COMPARISON OF FOREST FIRE MAPPING RESULTS FROM AERIAL RECONNAISSANCE AND FROM LANDSAT IMAGERY

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ABSTRACT

Landsat imagery was used to map forest fires that occurred between 1969 and 1980 on a 48,000 km^2 area east of Fort Smith, N.W.T. The accuracy of the conventional method for mapping forest fires was tested by comparing the areas of 1979 and 1980 fires mapped by that method with the results of mapping from Landsat imagery. One and two year old burns are readily identifiable as an interpretive category by manual analysis of Landsat data. Sixty-seven percent of the fires that occurred in 1979 and 1980 have larger areas when mapped from Landsat imagery. Unburned inclusions and water covered areas represent from 10% to 52% of the total area within the perimeter of specific fires. The boundaries of seven 1979 and two 1980 fires in the project area were not shown on official copies of fire maps for the area. Two types of errors were observed concerning the seven fires that were not mapped. Some fires (5) had been surveyed by the conventional method but not mapped and two fires had apparently not been surveyed. Digital analysis of Landsat data for forest fire mapping is recommended.

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INTRODUCTION

Fire is recognized as an important factor in controlling wildlife habitat conditions throughout the boreal forest region of the Northwest Territories (N.W.T.). From 1970 to 1979 the average area of N.W.T. forests annually affected by fire was 0.48 million hectares, while yearly totals during that period ranged from 0.04 to 1.99 million hectares (Murphy et al. 1979). The latter figure represents widespread burning in 1979 that developed under hot and dry conditions. Burning in the N.W.T. on the scale of that in 1979 has not been previously reported.

In response to concerns about the impacts of forest fire in the N.W.T., the Minister of the Department of Indian Affairs and Northern Development (DIAND) appointed a Fire Review Panel to review all aspects of fire management policy and operational procedures. In their report to DIAND, the Panel discussed the use of Landsat imagery to delineate fire boundaries and to study fire effects (Murphy et al. 1979). In an earlier study, Thomson and Dixon (1975) concluded that monitoring and mapping forest fires in the N.W.T. from Landsat imagery is both inexpensive and practical. Earlier studies did not test the accuracy of the conventional method[1] for mapping forest fires.

In areas where there is intensive forest management for production of timber products, annual depletion of forests from burning is computed as meticulously as depletion from cutting. In

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1 The practise of observing a forest fire from an aircraft and plotting the fire's perimeter on a 1:250,000 scale topographical map is referred to here as the conventional method.

the N.W.T., where forested lands comprise 166.6 million hectares, accurate monitoring of year to year changes in remote areas presents a unique challenge because only nine percent of the total is productive forest land (Bickerstaff et al. 1981). Forest managers may place a lower order of priority on monitoring burned-over areas in the 91% of forests where timber stands of commercial grade do not occur. Therefore, it is not unusual to find that mapping of fires in remote areas is far from meticulous or that some burns do not appear on fire maps prepared from the conventional method.

Sound wildlife management requires a thorough understanding of habitat potentials. Therefore, patterns of habitat change in terms of time and space must be accurately monitored in order for effective wildlife management programs to be developed. In the boreal forest ecosystem the baseline information on which management decisions are formed is not complete unless the effects of fire-induced changes are known. An accurate description of the areas affected by fire is mandatory for assessing these effects.

PRESENT FIRE MAPPING TECHNIQUES

Under the system presently in use, forest fires are mapped on to National Topographic System (NTS) maps at 1:250,000 scale. Resource Management Officers (RMO's) employed by DIAND conduct aerial surveys of burned areas and plot the fire perimeters on NTS maps.

DIAND administers the forest management and fire management programs in the Northwest Territories. Fire management is applied in accordance with a priority zone system that reflects values at risk in terms of human safety, economics and other societal descriptors. The amount of effort that is put into fire mapping is linked to the priority system and no attempt is made to systematically monitor and map every fire in woodlands that are in the Observation Zone[1]. Under the present system, RMO's will map fires that receive suppression effort and other fires that they discover during flights in relation to other land-management responsibilities, but reconnaissance flights for the express purpose of locating and mapping fires in the Observation Zone are not carried out. Information may be gathered on any fire, including those that are not suppressed, but only in cases where there is a need for such information in order to answer DIAND's operational requirements. However, those requirements do not include gathering information about the effects of burning on wildlife habitat.

