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Evaluation of Landsat Data for Forest Pest Detection and Damage Appraisal Surveys in British Columbia

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ABSTRACT

LANDSAT-1 and -2 multispectral scanner data were evaluated for detecting and appraising forest pest damage in the coniferous forests of British Columbia. Many examples of this damage were examined using aerial observations and color aerial photography as ground truth. In a few instances where contrast to surrounding areas was high, heavily defoliated forest stands were visible on color composite images prepared by the Canada Centre for Remote Sensing (CCRS). These images proved superior to spectral classifications of digital data performed with the CCRS Image Analysis System. It was concluded that pest damage detection from LANDSAT was not sufficiently accurate, in most cases, to be of significant assistance in mapping or assessing forest pest damage. LANDSAT data, however, can provide a compact over-view of forest types for planning of more intensive pest surveys. Future improved resource satellites with higher spatial resolution are likely to be more useful in forest pest management. Until such satellites are available, it is recommended that research and development continue in the use of aircraft microwave, visible and infrared sensors, and in new automated interpretation techniques for detection of pest-damaged areas.

RÉSUMÉ

On a enquêté sur l'utilisation des données du déchiffreur multispectral des satellites LANDSAT 1 et 2 pour découvrir et évaluer les dégâts causés par les fléaux forestiers dans les forêts de résineux de la Colombie-Britannique. De nombreux exemples de ces dégâts furent étudiés à l'aide d'observations aériennes et de photographies aériennes en couleurs, utilisées comme s'il s'agissait du terrain même. Dans certains cas où le contraste avec les régions avoisinantes était frappant, les peuplements forestiers fortement défoliés étaient visibles sur des reproductions en couleurs préparées par le Centre Canadian de Télédétection (CCT). Le classement spectral fourni par le système d'analyse d'images du CCT n'a pas amélioré l'identification de ces régions. Donc, la détection à partir du LANDSAT, des dégâts dus aux fléaux n'est pas assez précise, dans la plupart des cas, pour aider significativement à la cartographie ou à l'évaluation des dégâts dus aux fléaux des forêts. Toutefois, les données du LANDSAT peuvent fournir une vue d'ensemble des types de forêts qui serait utile à la planification de relevés plus intensifs des fléaux. Les satellites-ressources améliorés de l'avenir, ayant une meilleure résolution spatiale seront vraisemblablement plus utiles aux responsables de la répression des ravageurs forestiers. En attendant la venue de tels satellites, la recherche et le développement pourront continuer à utiliser les systèmes à microondes des avions, les capteurs visuels et à l'infrarouge, ainsi que les nouvelles techniques d'interprétation automatisées qui servent aujourd'hui à localiser les régions dévastées par les ravageurs forestiers.

INTRODUCTION

Forest stands in the British Columbia and Yukon Region are surveyed annually from small aircraft by the Forest Insect and Disease Survey, Canadian Forestry Service. Damaged areas are sketch-mapped and estimates are made of wood volumes affected. Increasing demands for better information require improved techniques.

One technique under investigation is the use of resource satellites such as NASA's LANDSAT, which circles the earth, providing regular coverage of the B.C.-Yukon Region every 18 days with a four-channel multispectral scanner. Data are available digitally on computer compatible tapes (CCTs) from which maps or photographic images can be prepared. Each picture element (pixel) represents an area of 60 m by 80 m. The extremely small scale of the LANDSAT data and the routine availability simplifies the acquisition, minimizes handling and lowers individual user costs. These advantages are offset by the frequent coincidences of cloud cover with the passing of the satellites over areas of interest, and a lower spatial resolution which is coarser than that of color aerial photographs.

