CLASSIFICATION AND PURPOSE IN AUTOMATED VEGETATION MAPS*

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ABSTRACT. This study demonstrates the possibilities of present-day geographic information systems (GIS), operating under the analytical paradigm, for manipulating vegetation data bases. A case study of Mount Desert Island, Maine, compares applications of different vegetation-map classifications originally derived under the communication paradigm by A. W. Küchler in 1956 with their analytical counterparts. By using a GIS, field data are easily manipulated to produce map classifications from which vegetation components can be extrapolated or combined with other variables to form integrated terrain units. GIS automation greatly enhances the analytical capabilities and potential uses of vegetation maps.

VEGETATION maps play a significant role in real-world applications: they provide important indicators of ecological response to disturbance, act as baselines for studies of vegetational succession, and establish correlative data for additional environmental attributes. However, these maps traditionally have focused on communication rather than analysis. The predominant purpose of the map has been to produce a visual thematic pattern corresponding to the vegetation classification employed. Thus, at a uniform scale, the usefulness of the map is largely controlled by the thematic classification emphasized. Much quantitative map information is unavailable, except for measurements using manual tools such as planimeters and rulers (Marble 1990). This unavailability of information stems primarily from the classification process itself, in which numerous vegetative attributes are of necessity combined to classify a given area.

A modern geographic information system (GIS), by contrast, operates under the analytical paradigm (Tobler 1959) and incorporates the power of analysis into the cartographic process. GIS technology now allows the input, storage, manipulation, and output of individual vegetative attributes. Additionally, the incorporation of ancillary information is made easier, and quantitative manipulation of a variety of data layers provides a powerful enhancement in the application of vegetation maps to problems encountered in the real world. Usually, the vegetation map is a single input to the GIS data base, through a process known as integrated parametric mapping. This approach compresses environmental information into a single map (Dan-

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germond, Derrenbacher, and Harnden 1982) and has allowed the vegetation map to become part of the decision process available in a GIS (Küchler 1988).

Yet, in its own way, integrated parametric mapping also severely limits access to information, as it overlooks the data gathered preparatory to the production of manual vegetation maps. Traditionally, those who have produced such maps have been field oriented, and have collected information on individual species, species sociability, plant dimensions, and vegetative physiognomy. The communication paradigm that underlies the production of traditional cartographic products masks these important informational sources, limiting the map user to the cartographer's view of the data, but the GIS approach also makes insufficient use of the same resource. Were the original field data made available for input into a GIS, significant methodological improvements might accrue through single-variable manipulation of vegetation data (Burrough 1987). The utility of the vegetation map itself as an analytical tool in a variety of real-world settings could also be enhanced, as an examination of the thousands of classifications possible in choropleth maps would become available (Jenks and Caspall 1971; Evans 1977).

This article illustrates a prototypical parametric mapping approach to examine these possibilities. The base study is a 1956 article by the geographer A. W. Küchler (1956a), in which he examined the usefulness of vegetation maps by focusing on three large-scale maps, each of which emphasized a different class of data. In the current study, I show how these maps and, more importantly, the field data used in their preparation (Küchler 1956b) may be incorporated into a GIS. I have chosen this approach specifically to illustrate the capability of a GIS to go beyond the storage and archival method (van Der Zee and Huizing 1988), under which the classified vegetation map is created before digital input to the GIS. Given a knowledge of the vegetation itself, a background in vegetation-map classification, and access to field notes produced under the comprehensive vegetation-mapping method (Küchler 1955), multiple task-specific vegetation classifications can be designed within the GIS (Zonneveld 1988). Furthermore, my approach affords an opportunity, under controlled conditions, for comparing the traditional manual approach and the digital GIS method for handling the same data. The study provides repeatable evidence for the enhanced utility of a GIS for these tasks, and illustrates that the marriage of classical field methods with the advanced analytical power of the GIS makes for considerable functional improvement in both techniques.

Original Study and Field Notes

Küchler began his 1956 article by posing two apparently simple questions: "How good is a vegetation map? How can you tell?" (Küchler 1956a). In an effort to answer those questions, he constructed three identically scaled vegetation maps of southeastern Mount Desert Island, Maine, employing a distinct classification for each map. He then investigated the properties that contribute to the usefulness of each for practical purposes.

