Surficial Geology and Climatic Effects on Forest Clearcut Tone in RADARSAT Images of Northern Vancouver Island

by P.A. Murtha

RÉSUMÉ

Le "British Columbia Forest Practices Code" comporte l'obligation de protéger les biefs des rivières et des ruisseaux qui constituent des habitats pour les poissons au moyen d'un système de zones de réserve et de gestion riveraines. Les zones de réserve se présentent comme des lisières boisées recouvertes de boisé ancien au milieu des nouvelles zones de coupe à blanc. Les données RADARSAT en mode faisceau fin 2 peuvent imager ces lisières et leur détectabilité dépend de la condition et du contraste de ces lisières par rapport au fond environnant de la zone récente de coupe à blanc. Le présent article fait le point sur la plausibilité de l'effet combiné de la géologie des formations meubles (formes de relief) et du climat sur la teinte dans les images RADARSAT dans les zones de coupe à blanc au nord de l'île de Vancouver, en Colombie-britannique. Une forme de relief se définit comme une configuration de matériaux meubles constituant une unité de terrain identifiable sur une photo aérienne. Le relief de chaque parterre de coupe a été interprété par photointerprétation à partir des photographies aériennes couleur conventionnelles d'août 1995 à l'échelle du 1:20 000, et pour la région de la zone d'étude, à partir des photographies aériennes panchromatiques de 1986 à l'échelle du 1:60 000. Les formes de relief comprennent des moraines de fond, des tills et substratum rocheux, des plaines de till drumlinisées et des lits glacio-marins et lacustres. La photointerprétation a été corroborée par des données de terrain. Trente-deux zones récentes de coupe à blanc (depuis 1991) ont été évaluées pour la teinte sur les images RADARSAT en mode fin 2 acquises à six dates différentes, du 4 décembre 1996 au 24 mars 1999. Des échantillons de sites d'entraînement ont été utilisés pour dériver 53 valeurs moyennes de compte numérique (DN) en tant qu'indicateurs de la teinte des parterres de coupe pour les 32 parterres de coupe situés sur les cinq formes de relief différentes pour chacune des images RADARSAT. Des valeurs moyennes de DN ont aussi été dérivées pour onze peuplements anciens de cèdre et de pruche de l'Ouest et dix peuplements matures de pruche de l'Ouest et de sapin. Les valeurs moyennes de DN des parterres de coupe ont été classifiées selon les formes de relief ou l'année de coupe. Les parterres de coupe situés sur les cinq formes de relief ont été comparés aux peuplements forestiers. Les résultats suggèrent qu'au nord de l'île de Vancouver, les matériaux meubles de concert avec le climat jouent un rôle sur la teinte dans les coupes à blanc sur les images RADARSAT. Au cours de l'année, les parterres de coupe localisés sur des tills sont généralement plus pâles que les parterres de coupe sur les sédiments lacustres. Comparativement aux peuplements cèdre/pruche de l'Ouest et pruche de l'Ouest/sapin environnants, les parterres de coupe sont plus pâles durant les mois d'hiver, foncés ou plus foncés que la forêt en été, et pâle à nouveau en hiver. Le patron cyclique du pâle vers le foncé puis vers le pâle des parterres de coupe peut être utilisé dans le développement d'une stratégie de télédétection pour le suivi des terres forestières. Dans le cas des applications de RADARSAT en foresterie particulièrement en ce qui concerne le suivi des parterres de coupe et des lisières riveraines, il est recommandé d'utiliser des compositions colorées multidates créées à partir de deux images de parterres de coupe pâles et d'une image de parterres foncés.

Mots clés: *RADARSAT, mode fin 2, suivi de la forêt, coupes à blanc, zone de réserve riveraine, géologie des formations meubles, effets climatiques, pruche de l'Ouest, cèdre rouge de l'Ouest.*

SUMMARY

The British Columbia Forest Practices Code requires protection of fish-bearing river and stream reaches through a system of riparian reserve and riparian management zones. The reserve zones appear as strips of the old-growth forest left in new clearcuts. RADARSAT Fine 2 beam mode data can image these strips and their detectability depends on strip condition and contrast with surrounding background of the recent clearcut. This paper reports on the plausible combined surficial geology

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• Peter A. Murtha is with the Department of Forest Resources Management, University of British Columbia, Vancouver BC, V6T 1Z4, E-mail: murtha@interchg.ubc.ca.

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(landform) and climatic effects on RADARSAT image tone of forest clearcuts on northern Vancouver Island, British Columbia. A landform is defined as configuration of surficial materials into an airphoto recognizable terrain unit. The landform of each cutblock was photo-interpreted from August 1995, 1:20,000 normal colour aerial photographs, and for the region of the study area from 1986, 1:60,000 panchromatic aerial photographs. The landforms included ground moraine, till/rock, drumlinized till plain, glacio-marine and lake beds. The photo interpretations were confirmed by field data. Thirty-two recent (since 1991) clearcuts were evaluated for image tone on Fine 2 mode RADARSAT data acquired on 6 dates, starting December 4, 1996 and ending March 24, 1999. Training area samples were used to derive 53 mean digital number (DN) values as indicators of cutblock tone for the 32 cutblocks on the 5 different landforms for each date of RADARSAT imaging. Mean DN values were also derived for 11 old-growth cedar/hemlock stands and 10 mature hemlock/balsam stands. Cutblock mean DN values were sorted according to the landforms or year of cutting. Cutblocks on the five landforms were compared to the forest stands. The results suggest that on northern Vancouver Island, surficial materials in concert with climate play a role in the tonal appearance of clearcuts on RADARSAT images. Throughout the year cutblocks on glacially-derived till are usually lighter than are cutblocks on lacustrine sediments. Relative to the surrounding cedar/hemlock and hemlock/balsam stands, cutblocks are lighter in the winter months, as dark or darker than the forest in the summer, and light again in the winter. The cyclic pattern of light-to-dark-to-light cutblocks can be taken advantage of in developing a remote sensing strategy for monitoring the forest lands. For RADARSAT applications to forestry with special reference to monitoring cutblocks and riparian strips, multi-temporal colour composites created with two light cutblock-dates of imaging and one dark cutblock-date of imaging are recommended.

