Detection and mapping of mountain pine beetle red attack: matching information needs with appropriate remotely sensed data

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Abstract

Estimates of the location and extent of the red attack stage of mountain pine beetle (*Dentroctonus ponderosae* Hopkins) infestations are critical for forest management. The degree of spatial and temporal precision required for these estimates varies according to the management objectives and the nature of the infestation. This paper outlines a hierarchy of information requirements, from the perspectives of forest inventory, planning, and modeling. The capability of remotely sensed data to support these information requirements is presented, with specific focus on medium (Landsat) and high (IKONOS, Quickbird) spatial resolution imagery. The importance of matching the information requirement to the appropriate data source is emphasized as a means to reduce the overhead associated with data collection and processing

Keywords: mountain pine beetle, red attack, remote sensing, detection, Landsat, IKONOS, Quickbird.

Introduction

From a forest management perspective, estimates of the location and extent of mountain pine beetle red attack are critical; however, the degree of spatial and temporal precision required for these estimates varies according to the management objective under consideration (i.e. strategic, tactical, operational) and the nature of the infestation (i.e. endemic, incipient, outbreak). Information needs or business drivers, constrain the collection of data. Given the diverse information requirements of forest managers regarding mountain pine beetle infestations, it is unrealistic to expect that a single data source will be both sufficiently detailed and suitably cost effective to satisfy every information need. For this reason, information needs and data sources should be considered within a hierarchical framework. Matching the appropriate data source to the information requirement reduces the complexity of data collection and processing, and ensures that the required level of detail is provided to address the management objectives specific to that level of the hierarchy. Furthermore, a data hierarchy is cost effective; low spatial resolution, relatively inexpensive data sources may be used to guide the acquisition of more costly, higher spatial resolution data.

Information requirements

Forest inventory, planning, and modeling each have different information requirements regarding the location and extent of the red attack stage of mountain pine beetle. The specific information requirements for each of these are outlined in the following sections.

Forest inventory

Forest inventories capture forest composition and distribution at a specific point in time. Growth and yield projections, updates, and reinventories are all methods used to keep the forest inventory current. The length of the forest inventory update cycle varies by jurisdiction, ranging anywhere from 2 to 10 years. When infestations of mountain pine beetle reach the outbreak level, the damage caused by the beetles can dramatically and rapidly alter the composition of forests, thereby accelerating the need to update the forest inventory. The maintenance of the forest inventory is crucial since the inventory often forms the cornerstone for forest planning and modeling. In order to maintain the inventory, particularly for mountain pine beetle related disturbance, a timely and cost effective data source is required that can be easily integrated into the existing inventory.

Forest planning

Forest planning typically occurs at three distinct levels: strategic, tactical, and operational. At the strategic level, forest managers are primarily interested in planning over long time periods (several hundred years) and large spatial extents (the province or state level); strategic plans typically address broad objectives, and, as a result, are normally satisfied with coarse level information. Strategic level information on the intensity and spatial extent of the mountain pine beetle infestation is required for timber supply review, biodiversity conservation, and land use planning (Wiart 2003). A key component of strategic level planning is the modeling of various management scenarios and treatment activities over a protracted timeframe, in order to determine the impact of management actions on the beetle population, spread of the beetle, and total wood volume (Eng *et al.* 2004). Tactical level planning commonly addresses a five to twenty year period and a spatial extent analogous to a landscape or larger management unit. In a forestry context, this level of planning provides the structure for implementing the broad objectives outlined in the strategic plan, and includes activities such as the scheduling of harvesting and road construction. Operational plans are considered low level plans, providing the specific details necessary to execute each activity scheduled in the tactical plan. Block layout and road engineering are examples of the site-specific detail included in an operational plan. Overall, forest planning requires information on the red attack stage of mountain pine beetle infestations at various spatial and temporal resolutions – and with varying levels of accuracy and precision.

Forest modeling

Several different models have been developed at both the stand level and the landscape level[1]. These models attempt to address a range of questions:

- Where and when will the beetles attack?
- How severe will the damage be?
- What management response will be most effective?