Several researchers have tried LANDSAT

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data to discriminate between healthy and heavily damaged stands. Williams and Turner (1975) distinguished gypsy moth defoliation in Pennsylvania on LANDSAT band 7, and Rohde and Moore (1974) reported seeing fall cankerworm damage in Maryland on bands 5 and 7. Beaubien and Jobin (1974) used winter scenes of LANDSAT imagery, particularly band 7, to map tree mortality caused by hemlock looper on Anticosti Island and achieved results similar to those made during aerial sketch-mapping. Heller et al. (1974) and Weber et al. (1975) distinguished dying eucalyptus affected by low temperature on a two-date color composite image of the San Francisco area, when stands were over 500 m in extent. They also reported that mountain pine beetle infestations could not be detected with LANDSAT data, either visually or through computer-assisted mapping. Hall et al. (1974) distinguished tree mortality of lodgepole pine caused by lodgepole needle miner, and Kirby et al. (1975) succeeded in identifying red belt damage to 90% accuracy in the Rocky Mountain area of Alberta.

Previous work in British Columbia (Harris 1974; Lee et al. 1974) described damage caused by western spruce budworm visible on LANDSAT imagery near Pemberton, B.C. This report describes further investigations of forest pest damage from LANDSAT in B.C.

METHODS

Color aerial photography[1/] and aerial sketch maps, obtained for pest outbreaks in British Columbia from 1971-1975, as well as British Columbia Forest Service forest cover type maps were used as ground truth for evaluating LANDSAT data.

Color composite images prepared by the Canada Centre for Remote Sensing, Ottawa (CCRS), were examined visually and compared with ground truth to detect areas of heavily damaged trees. These color composites were made from 3 of 4 bands: 4,5,6;4,5,7; and 5,6,7. Most major forest pest damage in B.C. was examined (Appendix I).

In addition, some computer compatible tapes (Appendix II) were studied with the CCRS Image Analysis System (CIAS) (Goodenough 1977)[2/]. Representative areas were selected on a display screen and the computer classified entire scenes, using these data.

There are two types of site classification using the CIAS: unsupervised and supervised (Goodenough 1976, 1977). In the first, an area of any desirable size is selected and displayed on a CRT screen, and the CIAS automatically classifies the scene into up to eight different classes, assigning to

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1/ Hand held, 70-mm or 35-mm cameras were used from low-flying (up to 3,000 m a.s.l.), fixed-wing aircraft and helicopters. Stereoscopic coverage at scales of approximately 1:2,000 to 1:10,000 with about 60% overlap was usually maintained. Kodak Vericolor II negative film, processed to 5 x 5-inch prints, was used in the 70-mm (2¼ x 2¼ inch) format with 35-mm slides taken as a back-up.

Vertical, small scale, 9 x 9-inch aerial photography was taken by CCRS from about 6,600 to 12,000 m a.s.l. The major film types used were Kodak Aerocolor 2445 true color negative film and Kodak Aerochrome Infrared 2443 positive film.

2/ The CIAS identifies features on an image tape(s) having identical spectral characteristics for multiple bands. The system is informed as to which features are of interest and the machine extracts the multispectral properties of the selected objects(s). This process is called "training". When the spectral properties of the object are found, the CIAS scans the image by each picture element (pixel) and determines if the spectral properties of each correlate with the object of interest. This process is called "classification", and results in a thematic map in which the same pixels can be identified by color.

Each theme is assigned a color which is displayed on a color cathode ray tube (CCRT), with or without image background data superimposed. Black-and-white thematic digital maps are obtainable from a line printer. An additional output mode is through an electron beam image recorder (EBIR) from which color prints and transparencies can be obtained. Application of a classification filtering program reduces scattered pixels and fills in gaps in large areas, thus making classified areas appear more uniform (Goldberg and Goodenough 1976). Classification of every pixel of a LANDSAT image, which is 3,240 x 2,340 4-band pixels, is performed in segments, each segment composed of 512 x 512 pixels or 1/30 of the total image.