***Key words**: RADARSAT, Fine 2, Forest monitoring, clearcuts, riparian reserve zone, surficial geology, climatic effects, western hemlock, western red cedar.*

INTRODUCTION

The British Columbia Forest Practices Code (FPC) requires the protection of fish-bearing river and stream reaches through a system of riparian reserve and management zones (B.C. M. of F., and B.C. MELP, 1993). Collectively called riparian leave strips, these reserve zones are strips of old growth forest left in or beside new clearcuts. RADARSAT Fine 2 (F2) beam mode data can image these strips (Murtha, 1997). Riparian strip detectability depends on strip condition (Murtha and Mitchell, 1998) and contrast with the background clearcut (Murtha 1998a). To establish a remote sensing strategy to monitor the riparian strips, it is essential to understand when the forested riparian strips contrast with the clearcut cutblocks.

However during the 2 1/3 years of monitoring the riparian strips, the tone of the clearcut cutblocks varied from brighter than the forest in the winter to as dark or darker than the forest in the summer, then bright again in the winter. Shimabukuro *et al.*, (1998) reported clearings were bright in the wet season and through multi-temporal comparison, dark in the dry season on RADARSAT images. Other reports from studies in the boreal forest (Ahern and Banner, 1997; Ahern *et al.*, 1997) and eastern Canada (Leckie *et al.*, 1998) had indicated that forest cutblocks were variable in tone and generally darker than the surrounding forest. Kux *et al.*, (1998) reported date-to-date variations in clearing image tone, but didn't know whether the variations were caused by calibration variations, recent rainfalls, or differences in incidence angles. This paper reports on the results of linking surficial geology, weather and RADARSAT image tone of forest clearcut cutblocks on northern Vancouver Island.

STUDY AREA

Located on northern Vancouver Island, British Columbia, the study area is on Western Forest Products Ltd. (WFP) Tree Farm License (TFL) which lies between Rupert Inlet and Queen Charlotte Strait (**Figure 1**), southeast of Port Hardy. The TFL is in the Coastal Western Hemlock (CWH) Biogeoclimatic Zone (Klinka *et al.*, 1991; Krajina, 1965; Pojar *et al.*, 1991), and the ecology has been documented (Lewis, 1982). The CWH has a maritime climate with mild winters and cool moist summers. The mean annual precipitation is about 1700 mm (about 70 inches), 65 % of which occurs between October and February. The topography is flat to gently undulating. The surficial geology has been mapped according to textures, genetic materials, surface forms, and modifying processes (Lewis, 1982). The dominant tree species are western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western red cedar (*Thuja plicata* Donn), Sitka spruce (*Picea sitchensis* (Bong.) Carr), and balsam: tree species in the Abies genus i.e., amabilis fir (*Abies amabilis* (Dougl.) Forbes). The tallest trees are height class 8 (70.1 to 80 m tall) (Lewis, 1982). Two common forest types are found on the TFL: cedar/hemlock (CH) on poorly drained sites and hemlock/balsam (HB) on the better drained sites (Prescott and Weetman, 1994). The CH are old-growth forests with cedar up to 800 years old and 260 cm in diameter while the hemlock in the CH are up to 400 years old and 90 cm in diameter. In the CH hemlock average 388 stems/ha followed by cedar (120) and fir (60). The HB are second growth forests which originated from catastrophic windstorms. The HB stands range in age from 70 to about 100 years old. Of the trees greater than 4 m in height, hemlock were more abundant (467 stems /ha) than the balsam (99). Forest floors in the CH forests are wetter and have less soil fauna which leads to incomplete decomposition of litter and woody debris. The understory vegetation of the CH is dominated by salal (*Gaultheria shallon* Pursh) (49%) an

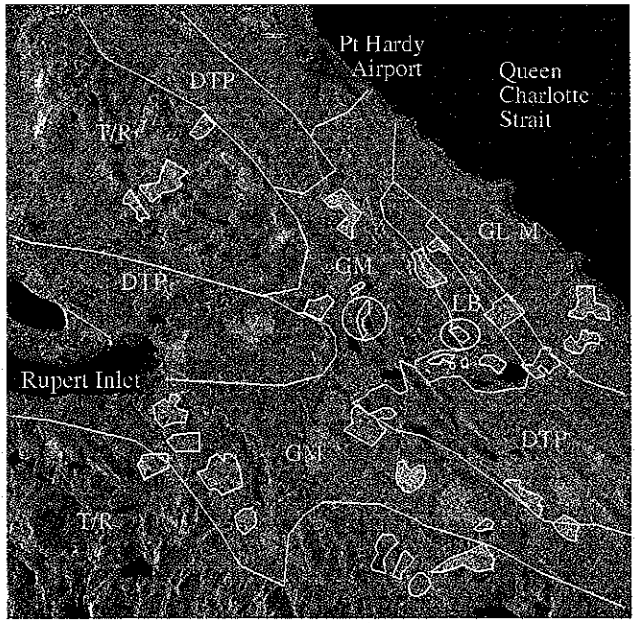

Figure 1.
Standard 4 multi-temporal colour composite of research area on northern Vancouver Island, BC, with 97/12/06, 96/12/11 and 97/07/15 as Red, Green and Blue. Study cutblocks are outlined in white, while the regional surficial geology unit (landforms) are outlined in yellow. Red cutblocks are from 1997. Landforms are DTP = drumlinized till plain; GM = ground moraine; GL-M = Glaciomarine; T/R = till over rock; LB = lakebed. See text for further explanation of the image. The subscene is 19.7 km across. Radar illumination is from the left. RADARSAT data copyright Canadian Space Agency 1996 and 1997.

ericaceous shrub, whereas the understory of the HB is dominated by mosses (Prescott and Weetman, 1994).

