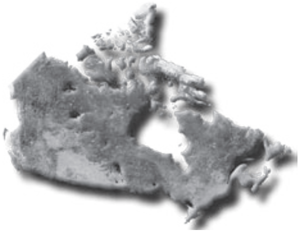

Enhancing forest inventories with mountain pine beetle infestation information

M. A. Wulder; R. S. Skakun; S. E. Franklin; J.C.White

Mountain Pine Beetle Initiative
Working Paper 2005–18

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Abstract
Polygon decomposition is an approach for integrating different data sources within a GIS. We use this approach to understand the impacts associated with mountain pine beetle red-attack. Three different sources of red-attack information are considered: aerial overview sketch mapping, helicopter GPS surveys, and Landsat imagery. Existing inventory polygons are augmented with estimates of the proportion and area of red-attack damage. Although differences are found in the area of the infestation, the affected forest stands have similar characteristics. Polygon decomposition adds value to existing forest inventories through update and the incorporation of new attributes applicable to forest management.

Résumé
La décomposition polygonale est une approche qui permet l'intégration de plusieurs sources de données à l'intérieur d'un SIG. Nous utilisons cette approche pour tenter de mieux comprendre l'impact associé au stade rouge de l'attaque des dendroctones du pin ponderosa. Trois différentes sources d'informations concernant le stade rouge sont prises en compte : croquis cartographiques par reconnaissance aérienne, relevé GPS par hélicoptère et imagerie Landsat. Les polygones d'inventaire existants sont assortis de valeurs estimées pour la surface présentant le stade rouge de l'attaque et la fraction qu'elle représente. Bien que des différences apparaissent dans le secteur de l'infestation, les boisés affectés présentent des caractéristiques similaires. La décomposition polygonale valorise les inventaires forestiers existants en permettant des mises à jour et l'incorporation de nouveaux attributs relevant de la gestion forestière.

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Introduction

An outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopkins), hereafter referred to as MPB, in the central interior region of British Columbia, has resulted in lodgepole pine (*Pinus contorta*) mortality over thousands of square kilometres. Historically, the management of beetle outbreaks has involved the rapid harvest of red-attack trees (infested pine with red discoloured foliage) (Figure 1) to minimize loss while maximizing the economic value of dead-standing timber (Safranyik et al. 1974). Red-attack trees lose value quickly due to the blue-staining fungi (*Ceratocystis* spp.) commonly left by the beetles in the sapwood area of the tree (Reid et al. 1967). Damage caused by MPB also creates a number of management problems, such as alteration of wildlife habitat and increased fire hazards (Shore et al. 1996). Mapping red-attack at the stand-level is required to assess damage levels in infected stands. Helicopter GPS surveys, aerial photography, and increasingly, satellite imagery, have been employed in such mapping assessments (Pilon and Wiart 1990; Franklin et al. 2003). The product generated from these surveys is generally a digital map indicating the location and extent of red-attack damage. This red-attack layer is then digitally overlaid with the existing GIS forest inventory dataset. Visually, this is an important resource for understanding and managing the infestation; a list of affected polygons or forest stand can be quickly generated using a logical 'and' operation within the GIS.

To supplement such visual and tabular assessments, we have developed an analytical GIS tool called polygon decomposition (Wulder and Franklin 2001). Polygon decomposition is an extension of the GIS intersection function (also referred to as the logical 'and' operation), generating stand-by-stand summaries of characteristics associated with the red-attack layer and other underlying polygonal data layers. Typically, these summaries take the following two forms:

1. A count or assessment of the area (e.g., the number of red-attack points or pixels) within each affected forest stand. Typically, these results are expressed as the proportion (in percent) and area (in hectares) of red-attack for each GIS polygon. The benefits of this approach are that both intensity of red-attack (e.g., 80% red-attack for polygon xyz) and extent of damage (e.g., 20 ha of red-attack for polygon xyz) can be evaluated. This information may be useful when prioritizing infected stands according to their socio-economic value and risk of timber loss (McMullen et al. 1986).
2. The actual characteristics of infested stands. Typically, these results are expressed as the relationships between red-attack points or pixels and the underlying GIS data on forest stand composition (e.g., stand age and location). Understanding such relationships has an important role in understanding forest stand susceptibility and vulnerability (Whitehead et al. 2001) to damage during an infestation. For example, Amman (1973), Safranyik et al. (1974), and Shore and Safranyik (1992), among others, have suggested the forest characteristics generally associated with susceptibility to beetle attack would include percentage of pine in a stand, percentage of susceptible pine basal area, stand density, and elevation. Stand susceptibility could subsequently be reduced by identifying non-attacked forest stands for partial cutting treatments (Mitchell et al.. 1983; McGregor et al. 1987; Amman et al. 1988) or other

canopy density modification (Waring and Pitman 1985). Numerous similar susceptibility studies have been conducted for a wide range of insects and forest conditions; Alfaro et al. (2001) related species composition, site index, stand age, and crown closure to increased susceptibility of defoliation by spruce budworm (*Choristoneura fumiferana* Clem.). The success of these studies - recognizing the forest characteristics as primary identifiers for assessing insect damage - suggests that non-attacked stands containing those characteristics should be monitored.

Figure 1. Oblique photo taken from a helicopter illustrating a range of attack conditions and severity; grey trees indicate attack by mountain pine beetle at least two years previous, red trees indicate attack by mountain pine beetle the previous year, with current attack potential existing for the green trees.

