[DA-016] GIS&T and Forestry

Abstract

GIS applications in forestry are as diverse as the subject itself. Many foresters match a common stereotype as loggers and firefighters, but many protect wildlife, manage urban forests, enhance water quality, provide for recreation, and plan for a sustainable future. A broad range of management goals drives a broad range of spatial methods, from adjacency functions to zonal analysis, from basic field measurements to complex multi-scale modeling. As such, it is impossible to describe the breadth of GIS&T in forestry. This review will cover core ways that geospatial knowledge improves forest management and science, and will focus on supporting core competencies.

Keywords: accuracy, forest, GNSS, GPS, inventory, modeling, planning, water, wildlife

Author & citation

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Explanation

1. Definitions

FIA - the Forest Inventory and Analysis Program, a nationwide network and sampling program to measure forest structure and health across the entire United States.

LiDAR - Light detection and ranging, a method that uses lasers to measure the three-dimensional locations of objects

GNSS - Global Navigation Satellite Systems: positioning systems based on a constellation of satellites that transmit location information, including the US GPS, European Galileo, and Russian GLONASS.

2. Introduction

One overarching characteristic influences the application of GIS&T in forestry: forests are extensive, often remote, and have distributed resources, many of which are low-valued alone but highly valued in aggregate (Köhl et al. 2010). Few individual trees are important, yet stands, hillsides, and whole forests provide wood, fiber, habitat, and water of immense local to global value. We directly gather information on individuals and small clusters, visiting single trees or plots to measure tree height, soil depth, species richness, or animal abundance, and then aggregate up to larger extents. This need for large area mapping of low-valued features, often in remote locations, brings GNSS, remote sensing, and interpolation/extrapolation to the fore in geospatial analysis for forestry (Lillesand et al. 2015). Forest science and management needs have spurred and benefited from new remote sensing technologies, both passive satellite and aerial systems (e.g., Landsat and FIA), and active aerial and ground-based LiDAR (Maltamo et al. 2014).

A breadth of interests is another hallmark of GIS in forestry. A traditional focus on wood and fiber production is certainly common, but in many instances GIS use in forestry focuses primarily on providing clean and abundant water (Getahum 2011), enhancing fish, wildlife, and threatened species populations, providing recreation opportunities, improving landscape resilience to fire, or for enhancing scenic values (Bettinger et al. 2017). This breadth of ends implies a breadth of means, so foresters use many spatial tools.

3. Inventory: Seeing the forest for the trees

Field measurements are the foundation of forestry, relied upon by every forest management organization. The goal is to map aspects of physical and biological structure that are relevant to the organization’s mission. Geospatial data depicting previous or current conditions are often used to help design the inventory, for example, a satellite image may be processed to identify forest lands, for improved plot placement (Wulder and Franklin 2007). Forest characteristics are measured at these field plots, such as tree size, health, dominance, or density, shrub or other plant condition, soil type, terrain slope, or other features. Plot center or perimeters are often collected using GNSS, and stand polygons delineated, sometimes in the field, often with the aid of aerial or high-resolution satellite images. Extensive attribute data are often collected, requiring a basic familiarity with data tables in GIS.

GNSS is key technology in modern forest management, allowing meter or better-level positioning under most field conditions, in most weather, day or night (Awange 2012). Forest plots, stands, roads, disturbances, important habitat, nesting sites, streams, and wetlands are just a few of the features regularly field-mapped by forest managers.

Aerial and satellite image interpretation, and increasingly LiDAR data analysis, are also key tools in developing quantitative and qualitative information for vegetation types, vegetation structure, and terrain morphology (Lillesand et al. 2015). Many national and regional organizations collect complete coverage with aerial photographs and/or satellite images, and use these to identify tree taxa, harvest areas, or to plan management activities. LiDAR methods are currently undergoing intense development for forest measurements, and have been proven as useful tools in measuring tree height, biomass, and density across regional to national extents (Maltamo et al. 2014). Unmanned aerial systems (UAS), also known as drones, are currently under intense development, and portend increased flexibility, currency, and resolution in forest imaging and spatial data collection.

