LEAF MARGIN: A Computer Simulation of Leaf Margin Variation in Indiana

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At the very heart of the study of synecology lies an understanding of the interaction between plants and their environment. Unfortunately, the detailed field studies required to illustrate this interaction are not easy to carry out in either introductory biology or ecology courses. When the time required to teach students about the local flora, environmental sampling techniques, and vegetational sampling techniques is considered, the reason why most laboratory exercises only illustrate these techniques and do not require the students to struggle with realistic experimental results is obvious. The problem exists when considering both local and regional vegetational analyses. At the local level, one solution to the time problem is to prepare a detailed map for a specific vegetation type. Then, the students can analyze the relationships found on the map rather than in an actual vegetation stand. This strategy was incorporated into an introductory ecology text for the analysis of the plant community of a desert alluvial fan in the Borrego Valley, San Diego County, California, by Cox (3). At the regional level, one solution is to use a computer simulation to help the students produce their own vegetation maps. LEAF MARGIN is a computer simulation designed to allow the students to study the leaf margin variation of the woody, dicotyledonous plants of Indiana. When used in conjunction with CLIMATE (7), possible environmental influences on this pattern can be studied. Both LEAF MARGIN and CLIMATE were designed to run on the Apple II+ or IIe microcomputer. Copies of these programs may be obtained by sending a blank disk to the author.

Background

The relationship between leaf margin type and climate was first studied by Bailey and Sinnott (1, 2). These researchers concluded that as mean annual temperature decreased with changing latitudinal position away from the equator or with changing altitudinal position at the same latitude, the percentage of woody, dicotyledonous species having leaves with entire margins also decreased. The only exceptions to this general rule were encountered in physiologically dry areas, such as deserts or tundra, where the majority of species always have leaves with entire margins. Bailey and Sinnott (1, 2) did not include monocotyledonous plants or gymnosperms in their study, because these plants almost always have leaves with entire margins. Herbaceous dicots can be studied, but they are normally omitted, because they are too numerous to survey effectively and because they cannot be used to make paleotemperature predictions.

The correlation discovered between mean annual temperature and the leaf margin variation of woody, dicotyledonous plant species in extant floras led Bailey and Sinnott (1, 2) to conclude that the percentage of woody, dicotyledonous species having leaves with entire margins in a fossil flora could be used to predict the mean annual temperature under which that fossil flora existed. The paleobotanical implications of their discovery have received the greatest amount of attention in recent years.

The work of Bailey and Sinnott was continued by J.A. Wolfe (10-14) using the extant floras of southeastern Asia and the fossil floras of the western United States and Alaska. After surveying the literature on the floras of southeastern Asia, Wolfe (13) concluded that the percentage of woody, dicotyledonous species having leaves with entire margins decreased by 3% for every 1 ° C decrease in mean annual temperature.

Using this correlation, Wolfe (12) was able to estimate the mean annual temperature under which 52 fossil floras from the Tertiary of the western United States and Alaska existed.

Unfortunately, the researchers supporting a close link between leaf margin type and temperature, as well as other researchers who have studied the relationship between leaf area and average annual precipitation (9), have disregarded the basic synecological principle that regional vegetational trends are rarely, if ever, controlled by one or two environmental factors. When studies (4-6, 8) have contradicted their work, these researchers have either completely disregarded the contradictory studies, or the conflicting data have been modified without further field testing to bring them into line with the existing hypotheses.

Using LEAF MARGIN, the students can carry out several types of analyses (see below) to discover what environmental factor or factors control leaf margin variation in Indiana. The students can also explore which conflicting hypothesis most closely accounts for the leaf margin variation that is discovered.

LEAF MARGIN

The variation in leaf margin type of the woody, dicotyledonous plant species of Indiana can be studied using the program, LEAF MARGIN. LEAF MARGIN is written in BASIC and is designed to run on the Apple II+ and IIe microcomputers. A generalized flow chart for LEAF MARGIN is illustrated in Figure 1. The program's