The objectives of this paper are to:

1. Demonstrate the use of polygon decomposition as a tool for integrating various sources of MPB red-attack information into an existing GIS forest inventory. Once these data are integrated into the inventory, comparisons between the location and extent of MPB red-attack, as indicated by each data source, are easily facilitated;
2. Present the stand characteristics of the polygons in the GIS forest inventory where MPB red-attack has been found using the remote sensing approach; and
3. Illustrate how disturbance maps from remote sensing change detection can be used to update GIS-based forest inventory databases. Update information includes: (i) susceptibility based upon polygon attributes and attack area, and (ii) proportion of attack, on a polygon basis, from the remote sensing change detection procedures.

To meet these objectives we considered three different data sources: aerial overview sketch mapping, helicopter survey data collected using a Global Positioning System (GPS), and multi-temporal satellite remotely sensed data. All three sources provide the location and extent of mountain pine beetle red-attack at different scales and with different levels of precision and accuracy. The sketch mapping and helicopter GPS data are both part of the existing operational data hierarchy (which also includes ground surveys) used to satisfy the business drivers at various levels of forest management. For example, the sketch mapping is an efficient and cost effective means of generating a synoptic view of MPB infestation across the province for strategic level planning. The information contained in the sketch mapping is subsequently used to guide the location of more detailed helicopter GPS surveys, which in turn are used to deploy field crews for ground surveys. Remotely sensed data are increasingly used as a source of information on MPB red-attack location and extent. At this time however, the use of satellite based remotely sensed data is not widespread or considered operational.

Polygon decomposition is a tool that can be used to understand the differences between these data sources in a forest inventory context – a context that is readily accessible to most forest managers. Such a comparison prevents the inappropriate use of data to support decision-making that is not commensurate with the information content (i.e., using broad sketch mapping estimates of red-attack to make operational level planning decisions). Furthermore, polygon decomposition adds value to the existing inventory by providing valuable information to maintain the currency of the inventory and by providing timely and relevant attributes that are critical for decision-making.

Study Area

Prince George Forest Region

The study area is a subset of the outbreak area of the 2001 MPB infestation in the Prince George Forest Region, British Columbia, Canada (Figure 2). The area selected for analysis was located in a productive forest approximately 5,000 km^2 (65km east/west x 78km north/south), centred at lat. 54° 33' N and long 123° 52' W. The study area is found within the Fraser Basin ecoregion, in the Montane Cordillera ecozone (Ecological Stratification Working Group, 1996). The mean annual temperature is 3˚C, and the mean annual precipitation ranges 600 to 800 mm. Most of the landscape is formed by gently rolling glacial deposits with elevations ranging from 600 to 800 metres above sea level. The main forest species include lodgepole pine, white spruce (*Picea glauca*), Engelmann spruce (*Picea engelmannii*), black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*), and interior Douglas-fir (*Pseudotsuga menziesii*), with a smaller component of western red cedar (*Thuja plicata*) and sub-alpine fir (*Abies lasiocarpa*). White and black spruce are climax species in this ecoregion and lodgepole pine is typically a fire succession species. For those areas dominated by lodgepole pine and white spruce, harvesting operations are most active along the eastern half and northern interior of the study area. A large percentage of the annual allowable cut within the study area has been redirected to salvage timber that is either infested or damaged by MPB (BC Ministry of Forests, 2003).

Data Collection and Preparation

Geographic Information System (GIS) Forest Inventory Dataset

A GIS forest inventory dataset was used as the primary source of information on the distribution and areal extent of forest stands, past natural and human disturbances, water resources, and logging road networks. The study area included a large number of non-forested polygons such as lakes, rivers, forestry roads, highway, agriculture, and urban areas. In addition, some forest stands were labelled non-productive forest. All of these non-forest polygons were removed from the analysis, significantly reducing the standard deviation of polygon size (Table 1). The forest inventory includes estimates of species composition (up to six different species, to the nearest 10 percent), stand age in years, crown closure (to the nearest 5 percent), stand height in metres, diameter at breast height in centimetres, and stand area in hectares (BC Ministry of Sustainable Resource Management, 2002). Much of the inventory information was temporally projected to represent 1999 forest conditions, although the database included map sheets that were updated as recently as 1998. The inventory and the subsequent data layers were projected to a UTM NAD 83 Zone 10 projection.

Aerial Overview Sketch Map Data and Helicopter GPS Surveys

The standard procedure for aerial overview sketch mapping was followed in the generation of red-attack maps for the study area (BC Ministry of Forests and Canadian Forest Service, 2000). Trained observers mentally averaged the infestation into larger mapping units and drew boundaries to indicate the infested areas. Conditions within the mapped area were assumed reasonably homogeneous and significantly different from

