INTERNAL REPORT 130

CONTRIBUTIONS TO A BETTER MANAGEMENT OF FOREST ECOSYSTEMS

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In only a few years, how can a program contribute to better management of forest ecosystems? Certainly not by initiating long-term field experiments throughout the United States. Such programs are already in progress through the sustained effort of the U.S. Forest Service and other agencies.

From the start of the Ecosystem Programs, we have attempted to reinterpret the results of specific experiments to see how the findings might be generalized. Sometimes we have found new ways of explaining puzzling results by such comparisons.

Our first goal was to understand more about these things called ecosystems before attempting to predict the effect of man and nature's impact upon them. Complete understanding is far from achieved, but the effort has been helpful in identifying important questions and in developing techniques to answer them.

At the simplest level, we recognize there are things common to all ecosystems. For example, they are complex and don't stop functioning just because some parts are removed. In looking at them (Fig. 1), we recognize oxygen, water, carbon dioxide, energy, and nutrients as common raw materials. The amount and balance of these throughout the years give rise, with sufficient time, to a forest with maximum accumulation of biomass. The weight of soil, including litter, also approaches equilibrium. These systems can be stressed by changing the amount or kinds of inputs, or by removing products at abnormal rates.

A major concern in forestry is maintaining the productive capacity so that the balance is not shifted to a less productive equilibrium (Fig. 2). From an ecosystem stand point then, we must know first what normal conditions are, and secondly, develop methods of assessing departure and predicting combinations of events that will produce less desired systems over time.

We also recognize the ecosystems we manage do not exist in isolation. What we do in one may affect the status of another by increasing the threat of fire, excessive wildlife, or the instability of the soil mantle (Fig. 3). There is then a spatial problem as well as a time dimension that must be handled. Finally, the land unites with aquatic systems in a crucial and dominating way. The location of roads and disturbance of stream-side vegetation may have long-term implications. In short, our ecosystem problems demand solution in a time, space, and interface dimension. Nothing less is adequate!

From conferences with federal, state, and private agencies, we know the priorities in managing forest ecosystems: (1) an accurate estimate of productive capacity for knowledge of management impact and future calculation of yields; (2) an understanding of disease, insect, and management interactions ....i.e., what helps and what hurts; (3) the effect of fire and its absence;

(4) the long-term implications of high yield forestry with dependence upon more energy, fertilizer, and genetic uniformity; and (5) the down-stream, down-wind, and down-town effects with both environmental and sociological implications.

A SEARCH FOR COMMONALITY

The biomes have tried to visualize how all these problems fit together and sought a common approach to the multitude of management questions. There is no super model, but perhaps there is a general way of framing questions. For a starter, we asked what carries material through ecosystems? the answer was simply water and biomass. That means if we know what happens in water and organic material, the impact of fertilizer, pesticides, and logging roads will follow the same routes. As you might gather, the routes are so complicated that a computer is needed to keep track. To keep track of what the computer is suppose to be doing, we draw maps that look something like this...(Fig. 4). A terrestrial ecosystem is thus conceptualized as a series of modular units or subsystems with routes connecting one to another. Energy or material follow the routes through the subsystems and may stay on the map or run-off into other areas.

Like small cities, the subsystems can be visited separately as long as one remembers the traffic flows in and out. To get around within the cities, of course, requires more detailed maps. This modular construction, adopted by both biomes, has two great advantages: first, one can trace the routes to subsystems more likely to have problems; and secondly, the internal structure and function of each subsystem can be studied independently before looking at the total effect of the traffic pattern upon the whole landscape. The computer programs, after three years of effort, now exist to handle these mapping and analytical problems in a logical and efficient manner.

APPLICATIONS

In Table 1, I have summarized some applications of biome research. The first category is an improvement in assessing productive capacity. We need such improvement because we wish to separate management procedures that speed up growth from those that increase or decrease the capacity of the land. Also, we are now faced with evaluating potential productivity under disturbed conditions where brush fields rather than forest exist. For these reasons, we have found that the amount of leaves an area can support is a far better measure of capacity than the growth of individual dominant trees. Following logging, the leaf area may reach a maximum in less than 4 years.

Through studies of transpiration with radioactive water, we found the basal area of sapwood gives a simple and accurate estimate of leaf area on conifers (Fig. 5). Thus with a core sample of sapwood, both stand growth and potential can be determined.

The Deciduous Biome has pioneered the development of conversion factors to transform agricultural yield and merchantable growth into net primary production values. In Wisconsin they found suburban residential areas were equivalent to adjacent forest in production because the fertilized and irrigated lawns and gardens more than offset nonproductive pavement and roof surfaces. Other studies have contrasted the energy cost and return of agriculture and forest production. The energy cost of forest products was 4.1 cal of manpower and fossil fuel invested/100 cal of harvested bolewood. Another contribution of the biomes is in quantifying early warning symptoms, such as the proportional decrease in mosses and lichens as air pollution increases. Trees under physiological stress can be identified by their abnormal respiration, water stress, or stomatal response. Tests can be made almost anywhere with light portable equipment now available.

In both biomes, precision growth models of forest stands keep track of the growth or death of individual trees and their interactions with each other. Figures 6 and 7 illustrate how closely basal area growth and tree number were predicted with such a model in an even-aged Douglas-fir stand.

In the fourth category are real ecosystem models that incorporate the relationships with other subsystems in providing water, nutrient, energy, and consumer impact. The close-up map of the primary production growth model (Fig. 8), indicates the processes of photosynthesis, translocation and respiration are incorporated. Stand components are grouped functionally in relation to position in the stand, light requirement, and kind of foliage. This model runs at weekly intervals for up to 10 years. It is adapted to handle the effects of air pollution, defoliation, fertilization, and changes in the physical environment through its process orientation and link to other subsystems. As you might expect, physiological process models are too detailed for some questions because we don't know all the required model parameters or can't afford to run the thing for 100 years. For these reasons, more general models that describe changes in stand growth, structure, and composition have been developed.

Where plant successional patterns are known and described, as for the western Great Lakes region, a sequence of normal change may be programmed (Fig. 9). On dry sites an intolerant oak type is replaced by a more tolerant red oak-white oak community. Within each compartment, three subdivisions representing seedling-sapling, poletimber, and sawtimber classes are represented. Data for the model were obtained from the ecological literature and U.S. Forest Service Continuous Forest Inventory plot records. The linkages among compartments represent the intrinsic replacement patterns of these forest types in the region. The equilibrium point of the model simulation provides an estimate of the potential composition of the vegetation of the region and serves as a reference point from which to examine the role of natural and man-induced disturbances and how they affect the extent and composition of forest in the region.

In the West, where uniform geography is lacking, we have attempted to relate more directly to the processes controlling plant growth and development. In an environmental grid which includes studies in Oregon, Washington, Alaska, Utah, Idaho, and Arizona, the coupling of environment to plant responses is provided through a series of basic indices. When we, for example, look at an oak, pine, or spruce dominated forest, the drought stress is compared with the

the pressure bomb technique to give a complete vascular cardiograph for the three systems (Fig. 10). Other indices related to the growth response to temperature and year around photosynthesis define the environmental space for different vegetation types (Fig. 11). Within a particular region, a simple two-dimensional analysis can often precisely define the growing space for regeneration of different species (Fig. 12). If a particular management technique changes the plant response indices so that the environment falls outside the limits of potential regeneration, it can be clearly shown and predicted. Also, past experience can be drawn upon to define good and bad management practices. Productivity, too, can be estimated as it changes with the same indices (Fig. 13). Decomposition, fuel buildup, and animal populations are being linked to the same environmental grid. With such a framework, succession models running at 1 to 5 year intervals are being programmmed to simulate change over 1,000 years.

The stratified ecosystems models listed in category 7, represent our highest level of integration by including time, space, and land/water interactions. Here the sophistication of the hydrologic subsystem should be emphasized (Fig. 14). Under some conditions, the model runs at 15 minute intervals to assess the effect of high intensity storms, It is coupled to other stands as water flows downhill (Fig. 15). Our ability to match predicted with observed streamflow has increased 100 fold with this stratified hydrologic process model. This same coupling shown in the hydrologic model operates in the detailed erosion model (Fig. 16). Here, the processes of surface and mass erosion require knowledge of such things as soil cohesion, the angle of internal friction, rooting properties and strength, and the depth to shear plane. The erosion model is unique in coupling to the production of logs, other organic material, and in the updating of each slope compartment following an erosion event. Work has only begun on erosion, but the Forest Service has already committed manpower resources to help on this important study.

The question of providing a protection strip along the streams can also be evaluated in terms of its effect upon the production of fish in these aquatic systems. Dr. Sedell has noted major differences between decomposition of hardwood and cónifer foliage and their effect upon stream life and the complete switch of energy base following removal of the overstory. The contribution of the vegetation can be quantitatively assessed and their selected removal evaluated, both in terms of energy input, the productive capacity of watersheds, and changes in run-off.

