Integration of LIDAR, optical remotely sensed, and ancillary data for forest monitoring and Grizzly bear habitat characterization

Integração de LIDAR, sensores remotos óticos e dados auxiliares para o monitoramento florestal e caracterização do habitat dos ursos Grizzly

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Abstract

Forest management and reporting information needs are becoming increasingly complex in Canada. Inclusion of timber and non-timber considerations for both management and reporting has resulted in opportunities for integration of data from differing sources to provide the desired information. Canada's forested land-base is over 400 million hectares in size and fulfills important ecological and economic functions. In this communication we describe how remotely sensed data and other available spatial data layers capture different forest characteristics and conditions, and how these varying data sources may

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be combined to provide otherwise unavailable information. For instance, light detection and ranging (LIDAR) confers information regarding vertical forest structure; high spatial resolution imagery captures (in detail) the horizontal distribution and arrangement of vegetation and vegetation conditions; and, moderate spatial resolution imagery provides consistent wide-area depictions of forest conditions. Furthermore, coarse spatial resolution imagery, with a high temporal density, can be blended with data of a higher spatial resolution to generate moderate spatial resolution data with a high temporal density. These remotely sensed data sources, when combined with existing spatial data layers such as forest inventory and digital terrain models, provide useful information that may be used to address, through modelling, questions regarding forest condition, structure, and change. In this communication, we discuss the importance of data integration and ultimately, information generation, in the context of Grizzly bear habitat characterization. Grizzly bear habitat in western Canada is currently undergoing pressure from a combination of anthropogenic activities and a widespread outbreak of mountain pine beetle, resulting in a variety of information needs, including: detailed depictions of horizontal and vertical vegetation structure over large areas to support bark beetle susceptibility mapping and habitat modelling; moderate spatial resolution data to capture changes in infestation conditions over time to support change detection and wall-to-wall mapping; and, coarse spatial resolution data to provide increased temporal detail enabling capture of within-year alterations to Grizzly habitat.

Key words: remote sensing; GIS; forestry inventory; mapping; monitoring; habitat; Grizzly bear; LIDAR; spatial resolution; Landsat, MODIS.

Resumo

As necessidades do gerenciamento de florestas e do relato de informações estão ficando cada vez mais complexas no Canadá. A inclusão de considerações sobre madeira e não-madeira, tanto para o gerenciamento como para o relato de disponibilidade de recursos florestais, resultou em oportunidades para a integração de dados de diferentes fontes para a obtenção da informação desejada. As terras florestadas de uso potencial no Canadá têm um tamanho acima de 400 milhões de hectares e possui importantes funções ecológicas e econômicas. Nesta comunicação descrevemos como dados de sensoriamento remoto e outros dados espaciais disponíveis detectam as diferentes condições e características da floresta e como estas fontes de dados diversos podem ser combinadas, fornecendo informações que estariam indisponíveis de outra forma. Por exemplo, LIDAR (acrônimo de *light detection and ranging*) fornece informações sobre a estrutura vertical de florestas; imagens de alta resolução espacial detectam detalhadamente a distribuição horizontal e o arranjo da vegetação e as suas condições; enquanto imagens de resolução espacial moderada fornecem uma consistente visão das condições florestais em extensas áreas. Além disso, imagens com resolução espacial grosseira, com elevada densidade temporal, pode ser combinada com dados de resolução espacial mais fina para gerar dados com uma resolução espacial moderada, porém com alta densidade temporal. Estas fontes de dados de sensoriamento remoto, quando combinadas com camadas de dados espaciais, tais como inventários florestais e modelos digitais de terreno fornecem informações úteis que podem ser usadas para, através de modelagem, analisar questões referentes a condição florestal, estrutura e mudanças. Nesta comunicação discutimos a importância da integração de dados e finalmente a geração de informação no contexto da caracterização do habitat dos ursos Grizzly. O habitat deste urso no oeste canadense está atualmente sendo pressionado devido a uma combinação de atividades humanas e por uma infestação ampla do besouro do pinheiro (*pine beetle*), tornando necessária uma série de informações, incluindo: detecção da estrutura horizontal e vertical da estrutura da vegetação para mapear as áreas de susceptibilidade deste inseto e para modelar o seu habitat; dados de resolução espacial moderada para capturar as mudanças das condições de infestação ao longo do tempo, para suportar a detecção de mudanças e mapeamento detalhado; dados de resolução espacial grosseira para fornecer um aumento de detalhe temporal, para detectar as alterações inter-anuais do habitat do Grizzly.

