AN ECOLOGICAL REGIONALIZATION MODEL BASED ON NOAA/AVHRR DATA

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ABSTRACT

Ecoregions are developed to assist in natural resource management and policy making. A quantitative, multivariate regionalization model was developed and applied on vegetation region mapping of Nebraska, the United States. The model aggregated small ecosystems into larger regions in a hierarchical clustering procedure. Ecosystem elements were merged into clusters based on the similarities of their ecological features, and their spatial neighborhood derived from GIS topological files. Vegetation regions of Nebraska were generated using digital State Soil Geographical data and multitemporal NOAA/AVHRR NDVI data of the growing season in 1991.

INTRODUCTION

Ecoregions are geographical zones that contain a number of similarly functioning ecosytems. They may represent broad similarities in ecosystem components including climate, geology, geomorphology, soils, and vegetation (Bailey *et al.*, 1985; Wiken, 1986), or they may be designed to address more specific themes, such as vegetation types, soils, or water quality. Ecoregion frameworks are developed to assist in natural resource and environment management and policy making. In the United States, several ecoregion schemes have been developed. Kuchler (1970) mapped potential natural vegetation of the Unite States. The Land Resource Regions and Major Land Resource Areas (MLRA) were developed by the U.S. Department of Agriculture (USDA) to assist agricultural management (USDA, 1981). Other major frameworks are Ecoregions of the United States by the USDA Forest Service, and Ecoregion Maps compiled by the U.S. Environmental Protection Agency (Gallant *et al.*, 1989). Ecoregions provide a framework in which similar responses may be expected within relatively homogeneous areas. Therefore, it is possible to formulate management policy and apply it on a regionwide basis rather than a site-by-site basis (Bailey *et al.*, 1985).

Most previous ecological regionalizations have been completed by a qualitative approach which employs continual, interactive expert judgements for selecting, analyzing, and classifying data in order to generate regions (Gallant *et al.*, 1989). Quantitative tools are not sufficiently developed for incorporating the multivariate judgements needed to delineate regions. The objectives of this research were to develop a quantitative, multivariate regionalization model and apply it onto satellite imagery for vegetation zoning in Nebraska of the United States. The model was developed to aggregate small ecosystems into large ecoregions based on similarity of biotic and abiotic features. The mergers of ecosystems can be conceptualized by using a hierarchical dendrogram. In this research, State Soil Geographic (STATSGO) data map units were defined as the elementary ecosystems. Bi-weekly composites of Normalized Difference Vegetation Index (NDVI) derived from NOAA/AVHRR were used as surrogates of vegetation conditions.

STUDY AREA AND DATA SOURCES

The state of Nebraska lies between 40^0 and 43^0 north latitude, and between 95.5^0 and 104^0 west longitude (Figure 1). Nebraska is part of the broad region which gently slopes up from the Mississippi River in the east to the Rocky Mountains in the west. The sedimentary rocks of this area are of several types, including limestone, sandstone, and shale. Located in the interior of North America, Nebraska has a continental climate with a considerable temperature range from summer to winter. The total growing season precipitation is generally adequate for crop production (Searcy and Longwell, 1964). Nebraska is primarily a grassland area with some forests and woodlands distributed along river valleys throughout the state. Most of its land has been cultivated for agricultural use.

NOAA satellites provide daily Advanced Very High Resolution Radiometer (AVHRR) data at a ground resolution of 1×1 km. The coarse resolution and high repeat frequency of AVHRR data facilitate large area study and environmental monitoring. In vegetation mapping, it is possible to create phenological profiles from multitemporal AVHRR data to discriminate vegetation types (Loveland *et al.*, 1991). Vegetation indices derived from remotely sensed data have been found to be sensitive to the presence and condition of green vegetation. The Normalized Difference Vegetation Index (NDVI) is one of the commonly used vegetation indices (Goward et al., 1985). The U.S. Geological Survey, EROS Data Center has been compiling bi-weekly NDVI composites that identify peak vegetation growing conditions in each two-week period since 1990. One composite from each month of the growing season in 1991 was selected as input to the model for vegetation discrimination. The eight bi-weekly composites are listed in Table 1. The June image of the study area is shown in Figure 1.

Table 1. List of Bi-Weekly NDVI Images

Period	Month	Dates
1	March	15-28
2	April	12-25
3	May	10-23
4	June	07-20
5	July	05-18
6	August	02-15
7	September	13-26
8	October	11-24

The State Soil Geographic (STATSGO) data set is a digital general soil association map developed by the National Cooperative Soil Survey, USDA. It depicts information about soil features such as water capacity, salinity, layer depth, and organic matter. The STATSGO data are 1:250,000 scale statewide coverages generalized from more detailed soil survey maps at scales ranging from 1:12,000 to 1:63,360 (USDA, 1994). The purpose of using the STATSGO data in the model is to reduce data volume of remotely sensed images by summarizing ecological parameters (e.g. vegetation indices) within map units, and to use the polygon neighborhood relationship of vector maps to maintain the contiguity of regions.