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1 The term "Observation Zone" denotes an area where fires do not ordinarily receive suppression effort but some fires in that zone may be fought in accordance with guidelines set by DIAND.

Fire maps prepared by DIAND show the perimeter of burned areas but unburned inclusions inside the general perimeter are not shown. Bradley et al. (1982) estimated that unburned inclusions may comprise up to 50% of the total area in some burns. Estimates as to cumulative areas affected by burning, that are based on perimeter mapping, do not portray the actual impact of forest fires if unburned inclusions are not considered in area calculations. Annual rates of burn expressed as a percentage of total forested area may be inflated if homogeneity with the perimeter of every burn is assumed. Ecological effects of forest fires cannot be assessed if the variability of burned and unburned areas cannot be determined.

In recognition of the limitations imposed on fire mapping by the priority zone system, a project was carried out to assess the conventional method by mapping selected fires from Landsat imagery and comparing the results. The assessment considers factors that are important to fire mapping for the purposes of wildlife management. These factors include complete delineation of all fires and exclusion of unburned areas from the area calculations. It is realized that the level of detail required for wildlife management may exceed the information requirements for other purposes.

METHODS

A 48,000 km^2 area east of Fort Smith, N.W.T. comprised of NTS maps numbered 78C (Hill Island Lake), 75D (Fort Smith), 75E (Taltson Lake) and 75F (Nonacho Lake) was selected for the project (Fig. 1). This area experienced widespread burning in 1979 and has been the subject of considerable interest because of conflicting reports as to the ecologic effects of fire on wildlife, particularly on range relationships between the Beverly herd of barren-ground caribou and their winter range.

Satellite imagery was selected from the Manitoba Centre for Remote Sensing (MCRS) microfiche file of Landsat scenes on the basis of the most cloud-free post-1979 imagery for the area. Landsat imagery compiled on 30 and 31 May 1981 best suited the selection criteria. Interpretation of the imagery was done manually by the staff at MCRS.

Burned and unburned areas are visible in Landsat scenes because of variances in the type and brightness of reflectance from different types of forest cover. Each type of ground cover has a specific reflectance that is detected by scanners on board the satellite and transmitted to receiving stations on earth. The signal is processed to derive an image of a segment of the earth's surface in which areas with analogous reflectance are grouped into interpretative classes by colour enhancement or by shading.

Initial interpretation of NTS map sheets 75C and 75D was carried out using black and white imagery in the near infra-red 0.8 to 1.1 micron wavelength band (Band 7). Seevers et al. (1973) reported superior results from the use of satellite imagery in

