ANALYSIS OF ECOSYSTEMS IN THE EASTERN DECIDUOUS FOREST BIOME - U.S. INTERNATIONAL BIOLOGICAL PROGRAM[1,2]

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A new operational concept in ecology is being developed and tested within the biome programs of the US-IBP. Known as integrated research, it calls for the development of multidisciplinary teams working cooperatively within a program structured to promote coordination, rapid communication, and syntheses between environmental scientists. The Eastern Deciduous Forest Biome program involves a study of ecosystem processes in the great region east of the Mississippi River that supports two-thirds of the nation's people and harbors many of its more severe environmental problems.

The Eastern Deciduous Forest Biome is one of many similar types of integrated research programs currently operational in over 60 countries throughout the world. Its role among forest and woodland programs provides a vital international link toward a broader and more detailed understanding of forest ecosystem function. With knowledge of the intricate pathways of energy flow, carbon dynamics, water movement and utilization, decomposition processes, remineralization and nutrient cycling, it is probable that man can better plan and program all types of forest management, from timber production to recreation, from wildlife protection to watershed preservation, so that all peoples in the world may have greater access to the continued wise utilization of our forest resources.

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In the past, a great deal of forest research has been accomplished using the philosophy of treatment and demonstration. While yields of forest products (or other parameters of interest) have been established, the utility of treatment plots is limited and subject to many constraints. For example, many years must often elapse before specified effects of thinning can be proven, or extensive areas of forested land must be managed or manipulated to demonstrate watershed protection benefits to the general public. Now ecological science has advanced to the point where systems analysis is playing a greater and greater role. By careful study of functional processes, it is now feasible to model, by means of sets of mathematical equations, certain behavioral characteristics of forest ecosystems. Most often this is done by compartmentalizing the system into (for example) primary producers, consumers, and decomposer groups of organisms. By carefully designed field and laboratory experiments, we can then measure both the sizes of the compartment pools, and the amounts and rates of transfers between them. In this way we can follow the system dynamics and express these in mathematical terms.

The efficiency of modeling whole systems, however, lies in the potential use in forest management. If the dynamics of a forest ecosystem can be accurately portrayed in the language of mathematics, then computers can be programmed to simulate system function. Long term and/or large scale problems in forest management can then be analyzed by high speed electronic machines. No longer must we wait for a forest to grow for many years before treatment effects can be analyzed. Now it is possible to construct models, at least for certain regions or specific forest types, that aim to answer certain kinds of management questions. For example, if we know enough about the effects of fire, or insect damage, or thinning, or recreational use, based on previous experience and current study, to construct realistic models, then the models can be run for simulated periods of time to predict the consequences of management decisions.

Through the methodology of systems analysis, it is also possible to determine those parameters which exert the greatest influence on system behavior. Preliminary modeling efforts can thus illustrate which variables are necessary for study and which ones are inconsequential. The effects of major changes in certain nutrient levels, for instance, may be minimal in terms of timber production. On the other hand, small changes in concentration of critical nutrients may result in large changes in growth rates. Modeling may detect these potential idiosyncracies of system behavior before large expenditures of time and money are put into a research project.

The scientific goals of the Biome program are many and varied, general and specific, but all relate to the development of an understanding of ecosystems at several scales of area and complexity. We are analyzing ecosystem parameters related to productivity, geographic pattern and trophic structure and investigating the processes that regulate the transfer of energy and materials among and between ecosystem components.

These objectives were developed at a series of meetings at Williamstown, Brookhaven, and Atlanta from 1966 to early 1968. Basic to a subsequent refinement of original general goals was the implication that an understanding of the functional dynamics of the ecosystems into which natural processes are integrated was central to the IBP theme. Such understanding can serve as an effective guide to prediction of the changes that are likely to occur when ecosystems are subject to stresses, pressures, and manipulations and it may direct the management and wise use of natural and man-modified ecosystems.

Within this context, therefore, the first goal of the Eastern Deciduous Forest Biome is to assist in the development and provision of advanced syntheses of our knowledge of ecosystem processes. A corollary is to derive a scientific basis for resource management, including long-term utilization of land and water resources to insure maintenance of environmental quality. This must include derivation of the ability to quantitatively evaluate the impact of man's activities on regional complexes of ecosystems.

As stages in program development, the immediate objectives relate productivity, nutrient cycling, and energy flow to geographic pattern, age-size distributions, and trophic structure. In addition, we hope to analyze the processes regulating transfers of materials and energy among the components of these ecosystems, to synthesize the results into predictive models of ecosystem behavior, to develop an understanding of the influence of terrestrial ecosystems on the biological productivity of aquatic ecosystems, to compare production in natural and man-modified landscapes, and to evaluate the ecological efficiencies of both natural and managed ecosystems.