	Douglas-fir tussock moth		Western spruce budworm	
	Image no.	Date	Image no.	Date
Image without damage	10690-18234	13 June/74	10691-18295	14 June/74
Image with damage	20236-18181	15 June/75	10781-18263	12 Sept/74

each a color on the screen. With the supervised classification, as with the unsupervised, one or more training areas are used to create signature files; in this case, the CIAS automatically displays areas of the same spectral characteristics as the signature file of the training areas.

Specific CIAS analyses were carried out on damage caused by Douglas-fir tussock moth, Orgyia pseudotsugata McDunnough, near Kamloops (Figs. 1-3), and western spruce budworm, Choristoneura occidentalis Freeman, near Pemberton. Both species, destructive pests of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), reached epidemic levels during the study period, resulting in abnormal color changes over large areas. Several trial analyses were made, using unsupervised and supervised classifications. Analyses of individual scenes were carried out, as well as temporal analyses, combining data obtained when pest damage was present, with data from the same locality when no damage was present. Sample areas of damage were also segregated by slope direction and examined.

RESULTS

Classifying damage on color composite images, as illustrated for Douglas-fir tussock moth in Figure 4, required prior ground truth information for even the most distinct areas because the damage signatures were not unique. The size of damaged areas for both tussock moth and western spruce budworm visible on the imagery varied from about 20 hectares to continuous bands over 16 kilometers in length. Visibility of damage was enhanced by enlargements from the standard 9x9-inch scale 1:1,000,000 images to 1:250,000 or 1:125,000. Often the large damaged areas not visible on LANDSAT were on shaded north- and west-facing slopes where the darkness obscured damage.

After several preliminary CIAS analyses with single-date images, the final classification chosen as best illustrating pest damage was the multitemporal (two date) analysis. For the tussock moth, both unsupervised and supervised results were similar but, for the spruce budworm, the unsupervised classification gave better results. The images involved combined bands 5 and 7 and were as shown above.

The CIAS digital map of Douglas-fir tussock moth damage (three versions are shown in Figs. 5-7) matched the ground truth fairly well on the east-facing slope of the North Thompson River Valley, but failed to delineate damage in shaded portions of the image, mainly on the west slope, and included, in error, small areas outside the damaged area. The latter were mainly scattered areas of open range or logged areas that were adjacent to forest; on the LANDSAT image, these were similar in color tone to the damaged areas.

West- and east-facing slopes were segregated and errors in identification of damage were measured (Table 1, supervised classification). The classification accuracy for Douglas-fir tussock moth damage for the east-facing slope was 54% correct, while for the west slope, it was only 25%. Filtering improved the accuracy of correct classification on the east-facing slope, and decreased the error in the damage that was incorrectly classified outside the training areas.

The CIAS classification of western spruce budworm damage (Fig. 8) included more area than the known budworm defoliation; damaged pure Douglas-fir were indistinguishable from lodgepole pine-fir stand types in the area. It coincided, however, with a large part of the budworm damage, differing mainly in omitting areas that were darker on the image. This is especially noticeable along parts of the north-facing slope of the Lillooet River Valley near Pemberton.

When north- and south-facing areas were

Table 1. Comparison of area (number of pixels) for visual aerial interpretation and LANDSAT data interpretation of Douglas-fir tussock moth damage, Kamloops, B.C. Classification is spatially filtered migrating means.

Area type	Slope		
	West	East	West & east
Actual damage from aerial interpretation (area of polygons)	9,054	9,705	18,759
Area correctly classified as damage within polygons by CIAS	2,304 (25.4%)	5,309 (54.7%)	7,613 (40.6%)
Area classified as damage outside polygons by CIAS (error)	—	—	4,430
Total area classified as damage by CIAS	—	—	12,043

segregated for the lower half of the scene in Figure 8 (Table 2, unsupervised classification), the classification accuracy on south-facing slopes reached 75% by filtering. However, errors were much larger on north-facing slopes (only 18% correct) and could not be reduced by the use of a variety of spectral and temporal techniques.

