Multi-layered and Statistically Based Ecosystem Mapping

The de facto standard for land resource planning in the 21st century

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SUMMARY

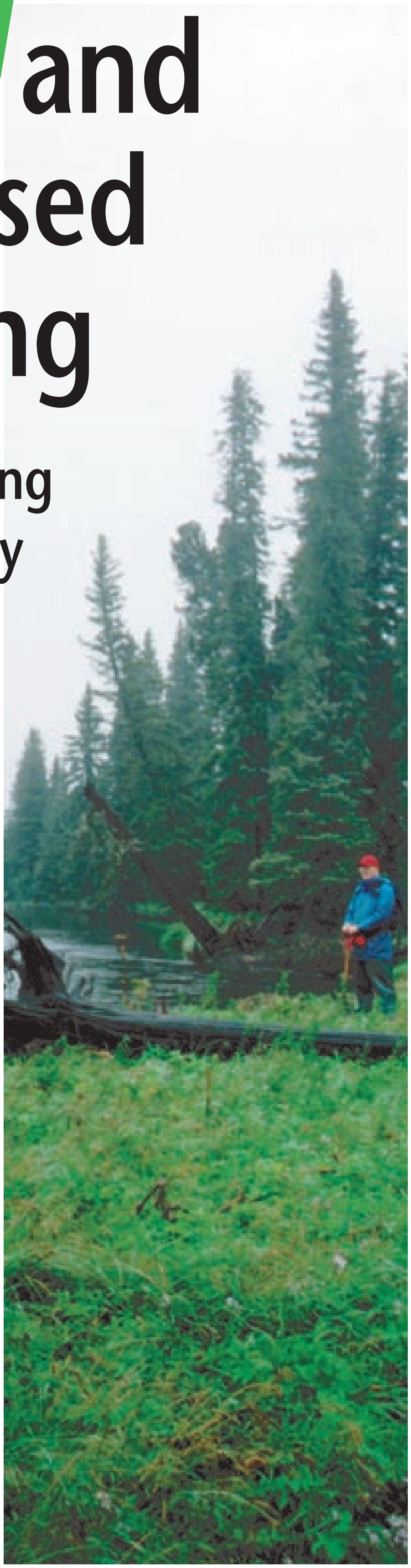
Mapping of small-area ecosystems is accomplished by using five off-the-shelf commercial software packages. Custom programming is the key tool used for merging raster-based information (topographic and remote sensing data) with vector-based information (vegetation inventories) and with relational databases (ecological attributes). Statistical packages and custom programming are used to identify meaningful ecological relationships for integration into GIS information overlays.

Geotechnologies Discussed:
GPS; vector conversions; multivariate analysis; satellite imagery; predictive mapping

Benefits:
Detailed planning to preserve ecological integrity, attain sustainable use of renewable resources, and assist multiple-landuse planning

As the century nears its close, it seems that the pace of industrial development is increasing along with public concern for the environmental integrity of not just the planet, but of small or regional areas as well. Simultaneously, population growth continues, along with a trend towards higher densities of urbanisation, particularly in developing countries. Coincident with these trends is the accelerated exploration for oil, gas, and mineral reserves and the exploitation of renewable resources (such as forests), which requires that sustainable management strategies be developed. With the restructuring and capitalisation of Russia and China and the eventual recovery of Asia, South America, and Africa, we can expect these converging trends to accelerate even further.

In western Canada, sufficient concern over the past 10 years has caused new approaches to be developed that respond to the conflicting demands of industry and public concern about the environment. Geographic Dynamics Corp. (GDC), of Edmonton, Alberta, Canada has created a truly innovative, predictive ecological mapping system, SiteLogix, to identify functionally different ecosystems at very fine spatial scales of resolution. These ecosystem delineations provide a new framework for organising and overlaying large numbers of ecological variables. The result of this effort is a predictive ecosystem map that allows 1) efficient and ecologically responsible development of resources and 2) clearer and more accurate communication between resource managers and the public. By the end of 1999, GDC will have successfully applied SiteLogix to over two million hectares (one hectare is equal to an area 100 m by 100 m, or 2.74 acres) of forest land for five international forestry companies operating in western Canada.



Ecological information is acquired and linked to GPS files by means of detailed field surveys.

