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Forest Cover Type Mapping and Spruce Budworm Defoliation Detection Using Simulated SPOT Imagery*

Abstract: *Forest cover-type mapping and spruce budworm defoliation detection were attempted using a June, 1983 SPOT simulation image of an area in northern Wisconsin (Sawyer County). The study site contained a diverse mix of cover types typical of the region, including sugar maple-yellow birch, white pine-red oak-red maple, white birch-balsam fir, aspen, and red pine stands (uplands), and black spruce, tamarack, and white cedar-balsam fir stands (low-lands). The imagery is being evaluated using both manual and computer-assisted interpretation techniques. Results, to date, of the interpretations show the potential for substantial improvement in the accuracy and specificity of forest cover type mapping, under Lake States' conditions, as compared to Landsat MSS data. Detail to level II of the Anderson-U.S.G.S. classification system was obtained manually with both the panchromatic and multispectral film products. The excellent spectral and textural information apparent in the multispectral data allowed additional visual discrimination to level III (species) for forest types throughout most of the scene. The digital interpretation (supervised) was extremely accurate at level I. Level II differentiation was achieved; however, discrimination of detail to level III was limited to lowland species only. Budworm defoliation detection was limited, by the date of the imagery, to differentiation of mortality from the previous years' defoliation. Acquisition of optimally timed SPOT imagery will likely allow further discrimination of forest damage caused by agents such as the spruce budworm. Overall, it appears that SPOT satellite data will likely provide forest managers with information that currently is obtained from medium and high altitude photography. The data's inherent amenability to computer processing in a geographic information system, wherein manual and digital analysis techniques can be integrated, is an added advantage.*

Introduction

Timely and accurate knowledge of forest composition and condition can be an invaluable forest management tool. The ability of remote sensing analysis to augment traditional forest resource evaluation procedures has been demonstrated by researchers for a diverse range of applications, imagery types, and analysis techniques (ASP, 1983). The study upon which this paper is based evaluated the possible future potential of SPOT (Système Probatoire d'Observation de la Terre) satellite data for two such forestry applications: forest cover-type mapping and spruce budworm defoliation detection.

In that we are continuing our research with the SPOT simulation data described herein, this paper should be considered as merely a progress report on our research. Here we limit our discussion to the

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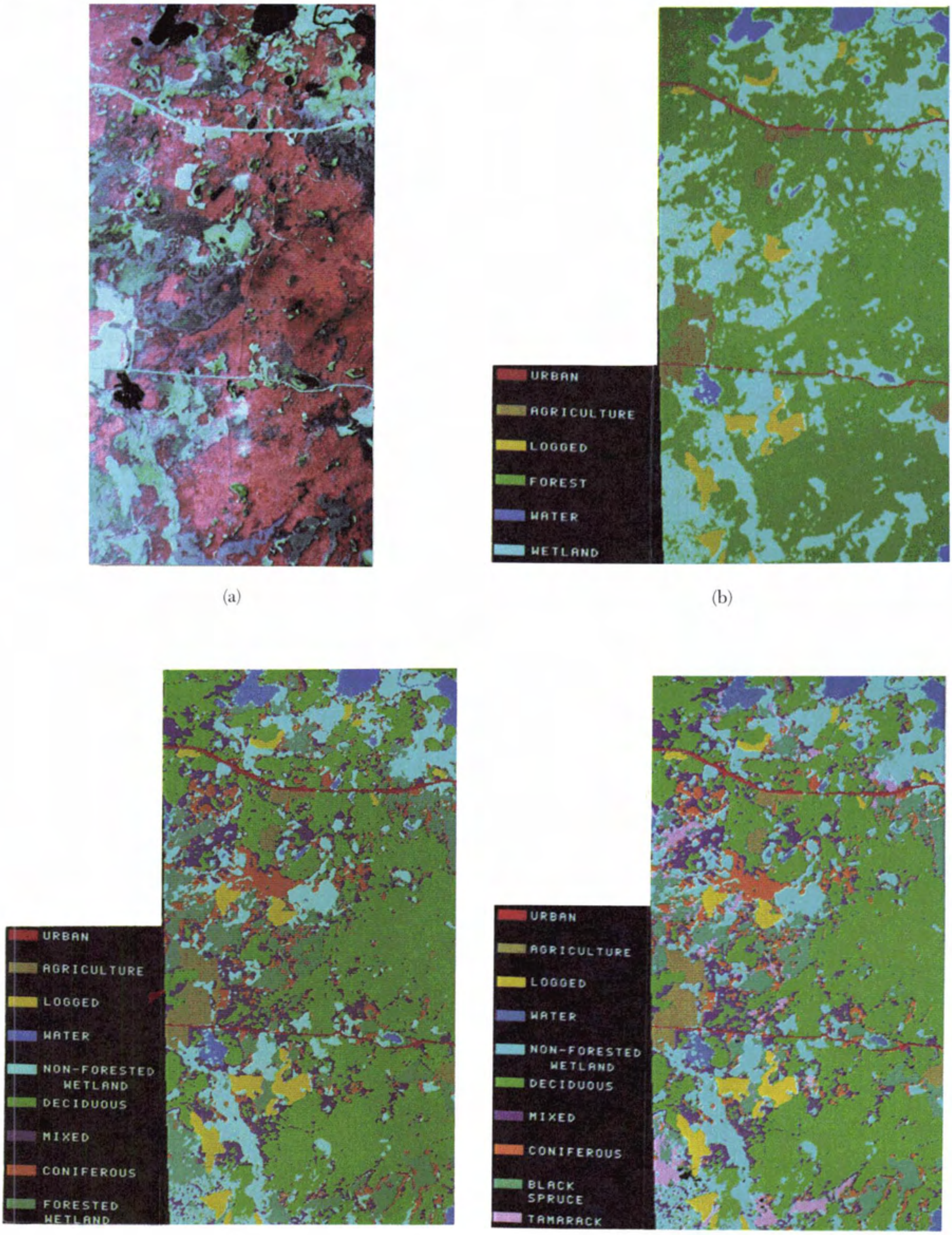

