Applications for Predicting Precipitation and Vegetation Patterns at Landscape Scale Using Lightning Strike Data

Deborah Ulinski Potter

Abstract—Previous publications discussed the results of my dissertation research on relationships between seasonality in precipitation and vegetation patterns at landscape scale. Summer precipitation at a study site in the Zuni Mountains, NM, was predicted from lightning strike and relative humidity data using multiple regression. Summer precipitation patterns were mapped using a Geographic Information System (GIS). Winter precipitation and vegetative cover were obtained from the Terrestrial Ecosystem Survey (TES). Finally, winter and summer precipitation amounts and their percent of annual precipitation were compared to grass and tree cover. Results indicated that winter precipitation influenced tree cover. Grass cover dominated by *Bouteloua gracilis* was most closely related to summer precipitation. Grass cover dominated by *Festuca arizonica* was most closely related to winter precipitation. This manuscript presents a synthesis of the dissertation research. It discusses how land managers can use lightning strike data and TES information. Ecosystem management applications for predicting precipitation and vegetation patterns at landscape scale are explored. For example, vegetation regeneration may be more successful if precipitation patterns are known. Understanding relationships between vegetation and precipitation patterns can also be used to assess the behavior of fire and for restoring disturbed areas. Additional research at landscape scale could improve our understanding of potential changes in vegetation patterns due to climatic warming.

Study Site and Methods

In New Mexico, 50-70 percent of the annual precipitation comes from convective thunderstorms in the months of June through September. This precipitation has high spatial variability that may not be detected by conventional precipitation monitoring stations. It can be accurately estimated using lightning strike data with a spatial resolution of about 2 km, and the method is appropriate for landscape scale (Gosz and others 1995).

Lightning direction finders detect cloud-to-ground lightning that is in progress. The instruments sense low-frequency radio pulses associated with lightning discharges. Lightning sensors are operated throughout the United States by Global Atmospherics, Inc. as part of a National Lightning Detection Network. Gosz and others (1995) developed algorithms between lightning and summer precipitation quantity to determine rainfall depth and distribution at the Sevilleta National Wildlife Refuge, NM. These methods were later applied to a 140 km^2 site (Pole Canyon) in the west Rio San Jose watershed near Grants, New Mexico (Potter 1996; Potter and Gorman 1996; Potter and others, in press). This study site was a prototype for ecosystem management located within the Mt. Taylor Ranger District of the Cibola National Forest.

First, summer precipitation was predicted from lightning strike and relative humidity data using multiple regression. Then summer precipitation patterns were mapped using a geographic information system (GIS). Winter precipitation and vegetative cover were obtained from the Terrestrial Ecosystem Survey (TES) of the Forest Service Southwestern Region (USDA Forest Service 1986). Finally, winter and summer precipitation amounts and their corresponding percent of annual precipitation were compared to grass and tree cover using modeling capabilities within the ARCINFO Geographic Information System.

Both precipitation and vegetation data were ranked and divided into three classes. Map overlay and cross-tabulation techniques were used to compute percent composition of vegetation classes within each precipitation class. Relationships between precipitation and vegetation by growth form (for example, trees and grass) were tested using Cramer's V statistic, a measure of association. Results indicated that winter precipitation influenced tree cover. Grass cover dominated by *Bouteloua gracilis*, a warm-season species, was most closely related to summer precipitation. Grass cover dominated by *Festuca arizonica*, a cool-season species, was most closely related to winter precipitation.

These results were consistent with findings by Phillips and Ehleringer (1995) that winter precipitation reaches deep soil layers and is subsequently utilized by tree roots while summer rains have minimal uptake by trees. Other factors that can affect vegetation patterns were also discussed in the dissertation. The following discussion focuses on applications of these research results and related studies.

Discussion

Gosz and others (1995) noted that contour plots of precipitation generated from lightning data could be combined with satellite data for vegetation, i.e., a greenness index, to identify areas that will have short-term increases in primary production of terrestrial vegetation. Knowledge of precipitation patterns could be used to maximize the

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Deborah Ulinski Potter is Physical Scientist, U.S. Department of Agriculture, Forest Service, Watershed and Air Management, 517 Gold Ave., S.W., Albuquerque, NM 87102.

effectiveness of restoration projects such as reseeding or sludge application. For example, degraded areas that recently received a high intensity of lightning strikes could be targeted for immediate restoration. Improved timing of the project could lead to greater success in the germination, growth and survival of seeded plants. Hogg and Schwarz (1997) investigated conifer regeneration across a moisture gradient from semi-arid to moderately moist climates. They found that regeneration capacity was related to a climatic moisture index.

Patterns in precipitation and vegetation could also be used to help determine desired livestock stocking rates and timing or to evaluate existing livestock management practices. Oesterheld and others (1998) determined relationships at regional scale between stocking rates and the normalized-difference vegetation index-integrated value (NDVI-I) obtained from advanced very high resolution radiometer (AVHRR) data. AVHRR data are used to estimate aboveground net primary productivity. Although the remote-sensing method was applied at regional scale, it could be adapted to predict stocking rates at regional scale, landscape scale, and for areas within a landscape. Variations in soil moisture, soil quality and other factors are also important in selecting or evaluating livestock management alternatives.

Lightning strikes are the primary cause of natural fire ignitions. Latham and others (1997) combined lightning location data and fire risk data (ignition potential based on fuel maps) to estimate probable fire occurrence. Predictions were compared to the sole use of lightning data and the National Fire Danger Rating System to assess wildfire potential. Results were better than using lightning strikes alone since some fires are short duration or fail to spread after ignition. Combining Latham's techniques with those of Gosz and others (1995) could improve wildfire predictions by accounting for the spatial variability in precipitation. Results could enhance the benefits of savings in fire suppression time and cost, and reduced risk to firefighter safety.

