AN APPLICATION OF LANDSAT DIGITAL TECHNOLOGY TO FOREST FIRE FUEL TYPE MAPPING

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ABSTRACT

Economic limitations prevent the mapping over large areas of forest fire fuel types using conventional forestry methods. The information contained in such maps would be a valuable tool for assisting in initial attack planning, presuppression planning and fire growth modelling. During the past several years, the Forest Fire Research Institute with assistance from the Canadian Centre for Remote Sensing, has examined the role of digital classification and enhancement methods for producing general forest cover classifications suitable as fuel maps. A Taylor enhancement (Dr. M.M. Taylor, Defence and Civil Institute of Environmental Medicine, Department of National Defence, Downsview, Ontario) was produced for an 8 million hectare fire control region showing water, muskeg, coniferous, deciduous and mixed stands, new clearcut logging, burned areas, regeneration areas, nonforested areas and large forest roads. Use of this map by fire control personnel has already demonstrated its usefulness for initial attack decision making.

Recent work has dealt with temporal overlays and has shown the merits of this approach. Future work is aimed at constructing a digital data base containing geometrically corrected temporal classifications for a large area. When completed, this data base should provide timely information to fire control decision makers and to a fire growth model.

FOREST FIRE FUEL MAPS

The type of forest fuel in which a fire burns is an important factor in determining the fire's rate-of-spread and difficulty of control. As long ago as 40 years, maps showing general forest cover types of fairly uniform fire behaviour characteristics were produced for small areas of the United States and Canada. These maps were made using conventional forestry photography and map-making procedures. However, high labor costs associated with their initial construction and later revisions, forced the abandonment of this approach by the late 1940's.

As timber inventory maps became available, attempts were made to group types into broad fire behaviour classes. Approximately one man-day was required to color a 100 square kilometer timber map. This high cost, the difficulty of keeping maps current, and the lack of complete timber map coverage has discouraged the general use of this approach.

Since the successful operation of the Landsat resource survey satellite, a whole new technology for mapping general forest fuel types has emerged. This technology offers the potential for inexpensive maps over huge areas showing previously economically unobtainable information necessary for a modern fire control operation. In 1974, the Forest Fire Research Institute in conjunction with the Canadian Centre for Remote Sensing (CCRS) began to investigate the capabilities and limitations of some of the various digital processing methods appropriate for forest fire fuel mapping. This paper briefly summarizes our progress, findings, and proposed future work.

INITIAL TRIALS

A test area 250 square kilometers in size was located 250 kilometers northwest of Ottawa in the Province of Quebec. The test area included a mixture of forest stands characteristic of both the northern Boreal and Great Lakes forest types. Conventional forestry aerial photography, low-level 70 mm and oblique photography, timber type maps, and ground checks were used to verify our results. Supervised maximum likelihood classification, unsupervised classification[1/] and digital enhancement[2/] methods were used. All data processing and image displaying were done on the CCRS's Digital DEC-10 computer and Bendix Multispectral Analyzer Display system.

Early experience was gained using supervised maximum likelihood classification. Water, new clearcut logging areas and pure deciduous and coniferous stands could be consistently classified over large areas provided suitable care was taken to identify and locate training areas. Because a large proportion of the test area consisted of all degrees of deciduous-coniferous mixtures, instabilities in the classification were encountered with this approach. Small changes in the training area locations and sizes in transition forest types resulted in significantly different classifications. Unsupervised classification, although it required as much ground truth and operator time as supervised classification, seemed to produce results closer to those shown on the original timber type map. Over large areas the following could be consistently classified: water (small water sources for fire pumps are very important), pure deciduous, coniferous and mixed stands, muskeg, nonforest, and newly cut logging slash areas.

Although in local areas broad species and age class groups could be separated when they occurred in homogeneous stands, it seems safe to conclude that, at the moment, coniferous age class, density and species seem hopelessly confounded over large areas. At the time of these experiments neither classification method produced geometrically correct output or the all-important forest road detail necessary for rapid access to remote fires.

The Taylor digital enhancement method was tried next. From the fire control field personnel's point of view, this approach represented a significant improvement over previous classification results. Enough geometric correction was carried out in the enhancement program to overcome previous field personnel complaints. The users felt that enhancement output closely resembled aerial photographs, in that, transition forest areas could be clearly seen. In addition to those types consistently identified by classification methods, the enhancements showed a broad measure of the degree of revegetation on clearcut logging and burned areas plus significantly improved road detail.