Palavras-chave: Sensoriamento remoto; SIG; Inventário florestal; Mapeamento; Monitoramento; Habitat; urso Grizzly; LIDAR; resolução espacial; Landsat; MODIS.

Context

What are the short- and long-term implications of forest harvesting, insect infestation, and timber salvage, upon Grizzly bear habitat in western Alberta, Canada? To address such a question requires the assessment of current conditions from the integration of forest inventory and remotely sensed data sources and the use of appropriate mapping approaches and modelling tools. The mapping is required to provide spatially exhaustive information of all relevant attributes for mountain pine beetle susceptibility and risk models, and for Grizzly bear habitat models. Additionally, mapping of the current beetle infestation and harvesting activities is also required (Where are the beetles now? What salvage or harvesting has occurred?). The modelling required is multi-faceted, requiring information on beetle susceptibility (Where is the beetle likely to attack?; Is the attack occurring over location of important Grizzly habitat? Can infestation projections be made to aid in habitat protection or management?). Integration of samples of LIDAR data with optical remotely sensed data also allows us to fill data gaps (i.e., over non-inventoried park-lands), or to address data vintage issues with forest inventory data to produce wall-to-wall model inputs. The integration of remotely sensed data with other spatial data within a modelling framework allows us to address important forest management and Grizzly bear habitat information needs.

Summary

Grizzly bear habitat modelling

What habitats best support Grizzly bear?

Remote sensed data has been identified as appropriate and useful for habitat mapping, especially when linked with a framework for linking ecological information needs with the types of data available from remote sensing and ancillary sources (McDERMID et al., 2005). High-quality grizzly bear habitats are generally characterized by the absence of roads and a mosaic of early seral-staged forests and natural openings set amongst more mature forest stands that provide cover and shelter. Timber protection and fire suppression activities often reduce the availability of these open structured habitats. Grizzly bears are found to use clear-cut harvested areas for a variety of food resources. Harvesting followed by a preclusion of human access can produce useful Grizzly bear habitat (NIELSEN et al., 2004). As such, consideration of Grizzly bear habitat, or the development of resource selection models (see NIELSEN et al., 2003), should include both a land cover and vegetation structure component (to provide an indication of food resources), and a spatial component (that incorporates the spatial arrangement and access to the various food resources).

Mountain pine beetle infestation and forest change mapping

Where is mountain pine beetle infestation occurring?

Where is forest harvesting or post-infestation salvage occurring?

At epidemic population levels, mountain pine beetles (*Dendroctonus ponderosae*) generally spread through mature stands and cause extensive mortality of large-diameter trees. Even though virtually all species of pine within the mountain pine beetle's range are suitable hosts, lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) is considered the beetle's primary host, due to the size, intensity, and the commercial impact of mountain pine beetle epidemics. In Canada, the mountain pine beetle population has reached epidemic levels, primarily in British Columbia, with the area of infested forest increasing from approximately 164,000 ha in 1999 to over 11 million ha in 2007 (WESTFALL and EBATA, 2008). The biological range of the primary host, lodgepole pine, exceeds the current range of the mountain pine beetle. Recent research has indicated that the beetle is expanding into new geographic areas (CARROLL et al., 2004), including an increased presence and distribution in Alberta (CARROLL, 2007).

The information needs of forest managers, in the context of addressing an infestation of mountain pine beetle, range from strategic planning over large areas, to detailed and precise location information for sanitation logging and treatment. Remote sensing has been demonstrated as an appropriate data source over a range of scales – considered both by detail and extent (WULDER et al., 2006a). Recent and select examples of remote sensing for mapping of mountain pine beetle infestation include high spatial resolution (WHITE et al., 2005; Coops et al., 2006), multi-temporal and high spatial resolution (WULDER et al., 2008a), hyperspectral (WHITE et al., 2007), and dense time series Landsat (GOODWIN et al., 2008). Most commonly, Landsat imagery is applied in a multi-temporal analysis approach to capture mountain pine beetle infestation (SKAKUN et al., 2003) recently augmented by a statistical modelling approach (WULDER et al., 2006b). The use of Landsat imagery is useful to provide large area coverage over spatial and spectral resolutions appropriate for insect and disturbance mapping (COHEN and GOWARD 2004; WULDER et al., 2008b).

To capture disturbance related to the mountain pine beetle infestation, forest salvage, and harvesting we follow the approach described by Wulder et al. (2006b).

Susceptibility to mountain pine beetle infestation

What is the likelihood a given location will be attacked by mountain pine beetle?