As is indicated by his own efforts, the task Küchler set was not as simple as it seemed. The need to employ the comparative method necessitated a large map scale (1:25,000) in a study area approximately seven miles on a side that included a sizable number of vegetation types and admixtures. Additionally, although Küchler originally anticipated comparing up to eight maps, each of which would employ its own classification system, further study showed that some of the proposed classifications were designed for mapping at medium or small scales. Küchler also correctly determined that ecological classifications—those requiring that mapping units be related to nonvegetative environmental factors—should be eliminated. This decision was very practical, because the selection, quality, and relative applicability of these environmental correlates add uncertainties to the interpretive process. Finally, based on his knowledge of the common vegetation-map classifications, Küchler decided on the three used in his study: the physiognomic classification, the floristic classification, and the physiognomic-floristic combination classification.

Grouping the myriad potential uses of vegetation maps into broad categories, Küchler decided on scientific, economic, and military purposes. Within these basic classes of potential use, he specified as examples of scientific applications the use of vegetation maps for mapping soils, for defining appropriate deer habitat, and for constituting part of a general description of an area's physical geography. In the economic realm, he settled on two potential uses: Internal Revenue Service (IRS) assessment of extensive forest landholdings, and location of potential commercial beehives. The hypothetical military application was the use of a map for covert travel by infantry troops. Each of the six applications had its own particular analytical and display needs, and therefore forced selection of one of the three maps as the optimum choice.

In the 1950s, before the advent of advanced digital remote-sensing devices, detailed field notes were used as a matter of course in the preparation of vegetation maps. Küchler's notes supply ample data to produce maps based on physiognomy, floristics, or any combination of the two. His lists demonstrate a compact codified information-storage technique. Included in the physiognomic data are deciduous and evergreen, broadleaf and needleleaf woody vegetation, graminous, forb or lichen and moss herbaceous vegetation, height, and vegetative density. The floristic data included both genus and species when available, as well as percent coverage and species sociability. Associated with these data is an outline map with six hundred regional categories or polygons describing the visually distinct vegetation. These polygons were identified from 1:24,000 black-and-white aerial photography and contain polygon identification numbers that explicitly link them to the numbers in the lists. Küchler describes the combination of the map plus the lists as defining an accurate record of the vegetation at the time it was mapped.

Though a compact system for printed presentation of the information, the method provided by Küchler lacks the flexibility necessary for input into a present-day relational data-base-management system. An extensive reconfiguration was performed to adapt the data to the appropriate form for input. The data transferred into the INFO data-base-management system (DBMS) of the ARC/INFO geographic information system possess a degree of flexibility necessary for performing numerous logical and mathematical searches and for producing multiple views of the vegetation data base (DeMers 1991). Because the INFO system is tied explicitly to the ARC graphics subsystem of the GIS, vegetation maps can be produced from any data-base view or logical subset selected.

Selection of the appropriate data-base view for a specific task depends on the physical parameters needed to solve a given problem. For the hypothetical vegetation-map applications used by Küchler, it was necessary for him to define the specifics for each task, to examine each of the three vegetation maps produced, and to make a subjective determination of the utility of each map. The current approach is similar, except that both the specific requirements and the degree of satisfaction can now be evaluated in a more definitive manner. The result is a superior, more flexible, and more objective approach to selecting the appropriate vegetation parameters for use under given circumstances. Specifically, each of the individual species, combinations of species, percentage of surface cover, growth form, density, height, and sociability can be selected or combined at will. The ability to manipulate each of the vegetation parameters suggests many more applications for the vegetation map than were originally possible. Also, the enhancements available by combining the original field-collection approach with present-day GIS technology show that modifications to the standard comprehensive vegetation-mapping approach would allow still greater flexibility and modeling capabilities.

Economic Case Studies

Having converted Küchler's data into useful digital form, I next applied them to the six case studies outlined in his original essay. Following, in a slightly different order from the one he used, are the results of my inquiry, beginning with the two case studies on economic issues.