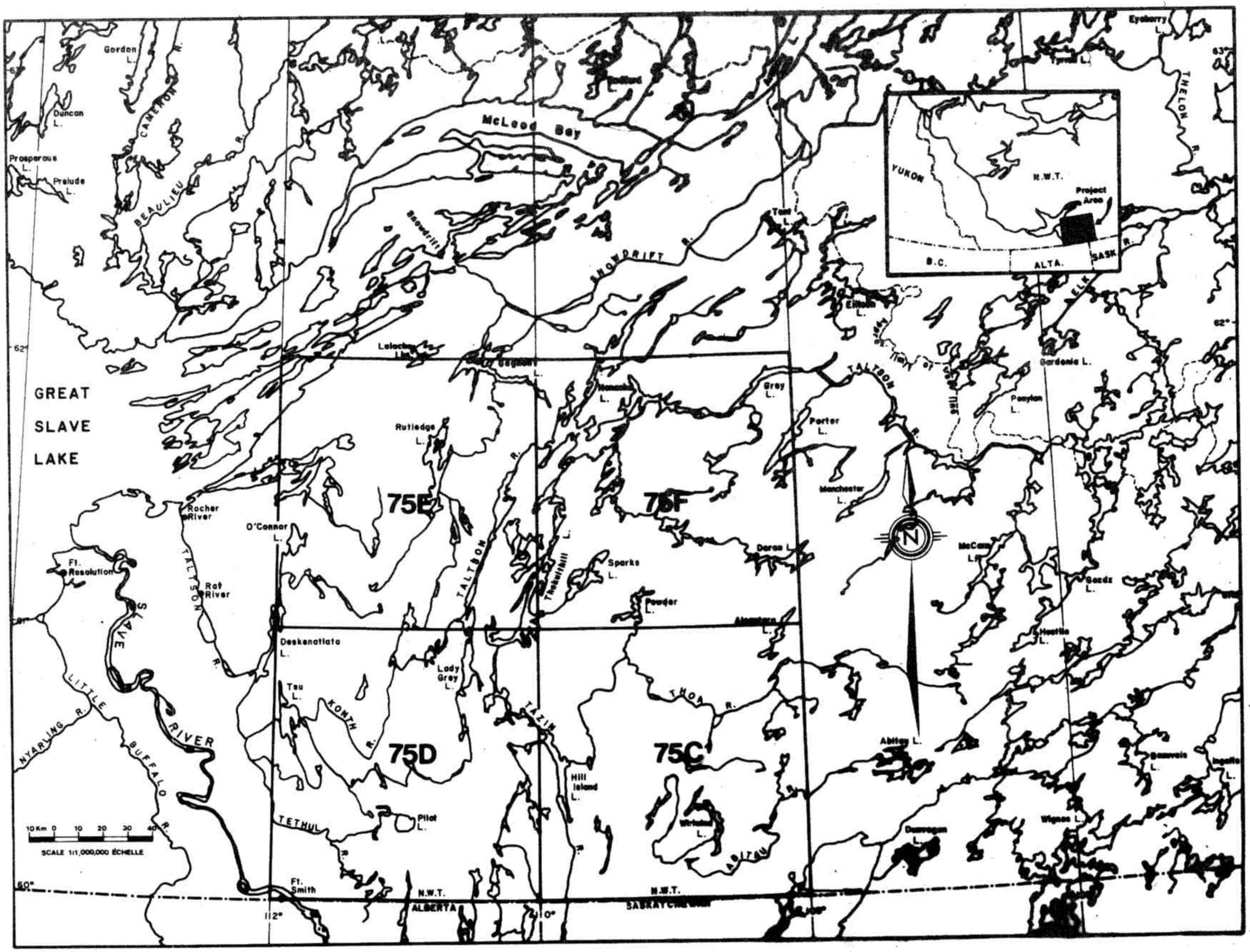

Figure 1. Area selected for comparison of fire mapping techniques.

Band 7 for monitoring range fires in Nebraska, as compared with imagery from sensing in the 0.5 to 0.6 and 0.6 to 0.7 micron wavelength bands (Band 4 and Band 5).

Multispectral scanner (MSS) imagery in Bands 4, 5 and 7 was used for mapping forest fires on the Taltson Lake and Nonacho Lake map sheets.

Landsat imagery in Band 7 for the Fort Smith and Hill Island map sheets was obtained from the Canada Centre for Remote Sensing (CCRS). The imagery was ordered in standard format black-and-white positive transparencies at 1:1,000,000 scale. The standard format imagery was enlarged to the mapping scale of 1:250,000 and black-and-white prints covering the area of each map sheet were prepared. Fire boundaries were copied from the Landsat enlargements to mylar base maps of the two respective map sheets. The base maps were official copies of maps used by DIAND for mapping fires by the conventional method and had fire boundaries on them.

By enlarging the Landsat imagery to 1:250,000, it was possible to transpose burn perimeters from Landsat scenes to NTS base maps over a light table without the use of a zoom transfer scope. The interpreter was able to align the NTS sheets and the Landsat imagery by slight adjustments in positioning of corresponding topographical features as the work progressed. Such adjustment was necessary because the Landsat scenes were not geometrically corrected.