PLATE 1. (a) Multispectral data, (b) Level I supervised classification, (c) Level II supervised classification, (d) Level III supervised classification.

visual interpretation of the imagery and the results of applying traditional supervised classification techniques to the data. Accordingly, this paper summarizes the results of a "first look" at SPOT simulation data using traditional data interpretation procedures. Research continues in developing computer classification methodologies to more fully exploit the information content of SPOT data.

Materials and Methods

STUDY SITE CHARACTERISTICS

The area chosen for study was a 5-km by 12-km rural site located in the Chequamegon National Forest in northwest Wisconsin (Sawyer County) (see Figure 1). This site was selected because it is typical of "Lake States' " extreme vegetational diversity and has been the subject of past University of Wisconsin forestry studies. Our site contained both upland and lowland forest types, as well as non-forested wetland areas. The upland types were dominated by sugar maple (*Acer saccharum*)—yellow birch (*Betula alleghaniensis*), white pine (*Pinus strobus*)—northern red oak (*Quercus rubra*)—red maple (*Acer rubrum*), white birch (*Betula papyrifera*)—balsam fir (*Abies balsamea*), and aspen (*Populus tremuloides* and *P. grandidentata*) stands, as well as several red pine (*Pinus resinosa*) plantations. The lowland forests were dominated by black spruce (*Picea mariana*) and tamarack (*Larix laricina*), with white cedar (*Thuja occidentalis*) and balsam fir in scattered areas. These species are consistent with those described by Curtis (1959) as common for northern Wisconsin forests (forests north of the Wisconsin "tension zone"). Of interest is the fact that land-cover classification based on Landsat MSS data under similar conditions has been generally unsuccessful (Mead and Meyer, 1977). Further, we wished to evaluate the performance of SPOT simulation data in the context of similar studies performed using Thematic Mapper Simulator data (Nelson *et al.*, 1984).