The characteristics of some stands tend to make them more susceptible to volume losses as a result of mountain pine beetle attack. Shore and Safranyik (1992) introduced a decision support system based upon the best features of previous systems, including the incorporation of continuous variables (rather than classes) and an attempt to relate the hazard rating index to the level of beetle-caused tree mortality in adjacent areas. Forest structure variables that are known to affect stand susceptibility are age, tree diameter, stand density, and climate. Stand composition is also an important determinant of likelihood of infestation and is included in the Shore and Safranyik models. The Shore and Safranyik (1992) risk rating system incorporated estimators of both stand susceptibility and beetle pressure. The susceptibility rating system provides an index of potential loss of stand basal area in the event of a mountain pine beetle infestation. The Shore and Safranyik (1992) system, while updated, generally considers stand risk as a function of both stand susceptibility to the mountain pine beetle and beetle population pressure on the stand: a susceptible stand can be at low risk if there is no beetle population present.

A rating system exists to calculate susceptibility and risk for each stand in a forested area (SHORE and SAFRANYIK, 1992). The calculation may be done simultaneously on multiple stands when represented within a digital geographic information system (GIS) database (such as a forest inventory). For producing information on stand susceptibility we follow the logic of the Shore and Safranyik approaches (WULDER et al., 2004).

LIDAR for estimation of forest inventory attributes

Can wall-to-wall information be produced through data integration to enable spatially exhaustive model inputs?

Optical remotely sensed imagery is well suited for capturing the horizontal distribution, composition, and structure of vegetation (WULDER, 1998), as well as for capturing changes in these elements over time (COHEN and GOWARD, 2004) while LIDAR data are more appropriate for capturing vertically distributed elements of forest structure and change (LEFSKY et al., 2002). The integration of optical remotely sensed imagery and LIDAR data provides improved opportunities to fully characterize forest canopy attributes and dynamics. Medium resolution remotely sensed data such as Landsat is relatively inexpensive to acquire over large areas (FRANKLIN and WULDER, 2002), whereas LIDAR covers small areas, at a high cost per unit area (LIM et al., 2002). These two data types may be combined to generate estimates of stand height over large areas at a reasonable cost (HUDAK et al., 2002).

Forest inventories in Canada are typically updated on a 10 year cycle (GILLIS and LECKIE, 1993). Applications requiring up-to-date estimates of height must often use growth and yield modelling to predict changes to height over time, based on a number of other inventory attributes. Wulder and Seemann (2003) presented an approach where image segments generated from Landsat-5 Thematic Mapper (TM) data were used to extend height estimates from samples of LIDAR data collected with the *Scanning LIDAR Image of Canopies by Echo Recovery* (SLICER) instrument. SLICER records data on canopy height, vertical structure, and ground elevation, collecting 5 full waveform footprints, typically resulting in a narrow-transect (< 50 m). Image segments were generated from Landsat-5 TM bands 1 to 5 and 7 using eCognition's segmentation algorithm (Definiens Imaging GmbH 2002). A regression model built using this area weighted mean LIDAR height, calculated from the within-stand image segments, enabled height predictions for forest inventory polygons within ± 6 m of the existing inventory height. Independent validation data was used to subsequently test the model, generating a R^2 of 0.67 and a standard error of 3.30 m. Nelson et al., (2003) present an approach for using plot based measures of forest structure to calibrate profiling LIDAR estimates to enable biomass (and subsequently Carbon) estimates over large areas.

For the purposes of our research, we will integrate LIDAR samples with Landsat imagery, to aid in the production of wall-to-wall depictions of attributes required for our mountain pine beetle susceptibility and Grizzly bear habitat modelling.

Within- and between-year dynamics through blending of Landsat and MODIS imagery

Can spatially detailed and temporally dense data products be created through the blending of Landsat and MODIS imagery?

Landsat imagery with a 30 m spatial resolution is well suited for characterizing landscape-level forest structure and dynamics. While Landsat images have advantageous spatial and spectral characteristics for characterizing vegetation, the Landsat sensor's revisit rate, or the temporal resolution of the data, is 16 days. When considering that cloud cover may impact any given acquisition, this lengthy revisit rate often results in a dearth of imagery for a desired time interval (e.g., month, growing season, or year) especially for areas at higher latitudes with shorter growing seasons (WULDER et al., 2008-continuity). In contrast, MODIS (MODerate-resolution Imaging Spectroradiometer) has a high temporal resolution, orbiting the Earth once per day, and depending on the spectral characteristics of interest, MODIS data has spatial resolutions of 250 m, 500 m, and 1000 m (JUSTICE et al., 2002). Gao et al. (2006) demonstrated that by combining Landsat and MODIS data, it is possible to capitalize on the spatial detail of Landsat and the temporal regularity of MODIS acquisitions.