In planning the research program, a number of facts had to be recognized. Among these were:

1. This region contains two-thirds of the people of the United States. Man's impact, in terms of pollution, recreation, housing, transportation, and use of food and fiber, is paramount.

2. In the Biome, 152,000,000 hectares are devoted to agriculture and about 141,000,000 hectares are in forest. This is roughly half of the total national forest area. In the southeast and parts of the north, almost 30% of the forest area is in pine (*Pinus* spp.).

3. Water covers about 8,000,000 hectares in the Biome (not including the Great Lakes or smaller rivers and streams). Already water is being used and reused before it flows into the sea, being returned after each use with added agricultural, industrial and human wastes.

4. Air, soil, and water pollution are contaminating food chains, including many that lead to man. The trophic pathways and rates of accumulation and transfer of these chemicals are not adequately understood.

5. Much ecological research and modeling talent is located in this region with a strong interest already developed in cooperative multidisciplinary research.

The research program is oriented toward ecosystem processes, including pathways of exchange of energy and materials. Process studies attempt to derive sets of functional expressions, leading to the development of mathematical simulation models that can predict future states of the system when the initial conditions are specified.

Early in its development, the Eastern Deciduous Forest Biome organized around the establishment of five major research sites (Fig. 1). These include the Coweeta Hydrologic Laboratory of the U.S. Forest Service near Franklin, North Carolina, administered through the University of Georgia; Lake George, administered at Rensselaer Polytechnic Institute at Troy, New York; Lake Wingra, operated under the aegis of the University of Wisconsin; Oak Ridge, utilizing the Oak Ridge Reservation of the Atomic Energy Commission; and the Triangle Site, focusing in and around Durham, Raleigh, and Chapel Hill, North Carolina, and administered by Duke University.

The five sites form a composite of conditions in the Biome region, each contributing a unique aspect of ecosystem composition, structure and function. The sites are related in a conceptual design (Fig. 2) that illustrates topography, management, and human impact conditions within the biome region.

The Triangle Site meets requirements of accessibility, uniformity of stand structure, soil condition, and topography. The research site is in east-central Alamance County, North Carolina. After aerial photo and ground reconnaissance of a 525 hectare forest that had been planted to loblolly pine in 1958, a block of about 3.5 hectares was chosen as the intensive study site.

A general survey of study area boundaries, soils, stand structure, and density has been completed. A 20-meter grid was established to facilitate the soil survey, and an analysis of tree uniformity as indicated by basal area was accomplished. Study plots were established to take advantage of row spacing and direction. The subplots are each 0.1 hectare with 2.44 meter buffer strips between plots. Each plot is identified in the field by flagged heavy gauge wire to define travel lanes and to restrict traffic on the plots.

At the Coweeta Site, primary attention is concentrating on four watersheds that have been gauged since the mid-1930's. These represent a weed stand,

a hardwood coppice stand, a white pine plantation, and a natural old growth oak-hickory forest. During the period 1958-1960, the timber on one watershed was harvested and a grass cover was established. A weed stand is present following complete killing of the grass by herbicide treatment in April 1966. This catchment will be allowed to undergo natural succession.

The existing gauged watersheds at Coweeta are being utilized for an initial set of studies which will then permit a subsequent replication on the larger, undisturbed Dryman Fork catchment which has not been gauged or studied. It is highly desirable to maximize information and efficiency on relatively small, manipulated catchments before implementing an expensive installation and considerable effort on a large virgin watershed. The eventual application of results from the four catchments in the much larger Dryman Fork watershed will test scalar relationships; that is, the applicability of conclusions reached on small watersheds to larger management units.

The Oak Ridge Site is in the Atomic Energy Commission Reservation located near Oak Ridge, Tennessee, including about 15,000 hectares of forest and former agricultural land. The topography consists of parallel ridges and valleys trending northeast. Four major rock units occur, including shale, siltstone, sandstone, limestone, and dolomite. A mantle of residual material is present nearly everywhere.

The 80 hectare Walker Branch Watershed was established in 1967 to investigate the drainage basin in a total ecosystem context. Weirs and associated automatic proportional water samplers and hydrologic data analysis system were all designed to provide an integrated data collection system for the study of vegetation-soil-water interactions and processes. Characterization of the soils, vegetation, topography, and surveys of stream biota were accomplished concurrently with the establishment of the project. A forest inventory plot system was superimposed on the area for permanent reference as a measure of baseline conditions with which to compare later the treatment responses. The watershed contains two subwatersheds and offers the advantages of experimental manipulation with adjacent control treatments.