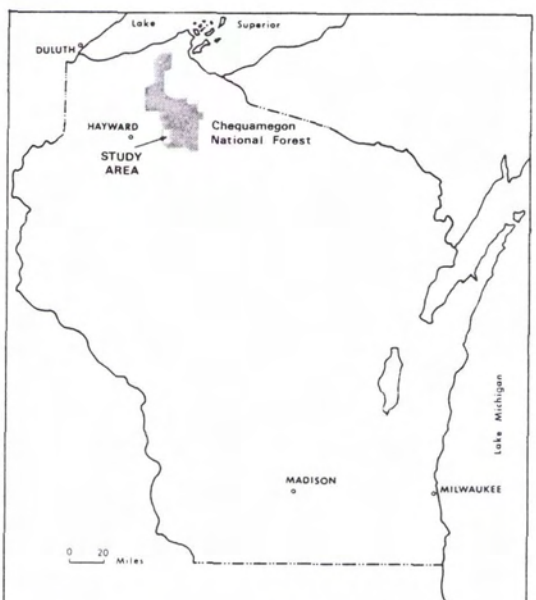

Fig. 1. Study site location.

IMAGE TYPES

Digital data covering the Sawyer County site was acquired on 18 June 1983 as part of the 1983 U.S. SPOT Simulation Campaign. The area was a "P" site; thus, both panchromatic (10-m resolution) and multispectral (20-m resolution) digital data were obtained (see Figure 2 and Plate 1a). The data package also included 1:42,000 scale color infrared photography of the area, photographic prints of the panchromatic and multispectral digital data, and black-and-white negatives for each band of the digital data. U.S.G.S. 1:24,000 scale topographic maps of the area were also available and were used as a base for plotting the photo and scanner coverage.

IMAGE QUALITY

In general, our imagery was of excellent quality; it contained only a small percentage (less than 2

Fig. 2. Panchromatic data (central portion of scene).

percent) of cloud cover. A routine assessment of the geometric integrity of the digital data was undertaken to estimate its planimetric accuracy. In this effort, the rural nature of the area made control point identification somewhat difficult and restricted control point spacing to below optimal levels. However, using second order polynomial transformation equations, a standard deviation of unit weight of about 0.75 pixels was obtained for the fit between the multispectral digital data and the 1:24,000 U.S.G.S. topographic maps of the study site. This figure should be viewed in light of the above mentioned problems and with the knowledge that the planimetric accuracy of actual SPOT satellite data will almost certainly exceed that of the simulation data (Weill and Saint, 1983).

ANALYSIS TECHNIQUES

In an effort to evaluate a wide range of applications of the SPOT imagery, both manual and computer-assisted image interpretation techniques were evaluated. The manual interpretations were done using the original photographic prints, supplied by SPOT IMAGE Corp., of the panchromatic and multispectral data. The multispectral photographic product was actually a composite derived from the panchromatic and multispectral data as described in the SPOT Simulation Handbook (1983). After the SPOT image products were interpreted, the supplementary color infrared photography was also visually analyzed. Classification was carried out according to the Anderson *et al.*—U.S.G.S. classification system (Anderson *et al.*, 1976).

The computer-assisted interpretation of the image data was accomplished using software available at the Environmental Remote Sensing Center's (ERSC) Image Processing Lab (IPL). While a range of supervised and unsupervised classifiers are available at ERSC (and are being tested with the simulated SPOT data), we limit this discussion to our experience with the maximum likelihood classifier available. The training areas required for this procedure were delineated on an interactive color display in the traditional manner. Decisions to merge or delete training sets were based upon calculations of transformed divergence and on two-dimensional plots of training set means. Again, the Anderson *et al.* system was used for cover type identification. Data input to the classification algorithm was limited to the "raw" spectral data provided by SPOT IMAGE Corp. No attempt was made to employ or evaluate ratio, texture, or context algorithms in the classification process at this point.

The defoliation detection study was limited to a small sub-area of the study site for which eastern spruce budworm (*Choristoneura fumiferana*) defoliation had been previously documented. The spruce budworm is an economically important defoliating insect common to Wisconsin's spruce-fir forests. An epidemic outbreak typically results in morphological change and physiological stress that can kill vast stands of timber. Several techniques have been tested previously for detecting, mapping, and evaluating budworm defoliation. These include ground surveys, aerial sketch mapping, and manual and computer-assisted interpretation of various types of photographic and nonphotographic images (Maclean and Giese, 1984). In this context, we again attempted both manual interpretation and automated classification of the SPOT simulation data to assess defoliation severity.