DISCUSSION AND CONCLUSIONS

These studies have shown that damage to forest stands caused by six forest pests was visible on 24 LANDSAT images, primarily on the standard color composites but also on some band 5 black-and-white imagery, where there was heavy tree defoliation and contrast to surrounding areas was high. Most of the damage was caused by two destructive pests of Douglas-fir, the Douglas-fir tussock moth and the western spruce budworm. The distinctive areas of defoliation were only parts of larger outbreaks, the rest of which, often with similar damage, were not visible. Areas in shadow, in particular, were not visible.

Damage seemed most readily discernible on the LANDSAT imagery after heavy or repeated defoliation, and often when tree crowns had dropped most or all of their damaged foliage. Patches of dead trees, or gray trees recently defoliated, often in the

Figure 1. Low-level oblique aerial photograph showing Douglas-fir stands defoliated and killed by Douglas-fir tussock moth (location marked by arrow on Fig. 2, taken July 9, 1975).

Figure 2. Small-scale vertical color infrared aerial photograph (A 37246-79) of N. Thompson Valley, showing Douglas-fir stands defoliated and killed by Douglas-fir tussock moth (arrow locates Fig. 1)(taken Sept. 6, 1975).

Figure 3. Small-scale vertical true color aerial photograph (A 37247-79), details same as Fig. 2 (Figs. 2 and 3 located in lower part of Figs. 4 to 7).

Figure 4. Portion of LANDSAT colour composite image 20236-18181 (Sept. 15, 1975), showing Douglas-fir stands defoliated and killed (see Figure 6) by Douglas-fir tussock moth in the N. Thompson Valley (Figs. 2 and 3 are in lower part of valley; see arrow locating Fig. 1).

Figure 5. Color print of CIAS CCRT display, showing areas classified as Douglas-fir tussock moth damage (blue color) for same area as Fig. 4 (temporal overlay of LANDSAT images 10690-18234 and 20236-18181).

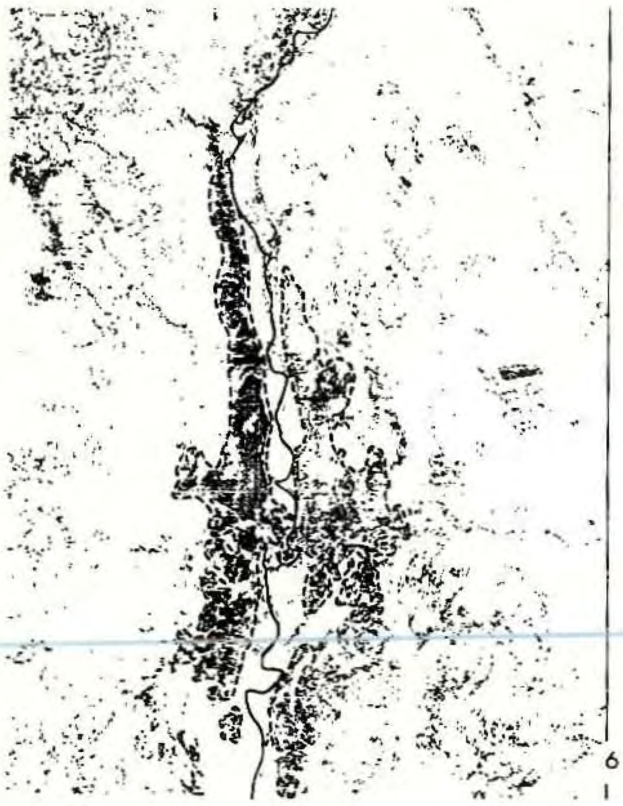
Figure 6. Scaled binary printout of Fig. 5; black areas correspond to blue color of Fig. 5, with damage mapped from ground truth outlined.

Figure 7. EBIR color print of Fig. 5; purple color corresponds to blue color in Fig. 5, yellow color depicts areas classified as undamaged Douglas-fir stand types.