The Lake Wingra watershed is located one mile from the University of Wisconsin, Dane County, Wisconsin. The drainage basin of Lake Wingra (about 92 square km), is almost evenly divided between rural and urban habitation. The University of Wisconsin Arboretum, about ten square km in size, is almost entirely within the drainage basin and contains 125 hectares of deciduous forest as well as other plant communities. The Arboretum has been in existence since 1933, and since that time no major disturbance has been permitted. Similar environments occur in the urban portion of the basin with both young and mature forest communities present in the residential areas. A number of microwatersheds suitable for monitoring nutrient and water losses in both the city and the arboretum are available. The plant and animal communities of the basin are diverse in type and, together with outlying sites, provide a good representation of the deciduous forests found in the upper Midwest.

The groundwater levels of the Lake Wingra watershed are of particular interest. Years of municipal pumping resulted in a substantial lowering of the water table on the northeast side of the lake, a drying up of all springs in the area, and a steepening of the groundwater flow toward the cone of depression. Pumping is now increasing in the urban area to the north and west of the lake, affording a good opportunity to study the potential of groundwater withdrawal to stop the remaining spring flow to the lake and to modify the productivity of land and aquatic communities in the basin.

The Lake George Site centers on a large, oligotrophic, stratified, soft water lake. It has a drainage basin surface area of 600 square km, 112 square km of which is lake surface. Surrounding the lake, a variety of land usages can be studied in terms of their effects on the land and the lake. Investigations over the past few years have shown that Lake George is heterogeneous in terms of its productivity. A gradient in productivity exists from the south to the north, undoubtedly a reflection of the land use pattern of the basin. The southern end of the lake has a wintertime population of approximately 4000 people that swells to 40,000 in the summer. At the northern end of the lake, most of the drainage basin is covered with forest. The forest is characterized by mixed northern hardwoods with spruce and fir in the upper elevations and red pine in lowlands. The influence of land cover and land usage within the drainage basin is very markedly evidenced by increased productivity. Within the drainage basin there is a minimum of agriculture. However, there are some areas in which the effects of animal storage and animal farms can be noticed as these facilities are located within small watersheds that drain into the lake. Use of fertilizers on lawns and cultivated areas in the drainage basin may also be assessed as a factor in the changes in the aquatic ecosystem.

The Eastern Deciduous Forest Biome program also recognizes the great needs in basic studies of ecosystem function at the process level. These processes are METEOROLOGY, HYDROLOGY, MINERAL CYCLING (with a dichotomy here into terrestrial and aquatic mineral cycles), and PRIMARY PRODUCTION, SECONDARY PRODUCTION, and DECOMPOSITION in both aquatic and terrestrial environments. In addition, cognizant that the landscape can be conveniently studied by using the watershed as its basic unit, a process called LAND-WATER INTERACTION was set up.

A summary of recent accomplishments leads to a great deal of optimism for the future of integrated research in forestry. Nutrient budget studies at both Coweeta and Oak Ridge are already significant, indicating major differences in system dynamics reflecting geologic differences in parent materials. Regional analyses of productivity have been completed for Wisconsin, Tennessee, New York, and North Carolina. These, in particular, should be of great interest to those countries with strong FAO programs. A carbon model of a forest ecosystem has been completed, based on a *Liriodendron* forest at Oak Ridge, that illustrates the movement and transformations of biomass among over 50 compartments of the forest ecosystem. Models of photosynthesis and

tree growth, being perfected at Triangle, are leading to an understanding of critical parameters and acclimation in growth of uniform plantation species. At Lake Wingra and Lake George, aquatic system models are being developed to simulate the effects of land use on lake systems, ranging from natural runoff from essentially virgin watersheds, to the effects of heavy urban impact on fish production and water quality. By studying the spectrum of lake conditions across the Biome region, insights are being developed which can lead to better management decisions in the future. Only in this way do we believe that we can improve and expand our use of natural forest resources to meet the demands of an increasing world population, and still maintain a quality environment for future generations.

SUMMARY

The Eastern Deciduous Forest Biome is a large integrated research program analyzing, synthesizing, and modeling all aspects of ecosystems in the eastern United States. As part of the International Biological Program, the Biome coordinates with similar forest research programs in a number of other countries. Systems analysis and modeling are being extensively used throughout the program, and computer simulation of processes, subsystems, and ecosystems is a primary objective. The potential for using ecosystem models in the management of forested areas is of great importance. Modeling also plays a role in experimental design and serves as a highly useful tool in guiding research.

Organized around major research sites in Wisconsin, New York, Tennessee, and North Carolina, the Biome research effort is focused on the analysis of ecosystem parameters related to productivity, geographic pattern, and trophic structure, and investigation of the ecological processes that regulate the transfer of energy and materials among and between ecosystem components. The research in terrestrial systems centers on Oak Ridge, Coweeta, and Triangle, while Lake Wingra and Lake George exemplify opposite ends of the spectrum of aquatic system conditions present in the biome region.