ACCURACY ASSESSMENT PROCEDURES

No attempt was made to quantify the accuracy of our visual interpretations of the SPOT data. Our assessment of the visual interpretability of the data is based, however, on our extensive familiarity with the study site on the ground (and the supplemental color infrared photography).

We are continuing to evaluate the accuracy of our digital interpretations in several ways. In this paper we describe only the results from

- Classification of the training sites: The training sets used to develop the classification discriminant functions were classified;
- Classification of validation sites: "Homogeneous" areas of known cover type (other than the training sites) were delineated and classified.

RESULTS

MANUAL COVER TYPE INTERPRETATION OF THE HARDCOPY IMAGE PRODUCTS

Detail to level II of the Anderson system was easily obtained with the manual interpretation of the panchromatic print. Excellent textural and tonal contrast on the print aided in the separation of hardwoods and conifers. Additional level III differentiation between conifer species was obtained in some instances. It was not possible, however, to distinguish small agricultural areas from similar size recently logged areas.

The multispectral image product allowed species delineation (level III) over most of the scene. Distinctions were made between black spruce, tamarack, and red pine. In some areas it was also possible to delineate stands of white pine from surrounding hardwoods. Although the heterogeneous nature of the deciduous stands in the study area made precise differentiation of deciduous types difficult, the textural and contextual information apparent in the image product enabled some visual separation between the aspen type and the sugar maple-yellow birch type. Recently logged areas were easily distinguished from agricultural areas on the multispectral image. A breakdown of the various classes interpreted from the multispectral image is shown in Table 1.

TABLE 1. INFORMATION CLASSES FOR THE VISUAL INTERPRETATION OF THE MULTISPECTRAL FILM PRODUCT. (DASHED LINES INDICATE LEVELS OF DETAIL NOT ATTAINABLE)

Classes:			
Level I	Level II	Level III	Principal Composition:
forest	deciduous	aspen type sugar maple— yellow birch type	
	coniferous	red pine balsam fir white pine	
	mixed	---------	sugar maple, white birch, red oak, aspen, red pine, balsam fir, white pine, yellow birch, red maple
water	lakes rivers/ open bogs	(no further breakdown attempted)	
wetland	forested	black spruce tamarack white cedar/ balsam fir	
	non-forested	bog vegetation (leather leaf, ericads) sedges/grasses alder	

DEFOLIATION STUDY

Evaluation of the defoliation subscene was limited, due to the early summer date of imagery acquisition (18 June 1983), to assessment of the previous year's defoliation. Two levels of damage were visually quantified: "severe" (75 to 100 percent of the foliage removed with top kill) and "dead trees." These same two levels of defoliation were detected with the computer-assisted classification of the defoliation subscene. It is postulated that a later date of acquisition would allow evaluation of the current year's defoliation into multiple levels. The ideal date of acquisition should be between mid-July and mid-August when peak browning of the clipped and webbed needles occurs.

SUPERVISED COVER TYPE CLASSIFICATION

Discrimination of detail to level II of the Anderson system, and, in some cases, to level III, was attempted during the supervised training process. Initial attempts at classification revealed discrimination problems between certain cultural (human-impacted) features, such as roads, plowed fields, quarries, and barren logged areas, and highly reflective wet-land areas. Given the nature of the study, it was deemed appropriate to eliminate these non-forest related discrimination problems by partitioning (or stratifying) the scene into cultural and non-cultural features through interactive manual delineation of the major cultural features in the imagery. The remainder of the classification iterations were then carried out utilizing the manually partitioned data set. This enabled attention to be focused on discrimination of forest cover rather than land cover in general.

The final supervised classification utilized 63 spectral classes to discriminate the eleven Anderson system information classes identified during the training process. These information classes are listed in Table 2. It can be seen from this table that level II discriminability was possible for all vegetation classes; however, level III forest type discrimination was possible only in the forested wetlands class. The level III differentiation obtained with the manual interpretation for the deciduous and coniferous classes was based primarily on visual textural and contextual clues and could not be attained in the computer-assisted analysis utilized here. Additionally, a good test of upland conifer type separability could not be carried out because only red pine was sufficiently abundant to be found in areas large enough to allow adequate training.

Training set classification accuracy was 100 percent for more than nine-tenths of the 63 spectral classes utilized. Inter-class confusion was limited to spectral classes within the same information class.