Küchler first examined the application of vegetation maps to an IRS assessment of the value of forest landholdings. In his discussion, the stated criteria included the extent, condition, and floristic composition of the forests. His comparisons showed that a combination of floristic and physiognomic classifications would be required for the IRS to evaluate the landholdings. The floristic-physiognomic map serves the agent's purpose, in Küchler's opinion, because it tells "clearly how much of the area is forested, which are the commercially most important trees, how they are distributed, and where they are concentrated." Especially useful in the combination classification is a map category that outlines commercial conifers and includes species letter symbols showing an approximate outline of the species. The definition of commercial is no doubt based on Küchler's field survey of tree heights and the percentage of cover occupied by them. However, for an IRS agent, especially one not well versed in reading vegetation maps, this category can be extremely misleading, as the quantitative data necessary to make a graded assessment of multiple landholdings are unavailable.

Using the data as given in the field notes, one can first display polygons that show the commercially viable species, such as white pine, red pine, white spruce, red spruce, and hemlock. This is accomplished by selecting only those polygons in the data base that contain codes corresponding to those species names. Once accomplished, this subset of the data base can be further queried for those polygons containing trees in a specific height range, such as higher than twenty-five meters tall; trees with a specific coverage, such as more than 75 percent; and trees that occur as continuous-growth, extensive sheets, identified by density and sociability in Küchler's field notes. In fact, analysis of the data base reveals that there are no portions of the study area that exhibit all of these criteria: no areas were found containing pine, spruce, or hemlock that were higher than twenty-five meters or had a coverage of more than 75 percent. Instead, the highest-value forest land in the study area was determined by commercial species that were between ten and twenty-five meters in height and that occurred singly rather than in continuous sheets (Fig. 1). Although this view demonstrates the ability to search the data base for commercial forest stands, it also suggests that the original maps produced under the traditional communication approach fully hide information relevant to such analysis. Stated another way, the original thematic maps suggest that there might indeed be large stands of commercially viable species in the area, but a detailed search of the data base shows this assertion to be incorrect.

Subsequent views could easily be constructed to categorize decreasingly valued timber landholdings, however limited they may prove to be. When value per acre or value per estimated board foot is substituted for each of these categories, the final map becomes one that an IRS agent can easily use in determining appropriate taxes. Additionally, if landownership data are included in the data base, specific taxation values for each landholder may be evaluated simply by querying for a combination of the landholder's name and the timber-value map, a simple map intersection or logical "and" function in the DBMS.

In his second economically oriented case study, Küchler discussed the use of maps in determining the potential for expanding a beekeeping operation. The key variable here is the presence or absence of rich, nectar-producing plants. Bees have no need for thickets or for other forms of shelter and protection from predators. Consequently, the physiognomic classification would not provide the apiarist with necessary information. Additionally, because the colors on Küchler's floristic-physiognomic map correspond more to physiognomy than to floristics, this map presents little information of value to the task at hand. Indeed, the apiarist would be interested almost exclusively in which nectar-producing species occur and where and, perhaps,