Year of cutting, site history, slash condition, surficial materials and silvicultural prescriptions are documented for each cutblock on the TFL. The cutblocks are located relatively close to each other, within a 15 × 20 km area (**Figure 1**). Before 1997, the clearcuts were slashburned which effectively removed only the small slash, and did not burn the coarse woody debris or the litter, fragmentation or humus layer (Prescott and Weetman, 1994). Soils in the cutblock are not exposed except along roads and landings. In 1997, the slash was piled instead of being burned. Within a year of cutting and slashburning, clearcuts are planted according to silvicultural prescriptions, fireweed (*Epilobium angustifolia*) invades the new cutblocks, and on the poorly drained wetter sites, salal and skunk cabbage (*Lysichiton americanum*) are common. In eight or nine years the young plantation trees begin to hide the logging debris and herbaceous plants. Weather records are maintained for the TFL, and Environment Canada maintains a weather station at the Port Hardy airport (**Figure 1**), which is adjacent to the study area.

METHODS

Remote Sensing Data

The TFL has been the site of SAR studies since 1993 (Murtha and Pollock, 1996). The remotely sensed data of the TFL included panchromatic and normal-colour aerial photographs, Landsat Thematic Mapper images, RADARSAT F2 and Standard 4 (S4) beam mode image data, and airborne observations. The RADARSAT data used to evaluate the tone of forest clearcuts are given in **Table 1**. All F2 and S4 RADARSAT data were acquired at 02:21 and 02:17 hours UTC respectively, or 18:21 and 18:17 hours Pacific Standard time (PST) on the previous day. (All RADARSAT imaging dates in this paper are given as the UTC date since all archived images for this project in the Canadian Space Agency have the UTC date.) August 1, 1997 (July 31 at 7:21 pm, Pacific Daylight time) was the only F2 acquisition date when it was not raining. December 11, 1996 (December 10 at 6:17 pm, PST), was the only S4 acquisition date when it was raining. Pacific frontal systems influence the entire northern part of Vancouver Island, thus when raining, the entire study area is affected.

Landform Data

A landform is an air photo-interpretable land feature (**Table 2** lists those in this paper) composed of surficial materials organized in a recognizable spatial configuration. Photo interpretation of landforms has been described by Belcher, 1997; Keser, 1976; Lillesand and Kiefer, 1994; Mollard, 1978; Ta Liang *et al.*, 1951, and Way and Everett, 1997. The surficial material of landforms relate to origin, e.g., glacial (ground moraine); glacial-fluvial (outwash deposits); fluvial (flood plain); marine or lacustrine (lake bed sediments), and aeloian deposits (sand dunes). Each landform has air photo-interpretable features that assist in identification, for example: ground moraine has a deranged drainage pattern (Keser, 1976).

A regional landform map was photo-interpreted from the 1:60,000 panchromatic aerial photographs and overlaid on **Figure 1**. Regional landforms contain inclusions of other landforms too small to map at a scale of 1:60,000. **Figure 1** has inclusions of other landforms within the ground moraine which can only be mapped at larger scales of mapping, i.e., 1:20,000.

Table 1.
RADARSAT data used to evaluate the tone of forest clearcuts. All Fine 2 and Standard 4 RADARSAT images were acquired at 02:21 and 02:17 UTC, or 18:21 and 18:17 hours, Pacific Standard time.

Local Date	UTC Date	Data	Orbit	Daylight	Weather
Dec 03/96	96/12/04	Fine 2	Ascending	No	heavy rain, strong winds
Dec 10/96	96/12/11	Standard 4	Ascending	No	heavy rain
July 14/97	97/07/15	Standard 4	Ascending	Yes	overcast, no rain for 6 hours
July 31/97	97/08/01	Fine 2	Ascending	Yes	overcast
Nov 28/97	97/11/29	Fine 2	Ascending	No	Heavy rain, 104.8 mm in 7 days
Dec 05/97	97/12/06	Standard 4	Ascending	No	Overcast, no rain for 24 hours
Aug 19/98	98/08/20	Fine 2	Ascending	Yes	light rain
Nov 23/98	98/11/24	Fine 2	Ascending	No	rain
Mar 23/99	99/03/24	Fine 2	Ascending	No	rain

Most notable are the many small glaciolacustrine deposits as well as areas with bedrock close to the surface which is overlain with thin layers of glacial till deposits called till/rock. Ground moraine has knob and kettle topography. The kettle-hole depressions are created by glacial ice blocks caught in the ablation till. The ice melts and fills the depressions with meltwater which creates small lakes and ponds. Sediments settle out and create a glaciolacustrine deposit, which is the lakebed landform. Since succession eventually vegetates these units, Lewis (1982) mapped them as mesic, organic veneer or blanket, swamps or bogs (**Table 2**). On aerial photographs, the lakebeds appear as flat, poorly drained landforms. The detailed landforms of each clearcut were interpreted from the 1:20,000 aerial photographs and verified by the TFL's surficial geology maps and field checks. The cutblocks included 5 landforms: ground moraine (GM), till/rock (T/R), drumlinized till plain (DTP), glacio-marine (Gl-m) and lakebed (LB). The surficial geology maps (Lewis 1982) describe the materials related to the landforms (**Table 2**).