As previously indicated, the ability to model the impact of various beetle management scenarios is an important component of strategic level forest planning. Inclusion of beetle impacts in management scenarios requires an accurate depiction of beetle population dynamics. Several models have been developed to describe the temperature-dependent growth of mountain pine beetle populations (Bentz *et al.*1991; Logan and Bentz 1999; Logan and Powell *In press*; Safranyik *et al.* 1975). A population dynamics model is currently being developed for mountain

[1] Canadian Forest Service, http://www.pfc.forestry.ca/entomology/mpb/tools/index_e.html

pine beetle, allowing the dynamics of beetle and host to be explored in the context of various management control options (Riel *et al*. *In press*). Other models predict the duration and impact of an infestation by diameter at breast height class, or alternatively, predict the stand mortality (percentage of basal area killed) based on the stand susceptibility rating (Bentz *et al.* 1993; Shore *et al*. 2000). Forest models that attempt to predict the spread and potential magnitude of an infestation require information on the location and extent of mountain pine beetle infested trees (Heavilin *et al.* 2005; Powell *et al.* 2000). Such predictive models may be calibrated by baseline information characterizing the stands currently infested. As is the case with forest planning, the information requirements of forest modelling that are inclusive of bark beetle populations are quite variable and depend on the scale of the model and its temporal parameters (Beisinger *et al.* 2000).

Satellite remote sensing for detection and mapping of red attack

The methods currently used to identify the location and extent of mountain pine beetle infestations range from broad aerial overview sketch maps to detailed field surveys. These data vary in terms of their cost and the level of detail provided (Table 1). The Canadian Forest Service held a workshop in June 2003 to investigate remote sensing research potential for the Federal Mountain Pine Beetle Initiative (Wiart 2003). Emphasis was given to those priorities with the potential to fulfill the information requirements of forest managers within government and industry. The key business drivers, or information needs, that emerged from the workshop were: provincial level red attack mapping; green attack detection for current sanitation; and operational mapping of red attack for layout and sanitation. The latter was identified as having the highest priority for remote sensing research. A variety of remotely sensed image data has been used to successfully detect and map mountain pine beetle red attack, providing varying levels of precision, and in turn, satisfying various levels of the information hierarchy. Table 2 provides a summary of some of the remotely sensed data sources that have been used, or have strong potential for use, in mapping mountain pine beetle red attack (based on the spectral and spatial properties of the sensor). Figure 1 illustrates the differing information content of a medium spatial resolution data source (Landsat) and a high spatial resolution data source (IKONOS). A summary of recent applications using medium and high spatial resolution remotely sensed data to map mountain pine beetle red attack is provided in Table 3. The potential of medium and high spatial resolution remotely sensed data is discussed in the following sections.

Medium Spatial Resolution Remotely Sensed Data: Landsat TM and ETM+

Medium spatial resolution remotely sensed imagery provides an information source that bridges the requirements of strategic and tactical levels of planning (Table 2). The spatial resolution for multispectral sensors that are currently operational varies from 10-metre (SPOT 5) to 30-metre (Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+). The cost per square kilometre also varies, ranging from $0.02 for Landsat to $1.22 for SPOT 5. The Landsat satellite will revisit the same location once every 16 days, while the SPOT 5 satellite will do so every 26 days (for nadir viewing). Due to its low cost, availability, large area coverage, and program longevity, Landsat TM and ETM+ data are the most widely used remotely sensed data. Unfortunately, recent technical problems with the ETM+ sensor have affected the quality of the data collected (Cohen and Goward 2004; Maxwell 2004). Mountain pine beetle red attack has been mapped using both single date (Bentz and Endreson *In Press*, Franklin *et al*. 2003) and multi-date (Skakun *et al*. 2003) Landsat imagery (Table 3).

High Spatial Resolution Remotely Sensed Data: IKONOS

There is an operational need for an efficient and cost-effective method to identify individual or small groups of red attack trees. Errors of commission, which occur when trees or stands are falsely identified as red attack, must be minimized. From an operational perspective, the deployment of field crews to sites falsely identified as red attack has greater consequence than sites where red attack trees are located, but where not every single red attack tree may be identified. Errors of omission are less problematic. Infested trees or stands are generally found close to other infested trees or stands; thus, if a field crew is deployed to one infested site, they will likely identify other infested sites that may have been omitted during the image interpretation. The availability of commercially delivered, high spatial resolution satellite data offers a potential source for the collection of accurate, consistent, and timely data regarding mountain pine beetle red attack.

