[DA-032] GIS&T and Natural Resource Management

Abstract

Geographic Information Systems (GIS) is a geospatial technology that has matured with the help of natural resource management applications. Since its early beginnings as an extension of cartography, GIS has been used to capture, manipulate, store, analyze and manage data. GIS has matured as additional sciences began to adopt and apply it to multidisciplinary problems. In the mid-90s, much of the emphasis moved to desktop GIS making the access and use more mainstream and capable on personal desktop computers. Government agencies with more available and distributed datasets through the internet enabled more applications and use across disciplines because of the access. Soil scientists, wildlife biologists, hydrologists, engineers, planners, and others could now pursue spatial problems efficiently and effectively. More and more advances were being made in the sciences due to the new technology. The following discussion will focus on the use and applications of GIS for natural resource management. Areas covered in this review will be for forestry, watershed analysis, wildlife management, and landscape analysis. First a background of the applications will be introduced followed by a discussion of their applicability and uses.

Keywords: forestry management, landscape analysis, landscape metrics, watershed analysis, wildlife modeling

Author & citation

Strager, M. (2019). GIS&T and Natural Resource Management. The Geographic Information Science & Technology Body of Knowledge (4th Quarter 2019 Edition), John P. Wilson (ed.). DOI: 10.22224/gistbok/2019.4.2.

This entry was first published on October 6, 2019. No earlier editions exist.

Acknowledgments

This chapter is based upon work supported by the National Science Foundation under Cooperative Agreement Number OIA-1458952. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The work was also supported by the USDA National Institute of Food and Agriculture, Hatch project, and the West Virginia Agricultural and Forestry Experiment Station.

Explanation

5. Landscape Analysis

1. Introduction

Natural resource management requires the integration of complex and diverse systems in which GIS can play a critical role (Mallawaarachchi, et al. 1996). GIS can be the great integrator since so many issues are inherently spatial. Locations of interest or of unique attributes must be mapped and analyzed in relationship to others to identity for determine features that would not be realized individually. The ability of spatial analysis to provide information about where features overlap and share areas, exist within distances, share a segment, or cross a boundary are fundamental basic spatial analysis functions. More advanced spatial analysis entails more sophisticated modeling in which multiple layers are combined uniformly or by using weights to emphasize importance (Tate, 2018).

Natural resource management relies on the ability to provide information about how one resource interacts with others or how human influenced actions to the natural environment result in changes to the natural resources. Spatial analysis is a critical tool to aid in natural resource management. In spatial analysis, it is in general the ability to discover information about spatial data based on its locational relationship to other spatial data. One of the main applications of GIS use in natural resource management has been in the area of dealing with environmental hazards such as floods, landslides, soil erosion, and drought (Grunstrabe, 2017). It is not possible to stop these events but GIS can be used to mitigate or decrease their impact. This can be done by using GIS to map and analyze land cover and terrain characteristics. A change detection usually done in raster GIS can show which land cover types and uses have changed over different dates and examine the causes as well as the implications related to potential impacts. Models can be constructed to perform scenario analysis in which inputs are altered to represent either the current or a future prediction and determine the cascading impacts of the change in model runs.

Many of the features that are the inherent foundation for natural resource management are from land use and land cover. Land is a very fundamental resource for all human uses that meet human needs (socio-economic) and environmental features and processes (biophysical) (Atesmachew, 2018). Land is a resource that needs to be used in a sustainable manner to ensure the benefits that accrue from existing land cover and use are available for future generations. It has been well acknowledged that the depletion of natural resources has many consequences. Some of which are not immediately noted such as an increase in the cost of living, changes in weather patterns, and a decline in the economic, social and cultural benefits that were accrued as a result of the land use (GIS Lounge, 2019). There is a big need to make sure land resources are effectively managed.

2. Forests

Forest land cover is a natural resource that benefits many aspects of the environment with proper management. McKendry and Eastman (1991) provide an early outline of forestry assessment activities which include: inventorying for harvests, fuel, food, recreation and conservation purposes. They also note the importance of topography, soils, hydrology, and climate to monitor changes to forests that can occur over time. Sustainable forestry practices include the proper harvests and timing to ensure species diversity and yield are maximized. GIS can aid in this process in many ways. The mapping of forests is often done using remote sensing procedures in which training data is created of known forest locations and type and a supervise or unsupervised classification approach may follow in which either the known forest locations are used to train the model before a classification or in the latter case, a model run sorts and partitions the extracted cover types to fit the spectral and scale information of the input.

With land cover mapped as forests, a change analysis can be accomplished with a raster based approach using spatial analysis procedures within a GIS. One of the most simplistic approaches is to reclassify the land cover maps into forest and non-forest areas as 1 and 0 respectively. Next, the forested area of the second-time frame can be reclassified as 5 and 0 in which 5 is the forest and 0 is the non-forest area. To determine the change, the raster calculator can be used to subtract one grid from the other which is part of grid algebra. The critical component is to make sure non-forest is always 0 and the two-time periods have different values on the forest class. In the example for our forest and non-forest areas, but subtracting the new forest grid (5,0) from the older forest grid (0,1) would result in values that include [-5, -4, 0]. Zero areas would be non-forest from both years, and -5 would be new forest, and 1 would be lost forest. Of the lost forest areas, it is always useful to first find the lost forest areas (i.e., 1) and multiply it by the newest land cover to determine what the forest cover was converted into. Was it now no longer forested because it was cut and became barren land? Was it converted to a mine site, well pad site or agricultural field? Sometimes at the urban/rural fringe extent forests are lost to construction of residential areas which are mostly high occupancy areas. This example is one which can be performed using any different time periods of the land cover data.