Image Registration, Multi-Temporal Composites and Cutblocks

In order to create the multi-temporal colour composites, 512 by 512 pixel subscenes were saved from each RADARSAT scene. The F2 subscene grid cell resolution of 7.6 m by 7.6 m approximated the scale 1:20,000 of the 1995 normal colour aerial photographs. The December 1996 subscenes were first registered to National Topographic Series map sheet (92L/11), then each remaining similar subscene was co-registered to the December image using image-to-image registration.

Initial studies had shown that cutblocks could be clearly seen on multi-temporal colour composites (Murtha 1998a). Date of cutting was derived from the forest cover maps and the RADARSAT images themselves. All cutblocks were easily mapped on the F2 multi-temporal colour composites. Thirteen new cutblocks not on the 1995 aerial photographs were mapped from the F2 subscenes and confirmed by forestry data. **Figure 1** shows the regional distribution of cutblocks on a S4 multi-temporal colour composite with red cutblocks which were created in 1997. They are red because the cutblocks had a very bright tone on 97/12/06, the image date assigned to the red colour display. However two cutblocks (circled in **Figure 1**), which were also created in 1997, do not show as red on the S4 image. **Figure 2** is a multi-temporal colour composite with 98/11/24 as red, 99/03/24 as green and 98/08/20 as blue. The cutblocks are yellowish, the forest stands are bluish. **Figure 2** shows one of the **Figure 1**-circled cutblocks (506) clearly on a F2 subscene multi-temporal composite. Cutblock 506 is on the LB landform that is too small to map in **Figure 1**. Cutblock 507

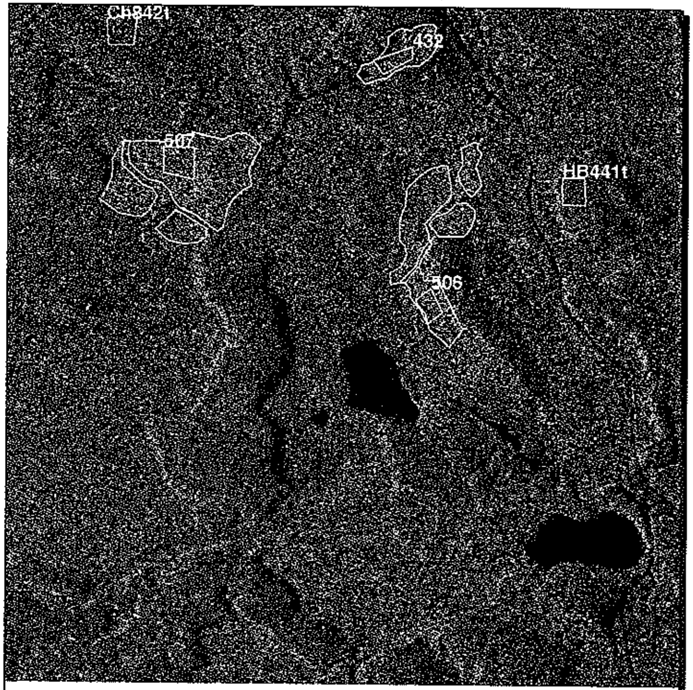

Figure 2.
Multi-temporal colour composite Fine 2 subscene with November 24, 1998, March 24, 1999 and August 20, 1998 as red, green and blue. The 1997 cutblocks are yellowish because they were bright in November and March. Training areas for pixel samples from this subscene are rectangular and found in cutblocks 432, 506, 507, and forest types HB441t and CH 842t. Cutblock 506 is on a lakebed landform, while cutblock 507 is on ground moraine and 432 is on till/rock. See text for further explanation of the image. The image subscene is 3.9 km on the side. Radar illumination is from the left. RADARSAT data copyright Canadian Space Agency 1998 and 1999.

Table 2.
Landforms (Keser, 1976; Mollard, 1978) that occur in the study area with landform codes. Map unit and surficial materials from surficial geology map by Lewis (1982).

Landform	Code	Map Unit	Materials
Ground Moraine	GM	sfMbh^1& mOvS^2	Ablation till,
Till/rock	T/R	sfMbh	Ablation till, bedrock
Drumlin	D	sfMbm^3	Basal till
Drumlinized till plain	DTP	sfMbm	Basal till
Glacio-marine	Gl-m	mOvS:sisWl^4	Glacial marine till and marine silts and sands
Lakebed	LB	mOvS	Glaciolacustrine fine sands, silts and clays

1. sfMbh = sandy fine morainal blanket, hummocky; 2. mOvS = mesic Organic veneer Swamp ; 3. SfMbm = sandy fine morainal blanket, rolling
4. SisWl = silty sandy marine level plain. (Terminology from Lewis (1985)).

is on GM, and 432 is on T/R. Cutblock 506 had an old-growth CH stand whereas 507 had a second growth HB stand, and both had riparian reserve strips. The logging debris consists of large stumps and slash which has been piled. Both had been cut at the same time: late spring, 1997. They are 1 km apart. Cutblock 507 is one of the red cutblocks in **Figure 1**. Cutblock 432 is a blowdown salvage operation at the edge of a HB stand. Field data confirmed that the two 1997 cutblocks which did not show red in **Figure 1** were on the lakebed landforms.

Sampling the Cutblocks and Forest Stands

Since some small cutblocks were barely perceptible on the S4 data, only the F2 data were used in the evaluation of the RADARSAT image tone of cutblocks. Because of comparable time frames, six dates of imaging were selected for the cutblock sampling: 96/12/04, 97/08/01, 97/11/29, 98/08/20, 98/11/24 and 99/03/24 (**Table 1**). Thirty-two cutblocks, which ranged in age from 6 years old to current year in December 1997, were evaluated for RADARSAT image tone. In a process similar to selecting training areas for a supervised classification, blocks of pixels were sampled from each clearcut to determine their mean digital number (DN) value. The size of the cutblock, flatness of terrain, and radar shadows (which were avoided) dictated the number of pixels that could be sampled. Each different training area sample covered the same area on all six dates.