1


2


3


6

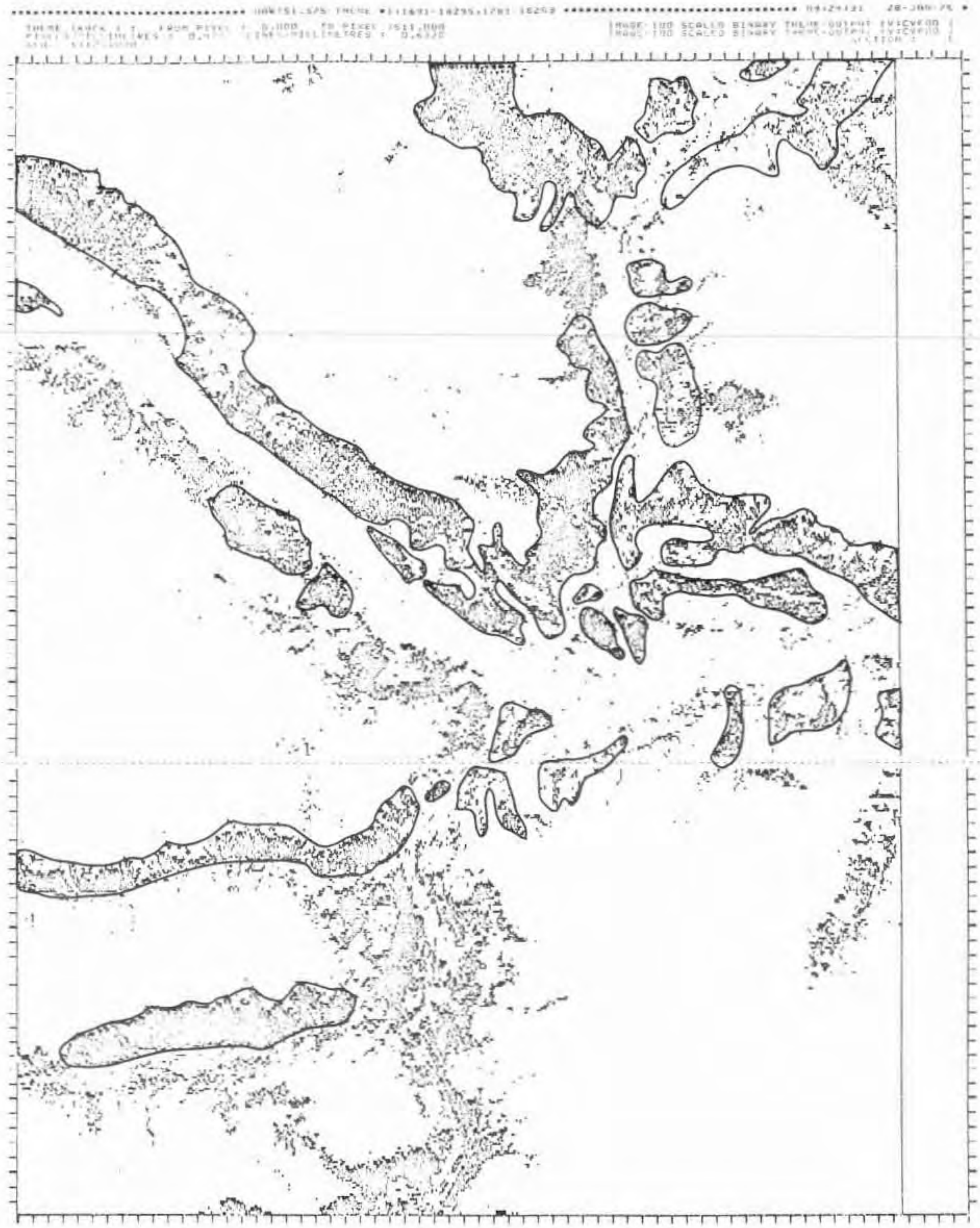


Figure 8. Scaled CIAS binary printout, showing areas classified as western spruce budworm damage, Pemberton area (temporal overlay of LANDSAT images 10691-18295 and 10781-18263), with damage mapped from ground truth outlined.