Perhaps more important, enhancement output to the field personnel resembled a map in which considerable human interpretation was still required. Their experience was essential in interpreting the imagery. Classification output lacked credibility, partially because the field personnel were not part of the interpretation "loop". This same problem arises frequently with conventional aerial photography and the corresponding timber maps produced from them. Recognizing the complexity of the forest and the classification difficulty, users frequently insist on using the original photography in conjunction with the timber map.

1/ Goldberg, M. and S. Shlien, 1976. A Four Dimensional Histogram Approach to the Clustering of Landsat Data. Canadian Journal of Remote Sensing, March, 1976.

2/ Taylor, M.M., 1974. Principal Components Color Display of ERTS Imagery. Paper presented at the Second Canadian Symposium on Remote Sensing, University of Guelph, Guelph, Ontario, April 29, 1974.

CONSTRUCTION OF A FUEL MAP

Based on the quality of results obtained in the test area using the enhancement method and the acceptance of these by field personnel, it was decided to produce a demonstration map of a large area. An 8 million hectare area protected by the Societe de Conservation de l'Outaouais (SCO) was selected. A map consisting of 120, 20 x 25 cm photographs of enhanced images at a scale of 1.25 km/cm spanning 5 Landsat frames was constructed and indexed in terms of the SCO's fire location grid structure. This grid, plus the abundance of small lakes in the region, made the location of any fire in the region a simple task on the Landsat enhancement imagery.

Approximately 5 man-days and several computer hours were spent in reaching the best overall set of enhancement parameters. Compromises had to be reached between the degree of coniferous and mixed-wood forest separation and the amount of road and clearcut detail. Another several man-days and about 3 hours of computer time were required to enhance the 120 images. A conventional 35 mm camera and film were used to photograph the display screen. These photographs were later enlarged to the final output size.

The most difficult task in producing the map was the search for and selection of suitable imagery. Experience had shown that only imagery during July and August should be used in eastern Canada. It is impossible to obtain early spring imagery in southwestern Quebec before the deciduous foliage appears without some snow on the ground or ice in the lakes. Later in the spring - say late May or early June, phenological differences between the time of leafing and the coloring of deciduous species coupled with terrain and microclimate influences result in confusion as to deciduous identification. The same confusion is present in September and October.

Winter imagery enables excellent coniferous-deciduous separation and presents a great deal of coniferous density and age class information. However, there is total confusion in the identification of nonforest areas, lakes and newly clearcut slash areas. Roads only show well when they run through coniferous forests.

Cloud and haze obstruction of imagery is a major problem in eastern Canada. During July and August the chance of obtaining a single nearly cloud-free frame is surprisingly low. For example, all frames in the Outaouais region during the summer of 1976 contained at least 50 per cent haze or clouds. Imagery from the summers of 1974 and 1975 were used to construct the SCO fuel map.

Atmospheric haze presented a more serious problem. Subtle changes in enhancement colors, caused by increasing and decreasing haze levels, could gradually take place across a frame eventually causing the user to misinterpret an area. Only after careful visual scrutiny of bands 4 and 5 in raw form was this problem reduced.

Although the Taylor enhancement color shadings varied from frame to frame for the same general forest cover type, the range of variation was small and presented no problem to the field personnel. Several weeks of personal comparisons, by fire control users, of the enhancement map to existing timber maps, aerial photography, personal knowledge of specific areas and field checks led to the confidence necessary for their general acceptance and use.

Field experience with the Landsat fuel map last summer immediately showed its value. One particular example stands out. A fire was reported and a conventional dispatch of ground personnel ordinarily would have followed. A check with the fuel map showed a large and very dangerous logging slash situation downwind from the fire. An immediate dispatch of water bombers and helicopters stopped the fire at the edge of the slash area. The savings were estimated to be between 20,000 and 50,000 dollars. The cost of the Landsat map was probably about 3,000 dollars.

We have not yet had the opportunity to test the usefulness of the fuel map for large fire suppression when conventional reconnaissance methods frequently fail because of heavy smoke.

TEMPORAL OVERLAY EXPERIENCE

Work has continued on this project aimed at improving our ability to map fuel types and other information relevant to fire control. Specifically, we have worked at improving our coniferous-mixedwood separation, forest blowdown mapping, access road detail, clearcut and burn regeneration aging, insect defoliation and geometric correction.