For each date, 53 samples were taken from the 32 cutblocks for each of the five landforms. Based on the forest cover maps, similar samples were also obtained for ten old-growth CH stands and 11 HB stands. **Figure 2** shows training area sample locations for cutblocks 432, 506 and 507, a HB stand (HB441t) and a CH stand(Ch842t). Once the training areas were selected and saved, statistics of each sample were calculated. The calculations provided details of the sample: number of pixels, area (ha), minimum and maximum DN value, mean, medium, standard deviation, and principal components. The date of imaging, number of pixels sampled, mean DN value of each sample, year of cutting and landform or forest cover type were recorded and entered in a database. The cutblocks were sorted according to year of cutting and the mean value for each year for the six dates of imaging determined (in this case the landform of the cutblock was ignored) and then graphed. The DN means were sorted according to landform (year of cutting was ignored) and forest cover, and an average value for each of the five landforms and two forest cover types for each of the six dates was derived and graphically displayed. The nine sample means of each of the five landforms and two forest types for the six dates of imaging were also tested for significant differences using the Wilcoxon rank sum test since the nine sample replications for each landform or forest cover type was very small (Wilcoxon and Wilcox, 1964; Siege, 1956).

Summary of Methods

- Photo-interpret landform of cutblocks from aerial photographs, ground verify;
- Landforms found included: ground moraine, drumlinized till plain, till/rock, glacio-marine and lakebed;
- Save 512 by 512 pixel subscenes from each F2 RADARSAT scene;
- Co-register each subscene in order to create multi-temporal colour composites;
- Select six imaging dates (96/12/04, 97/08/01, 97/11/29, 98/08/20, 98/11/24, and 99/03/24) for composites;
- Map the cutblocks on the multi-temporal composites;
- Select training areas in each cutblock to sample pixel digital numbers (DN) for the five landforms and two forest cover types (CH and HB);
- Calculate the mean DN for each training area;
- Record mean DN value of each training area, year of cutting and landform or forest cover type in a database;
- Sort, calculate and graph the average DN for each year of cutting for each of the six imaging dates;
- Sort, calculate and graph the average DN for each of the five landforms for each of the six imaging dates;
- Test for significance nine sample means for each of the five landforms for the six dates of imaging.

RESULTS AND DISCUSSION

Table 3 gives the averaged DN values from the 32 cutblocks for the five landforms and two forest cover types for the six dates of imaging. **Figure 3** shows the average DN fluctuation of cutblocks by year of cutting for six imaging dates ranging from December 4, 1996 to March 24, 1999. The cutblocks show high DN values in the November/December winter rainy period, and low DN values in August. **Figure 3** shows that by 99/03/04 the 1992 and 1991 cutblocks are darker than the other more recent cutblocks. The 1997 cutblocks were uncut on

Table 3.
Average DN values for cutblocks on 5 landforms DTP, T/R, GM, GL-M, and LB, as well as 2 forest types CH (cedar/hemlock), HB (hemlock/balsam), for 6 dates of RADARSAT imaging.

Landform or Cover	No of Samples	6/12/04	RADARSAT 97/08/01	Image 97/11/29	Date 98/08/20	98/11/24	99/03/24
DTP	10	113	83	109	83	112	106
T/R	10	109	82	118	69	114	110
GM	15	110	80	114	76	107	106
GL-M	9	122	76	115	78	113	110
LB	9	107	82	98	78	99	99
CH842[1]	11	88	97	88	92	90	90
HB441[2]	10	74	86	78	84	78	75

1. CH852 = cedar and hemlock, age class 8 (141 - 250 yrs), height class 5 (40.1 - 50 m), stocking 2 (normal).
2. HB441 = hemlock and balsam, age class 4 (61 - 80 yrs), height class 4 (30. - 40 m), stocking 1 (dense).

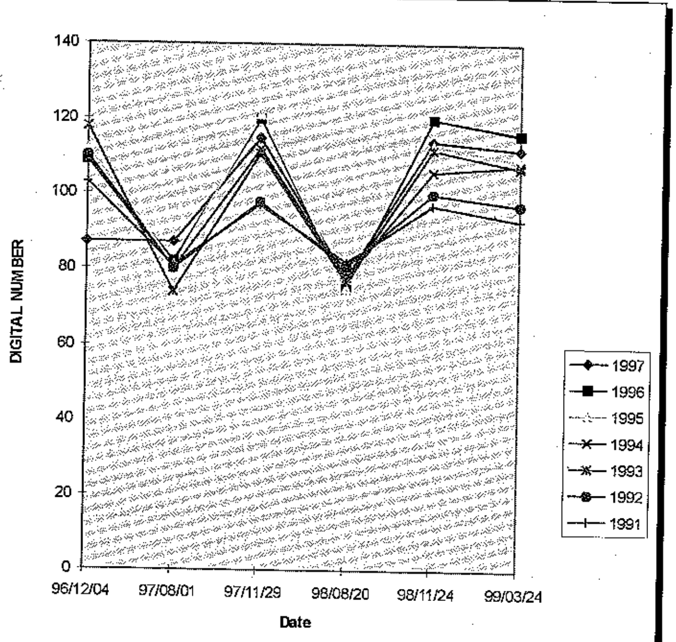

Figure 3.
DN fluctuations for cutblocks by year of cutting for six dates of RADARSAT imaging.