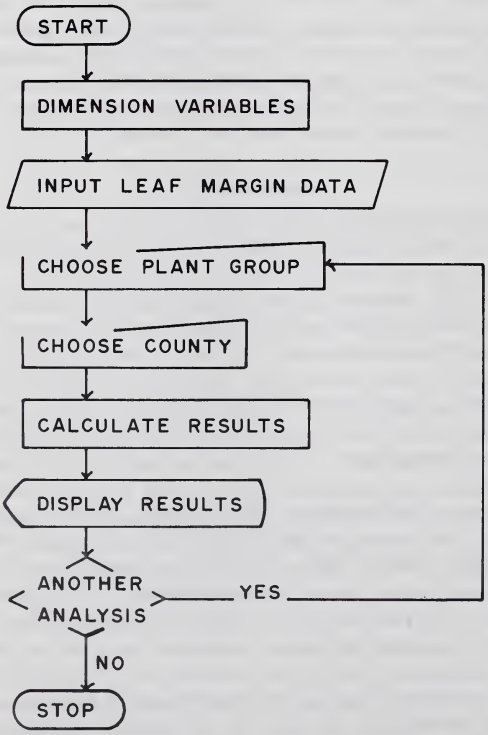

FIGURE 1. Simplified flow chart showing the overall operation of LEAF MARGIN.

first operation is to load the data base, LEAF MARGIN DATA, into random access memory. This data base contains all the information on leaf margin variation in Indiana required to run LEAF MARGIN. After the data base has been loaded into memory, the students must select the component of the woody, dicotyledonous vegetation of Indiana they would like to study. The possibilities include: the total vegetation, all the deciduous plants, all the evergreen plants, all the trees, all the deciduous trees, all the evergreen trees, all the shrubs, all the deciduous shrubs, all the evergreen shrubs, all the vines, all the deciduous vines, and all the evergreen vines. Finally, the students must select the county in which they would like to analyze the leaf margin variation and enter the appropriate county number. The counties are numbered from 1 to 92, and the students must consult a numbered map of Indiana (Figure 2) to find the cor-

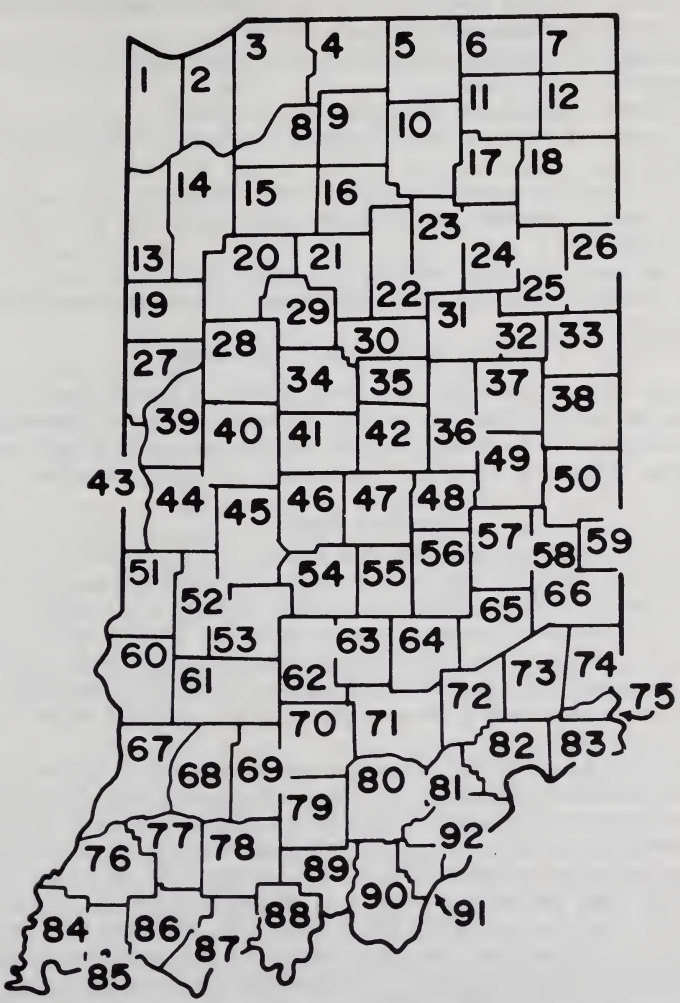

FIGURE 2. County numbers used to access the information in the data base, LEAF MARGIN DATA.

rect county number. After these two variables have been specified, the program will respond by calculating and then printing the percentage of woody, dicotyledonous species having leaves with entire margins in the plant group and county under study.