The watershed models can be extended to drainages, but for regional application, an approach developed by the Deciduous Biome has special merit. Information on cover, soil, and climate, from aerial photographs and maps are digitized for computer storage (Fig. 17). Once stored, the information can be called upon to look at alternatives in road or power line locations, the effect of urbanization on land resources, and even the damage of air pollution.

Certainly there are special problems involving disease and insects that require explicit knowledge of biological interactions. There are now models that can assess impact from defoliation or DDT, but those questions concerning the rise or fall of pathogen or pest populations are particularly difficult. For example, problems with bark beetles (Fig. 18) require knowledge of the health of individual trees and the reason for the population changing from one of hunting out weakened trees to one with a shark-pack-instinct toward the whole forest.

With such problems, we are beginning to communicate with groups specializing on these subjects. For example, the fire ecology group at Missoula, Montana is now incorporated within the biome structure. In Norway and Sweden, official cooperation is being planned in regard to air pollution effects upon trees, the soil, and aquatic systems. The forest biomes are also associated with the San Juan Ecology Project in Colorado, working on the effects of cloud seeding upon forest ecosystems.

Finally, in learning more about the components and general behavior of ecosystems, a means of communicating about ecosystems is developing. The responsibility to share knowledge with the public and with decision-makers encouraged us to establish ties with public outlets including display centers and newspapers. Such communication can provide a more knowledgeable public, which should result through their elected representatives in more ecologically sound legislation for the maintenence and enhancement of forest ecosystems.

In summary, the biome programs have developed a general framework for understanding ecosystems. We are struggling with the problems that affect ecosystems in the three dimensions of time, space, and interface. What we need now is the experience and guidance of resource management agencies to assure the most fruitful harvest of the public investment in the Analysis of Ecosystems Program. I assure you biome support in this endeavor.

TABLE I

SOME APPLICATIONS OF BIOME RESEARCH TO FORESTRY

	PROBLEM	APPROACH	KEY FACTORS IN ANALYSIS
1.	Better Assessment of productive capacity	Determine Maximum Poten- leaf area index	Allometric equations for different species groups, linear relation with sap-wood basal area
2.	Quick identification of forests under stress	Measure: decrease in bryophytes; increased respiration; increased stomatal resistance; decreased leaf area; increased plant moisture stess.	observe floristic groups measure CO_2 gas exchange measure with porometry measure sapwood basal area measure with pressure bomb
3.	More accurate estimates of stand growth	Mensurational model based on growth of individual trees. Predicts changes in basal area and number of trees annually for entire rotation.	Simulates yearly diameter growth, probability of death, and height-diameter relations from competive index. Requires initial map of stand. R^2 = .99 for Douglas-fir stands, predicted vs. observed.
4.	Short-term environmental impact on stands	Physiological process model for seasonal dynamics as well as annual growth, up to ten years.	Considers trees in groups related to kind of foliage, dominance class, and light response. Gas exchange is coupled to respiration and growth of foliage, wood, and roots. Driven by radiation, precipitation, humidity, and temperature. Air quality can be included. Responds through change in light penetration, temperature, available water, and nutrients.
5.	Long-term environmental impact on stands in Eastern U.S.	Eastern stand succession 1-500 years	Geographic approach describes known changes in forest composition and growth under general climate. Special effects of exotic disease or pollution can be introduced once understood.

APPLICATIONS OF BIOME RESEARCH TO FORESTRY (continued) page 2

	PROBLEM	APPROACH	KEY FACTORS IN ANALYSIS
6.	Long-term environmental impact on stands in western U.S.	Western stand succession 1-1000 years	Linked to ecosystem process models for stand growth through physiological indices for plant water stress, temperature-growth, transpiration, photosynthesis, and nutrition. Effects of pollutants, herbicides, or pathogens treated mechanistically.
7.	Impact on watersheds includes changes in productive capacity, runoff and storage, nutrient and sediment export	Stratified ecosystem models of watersheds applicable for both short and long term	Coupled to stand process model with link to models for hydrology, erosion, and organic export from adjacent ecosystems
8.	Regional impact of management decisions	Regional mapping model includes ability of simulating effects of various land use or impact alternatives	Reduction of data from maps by precision photography to computer. Can program to reflect current trends or various alternatives. Soil, climate, vegetation, and land use categories are major stratifications. Output plotted on maps with variable scale.
9.	Special hazards from fire, pollutants, insects, disease, or small animal population	Specific models for each hazard for both short and long term	Prediction of epidemics, or endemic effects for different hazards based on general environment, state of system, and resulting receptiveness.
10.	Communication of science and decision making to public	Development of educational displays in both interactive and passive modes	Cooperation with professional non-profit institutions both in preparation and presentation.

FIGURE CAPTIONS

FIGURE 1 — All forest ecosystems require the same raw materials: O_2, H_2O, CO_2, energy and nutrients. The system can be stressed by changing the amount or kind of input or by removing products at abnormal rates. The system depicted here is at equilibrium with a maximum accumulation of biomass and soil.

FIGURE 2 — All systems are dynamic. Managers try to maintain ecosystems in healthy states (A and B) where productive capacity is not reduced through loss of soil or cirtical biota (C).

FIGURE 3 — All systems are linked. Materials may move from one to another, eventually reaching a stream or lake.

FIGURE 4 — Major subsystem linkages in a terrestrial ecosystem. Energy and material arrive from outside the system and are partitioned mainly through the hydrologic and primary production subsystems. Information and material flow back and forth between subsystems. A record is kept of stand structure (biomass) and the amount and quality of dead organic material (detritus). Losses from the system are mainly carried by water or in the gaseous phase.

FIGURE 5 — In conjunction with studies of transpiration in conifer, a linear relationship between leaf weight and cross-sectional area of sapwood was discovered. This permits an accurate estimate of forest leaf area by sampling sapwood thickness and tree diameter at stump height or D.B.H.

FIGURE 6 — A mensurational stand growth model closely predicts change in basal area over a 17 year period in a Douglas-fir forest.

FIGURE 7 — A reduction in number of living trees also is predicted accurately by the stand growth model.

FIGURE 8 — The primary production growth model incoporates the processes of photosynthesis, respiration and translocation for each vegetation strata. Changes in growth and structure of forest stands can be evaluated following selective defoliation, frost damage or response to chemicals.

FIGURE 9 — Forest succession model structure for part of the Great Lakes Region. The labeled compartments indicate forest types indentified by dominant tree species. The three submodules within each compartment indicate dominant size category of trees within the given forest types. Arrows represent transfer of acreages of land from one block to another.

FIGURE 10 — Comparison of water stress patterns in black oak, ponderosa pine, and Engelmann spruce dominated stands. Measurements were made with a pressure chamber on 1-2 meter tall Douglas-fir just before dawn at different times throughout the growing season.

FIGURE 11 General distribution of western forest vegetation in relation to two plant response indices. The drought stress index represents the maximum value recorded in atmospheres during the growing season. The temperature index is a summation of daily potential growth as compared with optimum accumulation of biomass by Douglas-fir seedlings. Effects of both soil and air temperatures are included.

FIGURE 12 The potential for establishing regeneration varies with environment and the particular species. Light, evaporative demand, nutrition, year around photosynthesis and mechanical stress are other indices that help define the actual growth of regeneration or its ultimate failure.

FIGURE 13 Productivity, as measured by height growth of dominant Douglas-fir trees, shows a close relationship with temperature and moisture stress indices. Those environments with moderately high temperatures and low water stress have the largest trees. Colder and drier sites have less productive capacities.

FIGURE 14 The hydrologic model structure indicates how water is accounted for in its various states: vapor, liquid, frozen; and in its positions in a forest ecosystem. For each compartment, a series of interchangeable equations are available depending upon desired resolution and data.

FIGURE 15 Forest ecosystems are stratified, both vertically and horizontally in modeling watersheds. Material is carried primarily from uphill ecosystems downward to the stream.

FIGURE 16 The erosion model is tightly coupled to the hydrologic and primary production subsystems. It keeps track of organic material in the form of logs and active root structure. When the processes of surface and mass erosion occur, the model updates the status of each ecosystem unit on a watershed.

FIGURE 17 Regional models store information on cover, soil, and climate and permit comparisons to be made based on present trends or selected alternatives.

FIGURE 18 Qualitative model of bark beetle. The occurence of insect epidemics and their development requires more detailed hydrological understanding then predicting their effect. Studies are in progress to explain how bark beetle populations change from a state where they disperse to locate trees under stress to our where they fly in large concentrations, successfully attacking both healthy and susceptible trees.