METHODOLOGY

The regionalization model generates regions from polygonal map units according to their similarity in biotic and abiotic parameters. Regions remain spatially contiguous since only neighboring units can be assigned into one cluster in the aggregating process. The base map units are usually low level ecosystems that exhibit relative homogeneity of ecology properties of interest. The parameters are ecological features used to define ecoregions. For the vegetation zoning of Nebraska, the STATSGO map units were used as base units while multitemporal NDVI images were used as parameters for similarity computation. The regionalization model was written in C programming codes. The output maps could be displayed in GIS or remote sensing software packages.

Data Pre-processing

The eight NDVI images of the study area were transformed into Albers Conical Equal Area Projection to match the projection of the STATSGO map. Generalizing parameter values within base map units was the first step in the modelling process. Each of the eight NDVI images was overlaid with the rasterized STATSGO map and its pixel values were averaged within STATSGO map units. One of the generalized images is shown in Figure 2. After this process, each map unit was associated with a set of generalized NDVI values. The neighboring relationships between polygons (units) were extracted from GIS topological files. This data set was used to control the contiguity of ecoregions.

Region Partition

The regionalization model generated regions by aggregating base units through a hierarchical clustering procedure. Two criteria were used to control cluster mergers. One was the similarity between map units or clusters. The similarity index (SI) was calculated from Euclidean distance using the following formula:

$$SI^2 = \sum (X_{ik}-X_{jk})^2 \qquad k=1,2,3,...8$$

where, X_{ik} is the averaged NDVI value of band k for map unit i, and

X_{jk} is the averaged NDVI value of band k for map unit j.

For every two polygons, the smaller the similarity index, the closer their ecological characteristics. The other criterion was the neighborhood relationship between polygons. Two units can be assigned to one cluster only if their distance is small and they are spatially next to each other. The aggregating process iteratively searched for the pair of polygons with the smallest SI, merging them into one cluster, recalculating the area-weighted NDVI values for the new unit, and calculating new distance from this unit to its neighbors. Consequently, clusters grow larger and larger until they are large enough to be final regions. Since only spatially connected units were merged, the regions remained contiguous while they were growing. For Nebraska, the regional clustering started from 2,024 units (i.e., the total number of STATSGO map units in the state). The last 51 mergers are shown in the dendrogram of Figure 3. Each of the 51 clusters comprises more than 10 original units. Twelve regions were formed at distance level around 0.5, two of them were too small in area and dissolved into the surrounding regions. The dendrogram was broken down at this level because of two reasons. One was that the areal extent of regions at this stage are close to that of other ecoregion schemes for this area, the other was that several large regions (2, 3, and 4) merged at this level almost simultaneously.

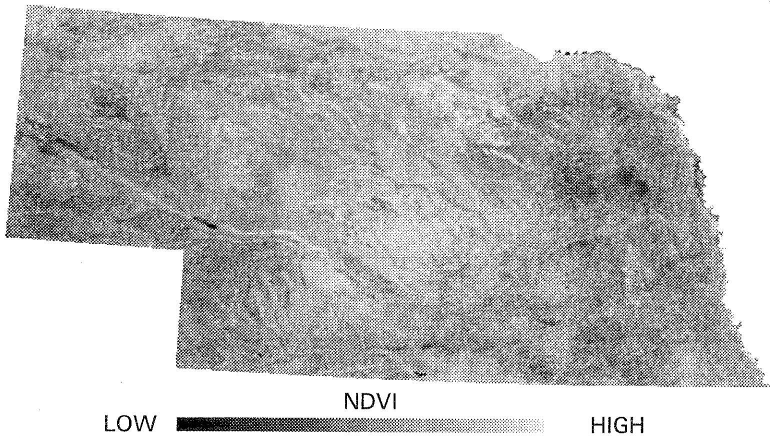

Figure 1 NDVI bi-weekly composite of Nebraska derived from NOAA-AVHRR imagery, June 07-June 20, 1991.

