dominated by pine (indicating a wet climate) were interspersed with periods with plentiful oak (*Quercus*), ragweed, and marsh elder (Ambrosia type) populations (Grimm et al., 1993). During the Holocene (i.e., the last 12,000 years), climate has fluctuated with periods of cooler, warmer, wetter or drier weather than at present. The greatest changes in climate probably occurred during deglaciation, approxiamtely 12,500 to 11,000 years ago. However in parts of the United States great shifts in plant distribution and composition occurred during the past 120 years, mainly resulting from anthropogenic factors (Miller and Wigand, 1994). From 1550 to 1850 a small ice age caused widespread starvation in Europe. Living things have been able to adapt to the warming since then, but widespread, rapid warming could be disastrous (Fajer and Bazzaz, 1992).

Integrated assessments of climate problems have been developed or are under way at various institutions, but none is completely satisfactory (Dowlatabadi and Morgan, 1993; Roberts, 1987). Nevertheless, most climate models predict that the continued buildup of carbon dioxide (CO,) and other infrared absorbing greenhouse gases is apt to lead to average temperature increases of 1.5 to 5 °C, as well as changes in precipitation patterns during the next 50 to 75 years (Adams et al., 1990). Evidence from high alpine environments in the Alps suggests that global warming is already having a serious effect on alpine plants, which are being pushed upward toward higher ground. As a consequence, plant species and communities at the crests of mountains may be eliminated (Grabherr et al., 1994).

Lessons from the Past

Climatic variability is the driving exogenous factor affecting community structure. Through the study of ice cores and lake sediment cores along with knowledge of planetary shifts and the use of atmospheric general circulation models (GCMs), past climate and vegetation regimes have been examined and described (Davis, 1986; Kutzbach, 1987; Kutzbach and Guetter, 1986; Webb, 1986; Webb and Wigley, 1985; Webb et al., 1987). Knowledge of past trends-in temperature, precipitation, radiation, and so forth, in addition to the consequent shifting of vegetation in terms of migration rates, distributional patterns, and so on, provide important clues to assessing present and future impacts of global climate change on the biodiversity of the southern United States.

The timing and direction of changes in the pollen record parallel the changing patterns of temperature, moisture, and radiation gradients. Webb et al., (1987) examined six pollen types, which are 1) sedge (Cyperaceae), 2) spruce (*Picea*), 3) northern pines (*Pinus*), 4) southern pines (*Pinus*), 5) oak (*Quercus*), and 6) prairie forbs (sum of sage *(Artemisia)*, Compositae, and pigweed (*Chenopodiaceae-Amaranthaceae)).* Overpeck and Bartlein (1989) used these same six pollen records plus a seventh, birch (*Betula*). They plotted response surfaces showing the relationship between the percentages of the pollen types and mean July temperature, mean January temperature, and annual precipitation. They found, for example, that the replacement of oak in the southern United States by southern pines was related to the increase in January temperatures. The response surface for pine pollen showed that the abundance gradient for southern pines paralleled that for winter temperatures and not summer temperatures. This suggests that the southern pines increased in abundance as winter temperatures increased in the latter part of the Holocene. As summers cooled beginning 6000 years ago in response to decreased radiation, spruce increased in abundance and moved southward. The response surfaces for oak also indicated a sensitivity to summer temperature. Similarily, birch was sensitive to both summer and winter temperatures, decreasing in abundance with an increase in these temperature variables.

Schwartz (199 1) provides insights about the speed and timing of the change and composition of forests over time from Holocene evidence. First, Holocene tree migrations proceeded at an average rate of 10 to 40 km per century, with a maximum rate of 200 km per century for spruce. Second, species-range changes often lagged in response to climate change. Third, the individual responses of species to climate change resulted in historical plant communities for which no present examples exist.

The temperature in North America apparently increased 2 to 3 °C several times during the Pleistocene. Sweetgum trees *(Liquidamber styraciflua* L.) grew as far north as southern Ontario (Wright, 1971). Osage oranges (*Maclura* sp.) and pawpaws *(Asimina* sp.) grew near Toronto, a good distance north of their present distribution; manatees (*Trichechus* sp.) occurred off the coast of New Jersey, and tapirs (*Tapirus* sp.) and peccaries (*Tayassu* sp.) lived in Pennsylvania (Dot-f, 1976). In contrast, the full glacial vegetation of the Atlantic coastal plain was very different. A deposit with spruce cones in Louisiana (Brown, 1938) was carbon dated 7,240 years ago, and the boreal conifer forest probably extended to the south-central United States, stretching west from Georgia (Wright, 1971). However, Delcourt and Delcourt (1987) propose that there since the last full glacial period, has been continued vegetational stability and dynamic equilibrium in the Gulf coastal plain, in the southeastern evergreen forest composed predominantly of southern pines (*Pinus*), tupelo gum (*Nyssa*), cypress ***(Taxodium distichum),*** Atlantic white cedar ***(Chamaecyparis thyoides),*** and hickory (*Carya).*

Climate Change Effects

The southern United States has an extensive coast line and mountainous areas, features that influence the large-scale flow of the atmosphere, and help define the regional weather, demographics, and biodiversity. Regions that differ substantially in background climate should have different levels of sensitivity to climatic change (Neilson and Marks, 1994). In this section, we will examine the sweeping effects that could occur under different climate scenarios and look with some detail specifically at the effects on the southern United States, its species and populations, and natural processes.

To assess the potential impacts of climate change, Miller and Brock (1989) conducted a modeling study using the Weekly Scheduling Model of the Tennessee Valley Authority (TVA) to simulate reservoir levels, river flows, and hydropower generation for wet and dry scenarios’, based on the runoff estimates from the Goddard Institute for Space Studies (GISS) doubled-CO, model run. Table 36.1 lists temperature results for a number of cities in the region from the GISS doubled-CO, scenario. Projected lake and reservoir levels have important implications for fish and wildlife populations, as well as recreation. Miller and Brock (1989) found that the wet scenario would largely eliminate present problems with low lake levels but that the dry scenario would make these problems the norm. Lower flows would reduce the dilution of municipal and industrial effluents discharged into the Tennessee river and its tributaries, thus the ability of streams to assimilate wastes would be reduced and water quality degraded. Water would remain at the bottom of reservoirs for a longer period of time, hence, the amount of dissolved oxygen would decline. This would directly harm fish, amphibians, aquatic invertebrates, and so forth. Although a drier climate would exacerbate many problems facing the TVA, a wetter climate would increase the risk of flooding and stream sediment loading. Under the wet scenario, Miller and Brock (1989) found that storage was inadequate at the tributary reservoirs, which could result in uncontrolled spillage over dams. The recent flooding along the upper Mississippi river in Iowa and elsewhere attest to the impacts of uncontrolled

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[1] GISS estimates high runoff, Miller and Brock use the inverse of GISS as a dry scenario.