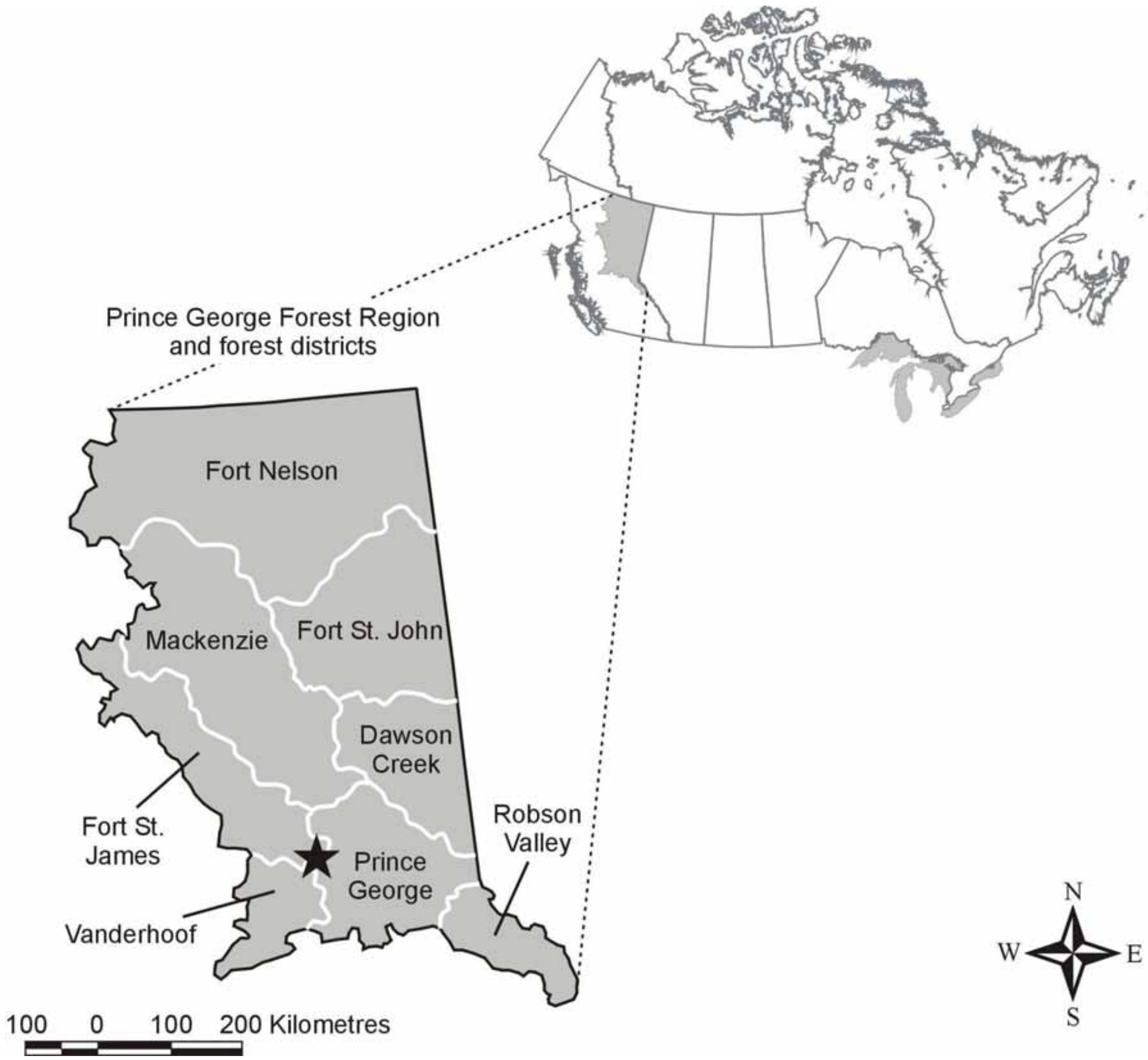

Figure 2. Study area location in the Prince George Forest Region, British Columbia, Canada.

areas not mapped as red-attack. It is important to note that aerial overview surveys address a broad range of forest health issues and do not specifically target mountain pine beetle damage. Furthermore, the production of sketch maps at a scale of 1:100,000 is qualitative in nature. Users must therefore be aware of possible spatial inaccuracies inherent in the methodology and scale associated with the overview sketch maps.

A MPB red-attack damage helicopter GPS point dataset was collected by trained observers flying in helicopters approximately 500 to1000 m above ground. The survey flights were conducted from early July through August 2001, to coincide with peak periods of insect damage (McMullen et al. 1986). Small groups of infestation were interpreted and recorded as a single point, where each point represented a group of 50 or fewer red-attack trees over an area of approximately 0.25-0.50 ha. The location of each point was recorded over the groups' epicentre using a GPS. Only estimates of current damage (red-attack trees) were recorded. Over 2000 attack points were recorded in the study area with the helicopter GPS method.

Table 1. General description of polygon size within the study area.

	Polygon Data Description				
	Total	**Average (ha)**	**Standard Deviation**	**Minimum (ha)**	**Maximum (ha)**
Polygons in Study Area	31, 858	16.6	58.0	1.0	4922.3
Forested Polygons in Study Area	26, 215	13.3	15.0	1.0	89.9

Multi-temporal Landsat ETM+ Satellite Image Data

Landsat ETM+ satellite images (Path 49, Row 22) acquired on June 26th 2000 and August 16th 2001 were geometrically and atmospherically corrected. The images were rectified to the GIS forest inventory with less than 0.2 pixel Root Mean Square error. The transformation was based on 36 ground control points located at key road intersections, utility corridors, and distinct geographic features dispersed throughout the scene. A third order polynomial transformation and cubic convolution resampling algorithm were used to determine pixel values in a 30 metre grid. The two ETM+ images were acquired on different dates, and therefore under different illumination and atmospheric conditions. To correct measured radiances for these differences, a model-based atmospheric algorithm was applied (Richter 1990). First, a standard atmosphere was estimated based on visibility conditions in each image. Second, a set of pseudo-invariant features were selected and radiances were then matched to actual reflectance characteristics under each image's solar illumination conditions. Finally, the image radiance values were converted to estimated surface reflectances, based on the training data and selected best-fit coefficients.