What makes SiteLogix unique is that rather than being a software package, it is a process that integrates GIS applications, statistical techniques, and ecological knowledge in order to create a seamless mapping product based upon statistically justifiable ecological relationships.

Ecological Background

Ecological information is usually available in nested levels of detail. The crudest maps have scales of 1:100 000 to 1:1 000 000 and contain information about dominant landforms, major soil types, and geological formations. At the 1:15 000 to 1:20 000 scale are vegetation cover, elevation, and contour maps.

The map scale, however, is not necessarily the determining factor in the accuracy and usability of ecosystem mapping. The complexity of detail contained in underlying information layers is the key to distinguishing functionally different ecosystems. For example, a forest cover map may be at a scale of 1:15 000, but additional information extracted from a landform map (even though it is at a coarser map scale) may indicate ecosystem differentiation not apparent from the forest cover map. The use of multi-layered ecological information is fundamental to the predictive mapping of SiteLogix and can include such overlying ecological parameters as landforms and topography; parent geological materials of the main soil types; soil, moisture, and nutrient characteristics; slope, aspect, and elevation; soil drainage characteristics; vegetation cover, including tree species distribution and productivity; climate factors; successional stages; and natural and human disturbances of the landscape.

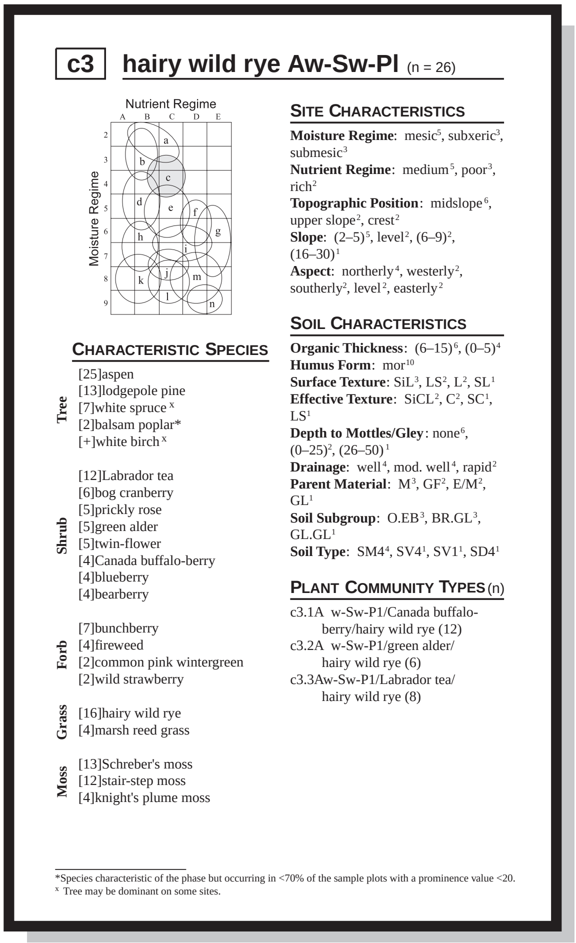
These ecological parameters are used to map functional ecological units. The fundamental ecological unit is named differently in different jurisdictions, but in most mapping completed with the SiteLogix system thus far, the appropriate ecological land unit has been called the *ecosite*. It can be as small as one hectare or as large as fifty hectares, depending on the data available and management objectives. Generally, the ecosite is an area where the climate, soil moisture, and soil nutrient characteristics are similar. *Ecosite phase* is a subdivision of an ecosite and is defined on the basis of the dominant plant species in the canopy.

Methodology

Given the vast quantities of ecological data that must be processed, GDC develops custom programming scripts to speed the analytical steps required to complete an ecosite or ecosite phase map in SiteLogix. More importantly, advanced statistical techniques are employed to identify ecological patterns and trends and assign probabilities to the ecological relationships. The result is a detailed predictive ecosite or ecosite phase map from which many sub-maps can be generated for resource value estimates and management interpretations. Thus far, we have identified eight distinct ecological information packages for management purposes.

What makes SiteLogix a particularly efficient process is the custom programming that, at critical steps in the process, connects five off-the-shelf applications: MicroImages TNTmips, TYDAC SPANS, Statistical Analysis System (SAS), ARC/INFO, and ArcView.