Table 36.1. The GISS Doubled-CO, Scenario: Frequency of Hot and Cold Days Given in Degrees Fahrenheit

	Number of winter days				Number of summer days					
	Daily low < 32		Daily high ≥ 70		Daily high < 80		Daily high > 90		Daily high ≥ 100	
Location	Hist	2 × co,	Hist	2 × co,	Hist	2 x co,	Hist	$2 \times CO_2$	Hist	2 x co,
Atlanta, GA	38.3	20.5	4.2	13.6	10.0	2.2	17.1	53.3	0.6	4.2
Birmingham, AL	35.5	8.1	7.1	30.7	4.5	0.4	34.1	72.5	1.5	10.7
Charlotte, NC	42.1	23.8	3.4	9.9	11.9	3.7	23.1	56.5	0.1	5.9
Jackson, MS	33.5	5.9	15.3	43.5	0.8	0.2	55.1	83.1	2.0	19.5
Jacksonville, FL	9.3	1.7	34.6	49.6	2.3	0.3	46.4	81.3	0.6	14.1
Memphis, TN	41.2	8.1	5.2	23.6	4.9	0.7	50.5	74.8	2.6	19.1
Miami, FL	0.2	0.0	72.9	82.7	0.6	0.0	29.8	83.5	0.0	2.5
Nashville, TN	42.5	15.4	0.3	8.6	60.4	33.7	10.5	20.2	0.3	3.5
New Orleans, LA	14.9	3.5	24.9	39.5	0.9	0.1	55.4	84.9	0.3	13.5

flooding, not only to human populations and property, but to plant and animal communities as well. In addition to the dangers of flooding, increased runoff would elevate the amount of suspended sediments, degrading the recreational quality of surface waters, filling reservoirs, raising water treatment costs for sediment removal by municipalities and industry, and disrupting fish spawning grounds.

To assess the possible impacts of climate change on southern forests, Urban and Shugart (1989) applied a forest simulation model to upland sites near Knoxville, Tennessee; Macon, Georgia; Florence, South Carolina; and Vicksburg, Mississippi. Their study considered the Oregon State University (OSU), Geophysical Fluid Dynamics Laboratory (GFDL), and GISS scenarios for doubled CO_2, as well as the GISS transient A scenario through the year 2060. These researchers used a modified version of FORET, a gap forest dynamics model originally developed by Shugart and West (1977) and they made a number of simplifying assumptions. For example, they assumed loblolly pine (*Pinus taeda* L.) could not tolerate more than 6,000 cooling degree days per year. Also, they did not consider the potentially beneficial effects of CO, fertilization on photosynthesis, improved water use efficiency, or leaf area.

Following World War II, substantial amounts of farmland have been removed from agriculture, and much of this land has reverted to forest. Unfortunately, the simulations by Urban and Shugart (1989) question the ability of southern forests to be regenerated from bare ground, particularly if the climate becomes drier and warmer-an important point, because seedlings and saplings may be more sensitive to climate change. For the Knoxville site, the dry GFDL scenario indicated that a forest could not be started from bare ground; the GISS and OSU doubled-CO, scenarios showed reductions in biomass of 10 to 25%. For the South Carolina site, only the GISS climate would support a forest, but at less than 50% of present productivity. The Georgia and Mississippi sites, based on the three climate scenarios, could not generate a forest from bare ground.

The GISS transient A analyses suggest that mature forests could die if the climate changes. The analyses indicate significant destruction would not occur before 2030, a lag effect, but all forests would be substantially affected by 2060. The Mississippi forest would be lost by 2040, and the South Carolina and Georgia ‘sites by 2060. The Tennessee site, being much cooler, would remain somewhat healthy, but lose about 35% of its biomass. If forest decline and mortality truncate southern distributions of tree species, affected areas would then be susceptible to weed expansion and pest outbreaks, which can eliminate native species (USDA, 1971). For instance, Kudzu (*Pueraria lobata* Ohwi) and japanese honeysuckle *(Lonicera japonica* Thunb.), two exotic species, are predicted to expand northward approximately 500 km under a doubling of CO, (Sasek and Strain, 1990).

Animals

The most rapid responses to climate change occur among animals. Animal behaviors such as feeding and reproduction vary with climate and are apt to change considerably if global warming occurs. Such extremes in weather as severe storms and harsh winters can destroy food supplies and decimate local populations (Davis, 1986). An increase in local temperature can speed up insect metabolism, affecting local population density. Species could evolve the capacity for extra life cycles per year, with considerable economic impact in the case of crop pests. Warmer winter temperatures probably will expand the overwintering ranges of many insect pests (Smith and Tirpack, 1989). Drought stress on plants may indirectly alter the feeding and reproduction of insects (Rubenstein, 1992), for example, drought-stressed plants are more suitable for the growth and reproductive success of such insects as butterflies, moths, and grasshoppers (Mattson and Haick, 1987).

An increased CO, concentration may indirectly affect secondary plant metabolites in environments where water or nutrients are limiting. It may lead to reduced protein synthesis and to diversion of phenylalanine or tyrosine into phenolics. It is not clear whether this will result in decreased herbivory or if herbivores will eat more of plants that are less nutritious (Lambers, 1993).

Although the physiological responses of organisms to temperature are understood, ecological responses of populations are not, especially for terrestrial animals (Tracy, 1992). Examples from the southeastern United States can be useful in predicting responses of populations to climate change. Brisbin (1974) found that a cove of Par Pond at Savannah River Plant that received hot water from one of the nuclear reactors always had fewer numbers of species and less abundance of waterfowl than a second cove that was about 10 °F cooler.

Rapid changes in range are possible for birds, because they are mobile, and species that are present every year as visitors may begin to nest as soon as conditions become favorable. Other species may attempt to nest for several years after conditions have changed, and therefore may lag behind habitat and climate changes (Davis, 1986). Jarvinen and Ulfstrand (1980) suggest, however, that changes brought about by humans have had greater influence on birds than climate.