Most forests are mapped as part of the national land cover dataset as deciduous, mixed, or coniferous. This limits many wildlife prediction or probability models that may require specific forest types to better understand and map the species range and extent. One way to infer forest vegetation communities is through landform analysis. Different landforms may give rise to a variety of vegetation types due to different environmental settings. Certain trees associated with different slopes and different land forms. For example, in a very simplistic landform analysis, conifer red spruce trees prefer shady and moist areas where deciduous oak trees like drier areas. The moist and dry areas can be calculated from the ecological land units of landforms which can consist of round summits, flat summit, slope bottom, cliff, side slope, slope crest, upper slope, cove/draw/toe slope, dry flat, moist flat, wet flat (river or stream). One approach to relate these ecological land units or landforms to eastern forests consists of the approach demonstrated in Figure 1.

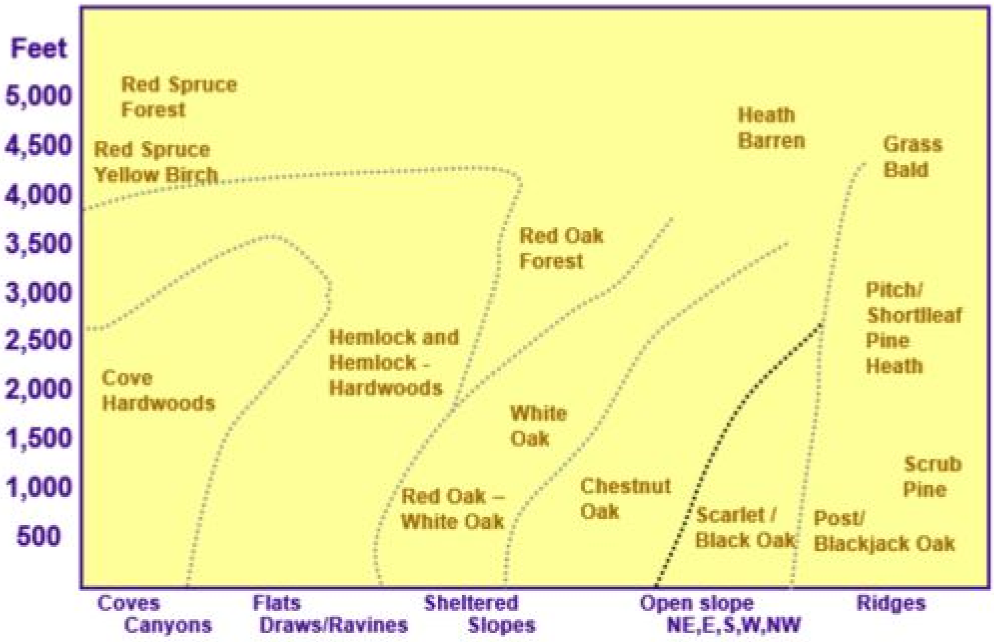

Figure 1. Eastern Forest landform to forest species relationships. Source: author.

While these relationships are only to be used to infer species, the approach can help with forest management and planning when the highest yield forests are matched with the preferred landscape terrain.

3. Watershed Analysis

Another GIS and natural resources application that uses terrain analysis is watershed management. GIS can be a valuable tool to help in identifying regional stresses such as those from sedimentation, riparian habitat, mine drainage, acidic deposition, phosphorous and nitrogen. The watershed-based framework to water quality regulation and management is an integrative approach to address pollution sources degrading the quality of rivers, streams and lakes. This approach to water quality management has its legislative roots in the 1972 Clean Water Act (CWA). While water quality concerns focused on point sources for the first twenty years of the CWA, the stated goal of the CWA was to clean-up and protect U.S. water bodies from both point and non-point sources (NPS) of pollution. The importance of addressing non-point sources and their contribution to water quality problems has become evident. In most states in the US, the NPS pollution problem dominates the listing of impaired streams not meeting their designated uses. Fortunately, the watershed-based approach that integrates point and NPS problems can help improve water quality by including all the identified possible sources of pollution. Many regional and local studies have used a watershed framework in combination with GIS to aid in water quality analyses and watershed management.