With much assistance from CCRS, we have been able to overlay sections of different frames, as large as 1/2 million hectares, with a maximum error of about 1 pixel. Overlays have been made using winter bands onto summer bands and winter bands onto winter bands. Each Taylor enhancement of an overlay combination resulted in new information. Some combinations were much better than others. Of the few combinations tried to date out of the many possible, the most informative has been band 5 of winter overlaid onto band 5 of summer with the remaining summer bands left unchanged. An enhancement of this combination resulted in road detail better than previously obtained, separations of the general cover types into such distinct color groupings that the output resembled a classification, plus three fairly distinct clearcut logging regeneration age classes. In addition, the area logged during the time between the two satellite passes was clearly identified as a unique tone both by a 3-color display of "raw" data and by the Taylor enhancement.

In eastern Canada wind storms destroy significant areas of coniferous forest. The large fuel quantities remaining in these areas present serious problems to fire control. It is most difficult, if not impossible, to map these areas either on summer or winter imagery. On summer imagery blowdown areas can resemble regeneration areas and on winter imagery they cannot be separated from deciduous types. Experiments with temporal overlays showed that enhancements of winter-winter overlays clearly identified blowdown areas. Here a winter frame made previous to the blowdown was overlaid onto a winter frame made after the blowdown (i.e. band 4 onto band 7). Although we have not tried it, this same technique seems to offer the greatest potential for mapping areas of severe defoliation of conifers by insects. We have already seen that such defoliation can be identified on winter enhancements.

LANDSAT FUEL DATA BASE

Temporal overlaying currently is a difficult, time-consuming process and consequently has not seen much experimentation. We have done enough of it to recognize its potential and also to identify some of the problems associated with it. Most serious of the problems encountered to date is the apparent instability of the information content for a given overlay combination in widely separated locations. For example, the most informative winter-summer combination in our test area was not the best combination several hundred kilometers away. In fact, the Taylor enhancement resulted in totally different color schemes in the two areas even though the band combinations were the same. Clearly, radiometric variations, haze and phenological differences are much more important in temporal overlaying.

The ability to automatically identify changes over large areas using temporal overlays must be the key to the Landsat program's future. We already have demonstrated two feasible and useful change detection functions for fire control - namely clearcut and blowdown monitoring. Our future work is aimed at the construction of a geometrically correct digital data base, covering the 8 million hectare area of the SCO fire region, in which classifications of many registered frames can be stored. Our first step toward this goal has been to outline the general data base structure and to geometrically modify a 2.5 million hectare area of summer data to match a Universal Transverse Mercator grid map using 1/2 hectare, square data cells. Future overlay frames will be modified using the same base and hopefully will be registered with sufficient accuracy for fire control purposes. The next step, and the one now underway, is to classify this data into the broad fuel categories previously mentioned. This will be a two-step process using an unsupervised classifier and stratified data. Step one will be aimed at classifying forest cover types using data within the limits of their spectral ranges of the forest fuel types. Step two will be aimed at producing improved road and clearcut information. To do this, the unsupervised classifier will be restricted to work with only the data with reflectances above 14 in bands 4 and 5. Results from the two-step process will be merged within the data base.

Once the SCO region has been completed using summer data, the process will then be repeated using winter data. The data base will have the potential to store the results and the dates of up to 4 temporally different classifications for each 1/2 hectare cell. In addition, a scheme is being developed to identify and place a reliability measure on the most likely fuel type of each data cell. The reliability measure will be based on permanent ground truth plots, spatial information and logical temporal and phenological possibilities.

The data base itself will be contained on a series of magnetic tapes and used on a Digital PDP-11 T34 mini-computer. Special computer programs will be written to be used by fire control personnel in their daily decision making process. These programs will extract from the data base the distance from a given fire location to the nearest water source for fire pumps, the nearest road for ground access, the nearest long lake for water bomber pickup, the distance and direction of logging slash areas and a summary of fuel types within a given range of the fire. This information will be useful in deciding the type and strength of initial attack on the fire. FFRI has developed a contagion fire growth model that can predict future perimeter locations of a large fire, given weather forecasts, fuel moisture estimates and fuel types on a two hectare grid. The data base will be used to furnish the fuel data to this model.

CONCLUSION

The fire control application described in this report seems ideally matched to Landsat's capabilities. We have demonstrated that useful forest fuel maps can be produced for large areas for low costs using existing digital processing equipment and software. Enough experimentation using temporal overlays has been carried out to demonstrate their potential in increasing the information extracted from Landsat data. Presently we are attempting to construct a digital data base to be used within the operational fire environment to assist in initial attack decision making and fire growth modelling. This same data base should provide change detection information such as locations of new roads and logging slash areas, important to long-term fire control planning.

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