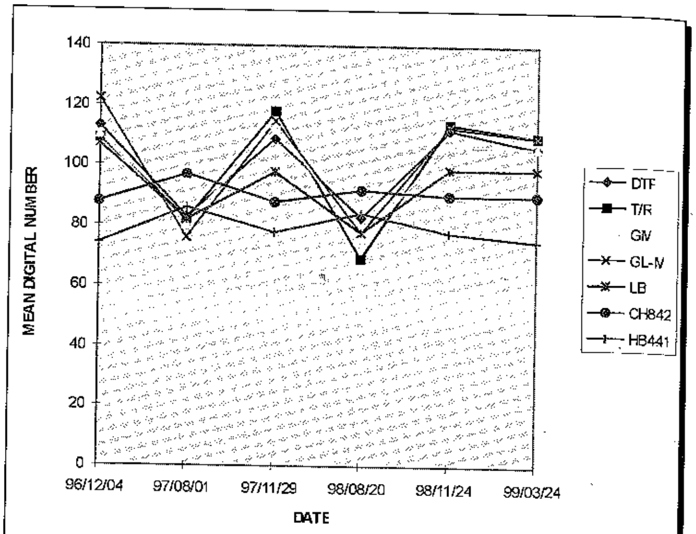

Figure 4.
DN fluctuation for cutblocks by landform and two forest types for six dates of RADARSAT imaging. Landforms: DTP = drumlinized till plain; T/R = till/rock; GM = ground moraine; Gl-M = glacio-marine; LB = lakebed. Forest types: CH842 = cedar/hemlock, oldgrowth, 30 to 40 m tall with normal stocking; HB441 = hemlock/balsam, 61 to 80 years, 30 to 40 m tall with dense stocking.

96/12/04. The DN for the 1997 cutblocks in **Figure 3** on 96/12/04 represents the uncut forest. Note that the 1997 DN value is similar to the DN values for the 1992 and 1991 cutblocks on 98/11/29 and 99/03/04. Field observation of the 1991 and 1992 cutblocks in August 1998 showed substantial revegetation of the cutblock to the extent that logging debris was hidden. TFL records indicate that within eight or nine years, the young plantation trees begin to hide the logging debris and herbaceous plants. The low values for 1991 and 1992 cutblocks in November 1997, 1998 and March 1999 are attributed to vegetation on the cutblocks.

Figure 4 shows the fluctuation of the average DN values of cutblocks and forest stands over the period of 2 1/3 years. The data indicate that cutblocks on the glacially derived till landforms are generally but not uniformly brighter than cutblocks on the lakebed deposits. During the winter rainy season (November/December) the clearcuts were consistently brighter than the surrounding forest stands. In the warm and usually drier August summer period, the cutblocks were similar to or darker than the surrounding forests. The north Vancouver Island RADARSAT summer imagery from 1997 and 1998 made cutblocks appear similar to cutblocks and land clearings reported in other studies (Ahern *et al.*, 1997; Leckie *et al.*, 1998; Shimabukuro *et al.*, 1998) which were reported as dark relative to the surrounding forest. In November the cutblocks were again light in tone. The light-to-dark-to-light cycle, first observed with the 1997 data, was repeated with the 1998 data (**Figure 4**).

The Wilcoxon test (Wilcoxon and Wilcox, 1964) ranked the mean DN for the cutblock samples (**Tables 4** through **8**) and showed that when the cutblocks were bright, the LB cutblocks were darker than cutblocks on the other landforms (**Tables 5, 7,** and **8**). There were significant differences in cutblock tone on 97/11/29 (**Table 5**), and 98/11/24 (**Table 7**). The significant differences or lack thereof are represented by the spread of DN values in **Figure 4**. It was not raining on 97/08/01, and one would expect that this date would have the smallest DN spread. However this in not the case since the spread of mean DN was the smallest on 98/08/20, when it was raining. The largest spread occurred when the cutblocks were brighter than the forest stands (November/December images), while the narrowest spread happened when the cutblocks were darker

Table 4.
Critical values for cutblock landforms for 97/08/01.

Land form	**Rank Sums**	**GM 250.5**	**DTP 249**	**T/R 217.5**	**Gl-m 198.5**	**LB 116.5**
GM	250.5	-	-	-	-	-
DTP	249	1.5	-	-	-	-
T/R	217.5	33	31.5	-	-	-
LB	198.5	52	50.5	19	-	-
Gl-m	116.5	134.5	132.5	101	82	-

P = .01 when computed difference => 181.
P = .05 when computed difference is =>152.

Table 5.
Critical values for cutblock landforms for 97/11/29.

Land form	**Rank Sums**	**GM 304**	**T/R 276.5**	**Gl-m 221**	**DTP 153**	**LB 70.5**
GM	304	-	-	-	-	-
T/R	276.5	27.5	-	-	-	-
Gl-m	221	83	55.5	-	-	-
DTP	153	151	123.5	68	-	-
LB	70.5	235.5**	206**	150.5	82.5	-

**P = .01 when computed difference => 181.
P = .05 when computed difference is =>152.

Table 6.
Critical values for cutblock landforms for 98/08/20.

Land form	Rank Sums	DTP 280	GM 212.5	GL-m 186.5	LB 186.5	T/R 172.5
DTP	280	-	-	-	-	-
GM	212.5	67.5	-	-	-	-
Gl-m	186.5	93.5	26	-	-	-
LB	186.5	93.5	26	0	-	-
T/R	172.5	107	40	14	14	-

P = .01 when computed difference => 181.
P = .05 when computed difference is =>152.

Table 7.
Critical values for cutblock landforms for 98/11/24.

Land form	Rank Sums	T/R 266	GM 257.5	GL-m 221.5	DTP 202.5	LB 87.5
T/R	266	-	-	-	-	-
GM	257.5	8.5	-	-	-	-
Gl-m	221.5	44.5	36	-	-	-
DTP	202.5	63.5	55	19	-	-
LB	87.5	178.5*	170*	134	115	-

P = .01 when computed difference => 181.
* P = .05 when computed difference is =>152.