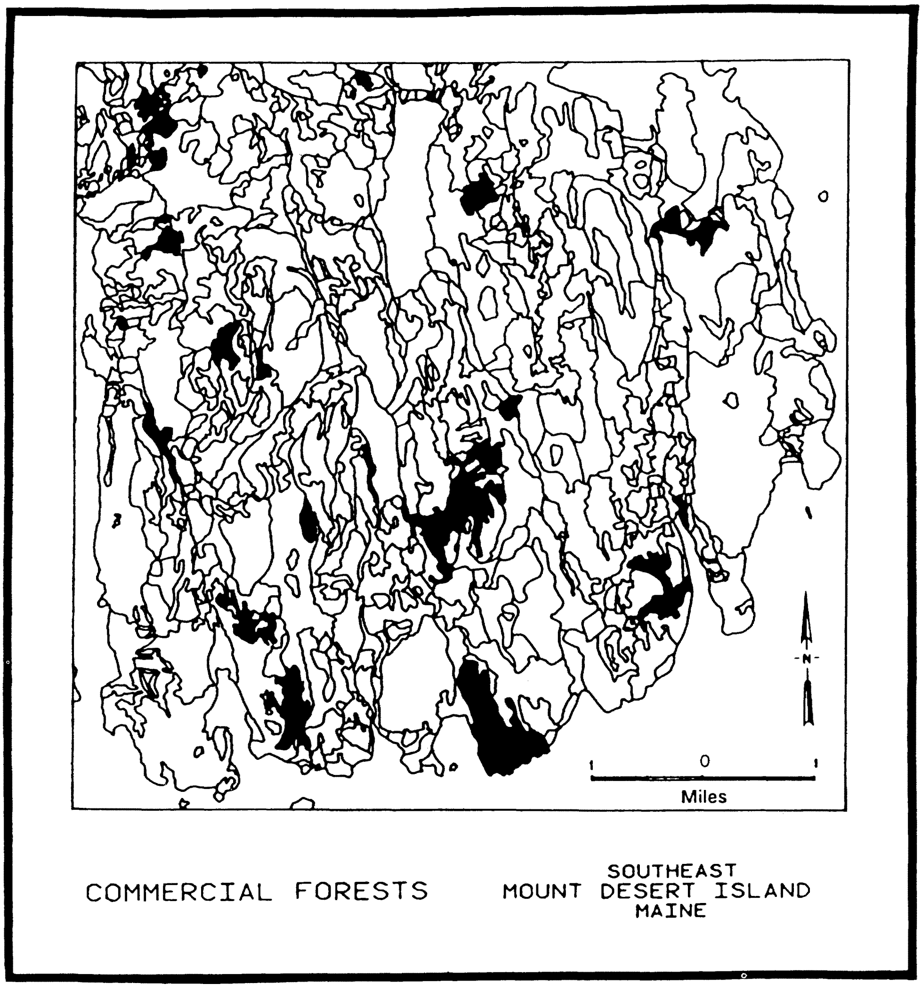

FIG. 1—Map of commercial forests developed by removing only economically harvestable species from the data base.

in what abundance. This information is readily available in the floristic classification map; however, detailed quantitative information is once again hidden by the general thematic categories.

The GIS presents a very simple solution to this dilemma, by allowing the apiarist to create a separate view of only the species that are known to be important nectar sources in the region (Fig. 2). By recasting these selected floristic data using numerical ranges assigned to the percentage cover for each polygonal area, the apiarist has access to a map that shows both where the necessary species are and to what degree. The data base may also be manipulated, as determined by the apiarist's criteria, to show regions of high, medium, or low potential for the expanded bee operation.

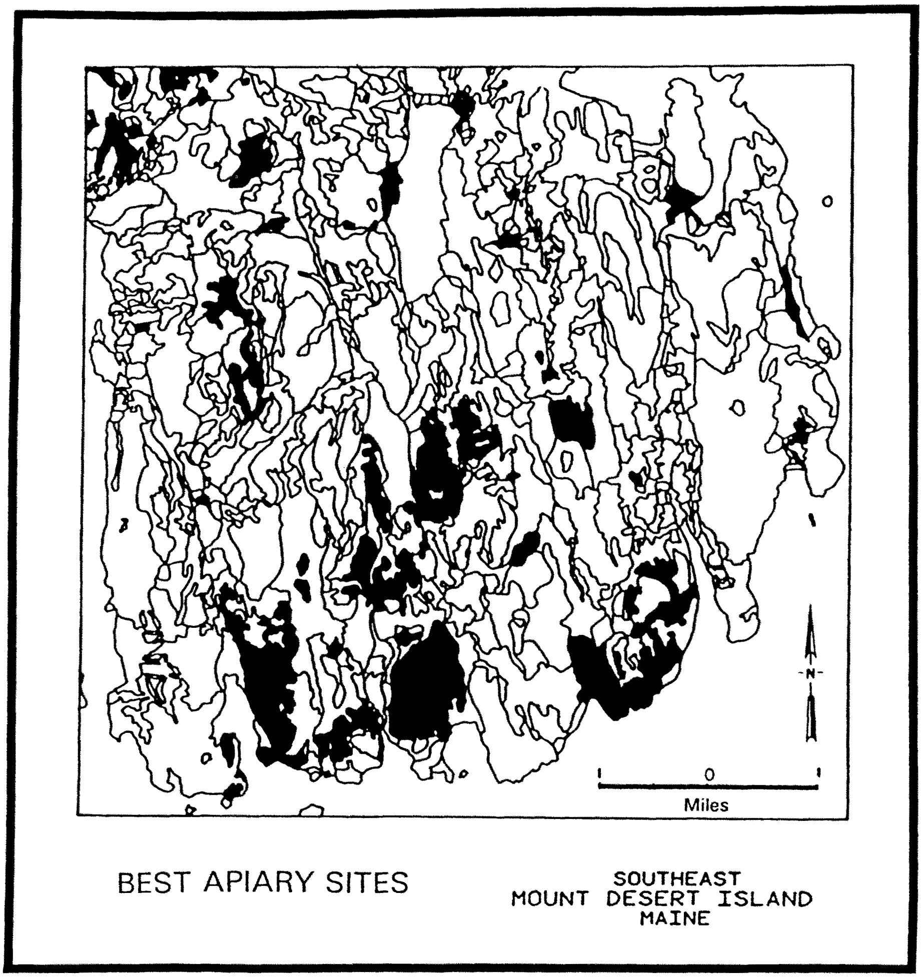

FIG. 2—Map of sites for apiary use made by selecting only sites known to have plants utilized by bees.