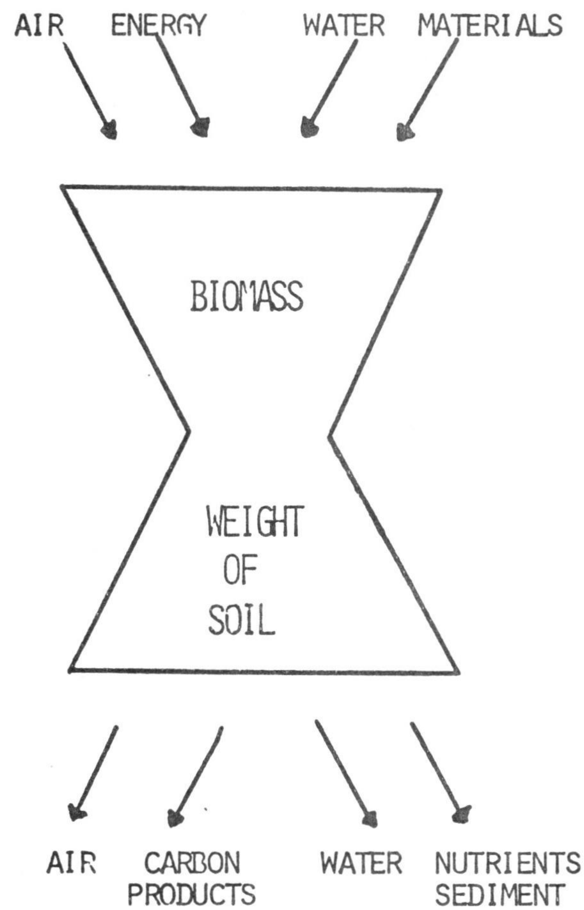


FIGURE 1. INPUT - OUTPUT SYSTEM

ALL FOREST ECOSYSTEMS REQUIRE THE SAME RAW MATERIALS O_2, H_2O, CO_2, ENERGY, AND NUTRIENTS. THE SYSTEM CAN BE STRESSED BY CHANGING THE AMOUNT OR KIND OF INPUTS, OR BY REMOVING PRODUCTS AT ABNORMAL RATES.

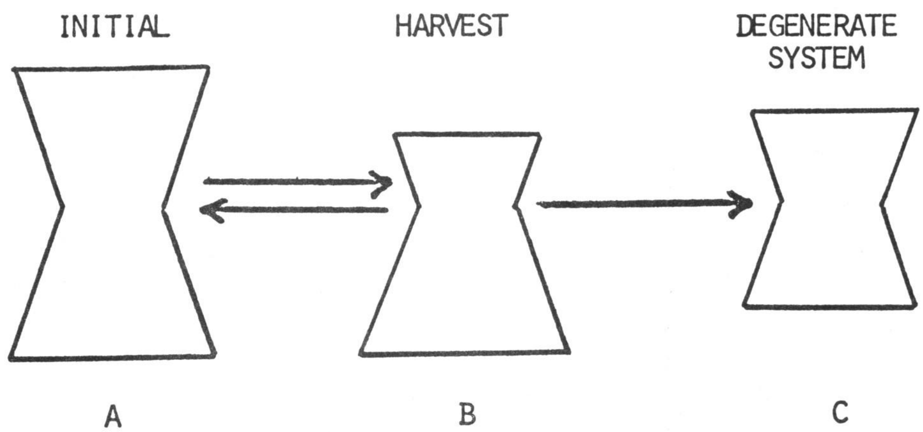


FIGURE 2. DYNAMICS

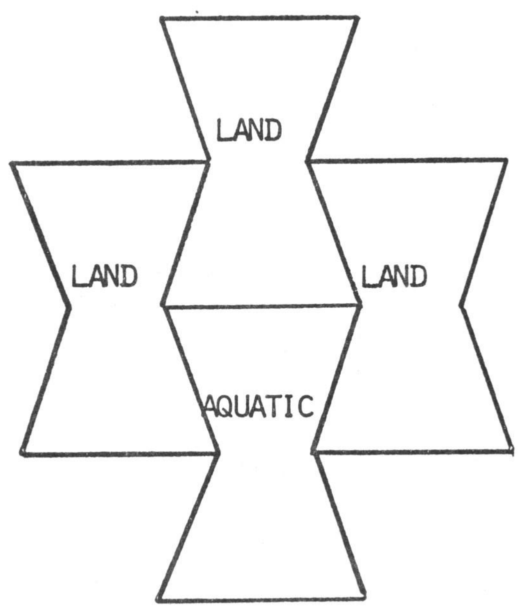


FIGURE 3. SPATIAL LINKAGE AND INTERPHASE

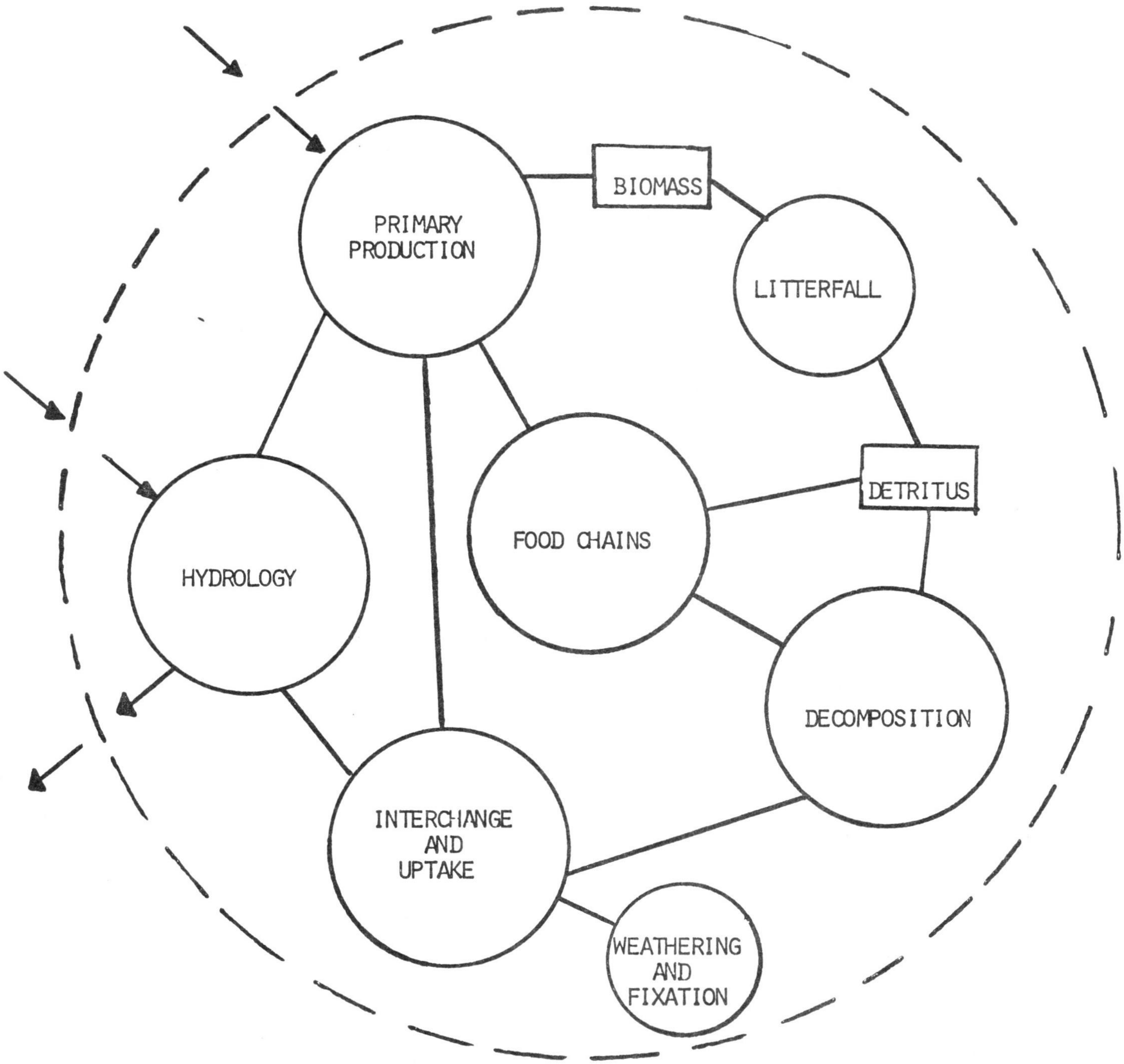
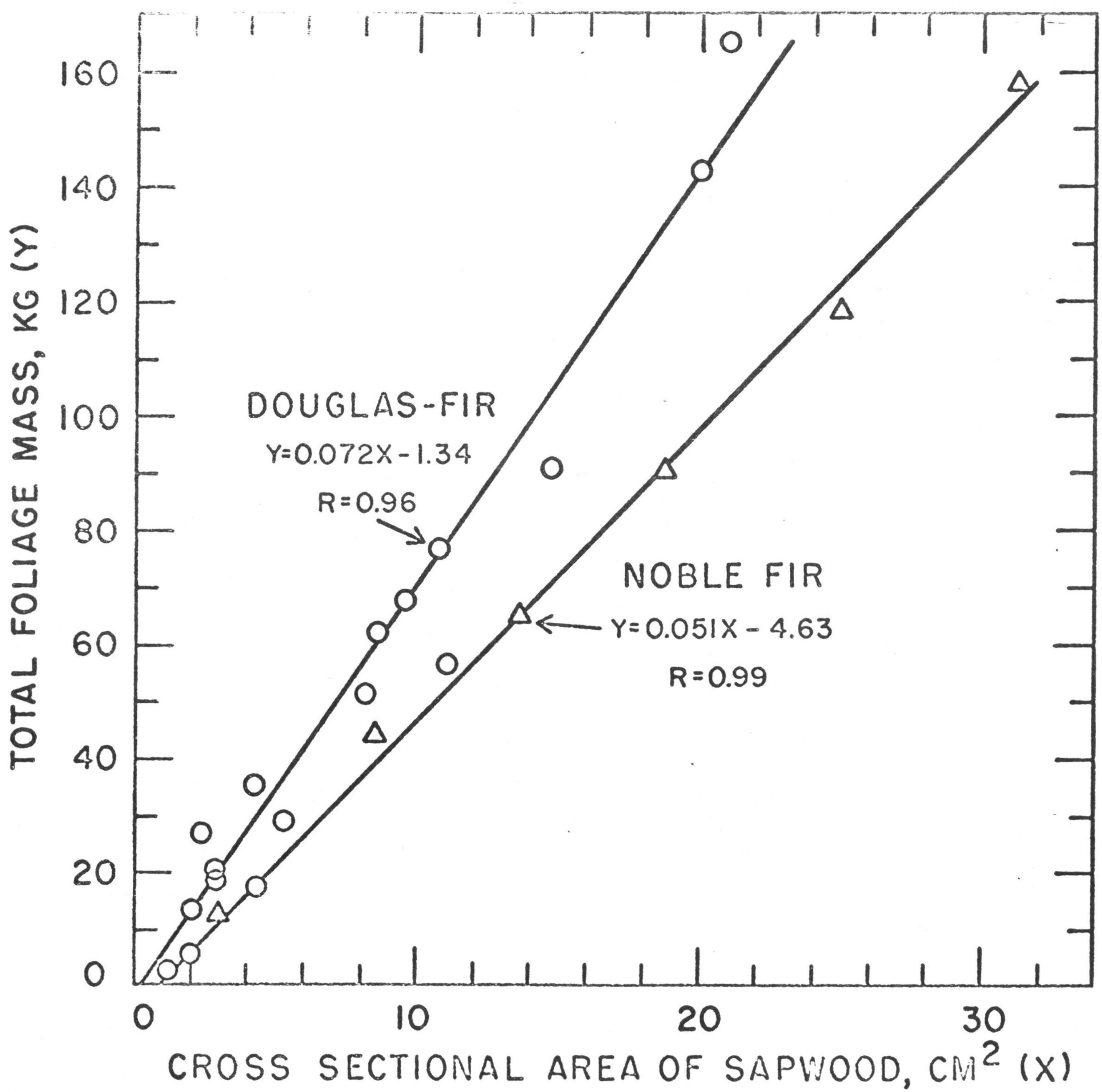