TABLE 2. INFORMATION CLASSES FOR COMPUTER-ASSISTED CLASSIFICATION. (DASHED LINES INDICATE LEVELS OF DETAIL NOT ATTAINABLE)

Classes:			
Level I	Level II	Level III	Principal Composition:
forest	deciduous	---------	sugar maple, white birch, red oak, aspen, yellow birch, red maple
	coniferous	---------	red pine, balsam fir, white pine
	mixed	---------	sugar maple, white birch, red oak, aspen, red pine, balsam fir, white pine, yellow birch, red maple
water	lakes	(no further breakdown attempted)	
	rivers/ open bogs		
wetland	forested	black spruce tamarack white cedar/ balsam fir	
	non-forested	bog vegetation (leather leaf, ericads) sedges/grasses alder	

The validation sites had overall level I accuracy of 96 percent, overall level II accuracy of 91 percent, and overall level III accuracy of 90 percent. The average accuracy for all classes involved at each level of classification was 97 percent, 87 percent, and 81 percent, respectively (see Tables 3, 4, and 5). The final classifications are shown in Plates 1b (level I), 1c (level II), and 1d (level III) (color plates).

DISCUSSION

Although the accuracy assessment procedures completed so far probably over-estimate total classification accuracy somewhat, it appears from Tables 3, 4, and 5 that very accurate forest cover type discrimination was achieved utilizing supervised classification. This is particularly true for level I and, to lesser extents, for level II and level III of informational detail. The only major discrimination problems encountered, which accounted for the vast majority of classification error, involved three sets of classes:

TABLE 3. LEVEL I VALIDATION AREA ACCURACIES FOR THE SUPERVISED CLASSIFICATION

Verified	Observed			
Class:	4	5	6	percent correct
4	644	0	9	98%
5	0	175	0	100%
6	42	0	573	93%

Overall accuracy: 96%; Class average: 97%
Classes: 4: forest
5: water
6: wetland

- Forested wetlands. Spectral overlap was evident among certain small, scattered areas of tamarack, white cedar/balsam fir, and black spruce. This may, in part, have resulted from the distributional nature of the species involved. White cedar and balsam fir are not found in large, homogeneous stands within the Sawyer County study area. As is typical of northern Wisconsin lowland forests in general (Curtis, 1959), the lowland forests of the study area vary in composition from stands of pure tamarack to almost pure black spruce, with lesser dominant species (such as white cedar and balsam fir) generally found in areas of mixed species composition. This lack of relatively large, homogeneous white cedar/balsam fir stands inhibited the training process. In general, however, this was not a critical problem, particularly because the white cedar/ balsam fir class constituted less than two percent of the image.
- Deciduous—mixed—coniferous. Problems in separating deciduous forest from mixed forest, and coniferous forest from mixed forest occurred in some areas. These types of discrimination problems are to be expected, however, whenever gradational classes (such as "mixed forest") are utilized in a

TABLE 4. LEVEL II VALIDATION AREA ACCURACIES FOR THE SUPERVISED CLASSIFICATION

Verified	Observed						
Class:	41	42	43	5	61	62	percent correct
41	454	0	0	0	0	0	100%
42	0	71	1	0	0	0	98%
43	22	37	59	0	0	9	46%
5	0	0	0	175	0	0	100%
61	0	1	6	0	325	0	100%
62	3	29	3	0	8	240	84%

Overall accuracy: 91%; Class average: 87%
Classes: 41: deciduous 5: water
42: coniferous 61: forested wetland
43: mixed 62: nonforested wetland

classification procedure. This problem was exacerbated by the wide variation in composition of the mixed stands throughout the study area. Additionally, this type of "gradational error" was also evident between the non-forested wetland and forested-wetland classes.

- Coniferous forest—wetland. A small red pine plantation in the northern portion of the scene was spectrally very similar to certain areas of bog vegetation (wetland). This spectral overlap was one of the major contributors to the level I error found in Table 3.