Climate effects on the growth of individual trees and species can be derived at fine spatial scales from statistical relationships between ring widths and monthly total precipitation and monthly mean temperature. Relationships between trees and precipitation will vary among species, and results of this investigation were similar to ring-width studies of confers. Meko and others (1994) reconstructed amounts of cool-season precipitation from ring-width indices of conifers in the Sonoran Desert that are drought-sensitive. They also analyzed the relationship between summer precipitation and ring-width components formed before and after the summer rainy season began. Results showed no relationship between summer rainfall and total ring width. Growth was strongly related to winter precipitation. However, a relationship with summer precipitation was detected in the late-growth component of separated ring widths.

Any application of the research for ecosystem management needs to be framed in an ecological context. According to the Ecological Society of America's Committee on the Scientific Basis for Ecosystem Management (Christensen and others 1996) "ecosystem management is management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function." The following seven components are essential:

"1. long-term sustainability as fundamental value; 2. clear, operational goals; 3. sound ecological models and understanding; 4. understanding complexity and interconnectedness; 5. recognition of the dynamic character of ecosystems; 6. attention to context and scale; 7. acknowledgment of humans as ecosystem components; and 8. commitment to adaptability and accountability." Products from the dissertation study contribute to ecological modeling at landscape scale and our understanding of ecological complexity and the dynamic character of ecosystems.

TES Applications

The Southwestern Region's Terrestrial Ecosystem Survey for classifying and mapping terrestrial ecosystems is a valuable source of soil, climate and vegetation data. A secondary benefit of the lightning research was to explore a new application for TES data. More recently, the practicality of using TES data as input variables to predict fire behavior was investigated by Mark Grupe.

In Grupe's study (1998) the FARSITE model for predicting fire growth (Finney 1993) was applied to a prescribed fire planned at Barranco Canyon within the Cibola National Forest, Mountainair District. Data for tree height and canopy cover were direct inputs for FARSITE while crown base height and crown bulk density were interpreted from the TES. A Geographic Information System was used to handle data and for spatial modeling. Management applications of TES data and GIS will likely increase with time due to their ability to help address complex ecosystem issues.

Applications for Lightning Data

Lightning direction finders are one of several remote sensing methods to locate lightning and understand thunderstorm activity. A Lightning Detection and Ranging (LDAR) system has been developed to detect and locate VHF radiation emitted by lightning strikes (Forbes 1993). In addition to other types of ground-based systems, there are space-based precipitation radar systems and lightning detectors in geostationary orbit.

NASA plans to measure tropical rainfall using a space-based precipitation radar system. It's designed to provide high resolution, 3-D images of rainfall distributions and intensity over land and ocean. This Tropical Rainfall Measuring Mission (TRMM) will also provide information on cloud cover, type, and temperatures and radiative energy that is emitted and reflected from the Earth. A Lightning Imaging Sensor (LIS) associated with the TRMM Observatory will be used to study the global occurrence of lightning and its relationship to precipitation (Christian and McCook 1997). Resolution is 5-10 km with coverage over a large portion of the Earth's surface. These data can help quantify associations between tropical rainfall and global circulation of the atmosphere.

A Lightning Mapper Sensor from geostationary orbit will continuously map lightning discharged during day and night at a storm-scale spatial resolution. It will detect and locate discharges from both cloud-to-ground and intra-cloud lightning over large portions of the Earth. The data will be available in real-time for severe storm detection and warning, convective rainfall estimates and storm tracking. Another potential use is to improve long-term weather forecasting.

Applications for predicting relationships between climate and lightning vary by spatial scale. For example, Williams (1992, 1994) developed a method to analyze global temperatures from lightning flashes and subsequent changes in the amplitude of Schumann resonances associated with the earth's electromagnetic field. Methods developed by Gosz and others (1995) and refined by Potter and others (in press) are appropriate at the landscape scale. The National Weather Service (NEXRAD) radar system detects precipitation intensities within thunderstorms. Using surface observations, estimates of precipitation volume could be calibrated from the radar data. Thus, in the future Doppler radar could be used to quantify precipitation amounts at fine spatial scales.

Conclusions

In the dissertation study, canopy cover for grasses and trees was a function of seasonal precipitation. Vegetation measures vary and can be related to several factors. For example, Walker and Langrige (1997) found that the best indicator for grass biomass rates in Australian savannas was an index that incorporated subsoil and topsoil moisture. Similarly, Iverson and others (1997) used an integrated moisture index to predict forest productivity and species composition at dry versus mesic sites. Although average climate conditions were used in this study, climatic extremes can also be essential factors for vegetation patterns. Various factors affecting vegetation pattern were presented as alternate hypotheses in the dissertation.

Knowing how vegetation patterns are related to precipitation patterns at landscape scale can be useful in fire management, ecosystem restoration projects, and ecosystem management. Such information could be used to improve wildfire predictions and staffing plans. Degraded areas that recently just received a high intensity of lightning strikes could be targeted for immediate restoration projects such as reseeding or sludge application. Patterns in precipitation and vegetation could also help determine livestock stocking rates and timing, or be used to evaluate existing management practices. Understanding how the distribution of grasses and trees changes in response to precipitation and other climate variables might help managers determine whether desired plant distributions can be achieved and sustained.

In addition to management applications, there are potential research applications from the study. The modeling capabilities of ARCINFO could be used to help predict migration patterns of trees and grasses at landscape scale in response to various climate change scenarios. Anticipated improvements in wildland fire assessment by combining Latham's techniques with those of Gosz and others (1995) would require additional investigation or collaboration.

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