Each Landsat ETM+ image was transformed into brightness / greenness / wetness indices using the Tasselled Cap Transformation procedure described by Crist and Cicone (1984). This procedure was suggested by Collins and Woodcock (1996) as an ideal approach when mapping distinct forest canopy changes or mortality with Landsat imagery. The difference between the multi-temporal wetness indices (also known as the ‘enhanced wetness difference index’ or EWDI) was recently shown by Skakun et al. (2003) to be sensitive to MPB red-attack conditions; earlier work in New Brunswick (Franklin et al. 2001) used the EWDI to discriminate silvicultural and partial harvest canopy disturbances. In the MPB study, red-attack forest stands contained pixels over a consistent range of values in the EWDI data; we used these pixels and the helicopter GPS survey data to define a classification threshold for identifying red-attack forest stands. Larger numbers of red-attack trees within the stand created a stronger pattern of red-attack reflectance. The accuracy of this classification was assessed using a random sample of data points from an aerial survey and an existing forest inventory. Two classes were considered: red-attack and non-attack. The overall classification accuracy was 80%, while the producer's and user's accuracies for the red-attack stands were 82% and 88% respectively (Table 2).

Table 2. Discriminant classification results of the 2000/2001 EWDI based on a red-attack damage class and a non-attacked or healthy forest class.

		REFERENCE CLASSIFIER		
		Red-attack	**Non-attack**	**Total**
MAP CLASSIFIER	**Red-attack**	98	14	**112**
	Non-attack	22	46	**68**
	Total	**120**	**60**	**180**

Overall Accuracy = 80%

Producer's Accuracy (measure of omission error)
Red-attack = 82% (18% omission error)
Non-attacked forest = 77% (23% omission error)

User's Accuracy (measure of commission error)
Red-attack = 88% (12% commission error)
Non-attacked forest = 68% (32% commission error)

Methods

We applied the polygon decomposition tool utilizing the GIS forest inventory database to the three data layers: the aerial overview sketch map, the helicopter GPS survey points, and the thresholded Landsat EWDI data layer. In essence, this procedure is the equivalent of the GIS intersection or logical 'and' function with additional output specified as follows:

1. Intersect the GIS polygon 'and' the aerial overview sketch map, and output both the affected polygons and the affected pine polygons that were mapped as red-attack;
2. Intersect the GIS polygon 'and' the helicopter GPS survey points and output the area of each polygon and the number of points within each polygon that were mapped as red-attack;
3. Intersect the GIS polygon layer 'and' the EWDI red-attack layer, and output the area of the polygon (this time in pixel counts) and the number of pixels within that polygon that were mapped as red-attack. (Note: in this case, area (ha) estimates were obtained by multiplying the total count of red-attack pixels by 0.09, since 1 ETM+ pixel is approximately 0.09 ha).

Results

Visual Interpretation of GIS Intersection Results

We compared the visual patterns and trends in the spatial distribution of red-attack observations across the Prince George study area, as represented by the aerial overview sketch maps, helicopter GPS survey points, and the multi-temporal Landsat image analysis. Figure 3 shows a large subarea (12 map sheets, approximately 38 km by 45 km) and a smaller subarea (1 map sheet, approximately 13 km by 11 km) with the three representations of red-attack overlaid with the forest inventory data. A visual analysis of the outputs from the three data sources suggested that the representation of red-attack was quite variable. For example, the helicopter GPS survey points were more extensive (total area of red-attack was more than double the area mapped in the overview sketch mapping flights), and more dispersed across the study area (Table 3, Figure 3). The total area identified as red-attack using the Landsat EWDI was similar to that of the helicopter GPS survey points. However, the total number of polygons identified as containing red-attack reflectance patterns using the EWDI method was 10% greater when compared to the helicopter GPS survey points, and 25% greater when compared to the aerial overview sketch map (Table 3). The sketch map spatial depiction of red-attack was considerably less realistic than the helicopter GPS survey point data or the representation of red-attack generated from the EWDI. Red-attack damage is often heterogeneous in distribution (patchy) and the large, generalized polygons generated by sketch mapping do not reflect this knowledge of red-attack patterns. Inspection of the sketch map's attack magnitude codes provides detail on the amount of attack within the sketched polygons. The large areas that were mapped by the sketch mappers do not appear to represent the nature of the overall infestation, nor do they highlight the main areas of damage. In contrast, the image analysis and the aerial survey point data represent very similar spatial patterns that are in-line with current knowledge of MPB red-attack patterns.

Polygon Decomposition of red-attack

Polygon decomposition enables the analysis of polygonal data (forest stands) and the three different red-attack data sources (Table 4). Several characteristics of forest stands (species, age, crown closure, elevation), and individual trees (diameter-at-breast height - DBH), were considered the leading susceptibility criteria by Shore and Safranyik (1992). We therefore decomposed the three red-attack layers according to these attributes, and considered the impact of elevation, slope, and aspect on red-attack location. The following patterns emerged:

- The majority of stands with red-attack observations were pine-dominated. The sketch map included many more stands that were not pine-dominated compared to the other two red-attack maps. The red-attack areas identified from the image analysis were more strongly associated with pine stands. The latter is a result of the use of the GIS polygonal data in deriving EWDI thresholds; the existing forest inventory was used to stratify the image observations before their use as predictive or classification tools. This pre-stratification is a major strength of the image analysis approach.

Table 3. Polygon decomposition results for aerial overview sketch map, helicopter GPS survey points, and Landsat EWDI.

FOREST INVENTORY DATA			
	Sketch Map	**Helicopter GPS Survey Points**	**Landsat EWDI**
Number of polygons with red-attack	648	783	857
Total area of polygons with red-attack (ha)	11,461.3	24,554.3	28,782.6
AERIAL OVERVIEW SKETCH MAP			
Total area of red-attack indicated from the aerial overview survey sketch mapping = 6,256.10 ha			
HELICOPTER GPS SURVEY POINTS			
Count of red-attack survey points = 2,128 Estimated number of red-attack trees = 17,430			
LANDSAT EWDI			
Total area of red-attack delineated from the Landsat EWDI analysis = 4,961.79 ha			

- Older stands were generally more susceptible to attack (Shrimpton and Thomson 1985). Again, the sketch map indicated the widest range of age conditions as a result of the inclusive nature of the sketch mapping process. The results of the helicopter survey and image classification were more comparable to one another.