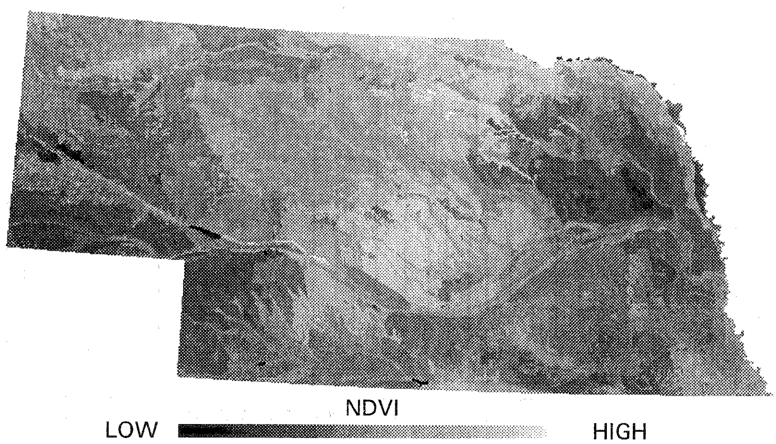

Figure 2 NDVI composite of June 07-June 20 after being generalized within STATSGO map units.

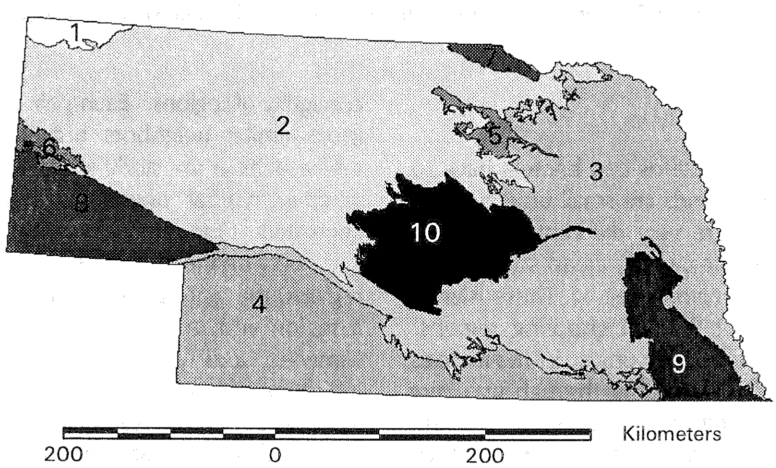

Figure 4 Vegetation regions of Nebraska derived from AVHRR data using the regionalization model.