The use of high spatial resolution remotely sensed imagery for this scale of red attack mapping provides a permanent record of the survey, which can subsequently be used by field crews who need to assess not only the exact location of the red attack, but also the extent and shape of the red attack stands and their relative position in the landscape. The spatial resolution for high resolution sensors that are currently operational ranges from 0.67-metre (panchromatic) and 2.44-metre (multispectral) for Quickbird, to 1-metre (panchromatic) and 4-metre (multispectral) for IKONOS (Table 2). Both of these sensors can be tasked to collect data over a specific area of interest and within a specified date range; however unlike Landsat, these sensors are not continuously collecting data, resulting in a non-comprehensive spatial coverage. Costs for acquiring new imagery are provided in Table 2. Although Quickbird has a higher spatial resolution, the smaller minimum order area required makes this data source less expensive than IKONOS – for study areas less than 64 km^2. High spatial resolution remotely sensed data provides a promising option for the detection of red attack at both local and landscape scales. The imagery has a high level of spatial detail, yet its spatial extent is greater than that of a 1:30,000 aerial photograph. For instance, the spatial extents of IKONOS and Quickbird images are 121 and 272.25 km^2 respectively, compared to 47 km^2 for a 1:30,000 aerial photograph. Furthermore, both Quickbird and IKONOS have operationally feasible acquisition schedules, returning to the same location every 1 to 3 days. These satellite images may be interpreted with manual or automated methods, depending on the attribute of interest. IKONOS 4 metre multispectral data has been used to map red attack in areas of low to moderate levels of infestation (Bentz and Endreson *In press*; Cutler *et al.* 2003; White *et al. In press*) (Table 3).

Conclusion

Maps of the location and extent of mountain pine beetle infestations drive mitigation and prediction activities. For example, the placement of field crews relies on accurate detection of insect activities over large areas. Similarly, output from decision support models are improved through the inclusion of accurate maps of attack conditions. The integration of remotely sensed data with existing forest inventories in a GIS environment generates value-added information for forest managers, and the forest inventory also provides a context for, and source of, validation data for the information extracted from the remotely sensed data (Wulder and Franklin 2001, Wulder *et al. In press*).

The concept of an information requirement hierarchy was introduced to demonstrate how different levels of forest inventory, planning, and modeling have different requirements in terms of the timeliness and precision of mountain pine beetle red attack estimates. The importance of matching the information requirement to the appropriate data source is emphasized as a means to reduce the overhead associated with data collection and processing. The use of inexpensive, low spatial resolution remotely sensed data - or aerial overview sketch mapping - to provide a synoptic view of mountain pine beetle red attack at the landscape level, and then subsequently to guide the acquisition of higher spatial resolution, more costly data, is one example of how a data hierarchy can be a cost effective and efficient tool.

The nature of the infestation (endemic, incipient, outbreak) should also guide the selection of an appropriate data source. Medium spatial resolution data, such as Landsat TM and ETM+, are better suited to mapping epidemic and outbreak levels of infestation. High spatial resolution data, such as IKONOS and Quickbird, are ideal for identifying small clusters or individual red attack trees. The relative costs, availability, and processing requirements of the various data sources are all important considerations for the end user. Satellite remote sensing can be a valuable tool in the management of mountain pine beetle, but the image source must be selected in accordance with both the information requirement of the end user and the infestation level.

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Table 1. Methods currently used to detect and map mountain pine beetle infestations in British Columbia, Canada.