Ducks are dependent on coastal wetlands for breeding, food, or wintering grounds. Shorebirds are primarily dependent on sand beaches. Both groups are especially vulnerable to two indirect effects of global warming which are 1) drought, and 2) rise in sea level. Disruptions in relative timing of food availability and bird migration may occur as a result of climatic change at specific sites. Also, the onset of migration, especially for long-distance migrants, is not sensitive to local temperature, but the onset of spring activity by insect larvae and emerging adults in the birds' breeding sites is very sensitive to local temperature (Myers and Lester, 1992).

Nonmigrating bird species could face problems as a result of changes associated with global climate change, for example more frequent hurricanes. During 1987, Hurricane Hugo destroyed 70% of the nesting trees of the endangered red-cockaded woodpecker (*Picoides borealis*) in the Francis Marion National Forest in South Carolina, where the largest population of the woodpeckers was located.

The whooping crane, a migrating species, also underwent serious population declines as a result of hurricanes during this century.

Reptiles and amphibians are an important component of the food chain and constitute an amazing amount of biomass of the forest community. As an example, population densities of the salamander *Plethodon cinereus* in the Eastern deciduous forest have been recorded as high as 0.9 to 2.2 individuals/m* (Heatwole, 1962; Jaeger, 1980). Many herpetofauna require a heterogeneous habitat structure (Bennett et al., 1980). One major consequence of changing climate in the South is an 8% predicted increase in the occurrence of wildfires (Simand and Main, 1987), which will greatly reduce these habitat structural components with obvious negative impacts on herpetofauna diversity.

Whiting et al. (1987) found that increasing drought conditions impacted both winter and spring amphibians in the east Texas pine-hardwood ecosystem during three dry years by reducing breeding sites. Williams and Mullin (1987) obtained similar results in loblolly-shortleaf (*Pinus echinata* Mill.) and longleaf (*Pinus palustris* Mill.)-slash (*Pinus elliottii* Engelm) pine ecosystems in central Louisiana. In these ecosystems, the greatest herpetofauna diversity occurs in mature stands, which Urban and Shugart (1989) suggest could be lost in the South if climate changes. Pearson et al. (1987) noted that little breeding of anurans (toads and frogs) took place in the longleaf-slash pine ecosystem in southern Mississippi during a spring drought, except in bayheads (mesic-hydric hardwood habitats). A number of factors, including water, ground cover, and overstory composition, influence amphibian and reptile community composition and relative abundances.

Large animals are affected by genetic problems caused by small population size, because they usually have low population densities and large ranges. This will increase as rising sea level, habitat conversion, and change caused by climate continue. The Florida panther is already demonstrating genetic problems related to these factors. Historically it occurred throughout the southeastern United States, but human settlement has limited its distribution to the southern tip of Florida (Harris and Cropper, 1992).

Plants

Experiments have demonstrated that elevated levels of CO, increase photosynthesis and decrease stomatal conductance in crop plants, causing reduced transpiration rate per unit leaf area and overall increase in water use efficiency during the growing season. Nevertheless, the stomata of many tree species are unresponsive to CO, after long-term exposure (Hollinger, 1987). Loblolly pine foliage in an intact forest that grew for 50 to 80 days under elevated CO, levels showed no evidence of adjustment in stomatal conductance from foliage that developed under current ambient CO, (Ellsworth et al., 1995).

These benefits should offset predicted changes in precipitation and temperature to some extent, depending on the severity of the change and short-term differences. Plants are responsive to short-term changes in weather, and there can be important short-term differences with similar averages (Adams et al., 1990; Roberts, 1987).

Changes in CO, can alter the competititive abilities of plants, thus changing community composition. Plants possessing C_3 biochemistry (e.g., wheat, rice, and all trees species) grow better in CO,-rich conditions than those species with C_4 biochemistry (e.g., corn, sugar cane and many dry land grasses). Even certain C_3 plant species grow better than others with increased levels of CO,. Under competitive conditions, plants which are more responsive to elevated CO, conditions grow at the expense of less responsive plant species, coopting water, light, and nutrients (Fajer and Bazzaz, 1992).

Carbon dioxide concentration in the atmosphere has escalated from 280 ppm before the Industrial Revolution to 350 ppm (Keeling et al., 1982), and some scientists think that it will double before the end of the twenty-first century. For the eastern half of North America, models using a doubled-CO, scenario predict an average 4 to 6 °C increase in temperature, a 0 to 2 mm/day decrease in precipitation, and a loss of 1 to 2 cm of soil moisture during the growing season (Mitchell et al., 1990). Such predictions require trees to migrate an order of magnitude faster than they did during the Holocene to maintain populations within appropriate climatic parameters. Davis and Zabinski (199 1) predicted potential future distribution for four tree species (beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* L.), eastern hemlock (*Tsuga canadensis* (L.) Can-.), and yellow birch (*Betula alleghaniensis* Britton) under two models of CO, doubling. For all species, they predicted northward range shifts in excess of 500 km. Thus, predicted climate change for the next century may outstrip many species' ability to stay within suitable climatic ranges, with fragmented habitats further reducing their ability to migrate.

Modem communities of trees should not be considered highly evolved, tightly linked complexes of species. Tree species will have a wide range of responses and response times to climate change that result from differences in life spans, seed production and dispersal rates, vegetative and sexual propagation, genetic diversity, phenotypic plasticity, competition, and disturbance. Tree population changes may follow climatic shifts by decades or centuries (Brubaker, 1986). Historical records demonstrate that some species can expand rapidly as climate becomes less limiting. Species that are rare today have the potential to become common under a changed climate and vice versa (Brubaker, 1988). Species with shorter life spans may be able to adapt more quickly (Davis, 1986). In contrast, trees with long life spans can delay the movement of range boundaries. Adult trees can remain in the vegetation for hundreds of years after seeds can no longer become established as a result of climate change (Brubaker, 1986).

Shugart et al. (1980) carried out a simulation of a stand of beech and yellow poplar under gradual changes in growing degree day values (GDD) in order to investigate the effect of different tree sizes and successional positions on population responses. Beech is a tree that regenerates in gaps left by either species, while yellow poplar is a large tree that requires substantial gaps. Growing degree day values were increased or decreased equivalent to a 1/93 °C change per year in summer temperature during 1,500 years. At 3,800 GDD, only beech occurred in the plots; at 5,300 GDD only tulip poplar occurred. In both experiments, the stand composition shifted over a 200-year period. The authors attributed the differences in the results to the effect of gap size on species replacement. The lag in response is related to the amount of time that mature trees remain in the canopy. From this and other experiments, Shugart (1985) concludes that the time necessary for forest change depends on the characteristics of the species involved.