Table 2. Comparison of area (number of pixels) for visual aerial interpretation and LANDSAT data interpretation of western spruce budworm damage, Pemberton, B.C. Classification is spatially filtered migrating means for lower half of scene only.

Area type	Slope		
	North	South	North & south
Actual damage from aerial interpretation (area of polygons)	4,231	6,316	10,547
Area correctly classified as damage within polygons by CIAS	769 (18.2%)	4,604 (72.9%)	5,373 (50.9%)
Area classified as damage outside polygons by CIAS (error)	—	—	9,034
Total area classified as damage by CIAS	—	—	14,407

centre of more lightly defoliated areas, seemed to enhance visibility. This may explain why damage appears to be more readily visible on imagery between mid-August and mid-September, considerably after the peak feeding period, at a time when most discolored foliage has dropped.

Suspected damaged areas observed on the LANDSAT imagery required appropriate ground truth, since the spectral signature of non-damaged areas on the imagery often resembled damage. When known, some damage could be better defined by referring to the imagery, but much damage was not visible. Thus, existing LANDSAT imagery alone is not adequate for close assessment and mapping of forest pest damage. Aerial photography or aerial observation surveys are required to adequately assess pest outbreaks.

Digital analysis of LANDSAT data with the CIAS provided no improvement over visual interpretation of color composite images. Spruce budworm damage was detectable with some reliability on south slopes, but tussock moth damage was poorly discerned under the best conditions. The CIAS digital maps representing damage always included more area classified as damage than actually occurred. Stands of lodgepole pine in relatively dry areas resemble defoliation from a distance such as from satellites and high level aircraft. These stands chronically suffer from physiological drought, usually appearing brownish with thin crowns.

The inadequacy of LANDSAT imagery or computer assisted classification for mapping forest pest damage relates ultimately to the spatial resolution of the current satellites. Some of the proposed satellites with improved resolution may overcome the present limitations. In the meantime, research on new sensors and interpretive techniques should continue as the results in many cases should be applicable to future satellites and there may still be means of extracting more data from existing ones.

REFERENCES

Beaubien, J. and L. Jobin. 1974. Forest insect damage and cover types from high-altitude color-IR photographs and ERTS-1 imagery. International Society for Photogrammetry Commission VII, Proc. Symposium on Remote Sensing and Photo Interpretation, Banff, 1974: 449-454.

Goldberg, M. and D.G. Goodenough. 1976. Analysis of a spatial filter for LANDSAT imagery. Proc. SPSE Conference on Image Analysis and Evaluation (Waverly Press), 13 pp.

Goodenough, D. 1976. IMAGE 100 classification methods for ERTS scanner data. Can. J. Remote Sensing 2: 18-29.

Goodenough, D.G. 1977. The CCRS Image Analysis System. Proc. 4th Canad. Symp. on Remote Sensing: 227-244.

Hall, R.C., S.L. Wert and T.W. Koerber. 1974. Application of ERTS-1 imagery and underflight photography in the detection and monitoring of forest insect infestations in the Sierra Nevada mountains of California. Natural Resources Management Corporation, 44 p.

Harris, J.W.E. 1974. Small-scale imagery in forest pest surveys in British Columbia. Canadian Surveyor 28: 155-161.

Heller, R.C., R.C. Aldrich, R.S. Driscoll, R.E. Francis and F.P. Weber. 1974. Evaluation of ERTS-1 data for inventory of forest and rangeland detection of forest stress. Pacific Southwest Forest and Range Experiment Station, 276 p.

Kirby, C.L., D. Goodenough, D. Day and P. Van Eck. 1975. LANDSAT imagery for Banff and Jasper National Parks inventory and management. Proc. Third Canadian Remote Sensing Symposium, Edmonton: 207-225.