Table 8.
Critical values for cutblock landforms for 99/03/24.

Land form	Rank Sums	GM 262	T/R 240	GL-m 212.5	DTP 184.5	LB 135
GM	262	-	-	-	-	-
T/R	240	22	-	-	-	-
Gl-m	212.5	49.5	27.5	-	-	-
DTP	184.5	77.5	55.5	28	-	–
LB	135	127	105	77.5	49.5	-

P = .01 when computed difference => 181.
P = .05 when computed difference is =>152.

than the forest stands (August images). With the narrow spread of DN values, cutblocks are more likely to blend with their surroundings, as they did during the August imagery.

Data from the CH and HB stands showed a reverse trend to that of the cutblocks (**Table 3**, **Figure 4**). When the northern Vancouver Island cutblocks were light in the November/December period, the forest stands were dark. When the cutblocks were dark in August, the forest stands were bright. **Figure 4** shows the cross-over in fluctuations for the two forest stands and the cutblocks. The CH stands were consistently brighter than the HB stands. Old-growth forests have distinctive structural characteristics which include the presence of a large number of snags, dead tops, trees with thin crowns and as well as many conifers with dome-shaped (rather than spire-shaped) crowns of old-growth trees (Nel *et al.*, 1992). These structural characteristics of size, shape, orientation and cover geometry are listed by NASA/JPL (1986) as important target parameters for SAR imaging. The normal stocking, semi-open canopy, many snags, dome-shaped crowns, plus many large candelabra-like cedar tree crowns in the CH stands would make these stands fit the description of Nel *et al.*, (1992) and the NASA/JPL (1986) list of parameters: hence the CH would be more radar reflective than the HB. The dense stocking, closed canopy, relatively even height and spire-shaped crowns of the HB stands would make the HB less radar reflective. The forest stands had, on average, relatively consistent tones when compared to the fluctuations in tone from the cutblocks.

When cutblocks and trees were ranked, the large differences between the trees and the cutblocks removed significant differences among the cutblocks (**Tables 9** through **12**). Cutblocks were significantly brighter than the trees in the November images (**Tables 10** and **12**). Trees were significantly brighter than the cutblocks in the August images (**Tables 9** and **11**), except that the DTP cutblocks were brighter than the HB on 98/08/20. The high value for the DTP cutblocks is attributed to vegetation on the DTP cutblocks which were cut in 1991 (**Figure 3**).

The HB stands are most commonly found on the till-based landforms (DTP, GM, and T/R) whereas the CH stands are found on the more poorly drained landforms (LB and Gl-m). The answer to the cutblock-tone question may lie in the forest site descriptions reported by Prescott and Weetman (1994). Some of the study plots for the Prescott and Weetman report lie between cutblocks 506 and 507 (**Figure 2**). They write that "The CH forest floors tend to be wetter than the adjacent HB forest floors, which could lead to incomplete decomposition and low rates of N mineralization." This leads to a buildup of coarse woody debris on the surface and in the litter, fragmentation and humus layers. Prescott and Weetman (1994) also reported the in the first 30 cm of the soil profiles, the percentages of sand, silt and clay were similar in the CH and HB. The CH had 41% sand, 37 % silt and 22 % clay, whereas the HB had 39 % sand, 38 % silt and 23 % clay. However the origins of the soils are different. The CH soils are derived from water-laid materials and are stratified. The HB soils are derived from ablation or basal till and they contain more coarse fragments and are non-stratified, which makes them better drained. The landforms determine the structure and type of surficial materials, which in turn influences drainage and site. Thus the cutblocks become very complex radar targets, with differences in backscatter and dielectric constants related to landform, residual structures (stumps and logs), surface conditions (litter, fragmentation and humus layers), drainage, vegetation (planted trees, fireweed, skunk cabbage, salal and mosses), and weather (heavy rainfall).

If wet stumps, logging debris and slash make the cutblocks more reflective (as suggested by Leckie *et al.*, 1998), then since it was raining (except on August 1, 1997) when the RADARSAT F2 data were acquired, then the cutblocks should remain bright over the year. But this is not the case as indicated by **Table 3** and **Figure 4**. **Figure 4** shows that the Gl-m had the greatest change in average DN between 96/12/04 and 97/08/01. Yet one of the Gl-m cutblocks created in 1994 became the site of a drainage experiment on 97/08/25 (PDT) because it was so wet and poorly drained. If subsurface moisture was influencing

Table 9.
Critical values for cutblock landforms plus trees for 97/08/01.

Land form	Rank Sums	CH 480	HB 321.5	GM 303	DTP 302.5	T/R 271	LB 236	Gl-m 134
CH	480	-	-	-	-	-	-	-
HB	321.5	158.5	-	-	-	-	-	-
GM	303	177	18.5	-	-	-	-	-
DTP	302.5	177.5	19	0.5	-	-	-	-
T/R	271	209	50.5	32	31.5	-	-	-
LB	236	244**	85.5	67	66.5	35	-	-
Gl-m	134	346**	187.5	161	168.5	137	102	-

** P = .01 when computed difference => 268.
* P = .05 when computed difference is =>229.

Table 10.
Critical values for cutblock landforms plus trees for 97/11/29.

Land form	Rank Sums	GM 466	T/R 438.5	Gl-m 383	DTP 325.5	LB 213	CH 135	HB 55
GM	466	-	-	-	-	-	-	-
T/R	438.5	27.5	-	-	-	-	-	-
Gl-m	383	83	55.5	-	-	-	-	-
DTP	325.5	140.5	113.5	57.5	-	-	-	-
LB	213	253*	225.5	170	112.5	-	-	-
CH	135	331**	303.5**	248**	190.5	78	-	-
HB	55	411**	383.5**	328**	270.5**	158	80	-

** P = .01 when computed difference => 268.
* P = .05 when computed difference is =>229.

Table 11.
Critical values for cutblock landforms plus trees for 98/08/20.