Climate has traditionally been considered the fundamental regulator of vegetation structure, composition, and productivity, but the studies of Johnson et al. (1993) support the hypothesis that CO, concentration is also important to vegetation. A large change occurred in the composition of twenty-six species of C_3 plants and seventeen species of C_4 plants grown from a native soil seed bank along a CO, gradient that was similar to the CO, increase of the last 150 years. Increasing CO, levels elicited a strong growth response for a number of C_3 species, but the C_4 plant increased in productivity as the CO, concentration decreased. It seems probable that changing CO, levels have had and will continue to have a significant influence on the control that climate exerts on vegetation productivity, species composition, and physiognomic structure.

Loblolly pine is limited on its southern border by moisture stress on seedlings. Miller et al., (1987) predict that the southern range of loblolly pine would move approximately 350 km to the north and northeast in response to global warming of 3 °C, based on its physiological requirements for moisture and temperature. Davis and Zablinski (199 1) predict that with doubled CO, levels, beech would become rare or die out except at high elevations throughout the eastern United States, while a smaller, new habitat would open up in Ontario and Quebec. A scenario presented by Woodman and Furiness (1989) has the northerly range of the southern pine forests shifting several hundred kilometers into the regions presently occupied by mixed hardwood species.

Pitcher plant (*Sarracenia* sp.) bog communities are floristically highly diverse communities that occur across the southeastern mixed forests where sandy uplands are underlain by impermeable layers of clay. Eleuterius and Jones (1969) list 27 1 taxa, representing 134 genera and sixty-three families, occurring in southern Mississippi bogs. These bog communities are fragile and do not respond well to disturbance. Though the amount of acreage of such communities is small within the southeastern mixed forest, they are a major biological diversity resource. Folkerts (1982) speculates that no significant amount of this habitat will survive into the twenty-first century.

Wetlands

A 10 cm rise in sea level could cause tidal rivers to move inland as much as 1 km, and a 2 m rise could eliminate 80% of our coastal wetlands (Hoffman, 1987; Leatherman, 1987). Coastal wetlands would migrate inland if that were possible, but in many cases the way will be blocked by levees, highways, seawalls, housing, and other human-made structures. Inland wetlands are not expected to do much better (Myers, 1992). Wetlands are already degraded, fragmented, and dissipated largely because of draining, which will leave them vulnerable to drying out in a warmer atmosphere (Gopal et al, 1982).

Loss of forested barrier islands could cause problems for neotropical migrant birds, which already face problems in their breeding and wintering habitats in the eastern deciduous and coniferous forests. These islands are the first places to rest and find food that the birds encounter after the long migration north across the Gulf of Mexico or the Atlantic each spring. An increased rise in sea level would destroy the island forests, making the trip longer and more difficult for migrating birds.

In the southern United States, 95% of the rare plants may be vulnerable to extinction as a result of climatic warming (Schwartz, 1991); one-third of these are found in mountainous regions, and therefore they may find refuge by ascending in elevation. Many rare plants have characteristics that place species at risk, such as small populations, being habitat specialists, or being endemics with limited geographic ranges. Distributional data provided by Kral(1983) on 3 16 rare, threatened, and endangered plants of forests in the southeast United States indicate that 114 taxa (36%) are confined to areas spanning 100 km or less in latitude. Forty-one taxa (13%) have ranges that span greater than 500 km in latitude, and only 15 species (5%) have continuous distributions with no disjunctions of more than 100 km.

The native dune vegetation of the higher elevations of Florida, with fifty endemic plant and animal species (Christman, 1988, in Harris and Cropper, 1992) has survived the extremes of several ice ages, and could no doubt withstand global climate change, except that development in the area has restricted the options for adaptation (Harris and Cropper, 1992). Florida's lower-elevation plant communities are vulnerable to rising sea level. For example, the mangrove ecosystems of south Florida would be imperiled by coastal erosion, and the Everglades could be damaged by massive saltwater intrusion. As the sea level has risen, the narrow coastal habitat of several species of beach mice and the Cape Sable sparrow *(Ammospiza maritima mirabilis)* has migrated inland, but encroaching human populations have reduced and fragmented the habitat. Exotics are already a problem in south Florida, where moderate hydrological changes in the Everglades have allowed invasion of a number of exotic plant species, including *Casuarina,* peppertree *(Schinus), Hydrilla,* water hyacinth *(Eichornia),* and *(Melaleuca)* (Ewel, 1986; Myers, 1983).

Ground and Marine Diversity

Many people, when considering diversity, fail to consider what is happening on or below the ground, or in the water. To begin, the great majority of vascular plants have evolved to a dependence on mycorrhizae, or root-inhabiting fungi. Most woody plants require mycorrhizae to survive, and most herbaceous plants need them to thrive (Harley, 1969; Marks and Kozlowski, 1973; Trappe and Fogel, 1977). Mycorrhizae function as a mutualistic, symbiotic biotrophy between a fungus and a higher plant host, and are key links in belowground nutrient and energy cycling. The several thousand species of fungi believed to form mycorrhizae encompass great physiological diversity. In turn, these fungi are intimately linked to such small mammals as squirrels, rabbits, mice, and voles, also to insects and birds. These animals depend on the mycorrhizal fungi as a source of nutrition and are essential for the dispersal of spores (Fogel and Trappe, 1978; Maser et al., 1978; McMahon and Warner, 1984; Li et al., 1986; Malajczuk et al., 1987). This complex, tripartite relationship among plants, animals, and mycorrhizal fungi appears to be integral to the healthy functioning of ecosystems.

Assuming inocula are present, mycorrhiza formation depends on environmental factors, host physiology, and soil microorganisms. Alteration of any of these may influence the number of mycorrhizae that can be formed in a particular soil (Parke et al., 1983; Perry et al., 1987). Most studies find fewer mycorrhizae formed on disturbed than on undisturbed sites, for example, clear cut, burned, or eroded sites (Reeves et al., 1979, Harvey et al., 1980, Loree and Williams, 1984). Persistence of mycorrhizal fungal spores and hyphal fragments varies with climate and soil. To the extent that survival of hyphal fragments is related to their respiration rate, the period would be shorter in warmer climates (Perry et al., 1987). Dormant spores presumably survive for long periods; however, they can be lost through erosion or leaching, or can germinate prematurely from chemical secretions from nonhosts (Harley and Smith, 1983). With the myriad possible effects of climate change, from higher temperatures to altered rainfall patterns, increased fires, and shifting composition of species, both plant and animal, the complex interactions among plants, animals, and mycorrhizal fungi may be severely disrupted, with disastrous ecological effects.