Lee, Y.J., E.T. Oswald and J.W.E. Harris. 1974. A preliminary evaluation of ERTS imagery for forest land management in British Columbia. Second Can. Symp. on Remote Sensing, Guelph: 88-101.

Rohde, W.G. and H.J. Moore. 1974. Forest defoliation assessment with satellite imagery. Proc. 9th Internat. Symp. on Remote Sensing of the Environment, Ann Arbor: 1089-1104.

Weber, F.P., E.H. Roberts and T.H. Waite. 1975. Forest stress detection. Ponderosa pine mortality from mountain pine beetle. Eucalyptus mortality from low temperature. In Evaluation of ERTS-1 Data for Forest and Rangeland Surveys: 44-61. USDA Res. Pap. PSW-112.

Williams, D.L. and B.J. Turner. 1975. Computer analysis and mapping of gypsy moth defoliation levels in Northeastern Pennsylvania using ERTS-1 data. NASA Earth Resources Survey Symp., Houston, 1975: 487-501.

Appendix I. LANDSAT imagery on which forest pest damage is visible in British Columbia, 1972 to 1975.

Pest species	Location	Date	Image no.[1]	Band[2]
Douglas-fir tussock moth	Kamloops region	19 July/74	10726-18223	8,9
		6 Aug./74	10744-18215	8,9
		23 July/75	20182-18191	8,9
		15 Sept./75	20236-18181	8
Western spruce budworm	Fraser Canyon	29 July/72	10006-18304	9
		4 Sept./72	10043-18364	8,9
		16 Sept./73	10420-18300	8,9
		23 July/75	20182-18193	8,9
	Hope-Princeton Hwy.	16 Sept./73	10420-18303	8,9
		5 Aug./74	10743-18170	8,9
		22 July/75	20181-18141	8,9
	Pemberton region	30 July/72	10007-18362	8,9
		4 Sept./72	10043-18364	5,8,9
		12 Aug./73	10385-18362	5,8,9
		20 July/74	10727-18284	8,9
		7 Aug./74	10745-18280	8,9
		25 Aug./74	10763-18272	8,9
		12 Sept./74	10781-18263	8,9
		12 Aug./75	20202-18303	8,9
		7 Sept./75	11141-18100	5
Western blackheaded budworm	Port Alice	2 Aug./72	10010-18534	8
	Kitimat region	12 Aug./74	10750-18551	8,9
		13 Aug./74	10750-19010	8,9
Western hemlock looper	Columbia River	10 Aug./73	10383-18243	8,9
Western false hemlock looper	Little Shuswap L.	10 Aug./73	10383-18250	9
Mountain pine beetle	Mable Lake	10 Aug./73	10383-18250	9

[1] The underlined images show damage best; in the others, damage is harder to see because of small size or poor contrast with background; a few images are very cloudy.

[2] 5- single LANDSAT band 5; 8- combined bands 4,5,6 or 4,5,7; 9- combined bands 5,6,7; foregoing are standard Canada Centre for Remote Sensing designations.

Appendix II. LANDSAT computer compatible tapes examined for forest insect damage analysis on the CIAS.

Pest species	Image no.	Date	Remarks
Douglas-fir tussock moth	10690-18234	13 June/74	For multi-date analysis with next 2 images.
	20182-18191	23 July/75	Image quality excellent, damage showing well.
	20236-18181	15 Sept./75	Slightly hazy, but damage shows best.
Western spruce budworm	10043-18364	4 Sept./72	Good image for showing budworm damage at Soo R.
	10385-18363	12 Aug./73	Best image for showing budworm damage at Lillooet R., but tape destroyed.
	10691-18295	14 June/74	For multi-date analysis with next 3 images.
	10745-18280	7 Aug./74	Image quality only fair.
	10763-18272	25 Aug./74	Good image for Lillooet R.
	10781-18263	12 Sept./74	Good image for Soo and Lillooet rivers.

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Report BC-X-182

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December 1978