Colour composit MSS imagery in Bands 4, 5 and 7 was used to delineate fire boundaries on the Taltson Lake and Nonacho Lake map sheets. The colour transparencies supplied by CCRS in 1:1,000,000 scale were enlarged to 1:250,000 scale and reproduced as an Ektacolour print for Nonacho Lake sheet and a Duratrans transparency for the Taltson Lake sheet. Transposing fire boundaries from MSS imagery to NTS maps followed the methods described above for Band 7 imagery.

Area calculations for all map sheets were carried out using a La Sico rolling disc planimeter. The areas of fires mapped by the conventional method were not recalculated to detect potential errors in the original planimeter measurements.

The area of unburned inclusions and water bodies was derived from the estimated percentage of such areas within the perimeter of each fire. Homogeneous tracts of unburned forest in the perimeter of fire number SM2/79 and other large fires were measured with the planimeter. Planimetric measurement of miniscule unburned areas distributed throughout most burns were not carried out because, even at 1:250,000 scale, they were too small for accurate delineation.

DIAND's system for numbering fires was adopted for clarity in making comparisons[1]. The areas of specific fires computed by DIAND form the basis for comparison between Landsat and conventional fire maps. Fires that extended beyond the project area were not considered in the comparisons because mapping of these fires from Landsat was incomplete.

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1 Fires are numbered serially according to district and year of occurrence. Thus, SM2/79 identifies a fire in the Fort Smith District that occurred in 1979.

RESULTS

Size Comparison

Forest fires surveyed in the project area by means of the conventional method totalled 1,853,034 hectares and the total from Landsat imagery was 2,011,307 hectares (Table 1). Areas of 19 forest fires that occurred in 1979 and 1980 are presented in Tables 2 to 5 but only 18 are used for basis of comparison because one fire, CR13/79 (Table 3) was incompletely mapped.

Twelve of the fires (67%) are larger when mapped from Landsat. Largest differences in size are in relation to small fires and the largest fires are most closely in agreement as to gross size. Thus, CR22/79 with an area of 450 ha from conventional mapping has a C/L ratio[1] of 0.22, while SM2/79 with a size of 725,399 ha has a C/L ratio of 0.96. Table 1 shows a C/L ratio of 0.92 for the total burned in the project area but the ratio for specific fires ranges from 0.22 on the Nonacho Lake sheet to 1.40 on the Fort Smith map sheet.

The total area burned within the perimeter of specific fires ranged from 49 to 90%. Thus, the net area affected by burning in SM2/79 was 446,013 ha or 59% of the gross area mapped from Landsat (Table 6). Areas burned within the perimeter of fires <10,000 ha

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1 The quotient of fire size from the conventional method (C) divided by fire size from Landsat mapping (L) is referred to here as C/L ratio. A C/L ratio of 1 would signify agreement in terms of gross size, while C/L ratios <1 signify that Landsat fire size was larger than from conventional mapping.

Table 1. Total area of fires in hectares within fire perimeters in the project area from 1969 to 1980.

Map sheet	Gross area (conventional)	Gross area (Landsat)	C/L ratio col. 2/ col. 3	Net area[1]	% burn
Fort Smith	978,089	715,656	1.37	421,562	59
Hill Island Lake	331,201	524,637	0.68	393,538	75
Taltson Lake	414,362	565,022	0.73	357,945	63
Nonacho Lake	129,382	205,992	0.63	159,156	77
Total	1,853,034	2,011,307	0.92	1,332,201	66

1 Gross area (Landsat) minus unburned inclusions and waterbodies.

Table 2. Area in hectares for 1979 fires on Fort Smith (75D) map sheet.

Fire No.	Gross area (conventional)	Gross area (Landsat)	Unburned inclusions[1]	Water	Net area[2]	% burn	C/L ratio col. 2/ col. 3
SM2/79	725,399[3]	755,602[3]	74,903(14%)	234,686(31%)	446,013	55	0.96
SM22/79	10,064	7,207	533(10%)	2,017(28%)	4,657	62	1.40

1 Expressed as percent of the actual land area.

2 Gross area (Landsat) minus unburned inclusions and water.

3 Includes contiguous areas mapped on Hill Island Lake (75C) and Taltson Lake (75E) map sheets, (see Table 6).

Table 3. Area in hectares for 1979 and 1980 fires on Hill Island Lake (75C) map sheet.