The importance of snags and downed woody material in the forest has been recognized for some time (Davis et al., 1983; Maser and Trappe, 1984). Some eighty-five species of birds utilize snags for nesting; snags and fallen trees are also important to mammals, reptiles, amphibians, and invertebrates as breeding, roosting, and foraging sites. So too, the importance of driftwood (wood carried by water from the forest to the sea) is being increasingly recognized as a critically important source of habitat and food for the marine ecosystem, including the deep-sea floor (Maser and Sedell, 1994). Such human activities as stream cleaning, firewood cutting, and product-oriented forest management, have impacted the driftwood, snag, and fallen wood resources, and have had an overall negative impact on biodiversity. We anticipate that climate change, through increased fires and dieback of coastal forests, would exacerbate this situation, though in the short-run, the amount of woody material may increase (Maser, 1994). The southern United States has an extensive coast along the Atlantic Ocean and Gulf of Mexico with many estuaries, so a decrease or loss of the marine wood resource would have economic implications on the fisheries and shellfish industries, though this has been little recognized (Turner, 1977, 1981; Xavier et al., 1992, in Maser and Sedell, 1994).

Predictions

Global climate change projections for the Southeast vary considerably; some predict increased precipitation, which may compensate to some extent for increased temperature. Also, the models cover large areas and do not take into account such local features as mountains or islands, so the changes and species' response to them will not be nearly as even as the predictions imply. For the purposes of this discussion, we will assume that warming in the Southeast will average 3 °C, precipitation will decrease 25 cm/year (10 inches) and sea level will rise 10 cm during the next fifty to seventy-five years. We know how some plant and animal species respond to environmental and competitive changes, but it is difficult to predict how the flora and fauna of southern forests will respond to future environmental change, because we really do not know what controls the abundance and distribution of most species. Global warming will no doubt alter some southern species' distributions and change the composition of some communities in unexpected ways. Many of the relations of plants and animals will be changed if climate change occurs as projected (Fowells and Means, 1990). However, we can predict from the many climate scenarios and forest dynamics simulations that the diversity of plants and animals is apt to be reduced as a direct result of global warming, leading to an overall simplification of southern ecosystems. We suggest that the change will cause a domino effect in southern forests, with each ecosystem losing species as it moves north and causing the demise of other species in the ecosystem it replaces. (Although entire ecosystems do not move as a unit, there will be a general migration of species to the north.)

When plant species are introduced into continental areas, few are able to become established except in disturbed areas. Only a small fraction of fish introductions have been successful. Bird introductions into continental areas are usually failures. A few introductions have been highly successful; the European starling (*Sturnus vulgaris*) spread over the entire United States and much of Canada within sixty years. The chestnut blight (*Endothia parasitica*) spread throughout the southeastern United States, but within forty years it had caused the demise of the American chestnut (*Castanea dentuta* (Marsh.) Borkh.), which made up 40% of the overstory of climax forests in the area. Most chestnuts were replaced by oaks, so the oak-chestnut forests are now oak or oak-hickory forests (Krebs, 1978).

As the species inhabiting pine forests move north into the very diverse (Braun, 1950) mixed hardwood forests, biological diversity will suffer. Although the trees will migrate, and foresters can plant the species of commercial importance in more favorable habitats, many of the plants and animals that are associated with southern forests may become threatened or extinct because they are unable to move as rapidly as the tree species that provide their habitat. Species with short seed-dispersal distances (many forest herbs) and low ability to colonize more favorable habitat will be especially at risk. The proximity of southern forests to the Atlantic Ocean and the Gulf of Mexico has important implications for the study area. The coast has been sinking for some time, and a rise in sea level associated with global climate change will increase the risk to wetlands and other species, and will increase the need for migration as species' former habitat is inundated.

Pioneer plant species (e.g., red cedar (*Juniperus virginiana* L.), the southern pines (*Pinus* spp.), and sweetgum occur in early successional stages. They exhibit characteristics that help them become established more quickly than competing vegetation, for example, large and frequent seed crops, efficient seed dispersal, adaptability to a wide variety of sites, and high juvenile-growth rates. These species are nomads, with each succeeding generation moving to new sites that have been disturbed or are vacant. Pioneer species probably can adapt to changing climatic conditions more readily than can species that occur in later successional stages.

With a decrease in precipitation, the water quality of southern streams will decrease, and lake levels will be lowered, with deleterious effects on aquatic animals and plants. Decreased precipitation will also increase the stress on forest species. Drier forests will lead to more frequent forest tires, with consequent alteration or destruction of forests. Loss of older forests will pose a particular problem for such species as the endangered red-cockaded woodpecker that require old-growth pine forests for nesting. Reptiles and amphibians that prefer mature stands also may be eliminated, because there will be no replacement forests for a long time.

Climate extremes are more important than averages. In the coming years, changes in the frequency of fires, hurricanes, and droughts may be more important to biodiversity than temperature change. Increased incidence and severity of tires with a hotter and drier climate could cause loblolly pine, for example, to become less common in the South as longleaf pine and other species favored by frequent tires become established over much of their formerly large ranges (Bums and Honkala, 1990). Increased frequency of hurricanes will also hasten the destruction of coastal plain forests and the plants and animals that inhabit them. The cypress–tupelo forests have evolved to withstand hurricanes better than other forest communities, but these are the forests that are most at risk from sea level rise.

Such large animals as the Florida panther and the black bear, which are already experiencing difficulties as a result of habitat alteration, will probably not survive. Climate change will probably play a major role in lessening herptofauna diversity, because all of the habitat characteristics that determine their community composition are dependent upon the age of the forest and the degree of disturbance to which it has been subjected. Although bird groups, for example, shorebirds and other coastal species (that may lose much of their habitat) and neotropical migrants (that are already threatened in their breeding and winter habitats) will be particularly impacted by climate change, other bird species that inhabit the more northern part of the study area may be better able to cope, and some of them will have potential areas of refuge available. Because of short life cycles, insects may be better able to cope with climate change than many other groups, but pest species may be more of a problem than they are at present. Climate warming will undoubtedly affect the flowering dates of many plant species, and insect pollinators may not be present when they are needed (Moore, 1995).