The spatial accuracy of field measurements and derived data bear particular attention in forestry, because multiple sources of inventory, measurement, and remote sensing data are often used (Mowrer and Congalton 2000). There are often few distinct landmarks, and data are collected under difficult environmental conditions, increasing chances for blunders in positional data collection or processing. Mis-alignment in plot, image, LiDAR, or other source material may lead to erroneous measurements or novel and unrepresentative combinations. These diminish the quality of data layers created from subsequent spatial processing, and diminish the utility of spatial analysis.

4. Analysis: Aggregation, Models, Estimation, and Prediction

Many spatial analysis techniques are used to scale measurements from plots to larger geographies, creating vector layers of stand boundaries or other categorical objects with important attributes, or for creating raster surfaces of forest condition, e.g., percent canopy cover. Plot or point-measured variables may be interpolated using splines, kriging, or other spatial estimation techniques (Bolstad 2016). Statistical summaries from field measurements are combined with boundaries defined via remote sensing, e.g., object-based image classification, to create vector polygons (Lillesand et al. 2015). LiDAR data may be combined with statistical summaries from field plots, and resultant empirical relationships applied with comprehensive LiDAR measurements to estimate important variables across the landscape (Matlamo et al. 2014).

Models are common, because we often can’t directly measure the resource of interest (Bolstad 2016), or because we wish to predict some future condition. Birds respond to habitat structure defined by the height, density, and tree species mix, and are denser where combinations are particularly appropriate for them. We use more detailed studies of animal density, foraging, reproductive success, or other measures of habitat use to create models based on forest structure, and then use measurements of forest structure to estimate species abundance (Drew et al., 2011). Forest fires evolve rapidly based on their current location and intensity, adjacent forest fuel loads and terrain, and near-term weather; models that predict fire behavior save lives, property, and money (Stratton 2006). Geospatial methods are at the heart of much pre-fire planning, fire management, and post-fire assessment and recovery.

Spatial models are developed and used to estimate water quality or quantity, or recreational value (Lyon 2002, Zwick et al. 2016). There is a rich literature describing the development and use of applied process-based hydrology models, to estimate the timing and quantity of water delivered from forest lands (Getahun 2011). Since forest often use more than fifty percent of the local precipitation, and this evapotranspiration varies by species, age, and density, forest management can greatly affect available water. Since water use varies across time and space, the specific combinations of trees, soils, terrain, and precipitation, and weather variables that control water use must be modeled both spatially and temporally.

Geospatial tools are also used in forest planning, to predict future forest states while optimizing for resource flows that are affected by natural, economic, or legal constraints. Forest planning includes selecting a set of desired present and future conditions, and identifying management activities to attain those conditions. Businesses tend toward a focus on wood and fiber supply, primarily under cost, revenue, cash-flow, wood sustainability, and legal constraints (Bettinger et al. 2017). Government managers often give equal measure to water quality, wildlife, recreation, fire protection, or additional other non-marked benefits.

Forest planning is an inherently spatial activity. The current distribution of tree species, ages, and sizes will affect possible future conditions. The survival and growth of trees are dependent on the soil nutrients, water, sunlight, and rainfall at their locations. Focus species, such as the ruffed grouse, Canadian lynx, or marbled murrelet, depend on the amount and spatial arrangement of specific forest types. Stream and river position, the location of erodible soils, and steep slopes all restrict the set of possible management options. The road network and condition affect the feasibility and economics of harvest, thinning, and other treatments.

Laws and policies also specifically incorporate geography, and require the use of GIS to implement and ensure compliance (Bettinger et al., 2017). Legally mandated harvest setbacks are common near streams, lakes, or other sensitive features. A maximum clearcut size is often prescribed, and certain harvest practices restricted on steep slopes. Some areas set adjacency constraints on harvest frequency, for example, a new cut areas may not share a border with any stand harvested in the previous five years. All these biological, physical, management, and legal constraints ensure that spatial analysis will continue to be an integral part of forest management.

In short, spatial science and technologies are inextricably embedded in modern forest management, and will remain so for the foreseeable future. Most forestry students, managers, and scientists would be well served by basic geospatial knowledge.

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