FIGURE 4. THE TERRESTRIAL SUBECOSYSTEM



TOTAL FOLIAGE MASS, KG (Y)
160
140
120
100
80
60
40
20
0
DOUGLAS-FIR
Y=0.072X-1.34
R=0.96
NOBLE FIR
Y=0.051X-4.63
R=0.99
0
10
20
30
CROSS SECTIONAL AREA OF SAPWOOD, CM2 (X)

FIGURE 5

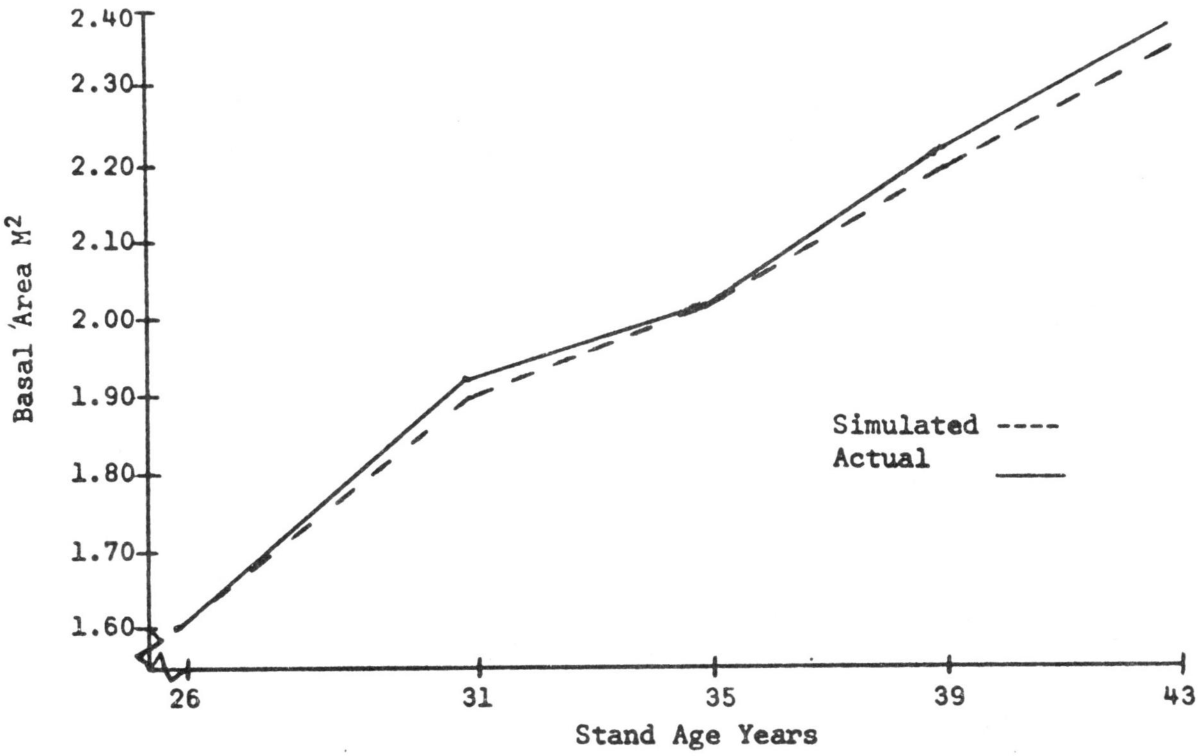


FIGURE 6

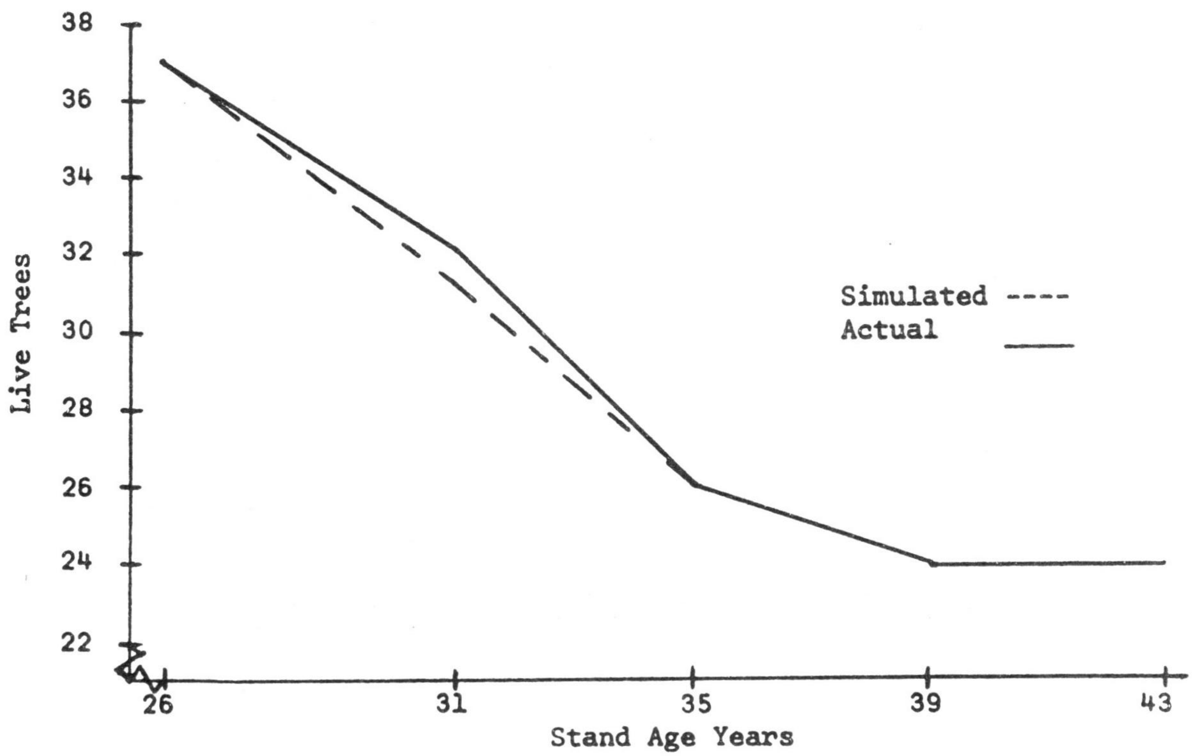
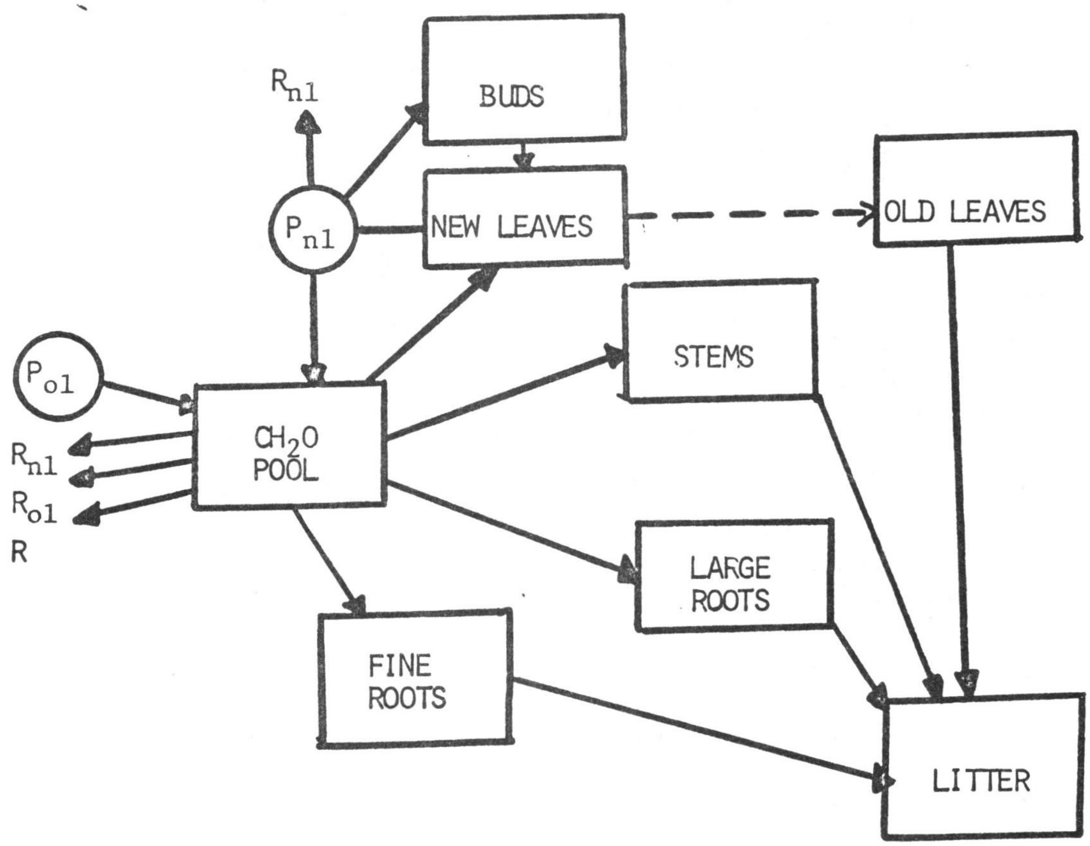