LEAF MARGIN DATA

The data base, LEAF MARGIN DATA, is a synthesized version of a much larger data base which was analyzed using the CDC 6600 at Indiana University, Bloomington. A total of eight and a half years were required to collect the data and to carry out the preliminary analyses. LEAF MARGIN DATA contains 92 records, one for each county in Indiana. Eleven variables (fields) are contained in each record:

1) County number;
2) Number of woody, dicotyledonous tree species having leaves with entire margins;
3) Number of woody, dicotyledonous tree species;
4) Number of deciduous, dicotyledonous shrub species having leaves with entire margins;
5) Number of deciduous, dicotyledonous shrub species;
6) Number of evergreen dicotyledonous shrub species having leaves with entire margins;
7) Number of evergreen, dicotyledonous shrub species;
8) Number of deciduous, dicotyledonous vine species having leaves with entire margins;
9) Number of deciduous, dicotyledonous vine species;
10) Number of evergreen, dicotyledonous vine species having leaves with entire margins; and
11) Number of evergreen, dicotyledonous vine species.

The record numbers correspond to the county numbers in Figure 2. For the shrubs and vines, the number of deciduous and evergreen species is recorded separately. The number of deciduous and evergreen, dicotyledonous tree species is not recorded separately, because there are no evergreen, dicotyledonous trees native to Indiana.

Auxiliary Programs

Three auxiliary programs are provided along with LEAF MARGIN: CREATE, PREVIEW AND MODIFY, and DATA DUPLICATION. CREATE was used to build the data base, LEAF MARGIN DATA. CREATE allows the user to enter the values for the eleven variables discussed in the preceding section. The information for each county (one record) is stored on the disk as part of a sequential access file. By changing the test value index in the FOR/NEXT statement in line 160 of the BASIC program, CREATE can be used to produce other data bases which will be stored as sequential access files.

PREVIEW AND MODIFY was used to check the original data for typographical errors introduced during data entry. The program will give the number of plant species in the ten plant groups (see above) for any county requested by entering the appropriate county number. If a piece of data is incorrect, that data field can be modified. A new listing will appear to allow the user to verify that the change was made correctly. The modified data base will be transferred to the disk, after the user specifies that all corrections have been made. PREVIEW AND MODIFY can be used to let interested students look at the raw data rather than dealing with the percentages that are the normal output of LEAF MARGIN. The original data base cannot be altered by a student using PREVIEW AND MODIFY, unless the modify option is chosen. If extra protection is desired, the program lines allowing records to be modified can be deleted from this program on student disks.

DATA DUPLICATION allows extra copies of the data base to be made. The program will load the initial data base from the disk. When this operation is complete, the program will request the user to insert a new disk. By typing the word "GO," the user instructs the computer to copy the data on the new disk.

Possible Uses

LEAF MARGIN has at least four possible uses:

1) Maps showing the variation in leaf margin type in Indiana could be prepared. This exercise would allow the students to practice preparing contour maps.

2) Maps showing the variation in leaf margin type could be compared with environmental maps for Indiana to see what environmental factors, if any, might underlie the observed variation.

3) Maps showing the variation in leaf margin type could be based on a restricted number of counties to simulate the care required when choosing sample sites and using field data. The students' maps could be compared with maps showing the total variation in leaf margin type to illustrate the importance of selecting the correct number and type of sample sites.

4) Maps illustrating leaf margin variation could be prepared using a restricted number of counties chosen after consulting a number of environmental maps of Indiana. The maps illustrating leaf margin variation could be compared with the environmental maps to see what environmental factors, if any, might underlie the observed leaf margin variation. The value of selecting counties that present different environmental regimes to the plants could be discussed.

Of the possible modes of use, methods two through four offer the most satisfying types of experiments with respect to the results produced.

By comparing maps showing the variation in the percentage of woody, dicotyledonous species having leaves with entire margins with climatic, soil, physiographic, and other environmental maps of Indiana, the students can explore whether or not the observed variation in leaf margin type is closely correlated with the variation in one or many different environmental factors (method 2). Published results (6; see below) indicate that several environmental factors are involved, and that the factors which influence one type of woody, dicotyledonous plant are not the same as those that influence others. Because the students will be using all the available data on leaf margin type as well as prepared environmental maps, this approach is most appropriate for use in an introductory biology course.