METHOD	SCALE	COST/HA	DESCRIPTION	CORRESPONDING INFORMATION NEED
Aerial overview survey	1:100,000 to 1:250,000	$0.01[1]	General location of damage, approximate gross area of damage, general trend in damage from one year to another at the provincial level. Note: The mountain pine beetle is only one of many forest health issues addressed in the sketch mapping survey.	Used for strategic planning, the identification of areas requiring more intensive survey, and for the allocation of mitigation resources (Ministry of Forests, 2003b).
Helicopter GPS survey	Variable (Output to 1:20,000)	$0.15[2]	A GPS position is taken at the centroid of individual infestation clusters. For each cluster, the number of infested trees is estimated and the infesting insect species recorded. The size of the clusters may vary; cluster area, shape and compactness are not recorded, rendering the helicopter GPS data difficult for subsequent use by field crews. British Columbia spends approximately $2 million on helicopter GPS surveys annually.	The information collected from helicopter GPS surveys is used primarily for expediting the deployment of field crews to areas which are eligible for suppression activities, or which require sanitation harvesting.
Measle maps	1:30,000 aerial photography	$0.15[3]	In spring 2004, British Columbia decided to replace helicopter GPS surveys with measle maps generated from 1:30,000 air photos. Photos must be collected according to rigorous photogrammetric standards established by the province. These standards facilitate the use of the photos for other applications (i.e. base mapping) and thereby aid in recovery of the acquisition costs.	Similar to helicopter GPS surveys.
Field surveys	1:1	$11[4]	Ground surveys of mountain pine beetle are intended to verify information gathered from aerial surveys and take two forms: walkthroughs and probes. Walkthroughs are designed to delineate most recent attack and are undertaken if the aerial survey indicates an area is determined to be less than 5% red attack or more than 25% red attack. If the aerial survey determines that the area is between 5% and 25% red attack, a full probe is conducted, provided the area is harvestable. Walkthroughs are unsystematic, reconnaissance type surveys, used to assess the stand and identify spatially discrete pockets of infestation. Probes are systematic strip surveys that collect very detailed information on stand conditions.	The information gathered from the probes is used for the purposes of designing logging and sanitation plans.

[1] Tim Ebata, personal communication, October 8, 2004
[2] http://www.for.gov.bc.ca/hcp/fia/landbase/dfam/AerialDetectionStandardforBarkBeetleManagement.doc
[3] Tim Ebata, Personal communication, October 7, 2004. Although the per hectare cost of the photography is the same as the helicopter GPS surveys, the total costs for the measle maps are estimated to be significantly higher. Helicopter GPS surveys focus on smaller areas and can be cancelled for logistical reasons (i.e. inclement weather). Approximately twice as much area was covered with photography that would have been done with helicopter GPS, however the airphotos are useful for a wide range of different applications.
[4] Wiart, R. 2003. Detecting and mapping mountain pine beetle infestations: Defining the role of remote sensing and establishing research priorities. Workshop summary report. June 26-27, 2003, Vancouver, British Columbia.

Table 2. Remotely sensed data sources with potential for mountain pine beetle red attack mapping.

SENSOR	Swath Width (km)	ARCHIVE Cost/km^2 (CAD$)	ACQUISITION Cost/km^2 (CAD$)	Revisit Cycle	Spatial Resolution (m)	Spectral Resolution (nm)
Landsat 5 TM	185	$0.02	N/A	16 days	30 MS*	450-2350
Landsat 7 ETM+	185	$0.03	N/A	16 days	15 PAN** 30 MS	450-2350
SPOT 1-4	60	$0.43/km^2 for 1986-2001 $0.69/km^2 for 2002+ 60 km^2 minimum	$1000/scene plus archive cost/km^2 (see left)	26 days (nadir) 1-4 days (oblique)	10 PAN 20 MS	500-1730
SPOT 5	60	$2.45/km^2 for 2.5m $1.22/km^2 for 5m and 10m 20 km^2 minimum	$1000/scene plus archive cost/km^2 (see left)	26 days (nadir) 1-4 days (oblique)	2.5, 5 PAN 10 MS	500-1730
IKONOS 2	11	$9.10/km^2 for PAN or MS $12.74/km^2 for bundle 49 km^2 minimum	$23.40/km^2 for PAN or MS $32.76/km^2 for bundle 100 km^2 minimum	3 days	1 PAN 4 MS	450-850
Quickbird 2	16.5	$23.40/ km^2 for PAN or MS $31.20/km^2 for bundle 25 km^2 minimum	$28.60/ km^2 for PAN or MS $36.40/km^2 for bundle 64 km^2 minimum	1-3 days	0.61 PAN 2.44 MS	450-900

*MS = multispectral, **PAN = panchromatic

Table 3. Recent applications using remotely sensed data to detect and map mountain pine beetle red attack.