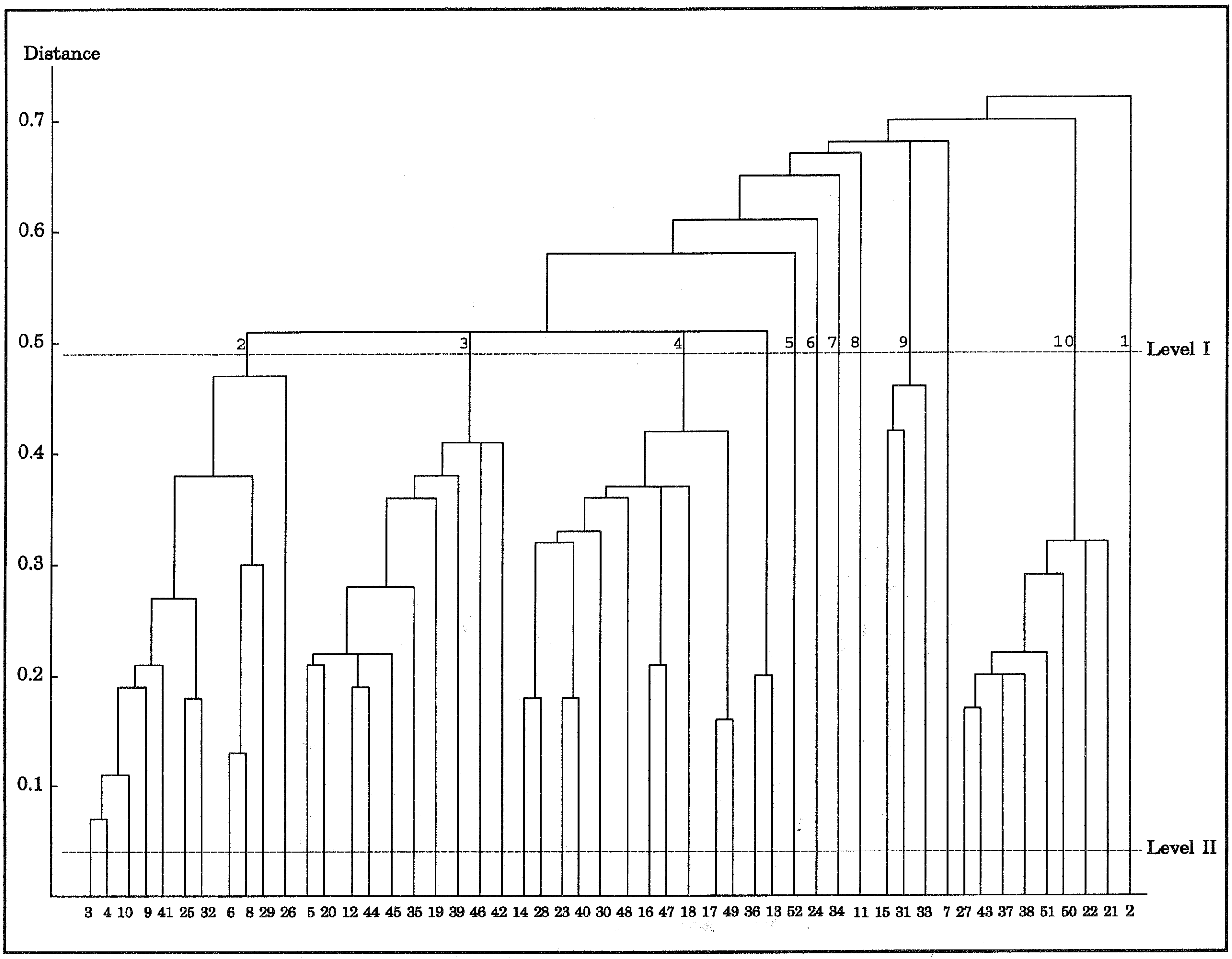

Figure 3 The dendrogram of the last 51 mergers in the aggregating process. The final vegetation regions are compiled from the clusters created at level I.

Modification

Some extreme cases such as islands and barriers have to be removed from regions. Islands are small units located within large regions. They are very different from their surroundings (e.g., water bodies, urban areas) so that they cannot be merged into the regions nearby. These islands were forced to join one of their neighboring regions. Barriers are another type of extreme units. In most cases they are small elongated units cutting through two very similar units. These barrier units were also identified and removed, resulting in the merge of similar areas which might otherwise be arbitrarily separated. The ten final regions are shown in Figure 4.

Evaluation

The fundamental difference between the region partition method developed in this research and the traditional hierarchical clustering method is that the former employs the polygon neighborhood relationship to maintain the contiguity of regions. Each pair of units merged were the most similar neighbors but not necessarily the most similar units in the study area. It is necessary to evaluate whether natural differences exist among the regions generated. One method used was comparison of within- and between-region variations. When constructing regions, the attempt is to maximize homogeneity within a region and maximize heterogeneity between regions (Amedeo and Golledge, 1975). Low variances are indication of homogeneity of regions while high variances are indication of heterogeneity. The multivariate F-test was used to compare variances and it was found that between-region variance was significantly larger than within-region variation at α=0.1 level. The second evaluation method used was comparison of the means. For each NDVI composite, the means of the ten regions were compared using Least Square Means method. No pairs of regions were found equal in more than two layers. These two types of evaluations prove that the regions generated by the model differ in NDVI of the growing season.

RESULTS AND DISCUSSION

To find out the vegetation type composition for each of the final regions, the vegetation zone map was overlaid with the Seasonal Land Cover Regions compiled from March-October 1990 AVHRR imagery. The dominant vegetation types for each region is list in Table 2. East regions 3, 9, 10, and 6 are dominated by agricultural crops while west regions are 2 and 8 are used mainly for ranches. Natural Tallgrass Bluestem Prairie covering east regions 3 and 9 has been replaced by cropland. Most of the western grassland is in native short grasses grazed by livestock.

Table 2. Major vegetation types in vegetation regions

Zone	Major vegetation types
1	Wheatgrass, blue grama, needleandthread, needlegrass
2	Bluestem, grama, wheatgrass, small grains
3	Corn, soybeans
4	Blue stem, grama, wheatgrass, buffalograss, wheat, sorghum
5	Irrigated agriculture, mixed row crops, corn, soybeans, woodlots
6	Irrigated agriculture, mixed row crops
7	Blue stem, indiangrass, switchgrass
8	Wheatgrass, blue grama, needleandthread, big sage
9	Corn, Soybeans, sorghum, irrigated ag, mixed woodlots
10	Mixed crops (wheat, sorghum, corn, alfalfa, oats)

AVHRR data have been an information source for large scale vegetation study. They have the potential to be an important vegetation surrogate in ecoregion mapping especially when combined with topography, soils, climate, and other ancillary data. Images from more than one year may be necessary to minimize the effect of yearly phenological variation and vegetation vigor variation. Among the images used in this study, the June layer is found having the best ability to differentiate regions. Some layers have obvious seams between two adjacent AVHRR paths, which could make false region boundaries. Image quality has to be carefully examined before input to the model.

The methodology developed in this study is reproducible. It can be applied to other regions or other thematic data sets not collected by remote sensors. When more than one type of thematic data are used to define ecoregions, the importance of parameters may be different. The selection of variables and the weights of variables have to be decided according to the nature of the particular area being studied and the theme of ecoregion.

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