The effects of global climate change should be most severe in the coastal habitat, lessening to the North. A moderate rise in sea level, in addition to the rise that has been occurring for some time, will probably cause the destruction of many coastal wetlands. We agree with Myers (1992) that this may well be the worst wildlife-related disaster of the greenhouse effect in the United States because the wetlands are already very disturbed and migration will be difficult because of human development. Regeneration of cypress (*Taxodium distichum* (L.) Rich.) has been a problem for some time. The salinization of ground and soil water that results as sea level rises has caused a reduction of pine forests in the Florida keys. If the sea level continues to rise, the Keys and other low-lying island ecosystems will experience a decline in diversity as the species-rich upland communities are replaced by simpler mangrove communities (Ross and O'Brien, 1994). Loss of coastal forests will result in increased mortality for migrating birds and butterflies, as well as for the organisms that inhabit the forested wetlands. Inland wetlands, in contrast, will suffer from decreased precipitation and increased frequency of fire. The loss of most bog communities will be a serious blow to southern pine forests. Florida will especially suffer the effects of global climate change, because of its large coastal area, and because of human development. Exotic species will probably be more of a problem than they are now.

During the Cretaceous and the Pleistocene, the Interior Highlands of Arkansas served as a refuge for plants and animals (Dowling, 19.56). This area may well serve as a refuge again if climate change disrupts plant and animal communities in the regions surrounding it. The Smoky Mountains are another large area that should provide shelter to numerous species during the disruptions caused by global climate change.

Many of the present goals and methods of conservation will not change as a result of global climate change, but conservationists already have much to do, and changing climate will reduce the time left in which to accomplish much of this work. Conservationists will try to ameliorate the effects of global climate change but conservation efforts may well be overwhelmed by the increased numbers of threatened and endangered species. Many less conspicuous species will probably not receive the help they are going to need.

Conclusion

These suggestions are for the southern United States, but many are appropriate for other parts of the country. A sensible way to begin preparing for climate change is to practice sound conservation measures now. Conservation plans should be flexible, to incorporate increased understanding of climate. Although there are many parks and preserves in the South, these protected areas are a small portion of the land, so any strategy to protect plant and animal species must consider public and especially private managed lands (public lands make up a small part of the acreage in the south). If we are concerned about conserving the region's biodiversity for the future, we must begin preparation now by practicing sound conservation and management, carrying out appropriate research, and using information about global climate change and biodiversity as it becomes available.

References

Adams RM, Rosenzweig C, Peart RM, Ritchie JT, McCarl BA, Glyer JD, Curry RB, Jones JW, Boote KJ, Allen, Jr LH (1990) Global change and US agriculture. Nature 345:219-224.

Bennett SH, Gibbons JW, Glanville J (1980) Terrestrial activity, abundance and diversity of amphibians in differently managed forest types. Am Mid Natur 103:412–416.

Braun EL (1950) *Deciduous forests of eastern North America.* Hafner Publishing Co., New York.

Brisbin IL (1974) Abundance and diversity of waterfowl inhabiting heated and unheated portions of a reactor cooling reservoir. In Gibbons JW, Sharitz RR (Eds) *Thermal ecology.* USAEC, Washington, DC.

Brown CA (1938) The flora of Pleistocene deposits in the Western Florida Parishes, West Feliciana Parish, and East Baton Rouge Parish, Louisiana. LA Dept of Conserv Geol Bull 12:59.

Brubaker LB (1986) Responses of tree populations to climatic change. Vegetatio 67: 119–130.

Brubaker LB (1988) Vegetation history and anticipating future vegetation change. In Agee JK, Johnson DR (Eds) *Ecosystem Management for Parks and Wilderness.* University of Washington Press, Seattle.

Bums RM, Honkala BH (Tech coords) (1990) *Silvics of North America, Vol. 1. Conifers.* USDA For Serv, Agriculture Handbook 654, Washington, DC.

Christman S (1988) *Endemism and Florida's interior sand pine scrub.* Florida Game and Fresh Water Fish Commission, Final Report.

Davis MB (1986) Climatic instability, time lags, and community disequilibrium. In Diamond J, Case TJ (Eds) *Community ecology.* Harper and Row, New York.

Davis JW, Goodwin GA, Ockenfels *RA* (Tech. coords) (1983) *Snug habitat management: Proceedings of the symposium.* USDA For Serv, Gen Tech Rep RM-99, Rocky Mtn For Exper Stat,.

Davis MB, Zabinski C (199 1) Changes in geographical range resulting from greenhouse warming: Effects on biodiversity in forests. In Peters RL, Lovejoy TE (Eds) *Consequences of greenhouse warming to biodiversity* Yale University Press, New Haven.

Delcourt PA, Delcourt HR (1987) *Long-term forest dynamics of the temperate zone.* Springer-Verlag, New York.

Dorf E (1976) Climatic changes of the past and present. In Ross CA (Ed) *Paleobiogeography: Benchmark papers in geology 31.* Dowden, Hutchinson and Ross, Stroudsburg, PA.

Dowlatabadi H, Morgan MG (1993) Integrated assessment of climate change. Science 259:1813, 1932.

Dowling HG (1956) Geographic relations of Ozarkian amphibians and reptiles. Southwestern Naturalist 1: 174-l 89.

Eleuterius LN, Jones Jr, SB (1969) A floristic and ecological study of pitcher plant bogs in south Mississippi. Rhodora 71:29–34.

Ellsworth DS, Oren R, Huang C, Phillips N, Hendrey GR (1995) Leaf and canopy responses to elevated CO, in a pine forest under free-air CO, enrichment. Oecologia 104: 139–146.

Ewel JJ (1986) Invasibility: lessons from south Florida. In Mooney HA, Drake JA (Eds) *Ecology of biological invasions of North America and Hawaii.* Springer-Verlag, New York.

Fajer ED, Bazzaz FA (1992) Is carbon dioxide a 'good' greenhouse gas? Global Envir Change, Dec:301–310.

Fogel RD, Trappe, JM (1978) Fungus consumption (mycophagy) by small animals. Northwest Sci 52:1–31.

Folkerts GW (1982) The Gulf Coast pitcher plant bogs. Am Sci 70:260–267.