Fire No.	Gross area (conventional)	Gross area (Landsat)	Unburned inclusions[1]	Water	Net area[2]	% burn	C/L ratio col. 2/ col. 3
CR6/79	136,847	161,170	16,170(12%)	24,255(15%)	120,745	73	0.85
CR9/79	55,350[3]	69,768[3]	5,554(10%)	12,188(17%)	52,026	73	0.79
CR13/79	70,000	34,386[4]	440	6,880	23,078	—	—
CR39/79	3,843	6,176	254(5%)	616(10%)	5,306	85	0.62
CR3/80	11,936	6,466	647(10%)	647(10%)	5,172	79	1.85
CR4/80	58,642	48,532	4,176(10%)	6,598(14%)	37,758	76	1.21

1 Expressed as percent of the actual land area.

2 Gross area (Landsat) minus unburned inclusions and water.

3 Includes contiguous areas mapped on Nonacho Lake (75F) map sheet.

4 Portion of CR13/79 extending onto Abitou Lake (75B) map sheet not mapped from Landsat.

Table 4. Area in hectares for 1979 and 1980 fires on Taltson Lake (75E) map sheet.

Fire No.	Gross area (conventional)	Gross area (Landsat)	Unburned inclusions[1]	Water	Net area[2]	% burn	C/L ratio col. 2/ col. 3
CR19/79	8,147	12,065	121(2%)	6,035(50%)	5,909	48	0.70
CR40/79	16,382	22,316	223(2%)	8,926(39%)	13,167	59	0.73
CR2/80	2,332	2,348	23(1%)	235(10%)	2,090	89	0.99
CR16/80	10,995	6,113	306(6%)	1,223(20%)	4,584	74	1.80
CR19/80	2,076	1,822	18(1%)	273(15%)	1,531	84	1.14

1 Expressed as percent of the actual land area.

2 Gross area (Landsat) minus unburned inclusions and water.

range from 65% to 90%. Burned areas within the perimeter of fires >10,000 ha range from 49% to 75%. The highest percentages of burned areas within the perimeters of specific fires are found on the Nonacho Lake map sheet (Table 5).

Delineation of Fire Boundaries on Landsat Imagery

Recent burns appear darker than adjacent unburned areas in the Band 7 black and white Landsat scenes (Fig. 2). This tonal variation results from the amount of infrared light that is reflected by fire-damaged and healthy forests. Foliage of plants that are photosynthetically active reflects more infrared light, thus areas with healthy vegetation are distinguished in the imagery as lightly shaded areas (Ontario Centre for Remote Sensing 1975).

In Figure 2 water bodies can be distinguished from burned areas because the former are darker. Unburned inclusions are recognizable as lightly shaded areas.

Features on MSS Landsat imagery are also discernable from the specific reflectance of different landscapes. Areas that have analogous reflectance are recognized as interpretive categories and appear as similarly coloured areas in the imagery. Thus, recent burns in Figure 3 are recognizable as areas of dark hue. Peak reflectance from stressed or dead foliage in the near-infrared 0.8 to 1.1 micron wave lengths (Band 7) is depicted in this colour composite image as blue-green. Reference to fire maps verified burning as the stress causing agent and established blue-green as an interpretive category for classifying other areas with similar reflectance. Other interpretive categories derived