SCIENTIFIC CASE STUDIES

The first of the three scientifically oriented examples selected by Küchler dealt with the applicability of vegetation maps in assisting a scientist mapping soils in a large forested area. Although a relationship exists between pedological and vegetative factors, the character of the relationship varies greatly from area to area. Still, vegetation maps may suggest the interaction of climate, organisms, relief, parent material, and time. Küchler argued that the map based on a floristic classification would be the most useful for this purpose, because species and species combinations are indicative of the distribution of soil types.

In this instance, the comparative method requiring either one map or another severely limits the potential user. Küchler himself admitted that "although the physiognomic features are of relatively little value . . . the indication of the dominant species is useful" (Küchler 1956b). Thus, if the most useful map, the floristic one, is used, relevant data available on the physiognomic map are unavailable to the pedologist. On the other hand, the combination depicted on the floristic-physiognomic map obscures the key element, the distribution of the floristic communities, so this map type also is inadequate for the task. This constitutes a classic example of the limitations of emphasizing communication rather than analysis when confronted with very large numbers of interrelated data.

Obviously, the analytical approach can enhance utility by limiting the choices for display to only the variables necessary for the soils-mapping project. Even more, the GIS can give detailed information about a selected area being mapped during any given period. If, for example, the pedologist wishes to begin work in coastal areas, in the southwestern portion of the map, and plans to cover only three or four areas separable in the aerial photography used for soils mapping, these specific polygons can be selected as a separate view of the data base, leaving all other areas blank.

Alternatively, a pedologist may examine certain similarities or differences between one polygon and another. Through a simple selection of these polygons as a subset of the map, a quantitative comparison of the types, amounts, and conditions of the vegetation can be produced by redefining the parameters. For example, a new column, detailing vegetation attributes in the data base that indicate species richness of a specific forest type, could very easily be produced by recording the table column and assigning a numerical value to each polygon showing the number of species found in each area. These numerical values could then be divided by the area of each polygon to yield the needed species-richness index, which subsequently could be displayed (Fig. 3). Such a measure might be very useful in determining whether the visual appearance in aerial photography indicates factors related to soil fertility, successional stages, and slope, or whether the appearance difference is merely an artifact of the aerial photography itself.

A second scientific test case was a hypothetical geographical report on the physical features of a landscape in an underdeveloped area, in which a vegetation map would be a part of the final report. Küchler assumed that the area would not be well known, that the geographer would require descriptive categories of identifiable vegetation, and that the final product would be a "graphic picture" that would be used for further inquiry. The last requirement limits the products to general thematic maps rather than to analytical ones. Küchler drew the fairly obvious conclusion that physiognomic classification is appropriate in this case. This classification produces a map showing no floristic detail, because the assumption of descriptive categories presupposes a poor knowledge by the geographer of the local