Proprietary code is used to automate the digitising of hardcopy maps; importation of digital terrain files; calculation of slope, aspect, and other topographic variables from digital terrain files; organisation and classification of ecological plot and polygonal data; statistical identification of interrelationships among the ecological variables; merging of neighbouring polygons that had common ecological parameters; and elimination of false-precision polygons, which had areas of less than 0.5 hectares.



c3 **hairy wild rye Aw-Sw-Pl** (n = 26)

SITE CHARACTERISTICS

Moisture Regime: mesic^5, subxeric^3, submesic^3
Nutrient Regime: medium^5, poor^3, rich^2
Topographic Position: midslope^6, upper slope^2, crest^2
Slope: (2–5)^5, level^2, (6–9)^2, (16–30)^1
Aspect: northerly^4, westerly^2, southerly^2, level^2, easterly^2

SOIL CHARACTERISTICS

Organic Thickness: (6–15)^6, (0–5)^4
Humus Form: mor^{10}
Surface Texture: SiL^3, LS^2, L^2, SL^1
Effective Texture: SiCL^2, C^2, SC^1, LS^1
Depth to Mottles/Gley: none^6, (0–25)^2, (26–50)^1
Drainage: well^4, mod. well^4, rapid^2
Parent Material: M^3, GF^2, E/M^2, GL^1
Soil Subgroup: O.EB^3, BR.GL^3, GL.GL^1
Soil Type: SM4^4, SV4^1, SV1^1, SD4^1

CHARACTERISTIC SPECIES

Tree
[25]aspen
[13]lodgepole pine
[7]white spruce ^{x}
[2]balsam poplar*
[+]white birch ^{x}

Shrub
[12]Labrador tea
[6]bog cranberry
[5]prickly rose
[5]green alder
[5]twin-flower
[4]Canada buffalo-berry
[4]blueberry
[4]bearberry

Forb
[7]bunchberry
[4]fireweed
[2]common pink wintergreen
[2]wild strawberry

Grass
[16]hairy wild rye
[4]marsh reed grass

Moss
[13]Schreber's moss
[12]stair-step moss
[4]knight's plume moss

PLANT COMMUNITY TYPES (n)

c3.1A w-Sw-P1/Canada buffalo-berry/hairy wild rye (12)
c3.2A w-Sw-P1/green alder/hairy wild rye (6)
c3.3Aw-Sw-P1/Labrador tea/hairy wild rye (8)

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*Species characteristic of the phase but occurring in <70% of the sample plots with a prominence value <20.
^{x} Tree may be dominant on some sites.

Summary description of one of numerous ecosite phases that have been mapped using SiteLogix.

Collecting and Preparing the Data

The key variables are derived from four primary sources of spatial data: vegetation coverage, soils data, digital terrain model, and ecological land classification data.

Additional data, which can be statistically modelled and queried, increases the applicability of the final model and include climate data, plant community inventories, habitat and wildlife inventories, disturbance history, management parameters and regulatory constraints, and riparian features and hydrological data.

The majority of the available resource maps and data are in hardcopy; the analysis procedure in SiteLogix demands that all data be available in digital form. Thus, one of the first steps is determining the level of effort required to digitise the existing information. A secondary issue is converting between different file formats in which the ecological information is available. For example, ecological data is usually vector-based while topographical data is usually raster-based. In one project, we used raster-to-vector conversion algorithms to produce a polygon coverage of a mapping area that indexed over 100 ecological and geomorphological variables.

We work with the client to determine the detail required and the accuracy desired for the predictive mapping. This means that, at the beginning of a project, we must be able to clearly identify and justify any field surveys. To assist our ecologists in precisely identifying where to most effectively collect field data, we use statistical procedures to select field plots. In one project, 45 unique site types were sampled over an area of 385 000 hectares by the strategic placement and description of 585 detailed ecological plots. Sampling intensity for each site type was based on the relative area of coverage for each type, ecological heterogeneity encountered in the field, and the accessibility of the site.

An essential task after the ecologists return from the field is to ensure the validity of the location data. This requires that the ecological data be cleaned, the GPS data be differentially corrected, GPS points and map plots be reconciled spatially, and plot locations be linked to digitised land resource data.