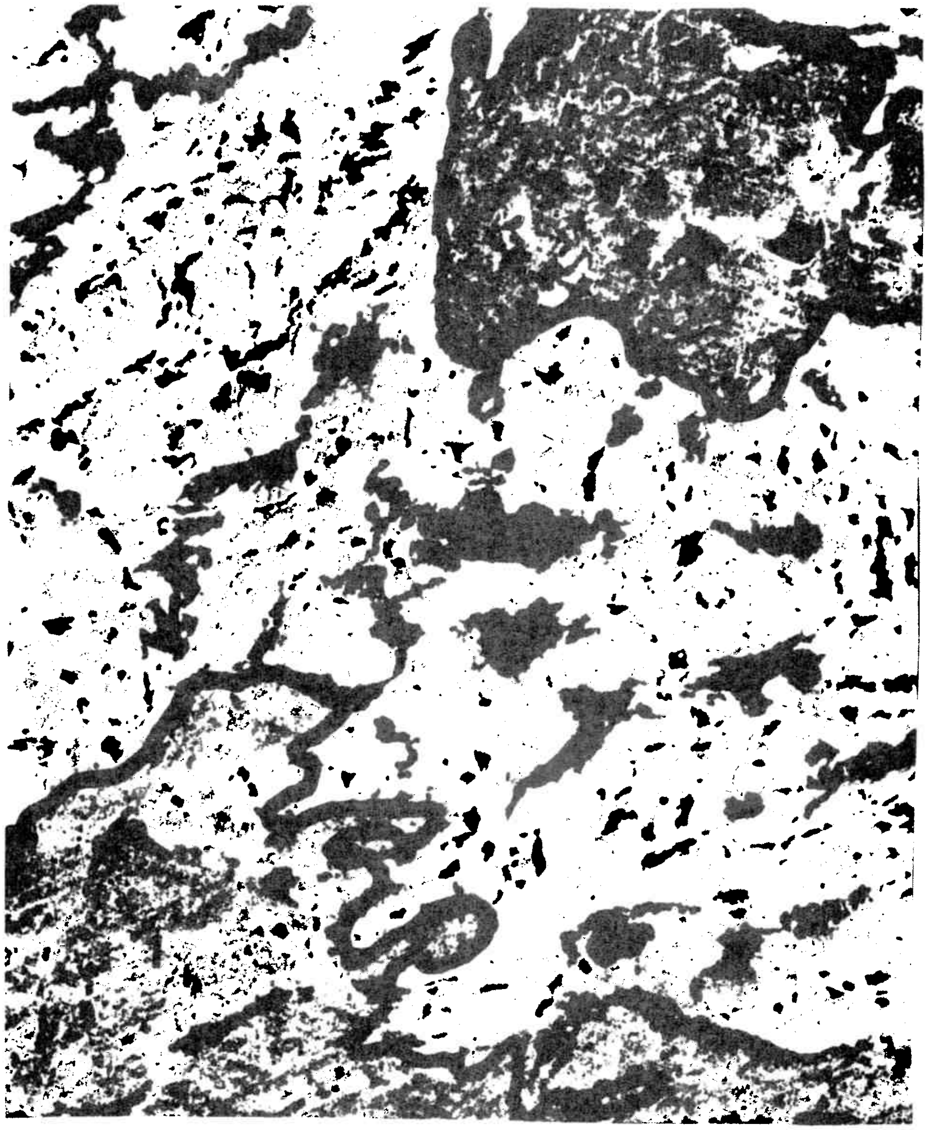

Figure 2. A segment from the Landsat scene (Band 7) of the Nonacho Lake map sheet showing parts of fires CR11/79(1) and CR23/80(2). The 1980 fire appears darker than the one that occurred in 1979. Unburned inclusions are lightly shaded areas within the fire perimeter. The perimeter has been outlined with black ink.