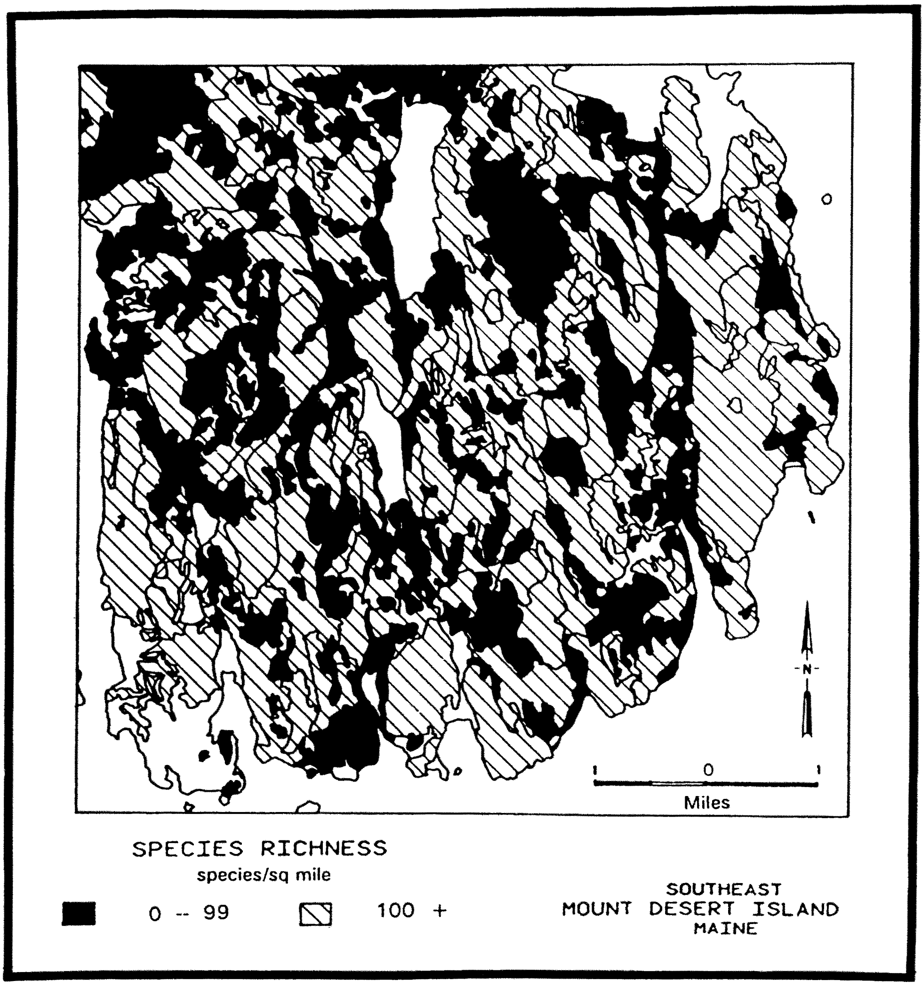

FIG. 3—Map of species richness resulting from division of number of species by area (square miles) in each polygon.

vegetation in such an unfamiliar region. At the same time, the physiognomic map illustrates ample vegetation detail rapidly and gives ready correspondence to the visible landscape that the geographer encounters.

Under the severe restrictions placed on the comparative method for this test case, there can be no argument that of the three methods of classification, the physiognomic system produced by Küchler (1949) for the express purpose of interregional comparison and user expediency should be selected. Because user expediency is among the most important factors needed for the production of such a map, the manual approach may actually be better in this instance than the production of a GIS data base from extensive fieldwork. However, it would be possible to reproduce such a physiognomic classification from a data-base view limited to the physiognomic factors found in the original field notes. Beyond the relatively rapid re-creation of the physiognomic classification, the GIS offers some additional enhancements that may be useful to a geographer under these hypothetical circumstances.

A single, general physiognomic depiction might prove less useful for thorough understanding of the environmental conditions in a little-known region than would a series of maps based on selected physiognomic parameters. A geographer might wish to determine the various degrees of vegetative density in any of the classifications. Although this information might be subsequently inferred from the existing map, its numerical counterparts are not readily available to the user. Using a series of simple relational reselect functions in the GIS, various categories showing the numerical values associated with vegetative density can easily be produced. Such information might be extremely useful in estimating soil productivity, available sunlight, or above-ground biomass. This again assumes that the geographer is not well suited to the task of floristic classification but that the information necessary to produce the physiognomic classification is available in the GIS data base. Numerous admixtures of the heights, densities, and growth forms could also be used for exploratory data analysis, whereas the traditional hand-drawn map would make this procedure impractical.

In his final scientific application, Küchler considered the needs of an animal ecologist interested in understanding the food and shelter habitat requirements of deer. This hypothetical example narrows the vegetative field of view by specifying that deer browse on and shelter predominantly under woody vegetation. More specifically, Küchler states that interests of the zoologist are "directed primarily to the distribution of certain plant species that serve the deer as food and to the structure and density of the vegetation," which serve to reduce wind velocity and discourage predators.