Early results from this integrated research include establishment of nutrient budgets, regional analyses of biological productivity, photosynthesis and carbon models of forest ecosystems, and primary production and feeding models for consumers in aquatic systems. Analyses of forest succession and geoecology are progressing rapidly and whole system models are being generated. The close coupling of terrestrial and aquatic systems through land-water interaction processes provides a unifying thread that will lead to a better understanding of functional aspects of forest behavior and subsequently to better forestry.

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Fig. 1. The five major research sites of the Eastern Deciduous Forest Biome.

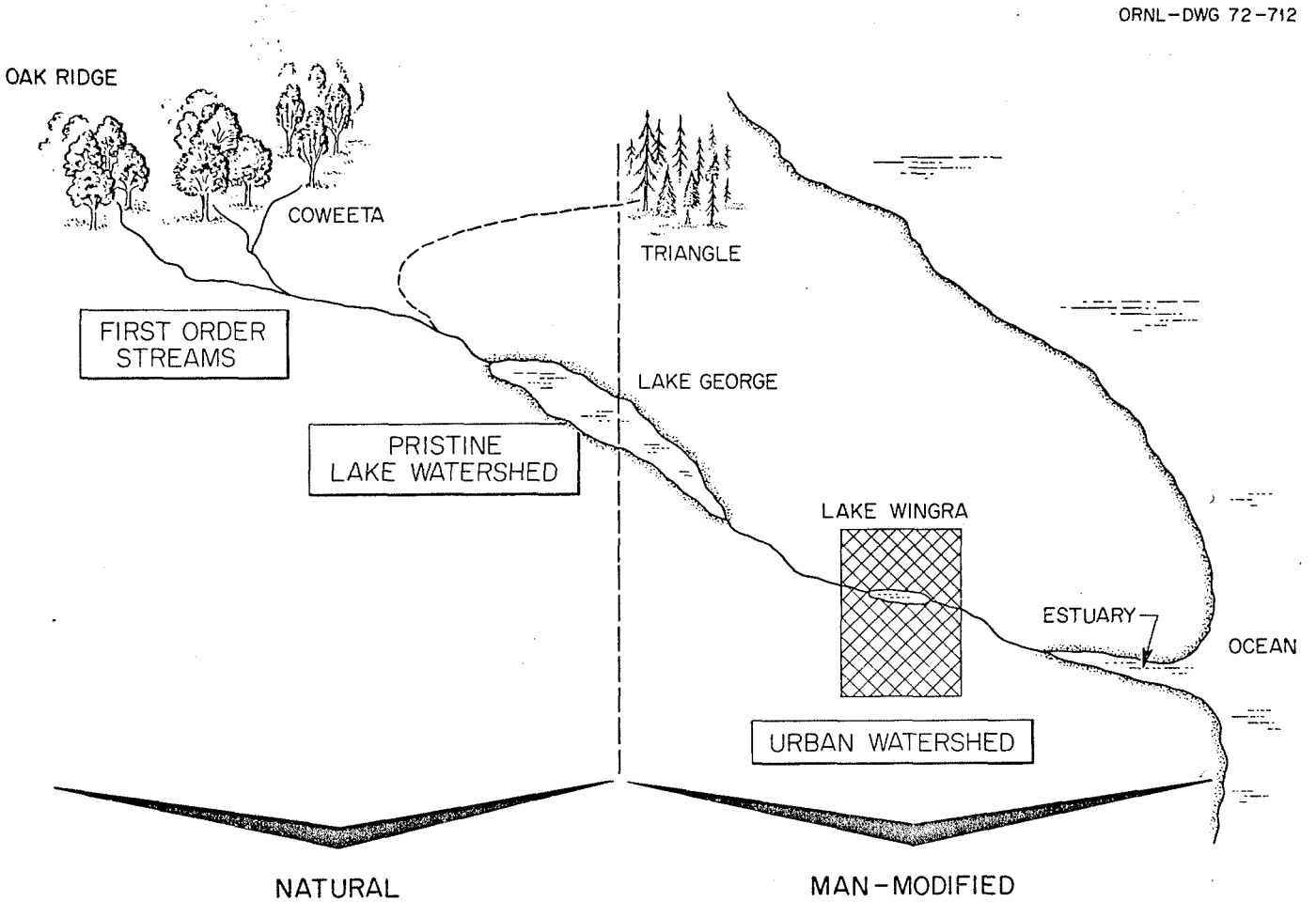

Fig. 2. Concept of the Integration of the Five Physical Sites into a "Biome".