- The tree diameter and stand crown closure characteristics also agree with expectations. For example, Mitchell and Preisler (1991) reported that incoming flights of MPB were observed to attack lodgepole pine >23 cm DBH. We found that stands with larger diameter trees contained more red-attack observations. Similarly, stands with moderate crown closure contained more red-attack, suggesting the beetles prefer fairly dense forest conditions. These results were similar for all three data sources.

Elevation, slope, and aspect do not appear to be a key characteristic of the beetle attack. It has been suggested that beetles will infest areas with mild winter temperatures to increase their chances for survival (Unger 1993). In the polygon decomposition of these stands, south facing slopes were to some extent preferred, possibly suggestive of a warmer microclimate that may have influenced the stands that the beetles did attack.

Table 4. Description of the forest characteristics generally used to assess stands with red-attack damage. Values represent the percent of polygons (forest stands) with the indicated characteristics.

a. Primary species

	AT	CW	FD	PL	SE	SW	SB
Points[1]	3	0	10	71	1	15	0
Sketch[2]	17	0	15	39	3	20	6
EWDI[3]	7	1	8	73	0	9	2

AT = trembling aspen; CW = Western red cedar; FD = Douglas-fir; PL = lodgepole pine; SE = Engelmann spruce; SW = white spruce; SB = black spruce

b. Stand age

	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-250	251+
Points	0	0	1	2	5	18	69	1	4
Sketch	7	5	2	8	8	22	37	7	4
EWDI	0	0	2	5	7	11	68	4	3

c. Diameter breast height (cm)

	1-21	21-22.5	22.5-25	>25	dbh = 0 age = 60-80	dbh = 0 age<60	dbh = 0 age>80
Points	3	7	39	51	0	0	0
Sketch	5	6	37	42	0	10	0
EWDI	3	13	39	40	0	5	0

d. Crown closure (%)

	0-5	6-15	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86-95	96-100
Points	0	0	1	1	3	8	33	31	10	8	5
Sketch	0	11	3	6	13	25	27	7	6	2	0
EWDI	0	1	2	2	5	12	24	27	11	7	9

e. Elevation (m)

	600-700	701-800	801-900	901-1000	1001-1100	1101-1200	1201-1300	1301-1400	1401-1500
Points	19	56	21	3	1	0	0	0	0
Sketch	20	39	18	11	5	3	2	2	0
EWDI	15	59	14	5	3	3	0	1	0

f. Slope (degrees)

	0-6	7-13	14-20	21-27	28-34	35-41	42-48	49-55	56-62	63-69
Points	51	33	14	2	0	0	0	0	0	0
Sketch	62	27	9	0	2	0	0	0	0	0
EWDI	48	36	15	0	1	0	0	1	0	0

g. Aspect

	Flat	N	NE	E	SE	S	SW	W	NW
Points	5	6	9	8	15	21	13	11	12
Sketch	4	7	8	6	13	24	11	15	12
EWDI	6	11	7	11	15	19	16	7	8

[1] Helicopter GPS points; [2] Aerial overview sketch mapping[3] ; Enhanced Wetness Difference Index derived from multi-date Landsat ETM+