DATA SOURCE	OBJECTIVE	ACCURACY RESULTS
Landsat TM (single date) Franklin *et al.* (2003)	Identify and map MPB red attack.	Overall accuracy = 72.3% Red attack = 73.3%
Landsat TM (single date) Bentz and Endreson (*In press*)	Identify and map MPB red attack.	Overall accuracy = 59% Plots with > 25 red attack trees = 79%
Landsat ETM+ (multi-date) Skakun *et al.* (2003)	Identify and map MPB red attack using change information for two multi-date scenarios: (i) 1999-2001 and (ii) 2000-2001.	<u>1999-2001</u> Overall accuracy = 74% 10-29 red attack trees: Producer's (red attack) = 67%; User's (red attack) = 73% 30-50 red attack trees: Producer's (red attack) = 75%; User's (red attack) = 78% <u>2000-2001</u> Overall accuracy = 74% 10-29 red attack trees: Producer's (red attack) = 68%; User's (red attack) = 68% 30-50 red attack trees: Producer's (red attack) = 78%; User's (red attack) = 81%
Single date IKONOS 4m multispectral White *et al*. (*In press*)	Identify and map MPB red attack in areas identified for suppression where infestation levels are either low (1-5% of trees in the stand are red attack) or medium (> 5% and < 20% of trees in the stand are red attack)	<u>Low levels of attack</u> True positive: 70.87% Omission: 29.13% Commission: 9.59% <u>Medium levels of attack</u> True positive: 92.35% Omission: 7.65% Commission: 2.05%
Single date IKONOS 4m multispectral Bentz and Enderson (*In press*)	Identify and map MPB red attack.	True positive accuracy for red attack = 95%

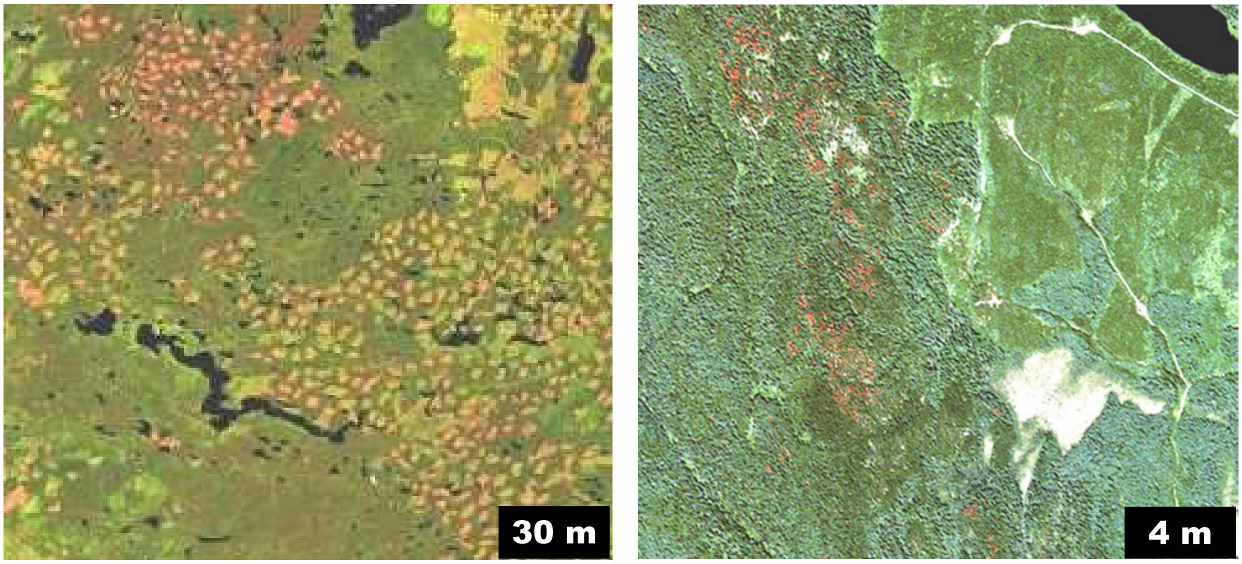

Figure 1. The information content of a medium resolution sensor such as Landsat ETM+ (left) compared to the information content of a high resolution sensor such as IKONOS (right).