To Küchler, the need to identify food requirements for deer initially suggests selection of the floristic classification. The classification, however, does not disclose the information necessary to define shelter requirements. Instead, physiognomic information, notably the density and structural characteristics needed for this determination, is available in the physiognomic classification. It is easy to see that a combined floristic-physiognomic classification serves the zoologist best in this case. However, on the floristic-physiognomic map, separating the needed data requires a fairly lengthy search.

A GIS data base, by contrast, can screen out irrelevant factors and create a map of virtually instant utility. Performing such an analysis requires first that the floristic data in the DBMS be used to reselect only those polygons that provide the necessary food species (Martin, Zim, and Nelson 1951). One might call this map "deer nutrition requirements" for archival purposes. Subsequently, the physiognomic data can be reselected to produce a map of "deer shelter requirements," on which the areas containing forests, thickets, and shrubs of necessary density are identified. A logical "and," or intersection,

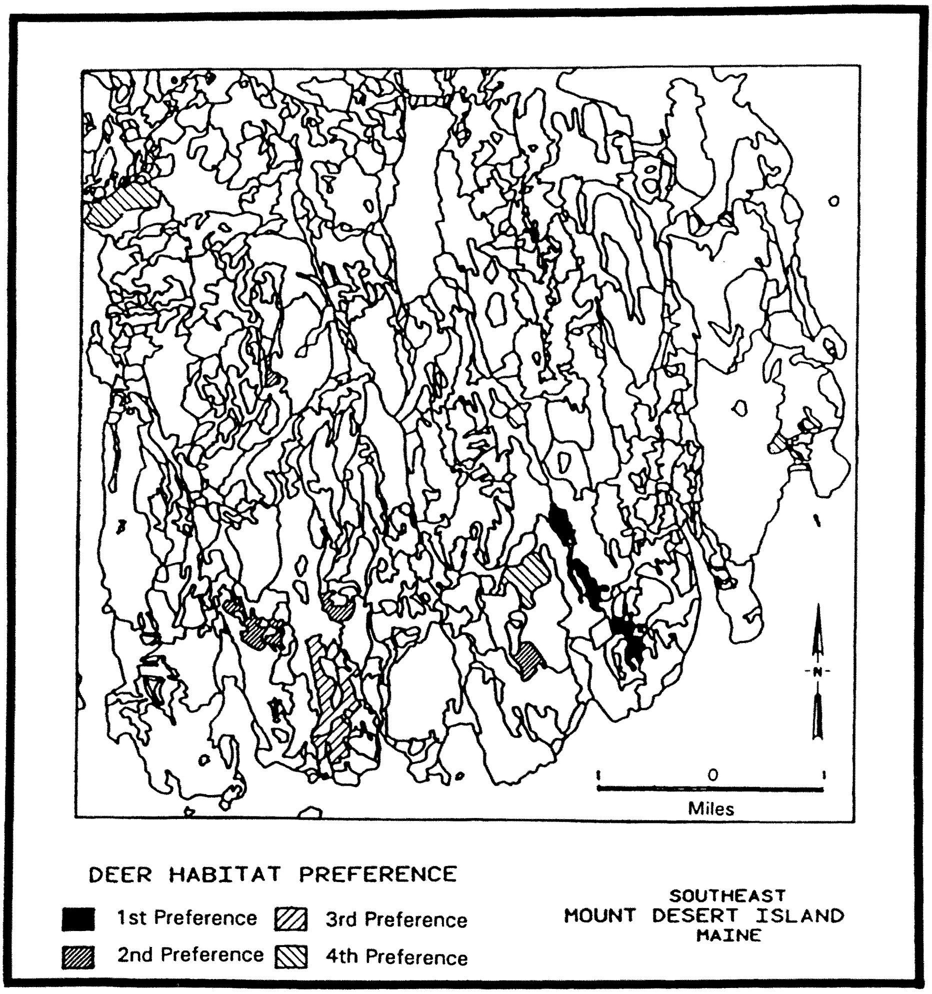

FIG. 4—Map of deer habitat based on selection of dense woods predominated by red maple, a favorite food of deer.

of these map layers produces an integrated terrain unit called "deer habitat," on which only those polygons satisfying both requirements are displayed (Fig. 4).