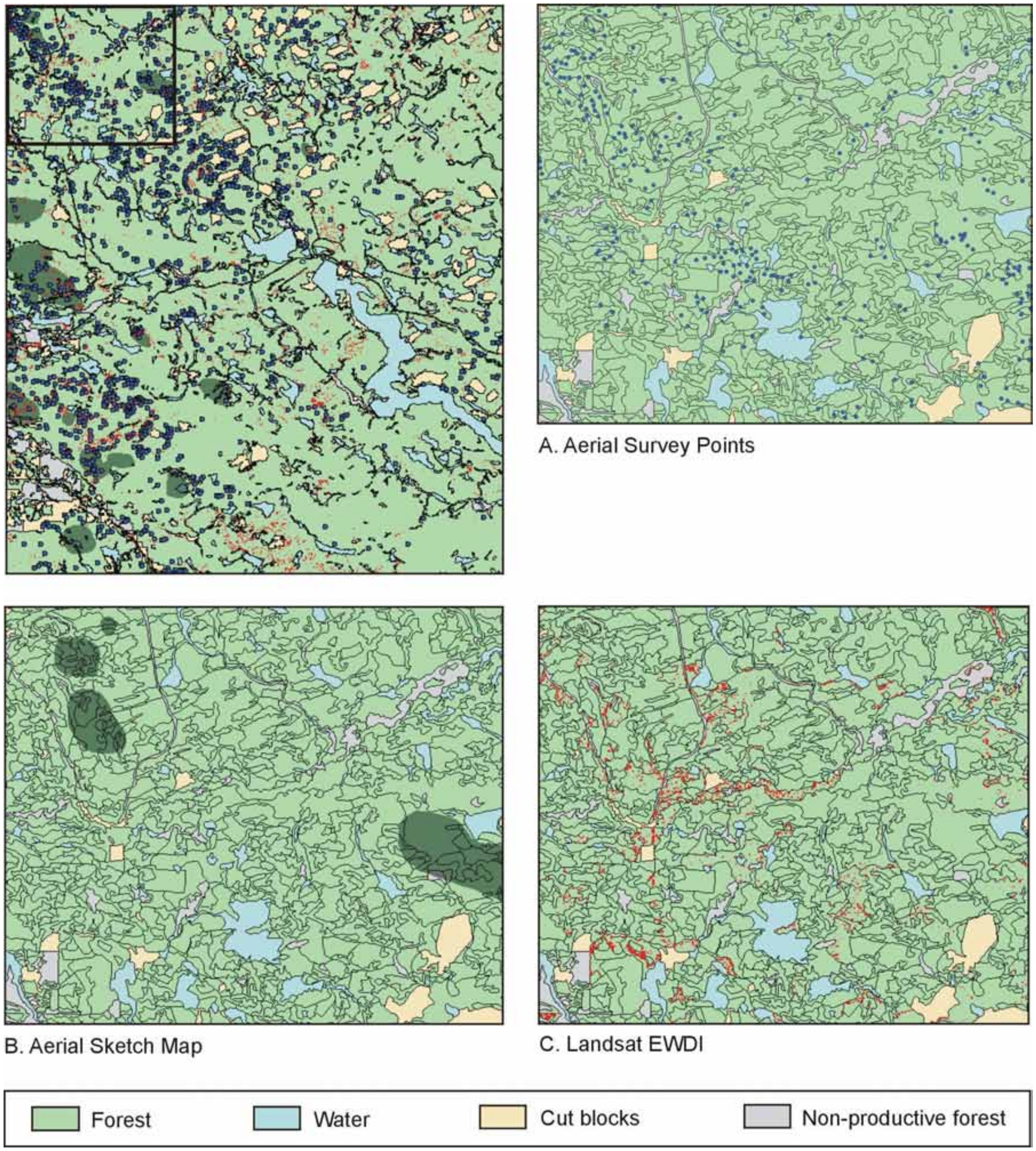

Figure 3. Representation of mountain pine beetle red-attack (all forms of survey data shown in top left). For a subregion of the study area, the insets show: A. helicopter GPS survey points, B. aerial overview sketch mapping, and C. satellite image change detection (EWDI).

This examination of attributes associated with infested stands further informs and validates models designed to determine the susceptibility of forest stands to infestation. Polygon decomposition could similarly be used to identify other forest characteristics that are important to understanding MPB infestation. Additional analysis of the polygon decomposition results could focus on evaluating and comparing the characteristics of non-attacked forest stands. In addition, the repeated mapping of red-attack stands over time, combined with the use of polygon decomposition, may provide an indication of the nature of long-term impacts of MPB infestations upon forest stands. For example, a time-series of polygon decompositions may provide insights into the shelf-life of timber found within impacted stands. The term shelf-life is defined as the rate at which timber will deteriorate to a non-merchantable condition after being killed (BC Ministry of Forests, 2003).

Example Polygon Decomposition Map Products

A wide variety of polygon decomposition output products are possible (Wulder and Franklin 2001) and in the context of MPB infestation, these products provide information that can be used to update forest inventories and gauge the susceptibility of forest stands. Samples of some of the useful outputs are illustrated in Figures 4, 5 and 6. Figure 4 shows the aerial sketch mapping results intersected with the forest stands. Species information was used to identify those stands with and without lodgepole pine that were identified as having red-attack from the sketch mapping. In Figure 5, the helicopter GPS survey points which fell within forest stands are shown for the same area as Figure 4. The zoomed-in subareas show the number of points and the number of trees in each polygon, respectively. It is obvious that in many instances, a large number of red-attack observations in a stand will also mean a large number of trees have been attacked; however, it is also possible that certain stands with only a few aerial survey data points may have many more trees infested. It is noteworthy that only a few of the stands indicated as red-attack in the overview sketch map coincided with the areas identified in the helicopter GPS survey data set. Where these two products agree, greater confidence in the actual conditions on the ground may result.

Figure 6 contains another example of the power of polygon decomposition, this time using the EWDI results from the satellite image analysis. In the top portion of the figure, the proportion of area of red-attack in a forest stand is shown in six classes (arbitrarily from 0-100%). In the bottom portion of the figure, the same area is shown but with the actual area of the forest stand depicted. Clearly, different perspectives on the extent of the infestation would be obtained by studying these two maps. Such information may be important in allocating resources to manage the infestation; for example, a large polygon with a large proportion of red-attack would also contain a large area of infestation, but a small polygon with a large proportion of red-attack may not represent a priority based on the actual area infested. For management purposes, the key lies in knowing the actual attack area by polygon.