Rarely does a plant ecologist have access to all the vegetational data for an entire region the size of Indiana without spending years collecting that data. Most ecological studies are carried out using a carefully selected subset of all the theoretically available data. The problems inherent in correctly choosing these sample sites can be simulated using the third and fourth methods outlined above. Limiting the number of counties that can be analyzed will require the students to choose the counties they wish to analyze very carefully. Failure to analyze the vegetation of the dunes will seriously influence the students' interpretation of leaf margin variation in northern Indiana. Failure to analyze the vegetation of the Wabash Lowland will prevent the students from discovering what influence the plants migrating up the Mississippi and Ohio River valleys from the south have on leaf margin variation in southern Indiana. The success or failure of a specific set of sample sites to approach the actual variation in leaf margin type in Indiana can be discussed by comparing the students' maps with the maps produced using all the data (method 3).

In most cases, the random selection of counties will not result in a map that is a good approximation of the actual variation in leaf margin type. A better method

of choosing counties is necessary; i.e., the students need to develop a hypothesis about how leaf margin type could vary, and then, they need to test this hypothesis by analyzing leaf margin data in the appropriate counties (method 4). After formulating such a hypothesis, county selection should be based on the careful study of the climate, physiography, vegetational types, water resources, and soil types found within Indiana. This approach is an extension of the third method, but it is exactly the opposite of the approach used in the second method. With the second method, the students simply collect their data and then compare their finished maps with various environmental maps supplied by the instructor. The fourth method requires that the data be collected with reference to a specific hypothesis based on the current theories in the literature. The counties would be selected to test the influence of specific environmental variables. The third and fourth methods are most suitable for use in an ecology course.

Leaf Margin Variation in Indiana

A preliminary analysis of the variation in leaf margin type in Indiana was published in 1984 (6), and a more detailed analysis is currently in preparation. The following is a brief summary of these results (Figure 3a-d). The percentage of woody, dicotyledonous species having leaves with entire margins (Figure 3a) is highest in northern and southern Indiana (> 20%) and lowest in central Indiana (< 15%). The variation in the percentage of woody, dicotyledonous species having leaves with entire margins in Indiana is not closely correlated with the variation in any single environmental factor or group of environmental factors. To understand its variation, the woody, dicotyledonous vegetation must be broken down into its component parts, i.e., the trees, shrubs, and vines. The percentage of tree species having leaves with entire margins (Figure 3b) decreases from north (< 15%) to south (>15%) in the same fashion as mean annual temperature and average annual precipitation. The response of the tree species to these two major climatic variables is a result of the direct exposure of the trees to the influence of temperature (solar energy) and precipitation. The shrubs and vines are not directly exposed to the action of solar energy and precipitation, and these two plant types are influenced to a lesser extent by these climatic factors. The percentage of shrub species having leaves with entire margins (Figure 3c) is highest in northern and southern Indiana (> 25%) and lowest in central Indiana (<20%). The vines follow the same basic pattern as the shrubs. The percentage of vine species having leaves with entire margins (Figure 3d) is highest in northern and southern Indiana (>20%) and lowest in central Indiana (0%). The distribution of the shrub and vine species is most strongly influenced by soil type, soil moisture levels, and exposure. The trees, shrubs, and vines respond to different environmental stimuli, and their responses account for the lack of correlation between climate and the variation in leaf margin type for the total woody, dicotyledonous vegetation of Indiana. Because the number of shrub and vine species is greater than the number of tree species in Indiana, the shrubs and vines exert a greater influence on the overall variation in leaf margin type than the trees. The form of the variation in leaf margin type of the total woody, dicotyledonous vegetation (compare Figure 3a with Figures 3c-d) shows just how strong the influence of the shrub and vine species is.