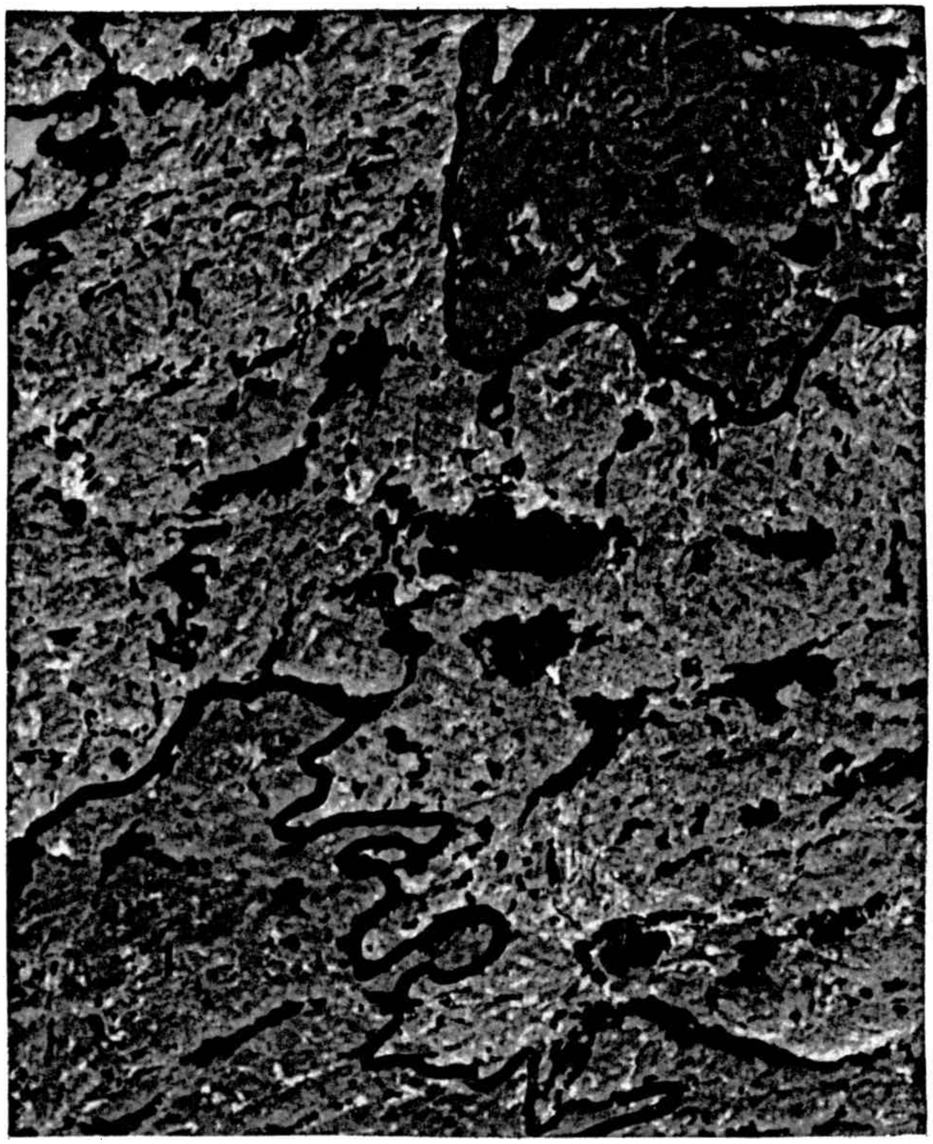

Figure 3. A segment from the MSS colour composite scene depicting the same part of the Nonacho Lake map sheet as is shown in Figure 2. Recent burns (1) and (2) are blue-green in colour and unburned inclusions are recognizable as lightly coloured areas. Tonal variations are more readily detected in MSS colour imagery than in the Band 7 black and white imagery.

from reflectance in MSS bands are recognized as different vegetation communities and revegetated burns.

Completeness of Fire Mapping

Several fires in the project area that were mapped from Landsat do not appear on the fire maps derived from aerial reconnaissance. On Hill Island Lake map sheet, two fires totalling 195,556 ha were not plotted on the corresponding fire map, although both fires had been surveyed and assigned fire numbers (CR6/79 and CR13/79, Table 3) by DIAND.

The Landsat scene of Nonacho Lake map sheet has three 1979 burns and two 1980 burns that were not plotted on the fire maps. One of the unmapped 1979 fires had been surveyed and designated as CR11/79 (Table 5). The two remaining unmapped 1979 fires, having a combined gross area of 9,900 ha, were not numbered. Ground truthing of the Landsat scene on 5 July 1982 confirmed the interpretation. The 1980 burns, that were not mapped on our copies of the fire maps, now appear on DIAND's new series of fire maps as CR15/80 and CR23/80 (Table 5).

The largest amplitude in C/L values is for Nonacho Lake map sheet (Table 5) where there is a fivefold difference between high and low values.