FIGURE 7



STRUCTURE OF PRIMARY PRODUCTION MODEL FOR EACH STRATA OF VEGETATION

P_{n1} = PHOTOSYNTHESIS OF NEW LEAVES

P_{o1} = PHOTOSYNTHESIS OF OLD LEAVES

R = RESPIRATION, NON-FOLIAGE

R_{n1} = RESPIRATION OF NEW LEAVES

R_{o1} = RESPIRATION OF OLD LEAVES

FIGURE 8

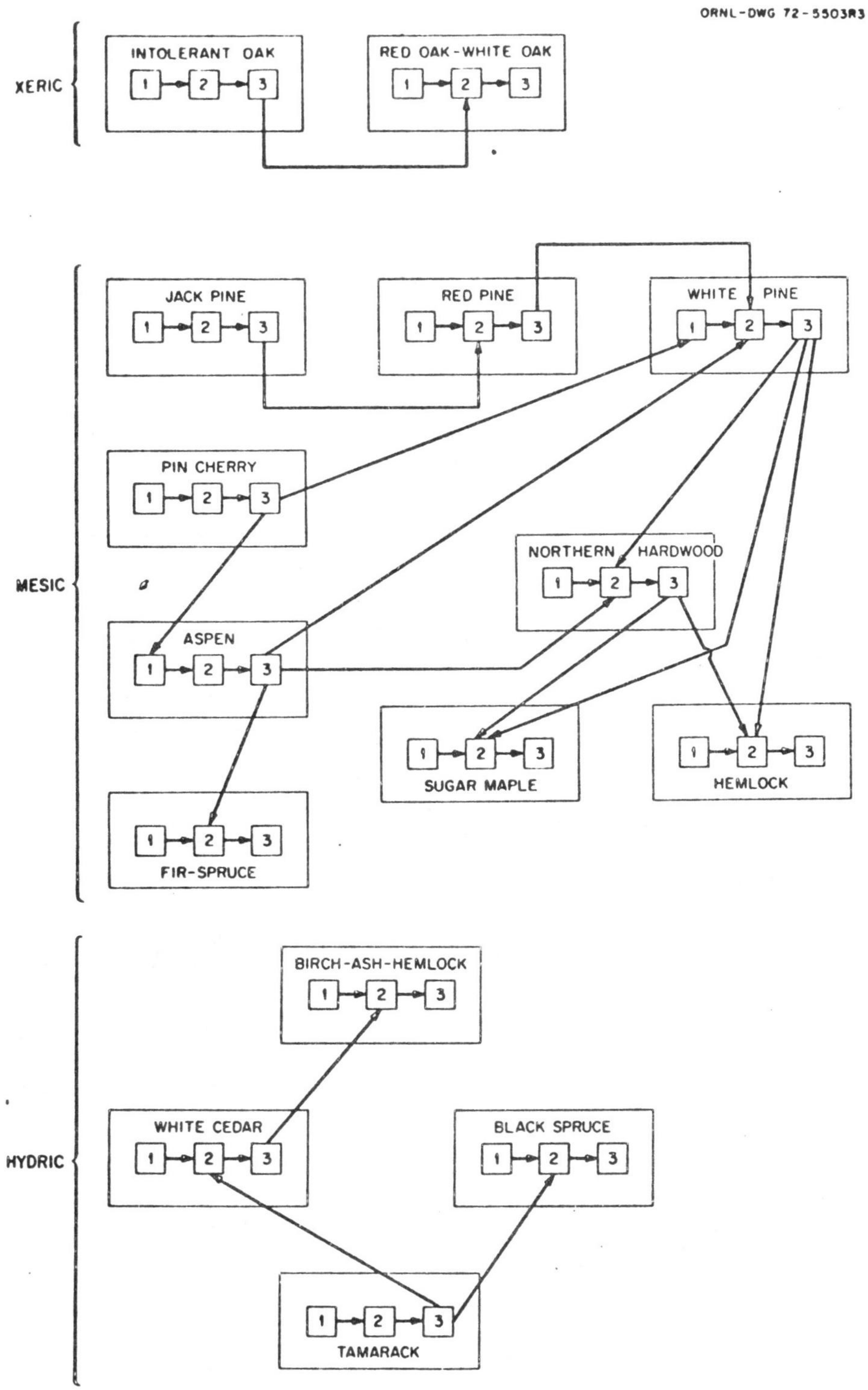

ORNL-DWG 72-5503R3
XERIC
INTOLERANT OAK
RED OAK-WHITE OAK
MESIC
JACK PINE
RED PINE
WHITE PINE
PIN CHERRY
NORTHERN HARDWOOD
ASPEN
SUGAR MAPLE
HEMLOCK
FIR-SPRUCE
HYDRIC
BIRCH-ASH-HEMLOCK
WHITE CEDAR
BLACK SPRUCE
TAMARACK

FIGURE 9

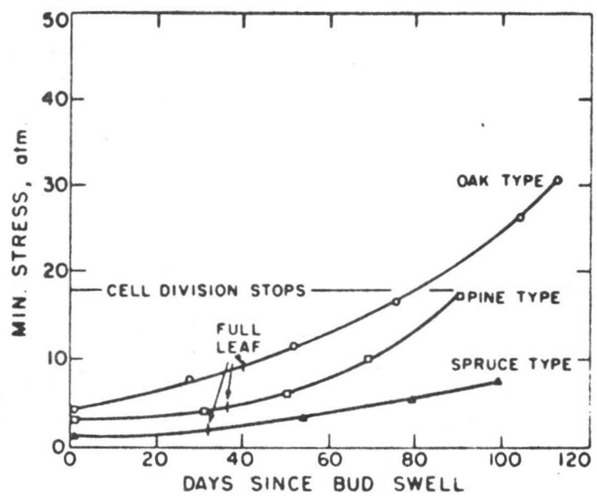

50
40
30
20
10
0
MIN. STRESS, atm
OAK TYPE
CELL DIVISION STOPS
PINE TYPE
FULL
LEAF
SPRUCE TYPE
0
20
40
60
80
100
120
DAYS SINCE BUD SWELL