Land form	Rank Sums	CH 496	DTP 336	HB 318	GM 238.5	LB 213.5	Gl-m 213	T/R 201
CH	496	-	-	-	-	-	-	-
DTP	336	160	-	-	-	-	-	-
HB	318	178	18	-	-	-	-	-
GM	238.5	257.5*	97.5	79.5	-	-	-	-
LB	213.5	282.5**	122.5	104.5	25	-	-	-
Gl-m	213	283**	123	105	25.5	0.5	-	-
T/R	201	295**	135	117	37.5	12.5	12	-

** P = .01 when computed difference => 268.
* P = .05 when computed difference is =>229.

Table 12.
Critical values for cutblock landforms plus trees for 98/11/24.

Land form	Rank Sums	T/R 427	GM 417	Gl-m 380.5	DTP 361.5	LB 229.5	CH 154	HB 47
GM	427	-	-	-	-	-	-	-
T/R	417	10	-	-	-	-	-	-
Gl-m	380.5	46.5	36.5	-	-	-	-	-
DTP	361.5	65.5	55.5	19	-	-	-	-
LB	229.5	197.5	187.5	151	132	-	-	-
CH	154	272.5**	262.5*	226	207	75	-	-
HB	47	380**	370**	333.5**	314.5**	182.5	107.5	-

** P = .01 when computed difference => 268.
* P = .05 when computed difference is =>229.

the radar return, then the cutblock should have been brighter than it was. However it was still darker than the surrounding forest. The Gl-m was also darker than the T/R, which is considered a well drained site. Simms and Bell (1998) found differences in radar backscatter related to surficial materials. It could be speculated that as the logging debris and surficial materials of the landform dry out during the summer, conditions are such that there is less radar backscatter. When the winter rains come in November, the surface materials on the cutblock become waterlogged and hence there is more backscatter.

In remote sensing image interpretation, it is unwise to remove items from their spatial context and temporal patterns. It is recommended that objects (i.e. cutblocks and riparian strips) not be studied in isolation or that single date RADARSAT images be used for forest monitoring. Mapping of cutblocks is easily achieved with multi-temporal data. For northern Vancouver Island, the best results were obtained with two bright cutblock dates, and a dark cutblock date. When cutblocks are bright, they are brighter than the surrounding forest, when cutblocks are dark they are darker than the surrounding forest. This provides a "remote sensing cross-over". This cross-over can be used advantageously in making multi-temporal colour composites. In the analysis of RADARSAT F2 data for evaluating riparian leave strips and windstorm damage, when the bright cutblock dates are assigned to red and blue, and the dark cutblock date is assigned to green, all trees will be green, and newest cutblock will be red (Murtha 1998b and Murtha 1998c). When the colour of the cutblock bleeds through the riparian strips, it becomes clear evidence that trees in the riparian strips have been removed or destroyed. Use of multi-temporal composites adds colour and removes difficulties in monitoring forests as has been encountered with single date imagery (Ahern *et al.*, 1997). In a remote sensing strategy to monitor the riparian strips in or beside cutblocks, knowledge that cutblocks on northern Vancouver Island are light toned in November/December and dark in August can be used to plan that monitoring strategy.

CONCLUSIONS

RADARSAT data for northern Vancouver Island, British Columbia support the following observations:

- There are cyclic seasonal fluctuations in the brightness of the cutblocks which are always bright in the winter rainy season and dark in the drier summer season (**Figure 3**);
- It is speculated that the bright cutblocks in the November/December rainy season can be attributed to the water-soaked logging debris and slash;
- When cutblocks are bright during the winter rainy season, the cutblocks on till-based landforms are brighter than cutblocks on stratified lacustrine sediments (**Tables 5** and **7**);
- When cutblocks are bright in the November/December rainy season they are brighter than the surrounding forest (**Figure 4**);
- When cutblocks are dark in the summer dry season they are as dark or darker than the surrounding forest (**Figure 4**);
- The August-dark cutblocks may be due to the summer dry logging debris, slash, detritus of the forest floor, and regrowth of herbaceous vegetation which would tend to hide some of the debris and slash;
- After eight or nine years, vegetation on the cutblocks hides the logging debris and the bright tones in November/March are reduced and the cutblock becomes darker (**Figure 3**);
- Because of the variation in cutblock tone, a cross-over exists between the clearcut cutblocks and the surrounding forest (**Figure 4**);
- The cross-over in cutblock tone can be used advantageously in creating multi-temporal colour composites for monitoring cutblocks and hence riparian strips;
- The old-growth cedar/hemlock stands have structural characteristics which make them good radar reflectors and hence brighter than the hemlock/balsam stands (**Figure 4**);
- The densely stocked hemlock/balsam stands are always darker than the old-growth cedar/ hemlock stands (**Tables 9** through **12**).

The results suggest that on northern Vancouver Island, climate in concert with the surficial geology and cutblock variables, play a significant role in the tone of clearcuts on RADARSAT Fine 2 images. Judging riparian strips within or beside clearcuts from single date RADARSAT Fine 2 images displayed in black-and-white is a difficult task, even when the clearcuts are bright. It is an impossible task when the cuts are similar to or darker than their surroundings as they are in July and August. For RADARSAT applications to forestry with special reference to monitoring cutblocks and riparian strips, multi-temporal colour composites created with two light cutblock-dates of imaging and one dark cutblock date of imaging are recommended.

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