The unmapped fires were confined to the most easterly map sheets. No such discrepancies were observed on the Fort Smith and Taltson River sheets (Fig. 1).

DISCUSSION

Accuracy of Landsat Interpretation

Landsat scenes that were used in this project clearly show recently burned areas. Fires that occurred in 1979 and 1980 were easily detected and accurately mapped.

The accuracy of Landsat interpretation is supported by considering the statistics for fires CR15/80 and CR23/80 (Table 5). The interpreter correctly dated these fires as having occurred in 1980. The fact that they were not on the corresponding fire map precludes all likelihood of "data snooping" by the interpreter. He mapped these continguous fires as one burn and the C/L ratio is 1.10, meaning that the Landsat size of CR15/80 and CR23/80 is 10% smaller than from conventional mapping.

Older burns, those dating to 1970 and 1971, were detected in the Landsat imagery. However, the interpreter may not have identified them without reference to DIAND's fire maps. Visual interpretation of Landsat imagery to detect and classify burns, whose chronology cannot be confirmed by comparing Landsat scenes from consecutive years, is of limited value. The visual method of evaluating Landsat derived data to detect forest fires is best suited for monitoring year to year changes.

Unburned Areas Within Fire Perimeters

Determining the unburned fraction within the perimeters of burns by visual interpretation of Landsat imagery presents a difficult problem. Estimating unburned areas within the perimeter of fire CR22/79 (Table 5) with the use of an area grid produced a tally 8% higher than the interpreter's estimate. Tallying unburned inclusions within every fire perimeter in the project area would be impractical, except for small fires, and even then most of the potential sources of error would be present. Digital processing of Landsat data to calculate the area of unburned inclusions is an attractive option for addressing this problem because the digital format eliminates area calculations by manual methods (Isaacson et al. 1982).

Incomplete Fire Mapping

Two types of errors were detected. Firstly, a number of fires (5) were surveyed but their boundaries were not transferred onto DIAND's master copy of the fire maps. The error was apparently one of omission in updating the maps because these fires were numbered. Secondly, other fires (2) were apparently not surveyed because they are not numbered. Both types of errors compromise the reliability of conclusions concerning the effects of fire on wildlife habitat based on conventional mapping techniques.

Similar ommisions were reported by Rowe et al. (1975) in their study area north of Yellowknife. Using satellite imagery they identified eight pre-1973 fires, with an estimated combined area of 47,000 ha, which had not been reported by conventional methods.

Fire mapping cannot be considered complete for the purposes of assessing habitat conditions unless the area calculations take into account unburned inclusions. Cumulative rates of burn based on simple delineation of fire perimeters may grossly overestimate the actual impacts of fire. As much as 52% of the area in specific fires can be unburned (Table 4).

Positive and Negative Aspects of Fire Mapping from Landsat

1. Recent burns are easily recognizable as an interpretive category that can be measured and evaluated by standard mapping techniques. Unburned inclusions can be delineated and measured. These factors are important in assessing the impacts of fire on wildlife habitat. The conventional method of fire mapping does not provide this level of detail.

2. The process of mapping fires from Landsat is cost effective. The cost of materials for this project was $296.78, including the Ektacolour MSS replicate of Fort Smith NTS sheet originally interpretated from black and white imagery in Band 7. The use of MSS colour composite imagery is recommended because spectral classes are more clearly visible.

3. Visual interpretation of Landsat scenes enlarged to a working scale of 1:250,000 enables the interpreter to plot fire boundaries directly onto NTS map sheets of the same scale.

4. Real-time landsat imagery may not be available to delineate fire boundaries during the fire season. Satellites have a periodicity that is set by their orbital parameters. Thus, there is a wait of 18 days between successive Landsat 3 images of a particular part of the earth's surface. If the

area of interest happens to be clouded over during successive orbits, there may be a lengthy delay in obtaining usable imagery or it may be totally unobtainable in the MSS bands.

5. Accurate estimates of unburned areas inside the general fire perimeter are difficult to obtain from visual interpretation of Landsat imagery. Digital analysis of spectral categories is recommended for assessing the distribution and size of unburned inclusions.

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