FIGURE 10

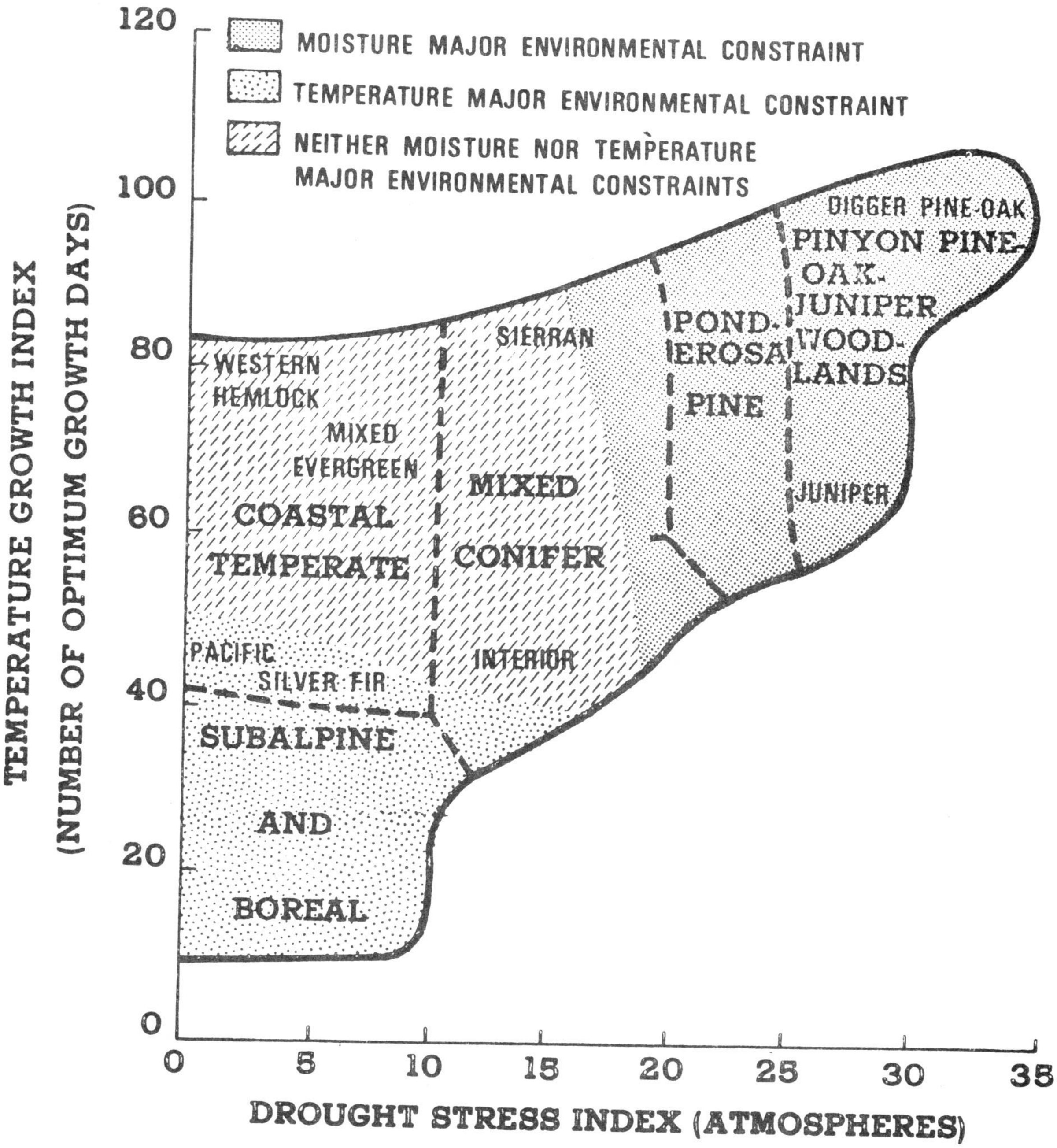
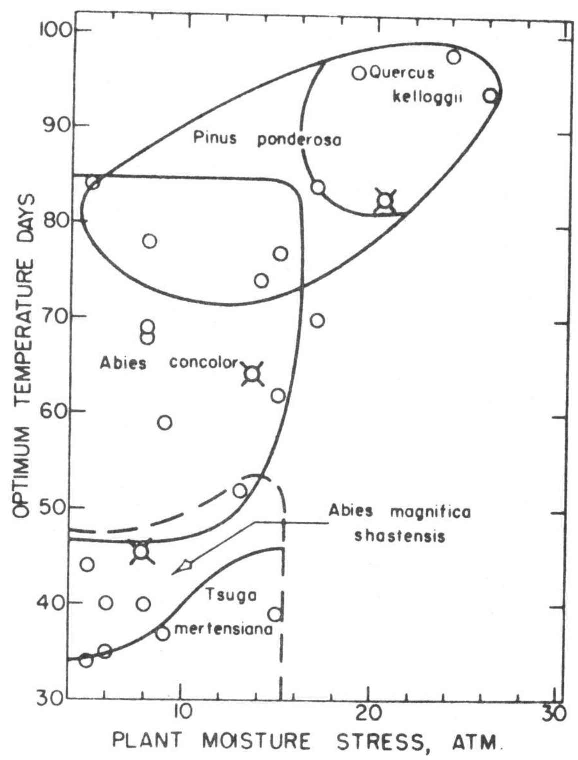

MOISTURE MAJOR ENVIRONMENTAL CONSTRAINT
TEMPERATURE MAJOR ENVIRONMENTAL CONSTRAINT
NEITHER MOISTURE NOR TEMPERATURE MAJOR ENVIRONMENTAL CONSTRAINTS
TEMPERATURE GROWTH INDEX (NUMBER OF OPTIMUM GROWTH DAYS)
DROUGHT STRESS INDEX (ATMOSPHERES)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
35
WESTERN HEMLOCK
MIXED EVERGREEN
COASTAL TEMPERATE
PACIFIC SILVER FIR
SUBALPINE AND BOREAL
SIERRAN
MIXED CONIFER
INTERIOR
PONDEROSA PINE
DIGGER PINE-OAK
PINYON PINE-OAK-JUNIPER WOODLANDS
JUNIPER

FIGURE 11



100
90
80
70
60
50
40
30
10
20
30
OPTIMUM TEMPERATURE DAYS
PLANT MOISTURE STRESS, ATM.
Quercus
kelloggii
Pinus ponderosa
Abies concolor
Abies magnifica
shastensis
Tsuga
mertensiana

FIGURE 12

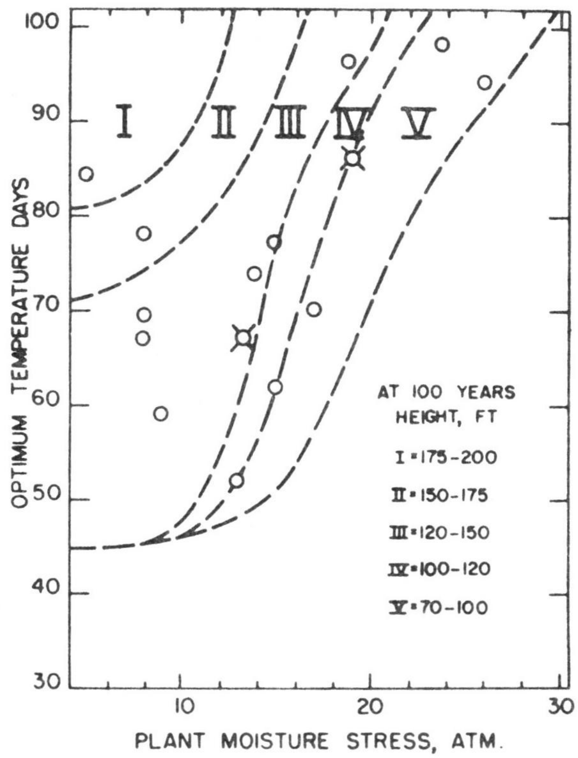

100
90
80
70
60
50
40
30
10
20
30
OPTIMUM TEMPERATURE DAYS
PLANT MOISTURE STRESS, ATM.
I
II
III
IV
V
AT 100 YEARS
HEIGHT, FT
I = 175-200
II = 150-175
III = 120-150
IV = 100-120
V = 70-100