Creating and Merging Ecological Layers

Digital terrain files are imported into the GIS, where hydrology breaklines and a 50-metre grid are used to produce an elevation model.

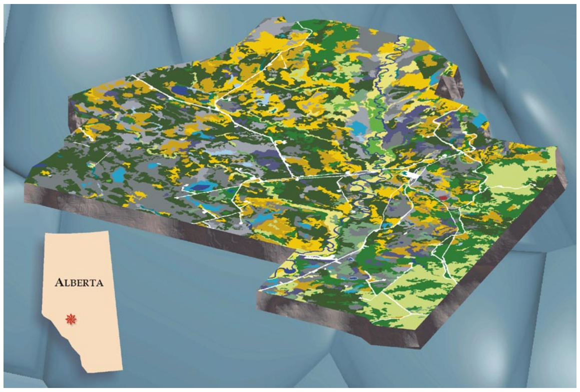
In one project, in order to capture major slope trends we grouped the slope model into 13 classes. Pixel noise (originating from the fine scale of the model) was removed by using a median matrix filter. Accumulated slope length and downslope curvature models were generated, filtered, and optimised for processing. The vector data were used to create an attribute table with nearly 130 ecological parameters.

Generally, raster data are vectorised to create a data layer that holds all the topographic variables. These variables are important for classifying and ranking areas according to their potential for moisture retention, water runoff, and nutrient characteristics.

Analytical Framework for Linking Spatial Data to Ecological Data

The data layers are now ready for integrating the GPS data, which provides a digital point reference file that is used to extract thematic information from the digital layers. Tabular databases are created for the ecological parameters, recorded on plot forms, and the data extracted from the GIS. The databases are subjected to statistical tests using Statistical Analysis System (SAS).

SAS is next employed to analyse the ecological plot and polygonal data in order to identify patterns and trends and to define statistically significant ecological relationships between the variables. Some of the multivariate techniques used include ANOVA together with cluster, regression, discriminant, ordination and correspondence analyses. Statistically justifiable relationships, patterns, and trends are identified by our professional ecologists. Based on the results of these analyses, the ecological model is modified to reflect the actual distribution of ecological units on the landscape. The advanced statistical techniques are iteratively applied to fine-tune the mapping parameters to the point where further iterations do not significantly change the ecosite map. It is not uncommon for 10 to 30 iterations to be required to optimise the mapping. In this way the best predictive model, with the available data, can be created.



A portion of the final ecosite map for an area located near Whitecourt, Alberta, Canada.

Refining the Mapping

The final steps in SiteLogix involve reducing the number of vector polygons by merging polygons that have shared ecological attributes. In one project, the number of polygons in the modelling area was close to 2 million. After merging, only 20 000 polygons remained.

The usual map scale is between 1:15 000 and 1:50 000. At these scales, polygons with areas of less than 0.5 hectares are not appropriate. To eliminate these minimum-size polygons, another merging algorithm is run, based (again) on shared ecological attributes of adjacent polygons.

Mapping Products

The unique nature of SiteLogix is threefold: predictive accuracy of the resulting ecosystem map can be determined, geomorphological alometrics are intrinsic to the model, and advanced statistical analyses are used for pattern and trend recognition as well as revealing ecological relationships. Using this framework, many different predictive databases and accompanying maps can be generated, depending on client needs: forest volume and productivity, biodiversity estimates, wildlife habitat assessment, successional stages, soil characterisations, carbon sequestering, pipeline and road routing, and restoration of disturbed sites.

The Future

Before the year 2001, satellite remote sensing data will have spatial resolutions of 1 metre by 1 metre. In addition, aerial remote sensing data with sub-metre spatial resolutions are currently available. The unprecedented level of detail offered by these technologies will make possible quantitative landscape studies that incorporate simultaneous measurements of environmental variables. The challenge facing researchers is to mine this enormous amount of data for the relationships that most accurately describe ecosystem functioning, given the fact that the data will contain inherently more variability and uncertainty. We have started adapting the statistical techniques developed for SiteLogix to high-resolution images, which will allow us to take our modelling procedures to the next level of accuracy and applicability for addressing integrated resource management needs.

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