Teaching Effectiveness

The effectiveness of LEAF MARGIN in teaching about the interrelationship between plants and their environment was tested using a pretest-posttest experimental design with experimental and control groups. The same 50 question pretest-posttest was given to both groups. Mean gain scores for each group were calculated from the test results. A separate variance estimate of the difference in mean gain scores and

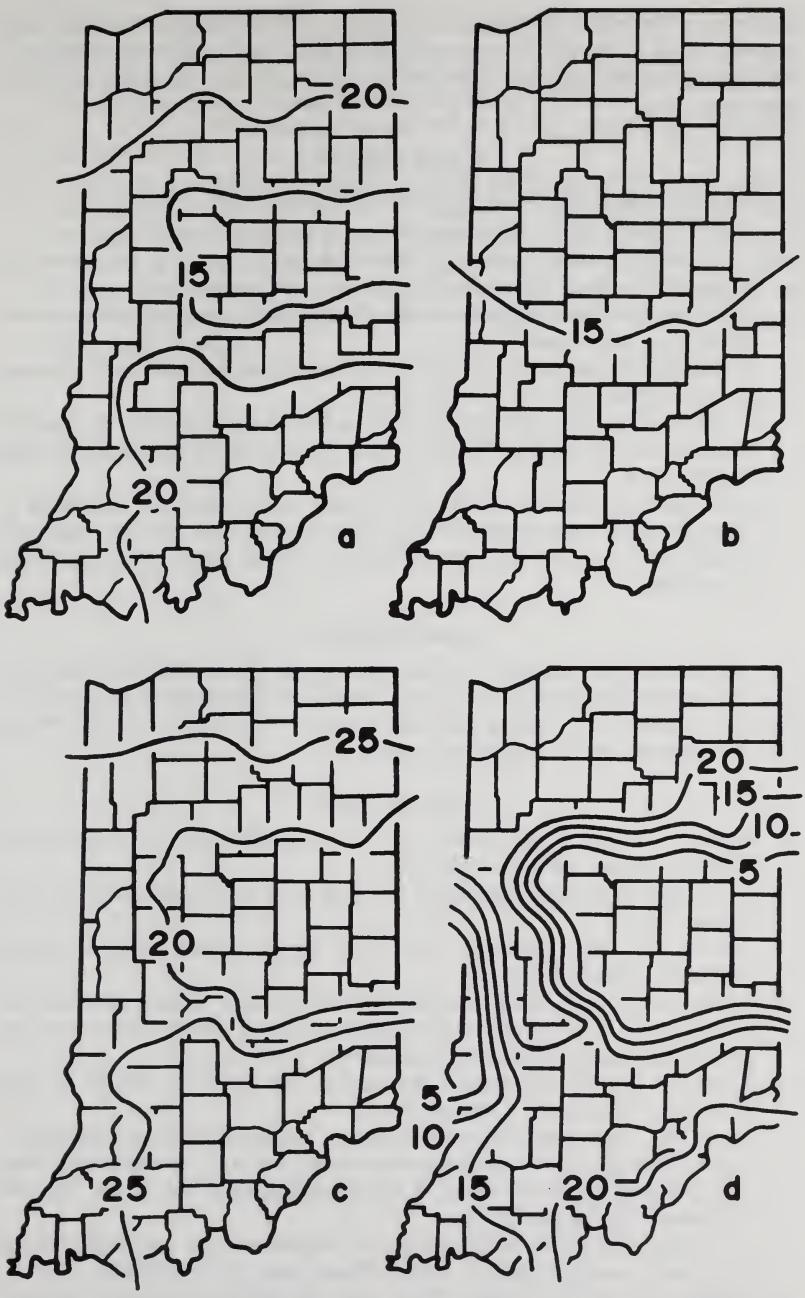

FIGURE 3. Variation in the percentage of woody plant species (a), woody tree species (b), woody shrub species (c), and woody vine species (d) having leaves with entire margins in the counties of Indiana.

an analysis of covariance for the posttest scores of the experimental and control groups were run to see if the gain in the experimental group was greater than the gain in the control group. In each case, the difference was found to be significant at the 5% significance level.

Student Outcomes

Six important student outcomes result from using LEAF MARGIN:

1) The students obtain experience in how to prepare contour maps.
2) The students become acquainted with the literature on the climate, vegetation, physiography, water resources, and soil types of Indiana.
3) The students can undertake a detailed analysis of the interrelationship between plant form and climate.
4) The students can study the effect of sample size and sample appropriateness on the experimental results they obtain.
5) The students gain experience in framing and testing hypotheses by carefully selecting counties to analyze based on the study of the many environments found in Indiana.
6) The students begin to realize that biology is not simply the cataloging of organisms or the memorization of facts, as they attempt to discover what hypothesis being debated in the literature best explains the variation in leaf margin type found in Indiana.

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