FIGURE 13

HYDROLOGIC SYSTEM WITHIN A TYPICAL WATERSHED AREA

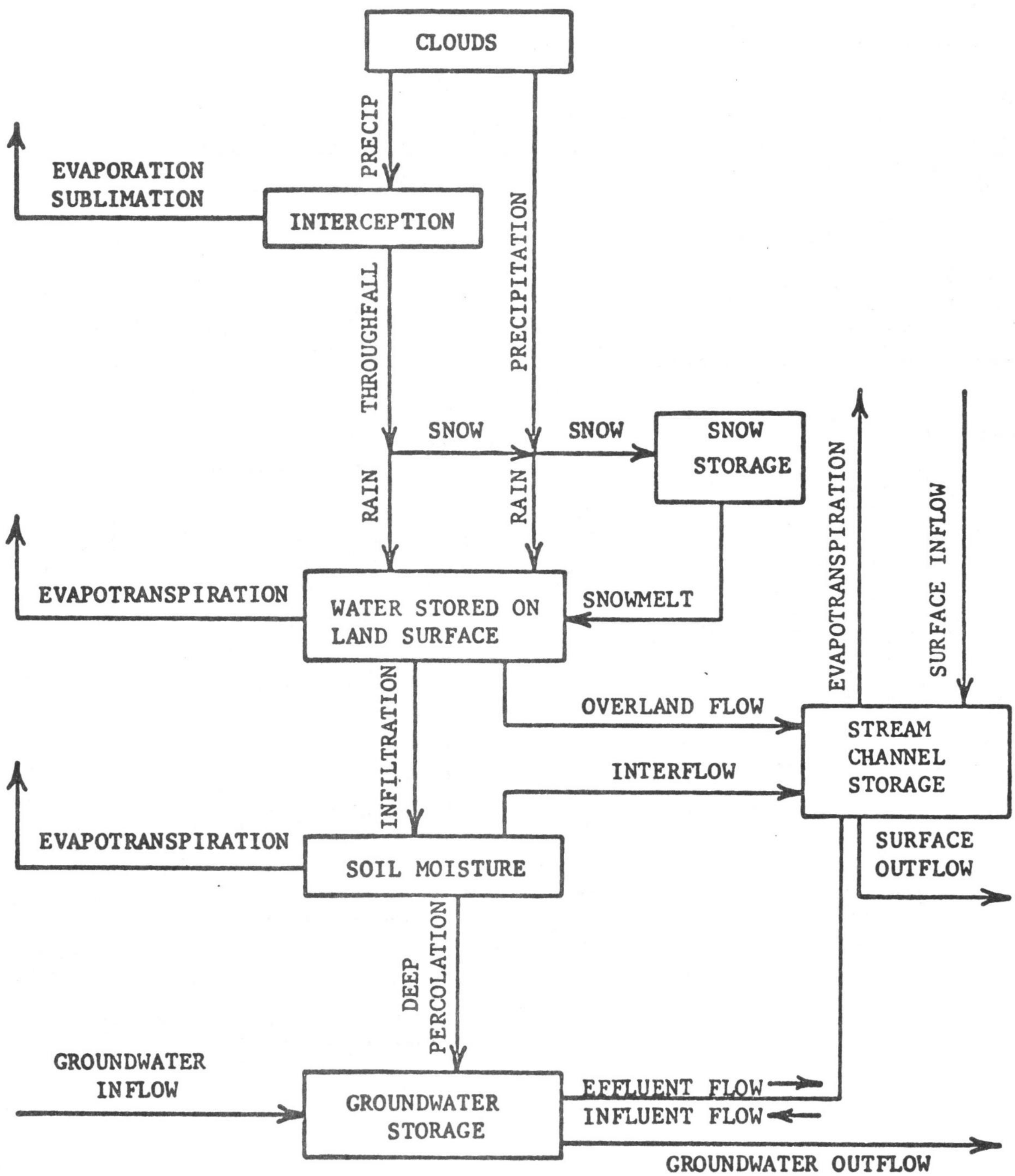


FIGURE 14

STRUCTURAL AND FUNCTIONAL RELATIONS FOR EACH SOIL-VEGETATION UNIT

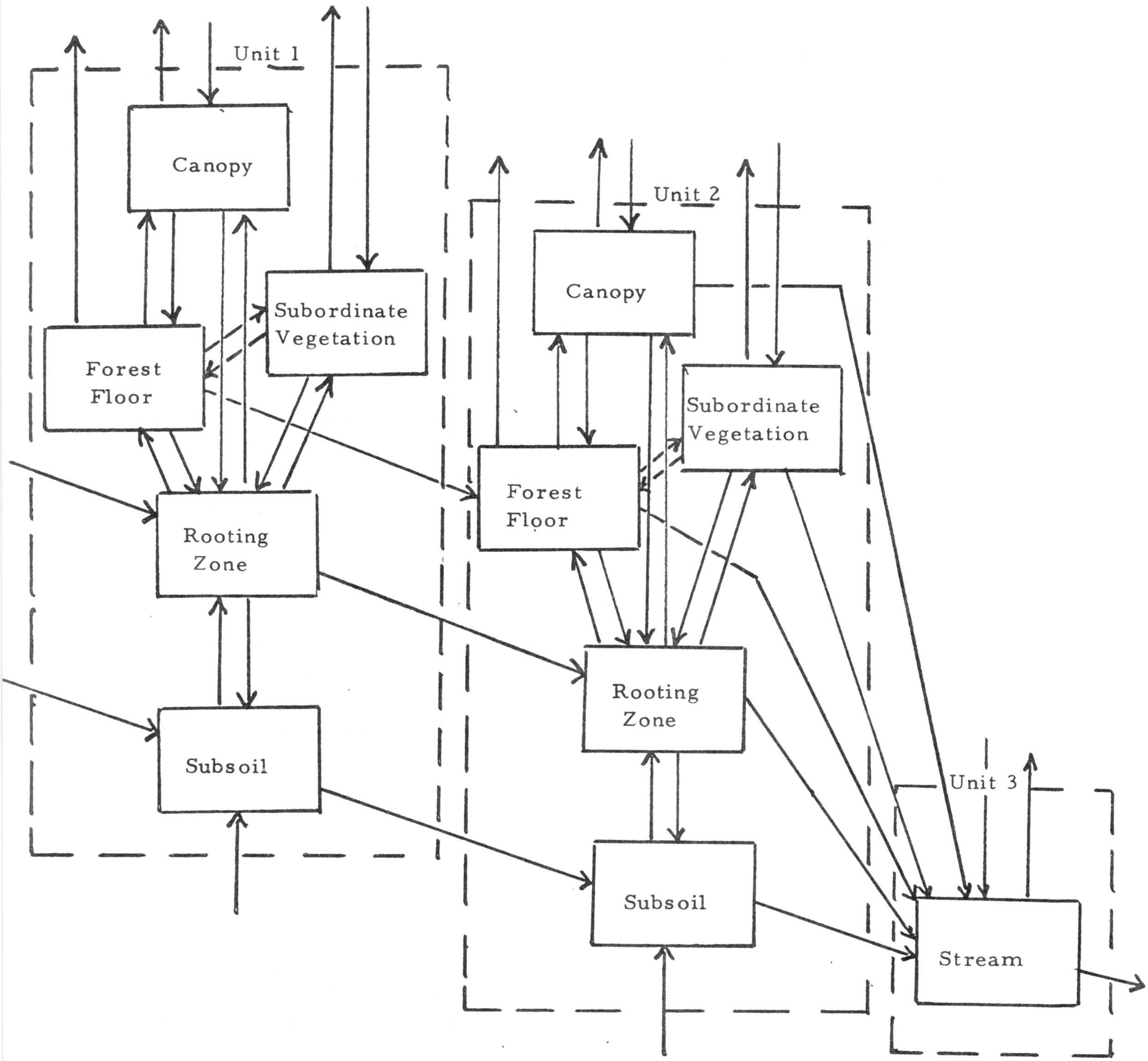
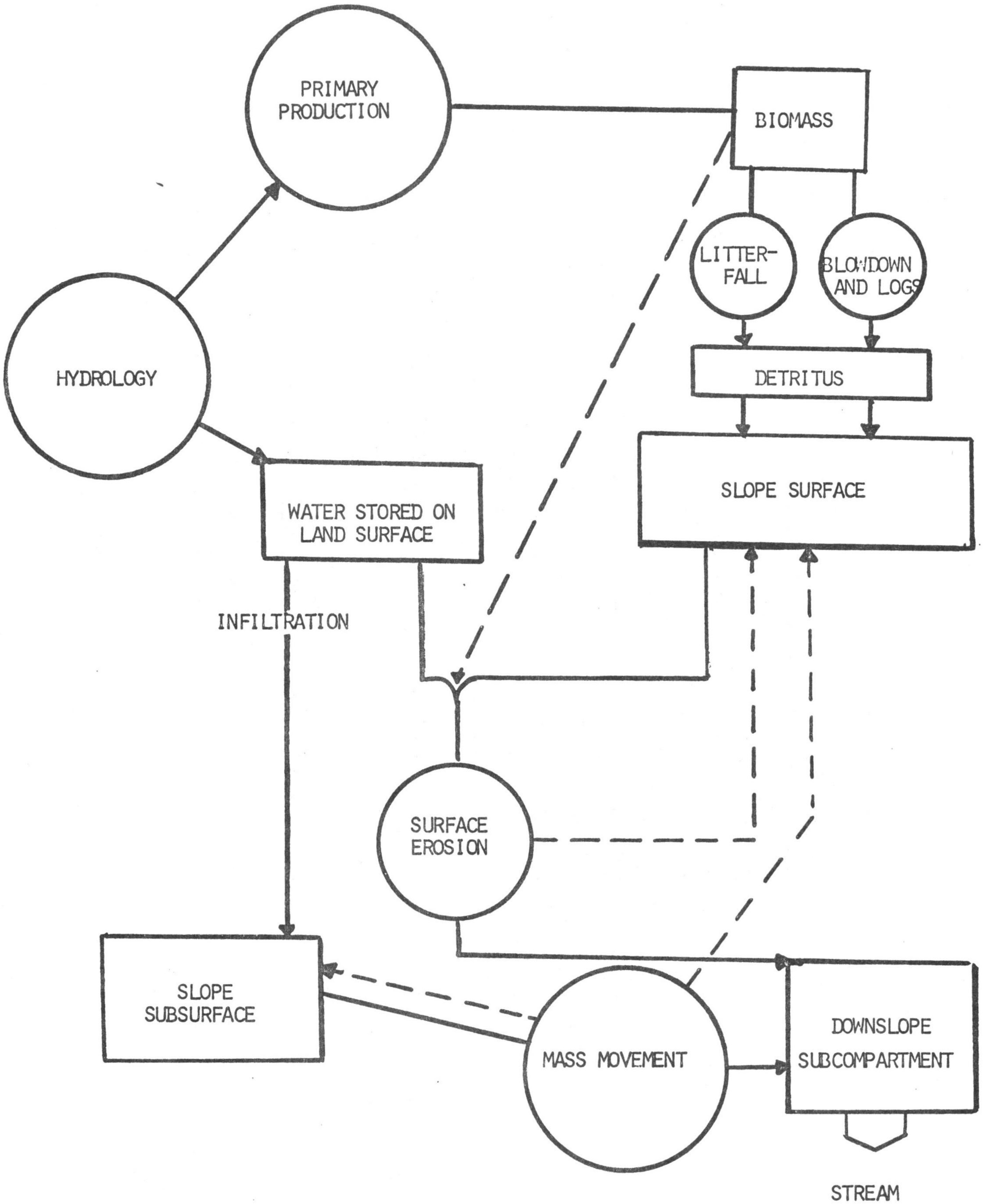