Fowells HA, Means JE (1990) The tree and its environment. In Bums RM, Honkala BH (Tech coords) *Silvics of North America, vol 2. Hardwoods.* USDA For Serv, Agriculture Handbook 654, Washington, DC.

Gopal B, Turner *RE,* Wetzel RG (1982) *Wetlands ecology and management.* International Scientific Publishers, Jaipur, India.

Grabherr G, Gottfreid M, Pauli H (1994) Climate effect on mountain plants. Nature 369:448.

Grimm EC, Jacobson GL Jr, Watts WA, Hansen BCS, Maasch KA (1993) A 50,000-year record of climate oscillations from Florida and its temporal correlation with the Heinrich events. Sci 26 1: 198-200.

Harris LD, Cropper WP Jr (1992) Between the devil and the deep blue sea: Implications of climate change for Florida's fauna. In Peters *RL,* Lovejoy TE (Eds) *Global warming and biological diversity* Yale University Press, New Haven.

Harley JL (1969) *The biology of mycorrhizae.* Leonard Hill, London.

Harley JL, Smith SE (1983) *Mycorrhizal symbioses.* Academic Press, New York.

Harvey AE, Larsen MJ, Jurgensen MF (1980) Clearcut harvesting and ectomycorrhizae: Survival of activity on residual roots and influence on a bordering forest forest stand in western Montana. Can J For Res 10:300–303.

Heatwole H (1962) Environmental factors influencing the local distribution and abundance of the salamander *Plethodon cinereus.* Ecology 43:460–472.

Hollinger DY (1987) Gas exchange and dry matter allocation responses to elevation of atmospheric CO, concentrations in seedlings of three species. Tree Physio13: 193-202.

Jaeger RG (1980) Microhabitats of a terrestrial forest salamander. Copeia 1980:265–268.

Jarvinen 0, Ulfstrand S (1980) Species turnover of a continental bird fauna: Northern Europe, 1850-1970. Oecologia 46: 186-195.

Johnson HB, Polley HW, Mayeux HS (1993) Increasing CO, and plant-plant interactions: Effects on natural vegetation. Vegetatio 104/105: 157-170.

Kral R (1983) *A report on some rare, threatened, or endangered forest-related vascular plants of the South.* USDA, Atlanta, Tech Publ R8-TP-2.

Krebs CJ (1978) *Ecology: The experimental analysis of distribution and abundance.* Harper and Row, New York.

Kutzbach JE (1987) Model simulations of the climatic patterns during the deglaciation of North America. In Ruddiman WF, Wright Jr, HE (Eds) *North America and adjacent oceans during the last deglaciation.* Geological Society of America, Boulder, CO.

Kutzbach JE, Guetter PJ (1986) The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18,000 years. J Atmos Sci 43:1726–1759.

Lambers H (1993) Rising CO,, secondary plant metabolism, plant-herbivore interactions and litter decomposition: Theoretical considerations. Vegetatio 104/105:263–271.

Leatherman SP (1987) *Impact of the greenhouse effect on coastal environments: marshlands and low-lying population areas.* Laboratory for Coastal Research, University of Maryland, College Park.

Li CY, Maser C, Harlan F (1986) Initial survey of acetylene reduction and selected microorganisms in the feces of 19 species of mammals. Great Basin Natur 46:646–650.

Loree MAJ, Williams SE (1984) Vesicular-arbuscular mycorrhizae and severe land disturbance. In Williams SE, Allen MF (Eds) *VA mycorrhizae and reclamation of arid and semiarid lands.* WY Agric Exper Stat Sci, Report No SA1261.

Malajczuk N, Trappe JM, Molina R (1987) Interrelationships among some ectomycorrhizal trees, hypogeous fungi and small mammals: Western Australian and northwestern American parallels. Aust J Ecol 12:53–55.

Marks GC, Kozlowski TT (Eds) *1973. Ectomycorrhizae-Their ecology and physiology.* Academic Press, New York.

Maser C (1994) *Sustainable forestry: Philosophy, science, and economics.* St. Lucie Press, Delray Beach, FL.

Maser C, Trappe JM, Nussbaum RA (1978) Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecol 59:799–809.

Maser C, Trappe JM, (Tech eds) (1984) *The seen and unseen world of the fallen tree.* USDA For Serv, Pac NW For Exper Stat, Gen Tech Rep PNW-133, Portland, OR,

Maser C, Sedell JR (1994) *From the forest to the sea: the ecology of wood in streams, rivers, estuaries, and oceans.* St. Lucie Press, Delray Beach, FL.

Mattson WJ, Haick, RA (1987) The role of drought in outbreaks of plant-eating insects. Bioscience 37: 110.

McMahon JA, Warner N (1984) Dispersal of mycorrhizal fungi: Processes and agents. In Williams SE, Allen MF (Eds) *VA mycorrhizae and reclamation of arid and semiarid lands.* WY Agric Exper Stat Sci, Report No SA1261.

Miller BA, Brock WG (1989) Potential impacts of climate change on the Tennessee Valley Authority reservoir system. In Smith JB, Tirpak DA (Eds) *Thepotential effects of global climate change on the United States-Report to congress. Volume A- Water Resources,* USEPA, Washington, DC.

Miller WF, Dougherty PM, Switzer GL (1987) Rising CO, and changing climate: major southern forest management implications. In Shands WE, Hoffman JS (Eds) *The greenhouse effect, climate change, and U.S. Forests.* Conservation Foundation, Washington, DC.

Miller RF, Wigand PE (1994) Holocene changes in semiarid pinyon-juniper woodlands. Bioscience 44:465–474.

Mitchell JFB, Manabe S, Meleshko V, Tokioka T (1990) Equilibrium climate change-and its implications for the future. In Houghton JT, Jenkins GJ, Ephraums JJ (Eds) *Climate change: The ZPCC scientific assessment.* Cambridge University Press, Cambridge.

Moore PD (1995) Opening time by degrees. Nature 375: 186-187.

Myers JP, Lester RT (1992) Double jeopardy for migrating animals: Multiple hits and resource asynchrony. In Peters RL, Lovejoy TE (Eds) *Global warming and biological diversity.* Yale University Press, New Haven.

Myers N (1992) Synergisms: joint effects of climate change and other forms of habitat destruction, In Peters RL, Lovejoy TE (Eds) *Global Warming and Biological Diversity.* Yale University Press, New Haven.

Myers RL (1983) Site susceptibility to invasion by the exotic tree *Melaleuca quinquenervia* in southern Florida. J Appl Ecol 20:645.