As expected, the great spectral diversity and spatial complexity of the simulated SPOT imagery made training set delineation more involved than has been the case with data of coarser spatial and radiometric resolution (i.e., Landsat MSS data). The high degree of local variability within the Sawyer County scene made it difficult to delineate an adequate number of pixels, with sufficient similarity and appropriate distributional properties, capable of accurately characterizing a spectral class. This problem was particularly acute for small, scattered classes. The high degree of overall variability in the airborne imagery made it difficult to become certain that all spectral variants within a given information class had been adequately characterized. As a result of these circumstances, the first several iterations of the maximum likelihood classifier were followed by re-training in areas that had not previously been visually identified as spectrally distinct and for classes that had not been adequately characterized. It is hoped that an unsupervised or hybrid classifier will provide a more comprehensive characterization of actual SPOT satellite imagery in a much shorter period of time. Our research is continuing in this vein, as is our use of ratioed data and spatially related classifiers with the SPOT data.

CONCLUSION

The limited experience gained, to date, with the SPOT simulation data described herein suggests that, in comparison to Landsat MSS data, SPOT satellite data will likely afford a substantial increase in the accuracy and specificity of forest cover type mapping under the spectrally and spatially complex conditions found in the Lake States region. Type maps, to detail of level III of the Anderson system, were obtained from both manual and computer-assisted

TABLE 5. LEVEL III VALIDATION AREA ACCURACIES FOR THE SUPERVISED CLASSIFICATION

Verified	Observed								
Class:	41	42	43	5	611	612	613	62	percent correct
41	454	0	0	0	0	0	0	0	100%
42	0	71	1	0	0	0	0	0	98%
43	22	37	59	0	0	0	0	9	46%
5	0	0	0	175	0	0	0	0	100%
611	0	1	0	0	239	0	0	0	99%
612	0	0	6	0	0	69	0	0	90%
613	0	0	0	0	11	0	6	0	35%
62	3	29	3	0	3	4	1	240	84%

Overall accuracy: 90%; Class average: 81%
Classes: 41: deciduous 611: black spruce
42: coniferous 612: tamarack
43: mixed 613: white cedar/balsam fir
5: water 62: non-forested wetland
(Class 613 constituted less than 2% of the image.)

image interpretations. The spectral, textural, and contextual information evident in the SPOT imagery enabled visual differentiation of major Lake States' forest types throughout the scene. Further, estimates of stocking density could also be made visually. This level of differentiation could be adequately obtained with supervised classification techniques only for lowland forest types. Thus, while traditional per point supervised classification procedures will likely provide acceptable type mapping results at level II of the Anderson system, it appears that the information content of the data can be more fully exploited through the application of texturally-based classifiers. In this regard, it is deemed essential that accurate and efficient textural and contextual classifiers be developed for use with SPOT data.

Results from the budworm defoliation study, being limited by the date of image acquisition, were somewhat less impressive. Classification of the previous year's defoliation into two levels, severely defoliated and dead trees, was achieved. Detection of tree damage and mortality due to agents such as spruce budworm, however, will likely be possible with SPOT satellite data. Optimally timed image acquisition could enable detection and differentiation of more subtle levels of damage than the two levels delineated here.

The differences in discriminability realized between the manual and supervised forest cover type classifications, as well as the problems encountered with the computer-assisted discrimination of cultural features, point out the need for integration of the traditionally separate manual and computer-assisted classification procedures. Until such time as textural and contextual classifiers are developed that more accurately mimic important manual interpretation skills, integration of manual and computer-assisted analysis techniques could provide improved accuracy and utility in remote sensing-derived classification products. This point is particularly relevant given the current widespread development of geographic information systems. In this context, cultural/non-cultural, forest/non-forest, or wetland/non-wetland "masks" (strata) may already exist in information systems, along with digitized road networks and other types of potentially useful information that would allow image classification to be focused on a particular area or resource of interest.

Additional analysis techniques, such as those alluded to previously, as well as examination of alternative- or multi-date SPOT imagery, could further enhance the overall utility of SPOT satellite data. At this point, it is not known if additional or alternative date imagery would significantly improve forest cover type discriminability. However, it is felt that the results of the budworm defoliation study could be substantially improved with a mid-July to mid-August data acquisition.

Overall, SPOT data will likely provide much of the forest management information currently extracted from medium to high altitude photography—with the added advantage of the data's inherent amenability to computer processing in a geographic information system.

Acknowledgments

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