FIGURE 15

EROSION MODEL



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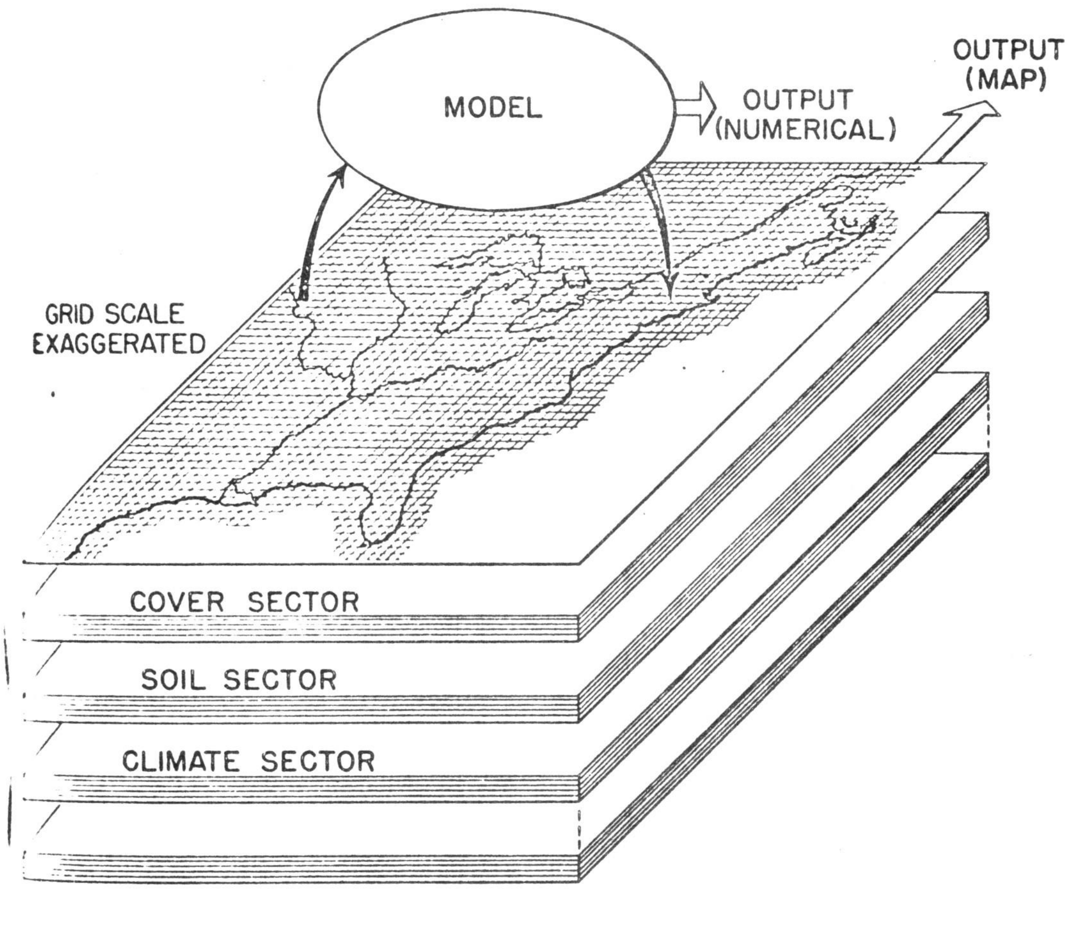
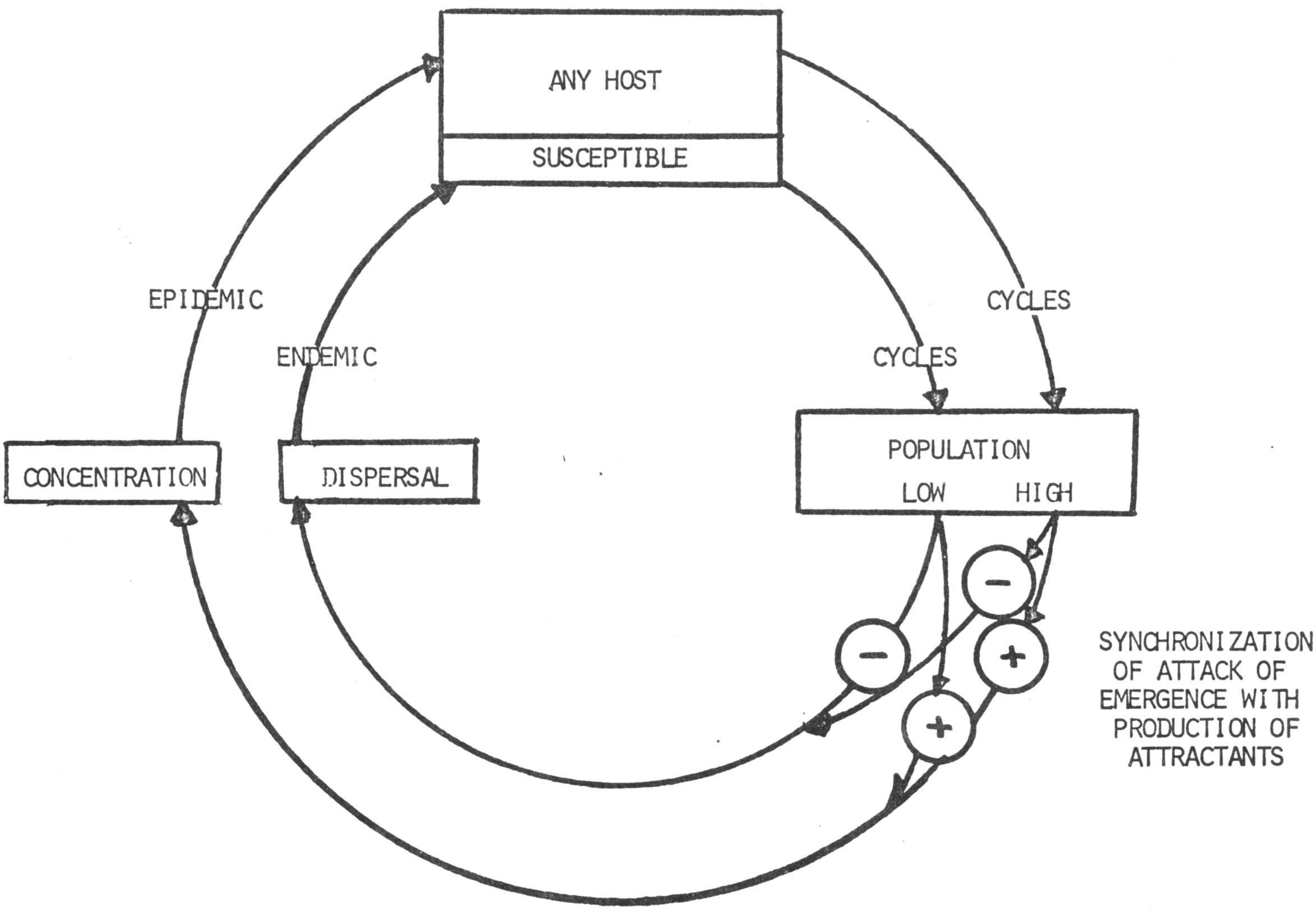


FIGURE 17



QUALITATIVE MODEL OF POPULATION DYNAMICS OF BARK BEETLES

FIGURE 18