Analogous utilization of selected habitat data layers in a GIS is common in the current applications, but the practitioners seldom possess the detailed field notes collected by the traditional vegetation mapper. The GIS specialist might gain new insights into the craft by looking to these experts for advice. Many GIS data bases are of limited use because the data collected are task specific and require additional input of data to accommodate other tasks. The comprehensive method employed by Küchler to map vegetation provides a ready prototype for GIS development that enhances its value and flexibility.

Military Case Study

The final example of vegetation-map applications was a military one. Küchler focused in this instance on an army officer who must move troops and provisions in secrecy, unobserved either from the surrounding terrain or from the air. Fundamental among the factors of concern to the officer is whether the vegetation has the required density to provide cover and where the cover is available in a continuous canopy. Additionally, tactical considerations might necessitate troop and supply movements during leaf-off periods, so a knowledge of whether the vegetation is deciduous or evergreen would be important.

The correct assumption here is, again, that the officer is not well versed in species identification. Also, as Küchler noted, the actual species names may well be unimportant, because the canopy cover of many species will be relatively similar. Thus the floristic classification should not be used in this example. The floristic-physiognomic map can readily be correlated to the aerial photograph from which its polygonal outlines were derived and clearly delineates between areas of grassland and forest. The principal disadvantages are that neither density nor vegetative height is available to the map reader; the commercial forest category is useless to the military officer; and the term woodland does not separate deciduous from evergreen, a needed datum for the seasonal-movement analysis.

The physiognomic classification provides the maximum information for the stated purpose. It shows the growth form, such as grass, dwarf shrubs, shrubs, and trees, and gives details of continuity of vegetation. In his analysis, Küchler suggests that the available information from the physiognomic map might recommend a route with continuous coverage of mixed deciduous and evergreen trees, because it would allow movement in any season, would provide a mottled appearance from above, and, perhaps, would give more continuous coverage than deciduous vegetation, where gaps in the cover occur.

Reproducing this pattern from the available physiognomic view of the GIS data base is relatively straightforward. Initially, the view must be further reduced to produce an interim dichotomous map of forest versus nonforest vegetation. When combined with a determination of trees that are more than twenty-five meters high and are connected in continuous sheets, this final view could distinguish potentially useful areas from useless ones. Such a simplified view is quickly and universally understandable and would provide a simpler map for untrained readers, if the officer becomes separated from the rest of the troops.

Though easily operationalized in the GIS, the military example illustrates once again the limitations of an approach stressing communication of data over its analysis. Detailed examination of the data base shows that, under the restrictions suggested in the model, the user arrives at a null set: the map showing good locations for troop movements is empty. The vegetation maps originally drafted by Küchler imply that they can provide information that, in reality, does not exist in the data base from which the maps were produced. This problem does not negate the utility of the original thematic maps for such tasks. It does suggest, however, that in certain circumstances the thematic character of the resultant maps can so effectively mask the true contents of the data base as to provide extremely misleading interpretations. Especially in a military scenario, they could have devastating consequences.

Conclusions

Automated geographic information systems can expedite the comparative method used by Küchler to determine appropriate uses of selected vegetation-map classifications. When a detailed version of his comprehensive original field notes is integrated into the framework, the information for separate categories becomes readily available through the retrieval and output subsystems of the GIS. Detailing the needed parameters for any given example and applying appropriate data-base search strategies allow production of a map for the specific purpose of the user and remove the limitations of the communication paradigm by replacing it with the analytical paradigm.

This approach does more than outline the utility of geographic information systems for vegetation-map applications. Illustrating the usefulness of detailed vegetation field notes should help make the GIS-applications expert aware of the multitude of data potentially available for single-classification uses and should enhance the ability for later development of integrated terrain units based on nonvegetative parameters. Additionally, the traditional vegetation mapper, accustomed to the communication paradigm and to manual cartography, can learn the power of present-day tools to advance research efficiently.

This study required a special concern for original field methods and data-collection techniques, because the principal goal was to connect old and new approaches. Beyond this goal, however, research is needed to illustrate advanced applications available through multiple classifications possible in a GIS. Many applications of vegetation maps not amenable to a comparison of three static map classifications can now be easily performed. Subsequently, with the ability to integrate additional mapped parameters in a meaningful manner, a comparison of ecological map classifications can be undertaken in the same study area. As a practical matter, Küchler had to eliminate ecological classifications for his study, because of the vagaries associated with the creation of ecological maps. Today these vagaries can be subjected to detailed examination under controlled conditions.

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