GIS has been shown to be a valuable tool for water resource management. Elevation which is the determinant of terrain is a critical dataset. From elevation, it is possible to delineate watersheds, track the flow from a point, find intermittent stream paths, and calculate drainage areas. The GIS use in the hydrological cycle can be thought of as mapping the overland flow path or surface as runoff is modeled. The use of elevation and processing to create flow direction, flow accumulation and flow length commands provide much insight into tracking water contributions and areas. Event mean concentrations can be attributed to land cover types to predict loadings at a cell and cumulatively across the landscape. Flow models which consider more inputs of the hydrological cycle improve water quality estimates. Being able to delineate watersheds from a user specified point, for each stream reach, or by a designated drainage area can help resource managers make cumulative analyses by relating the landscape disturbance to a drainage area extent or catchment and then link it to downstream impacts. Watersheds are a key unit of analysis for examining water quality issues. Scale issues require us to delineate smaller watersheds for local issues. Fortunately, more advances are being made all the time and Light Imaging and Detection Radar data (LiDAR) is more available to all states.

4. Wildlife Management

Another GIS and natural resource application that managers apply is habitat suitability indices which try to quantify specific habitat requirements of fish/wildlife species. The use of GIS is critical to this success to map key habitat elements, assign scores or values to each element and combine or overlay to get results. GIS use in data collection for aquatic systems differ from terrestrial habitats. Some examples of aquatic habitat characteristics include surrounding land cover, riparian vegetation, water depth, water quality, substrate, slope - stream gradients, valley segment types, geology (sandstone versus limestone). The GIS data and techniques can be used to describe landscape characteristics to assess habitat quality and quantity. Some examples of terrestrial habitat characteristics that are derived from elevation include slope, aspect, landform index and those derived from aerial photos include land cover, vegetation, forest stand composition, age, and size of the stand, and land cover diversity, variety and the majority. With the habitat suitability indices, it is often useful to develop models for species that fit the conservative (low estimate) or liberal (high estimate) ranges. Habitat suitability indexes or (HSIs) were developed by the US Fish and Wildlife Service to assess habitat quality and quantity for individual wildlife species. HSI models are based on calculating scores associated with variables representing requirements of particular species (such as food, cover) which are very specific to each species. An overall HIS score ranges from 0 to 1 where 1 is most suitable. Models exist for over 150 species. Some of the models lend themselves to the use of GIS to quantify certain variables. Not all variables in a given HIS can be found in GIS. Many are very site specific and require wildlife biologist to inventory the location and make field notes for the specific variable that needs to be present for the species to likely use or be at the location.

5. Landscape Analysis

The previously discussed natural resource management applications of GIS for forests, watershed analysis, and wildlife management all have components of landscape analysis. Landscape analysis also can be thought of its own natural resource management discipline. Landscapes are important in the area of wildlife by determining how the species can handle a large-scale disturbance such as a fire or flood. After a recovery period if the landscape has enough capacity the recovery is faster and more complete to allow the species population to exist. When the landscape struggles to sustain its composition as defined by its characteristics and values, another large-scale disturbance can likely mean the population is not able to persist. The need exists to measure the size, extent, composition, diversity, majority, etc of landscapes that meet a particular goal, benefit, or species. The landscape that is more intact and has the unique and important characteristics for the population will sustain the disturbance event.

To measure one landscape versus another, the goal is to study the landscape metrics. The pattern and process relationship is studied. This approach has been applied on literally hundreds of indices of landscape patterns. Some of the important considerations when using landscape metrics are that landscapes do not exist in isolation. They are nested within larger landscapes. There is also a degree of openness of a system in which from a geomorphological perspective, a watershed is a closed system. However, for a bird population, a watershed is an open system. The most important consideration when analyzing two different landscapes is scale in an ecological investigation. The landscape scale must be explicitly defined and the pattern or relationships relative to scale should be understood. It is very important to be very cautious when attempting to compare landscapes at different scales.

The four main classes of landscape patterns that are applied to spatial data are spatial point patterns, linear network patterns, surface patterns, and categorical map patterns (McGarigal et al. 2012). In spatial point patterns, the analyst is interested in the locations of the points. Are the points clustered, random, or dispersed? This is the primary question to ask over the quality or quantity of the points. For linear network patterns, a map of streams or riparian areas can be used to characterize the physical structure. Questions in linear network patterns are concerned with corridor density, connectivity, upstream and downstream access or link order differences. In surface patterns, no explicit boundaries are used in the analysis. Patches are not delineated, we are looking for spatial dependencies between the features and their neighbors. Some examples of datasets where the surface pattern is analyzed include elevation, precipitation, and other continuous data. The categorical map patterns are likely the most common forms of landscape pattern analysis. The land cover datasets can be used as inputs for finding the mosaic of discrete cover type patches. The goal is to characterize the composition and spatial configuration of the landscape. The characterization falls under composition where features associated with the variety and abundance of patch types but not considering the placement, attributes or location of the patches in the mosaic. The other characterization approach is spatial configuration which refers to the spatial character and arrangement, position, or orientation of patches within the class or landscape.

The applications of GIS in natural resource management are not limited to just those discussed here for forests, watershed analysis, wildlife management, and landscape analysis. There are many advances in the GIS and spatial analysis areas that are a result of specialists in applied natural resource fields asking spatial questions. GIS is the great interdisciplinary tool. While the field of Geography provides much of the science of location, it is also greatly enhanced by others that use the technology and tools to solve problems. The future will continue to be driven by innovation in this area as additional researchers and practitioners hone their spatial skills and advance their science and that of GIS and spatial analysis.

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