Neilson RP, Marks D (1994) A global perspective of regional vegetation and hydrologic sensitivities from climatic change. J Veg Sci 5:715–730.

Overpeck JT, Bartlein PJ (1989) Assessing the response of vegetation to future climate change: Ecological response surfaces and paleoecological model validation. In Smith JB, Tirpak DA (Eds) *The potential effects of global climate change on the United States-Report to congress. Volume D-Forests.* USEPA, Washington, DC.

Parke JL, Linderman RG, Trappe JM (1983) Effect of root zone temperature on ectomycorrhizal and vesicular-arbuscular mycorrhiza formation in disturbed and undisturbed forest soils of southwest Oregon. Can J For Res 13:657–665.

Pearson HA, Lohoefener RR, Wolfe JL (1987) Amphibians and reptiles on longleaf-slash pine forests in southern Mississippi. In Pearson HA, Smeins FE, Thill RE (Eds) *Ecological, physical, and socioeconomic relationships within southern nationalforests.* USDA For Serv, South For Exper Stat, Gen Tech Rep SO-68, New Orleans, LA.

Perry DA, Molina R, Amaranthus MP (1987) Mycorrhizae, mycorrhizospheres, and reforestation: Current knowledge and research needs. Can J For Res 17:929–940.

Reeves FB, Wagner D, Moorman T, Kiel J (1979) The role of endomycorrhizae in revegetation practices in the semi-arid west. I. A comparison of incidence of mycorrhizae in severely disturbed vs. natural environments. Am J Bot 66:6–13.

Roberts WO (1987) Time to prepare for global climatic change. In Shands WE, Hoffman JS (Eds) *The greenhouse effect, climate change, and U.S. forests.* Conservation Foundation, Washington, DC.

Ross MT, O'Brien JJ (1994) Sea-level rise and the reduction in pine forests in the Florida keys. Ecol Appl 491:144–156.

Rubenstein DI (1992). The greenhouse effect and changes in animal behavior: Effects on social structure and life-history strategies. In Peters *RL,* Lovejoy TE (Eds) *Global warming and biological diversity* Yale University Press, New Haven.

Sasek TW, Strain BR (1990) Implications of atmospheric CO, enrichment and climatic change for the geographical distribution of two introduced vines in the USA. Clim Change 16:31–51.

Schwartz MW (1991) Potential effects of global climate change on the biodiversity of plants. For Chron 68:462–471.

Shugart HH (1985) *A theory of forest dynamics: Ecological implications of forest succession models.* Springer-Verlag, New York.

Shugart HH, Emanuel WR, West DC, DeAngelis DL (1980) Environment gradients in a simulation model of a beech-yellow poplar stand. Math Biosci 50:163–170.

Shugart HH, West DC (1977) Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. J Envir Manage 5:161–179.

Simand AJ, Main WA (1987) Global climate change: The potential for changes in wildland fire activity in the southeast. In Meo M (Ed) *Proceedings of the symposium on climate change in the southern U.S.: Future impacts andpresent policy issues.* USEPA, New Orleans, LA.

Smith JB, Tirpak D (1989) *The potential effect of global change on the United States.* USEPA, Washington, DC.

Tracy CR (1992) Ecological responses of animals to climate. In Peters RL, Lovejoy TE (Eds) *Global warming and biological diversity.* Yale University Press, New Haven.

Trappe JM, Fogel RD (1977) Ecosystematic functions of mycorrhizae. In *The belowground ecosystem: a synthesis of plant-associated processes.* Range Sci Dep Sci Ser No 26, Colorado State University, Ft. Collins.

Turner RD (1977) Wood, mollusks, and deep-sea food chains. Bull Am Malacol Union 1976:13–19.

Turner RD (198 1) "Wood islands" and "thermal vents" as centers for diverse communities in the deep sea. Soviet J Mar Biol 7:3-9 (translation of Biol Morya 7:3-10).

United States Department of Agriculture (1971) *Common weeds of the United States.* Dover Publications, New York.

Urban DL, Shugart HH (1989) Forest response to climatic change: A simulation study for southeastern forests. In Smith JB, Tirpak DA (Eds) *The potential effects of global climate change on the United States-Report to congress. Volume D-Forests,* USEPA, Washington, DC.

Webb T (1986) Is the vegetation in equilibrium with climate? How to interpret late-Quatemary pollen data. Vegetatio 67:75–91.

Webb T, Bartlein PJ, Kutzbach JE (1987) Climatic change in eastern North America during the past 18,000 years: Comparisons of pollen data with model results. In Ruddiman WF, Wright Jr, HE (Eds) *North America and adjacent oceans during the last deglaciation: The geology of North America.* Geological Society of America, Boulder, CO.

Webb T, Wigley TML (1985) What past climates can indicate about a warmer world. In McCracken MC, Luther FM (Eds) *The potential climatic effects of increasing carbon dioxide.* USDE, Rep DOE/ER-0237, Washington, DC.

Whiting RM, Fleet RR, Rakowitz VA (1987) Herpetofauna in loblolly-shortleaf pine stands of East Texas. In Pearson HA, Smeins FE, Thill *RE* (Eds) *Ecological, physical, and socioeconomic relationships within southern national forests.* USDA For Serv, South For Exper Stat, Gen Tech Rep SO-68, New Orleans, LA.

Williams KL, Mullin K (1987) Amphibians and reptiles of loblolly-shortleaf pine stands in central Louisiana. In Pearson HA, Smeins FE, Thill RE (Eds) *Ecological, physical, and socioeconomic relationships within southern national forests.* USDA For Serv, South For Exper Stat, Gen Tech Rep SO-68, New Orleans, LA.

Woodman JN, Furiness CS (1989) Potential effects of climate change on U.S. forests: Case studies of California and the Southeast. In Smith JB, Tirpack DA (Eds) *The potential effect of global change on the United States: Report to Congress. Volume D-Forests.* USEPA, Washington, DC.

Wright HE (197 1) Late quaternary vegetational history of North America. In Turekian KK (Ed) *The late Cenozoic glacial ages.* Yale University Press, New Haven.

Xavier A, Delgado A, Fonteneau A, Gonzales C, Pilar F, Pallares P (1992) Logs and tunas in the eastern tropical Atlantic: A review of present knowledge and uncertainties. Paper given at the Inter-American tropical tuna commission, La Jolla, CA.