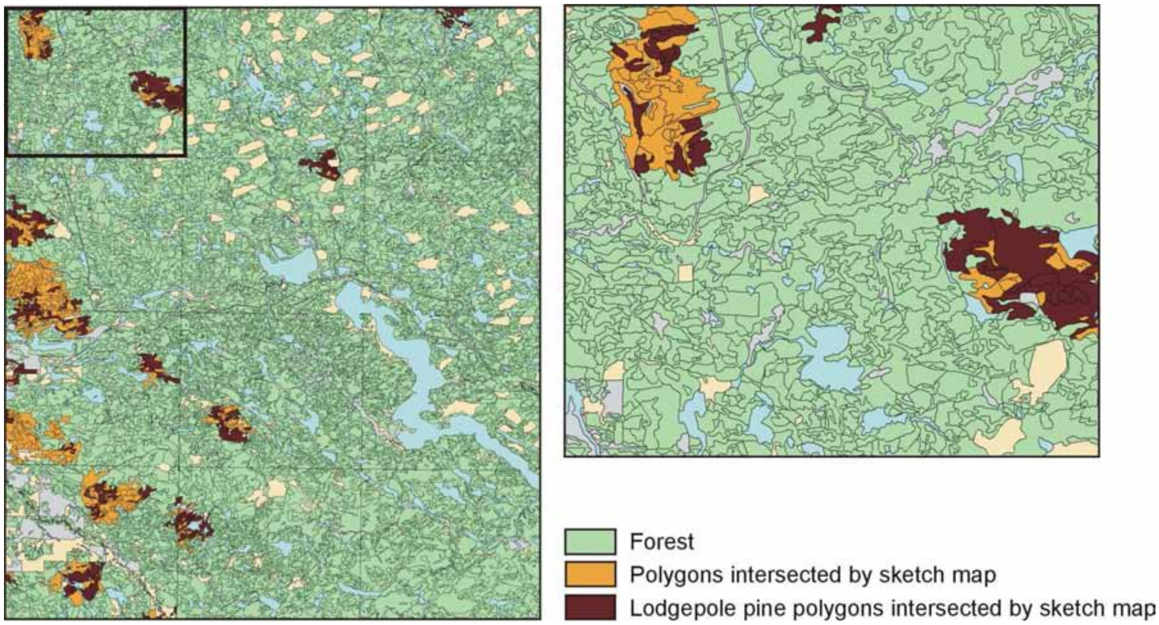

Figure 4. Intersection of the GIS polygons with the aerial overview sketch map.

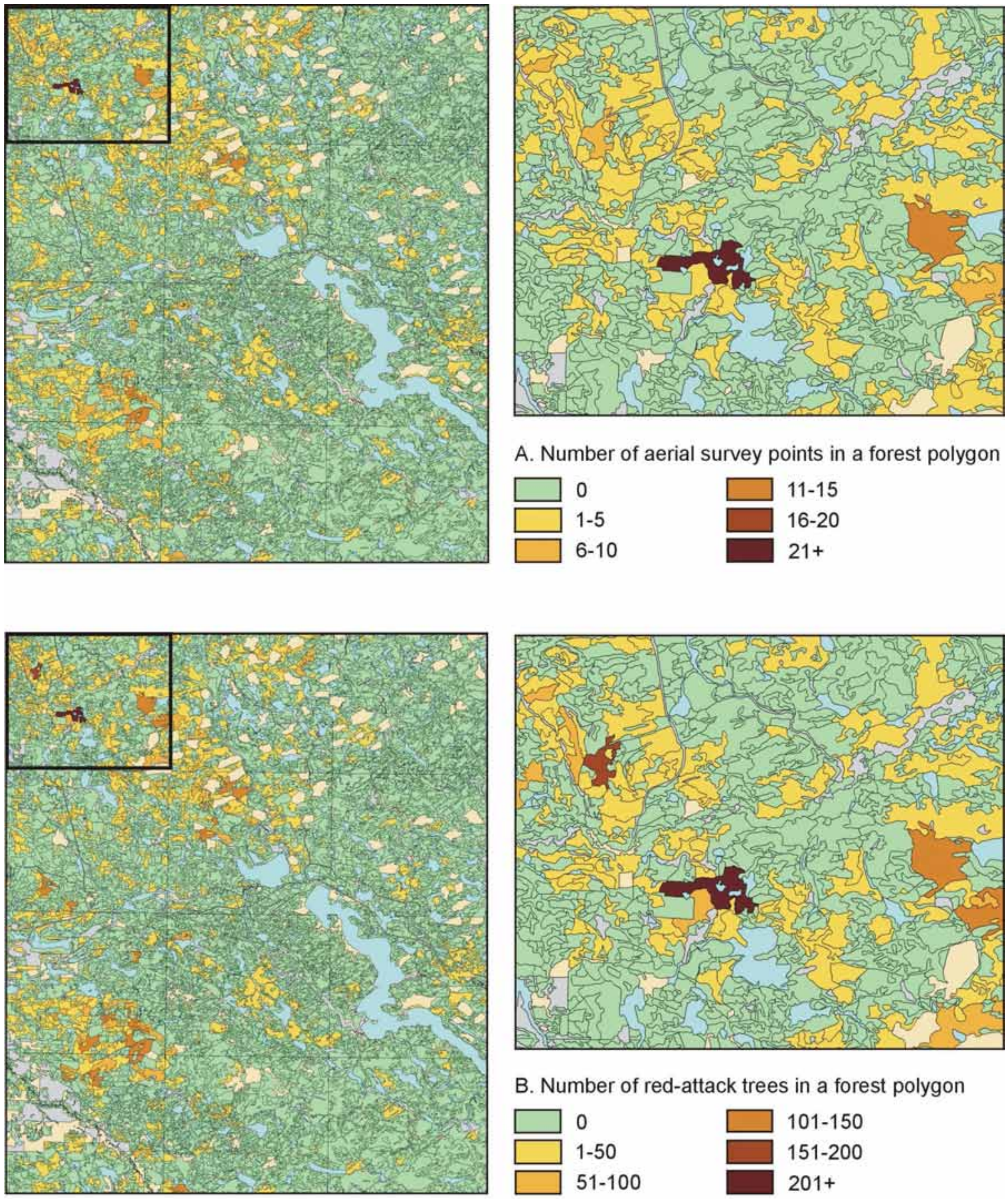

Figure 5. Polygon decompositions of the helicopter GPS survey points showing the number of GPS survey points (A) and the number of red-attack trees (B) in a forest polygon.

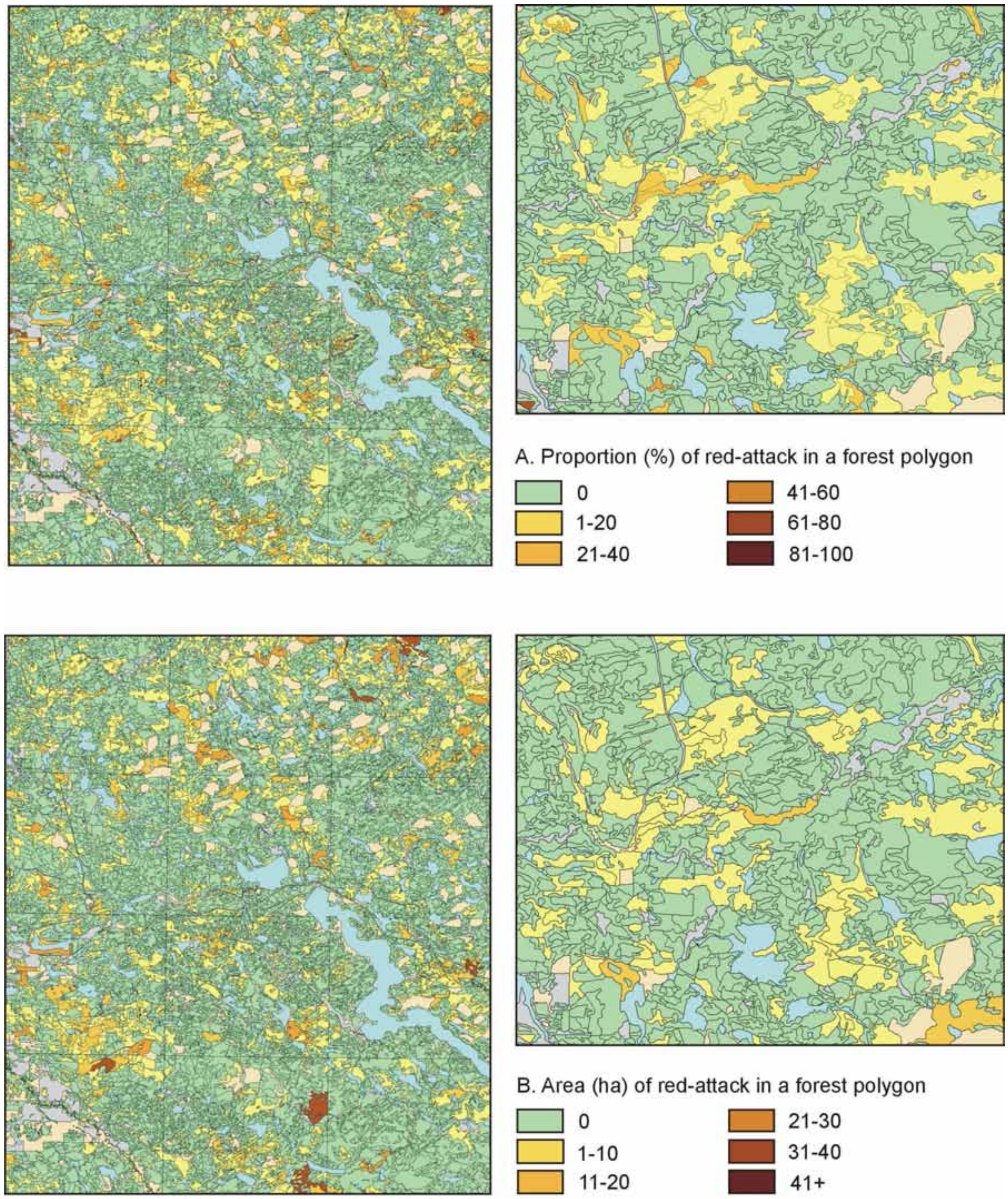

Figure 6. Polygon decomposition of the Landsat EWDI showing proportion (%) and area (ha) of red-attack in a forest polygon.

Conclusion

Timely observation and mapping of pine beetle red-attack in forest stands is an important information requirement if infestations are to be understood and managed. Traditionally, aerial overview sketch mapping and helicopter GPS survey techniques were deployed; increasingly, satellite remote sensing imagery is also being used to identify the location and extent of the infestation. These image data can provide accurate maps of spectrally distinct forest canopy changes – such as when foliage discolouration occurs. A new approach based on the Landsat enhanced wetness difference index (EWDI) has been shown to be useful because the EWDI captures the reflectance differences between healthy forest stands and red-attack stands (Franklin et al. 2001, Skakun et al., 2003).

The overview sketch maps, helicopter GPS survey points, and satellite imagery outputs form a data hierarchy, designed to satisfy a variety of information needs. Each of these data sources provides useful information for a particular purpose; users should be made aware of the differences and limitations associated with each. Polygon decomposition facilitates the integration of these data sources with the existing forest inventory, providing a mechanism for comparing the estimates of infestation from each source and allowing for the characterization of the forest attributes associated with the MPB infested stands. In this way, polygon decomposition can add value to an existing inventory by directly incorporating additional attributes at the forest stand level that are immediately relevant for forest management. These additional attributes can aid forest managers in understanding the location, extent, and potential impacts of the infestation, and can provide support for decision making processes.

More generally, a forest inventory database requires maintenance over time or the data will become outdated. Updating forest inventories can be an expensive and time consuming process. Polygon decomposition provides an efficient means to document the changes that have been caused by an insect infestation at the stand level. These attributes could then be carried until the inventory is fully updated – perhaps several years later. The example described in this paper demonstrated how useful polygon decomposition was for describing the area and proportion of red-attack trees within the forest inventory stands. Conversely, estimations of the proportion or the area of stands which are not infested, could also be estimated. In the future, it is expected that polygon decomposition could be used to assess non-attacked forest stands for susceptibility or perhaps for predicting movement patterns of mountain pine beetles.

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