To provide increased temporal density in our capture of disturbance and in the characterization of cover (and phenological development), we adapt and apply a data blending approach. For instance, we have found that reflectance data for select MODIS channels (at 500 m) and Landsat (at 30 m) may be combined to produce 18 synthetic Landsat images encompassing a single growing season (May to October). We compared, on a channel-by-channel basis, the top-of-atmosphere (TOA) reflectance values (stratified by broad land cover types) of four real Landsat images with the corresponding closest date of synthetic Landsat imagery, and found no significant difference between real (observed) and synthetic (predicted) TOA reflectance values (mean difference in reflectance: mixedwood, broadleaf, coniferous). Investigating the trend in NDVI values in synthetic Landsat values over a growing season revealed that phenological patterns are well captured; however, when seasonal differences lead to a temporary change in land cover (i.e., snow cover), the algorithm used to generate the synthetic Landsat images was, as expected, less effective at predicting reflectance. We will continue to develop and apply this logic to produce increasingly temporally dense habitat suitability information.

Conclusions

Is infestation and mitigation of mountain pine beetle impacting short- and long-term Grizzly bear habitat?

Though modelling can we develop scenarios to minimize the impacts of mountain pine beetle mitigation upon Grizzly bear habitat?

The preceding sections may be considered as puzzle pieces to allow us to address questions linking on-going management activities and emerging impacts (as a result of insect infestation) to provide insights to how Grizzly bears, or initially Grizzly bear habitat, is impacted.

We expect that through the integration of remotely sensed data and other spatial data within a modelling framework, we can generate otherwise unavailable information to aid in the understanding of the linkages between mountain pine beetle infestation, salvage, mitigation, and on-going anthropogenic and management activities upon Grizzly bear habitat in western Alberta, Canada.

References

CARROLL, A.L., TAYLOR, S.W., REGNIERE, J., SAFRANYIK, L., 2004. Effects of climate change on range expansion by the mountain pine beetle in British Columbia. In: Shore, T.L., Brooks, J.E., Stone, J.E. (Eds.), Mountain Pine Beetle Symposium: Challenges and Solutions, 30–31 October 2003, Kelowna, British Columbia, Canada. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, *Information Report BC-X-399,* pp. 223–232, 298.

CARROLL, A.L. 2007. The mountain pine beetle *Dendroctonus ponderosae* in Western North America: Potential for area-wide integrated management. Pages 297-307 in M.J.B. Vreysen, A.S. Robinson, and J. Hendricks (Eds.) Area Wide Control of Insect Pests.

COHEN, W. AND GOWARD, S. 2004. Landsat's role in ecological applications of remote sensing. *BioScience.* 54(6):535-545.

COOPS, N. C.; JOHNSON, M.; WULDER, M. A., AND WHITE, J. C. 2006. Assessment of QuickBird High Spatial Resolution Imagery to Detect Red Attack Damage Due to Mountain Pine Beetle Infestation. *Remote Sensing of Environment*. 103:67-80.

FRANKLIN, S. E. AND WULDER, M. A. 2002. Remote sensing methods in medium spatial resolution satellite data land cover classification of large areas. *Progress in Physical Geography*. 2002; 26(2):173-205.

GAO, F.; MASEK, J.; SCHWALLER, M., AND HALL, F. 2006. On the Blending of the Landsat and MODIS Surface Reflectance: Predicting Daily Landsat Surface Reflectance. *Transactions on Geoscience and Remote Sensing.* 44(8):2207-2218.

GILLIS, M. AND LECKIE, D. 1993. Forest inventory mapping procedures across Canada. Forestry Canada, PNFI; *Information Report PI-X-114.* 79.

GOODWIN, N.R., N.C. COOPS, M.A. WULDER, S. GILLANDERS, T. SCHROEDER, AND T. NELSON. 2008. Estimation of insect infestation dynamics using a temporal sequence of Landsat data. *Remote Sensing of Environment.* Vol. 112, pp. 3680–3689.

HUDAK, A. T.; LEFSKY, M. A.; COHEN, W. B., AND BERTERRETCHE, M. 2002. Integration of LIDAR and Landsat TM+ data for estimating and mapping forest canopy height. *Remote Sensing of Environment.* 82:397-416.

JUSTICE, C. O.; TOWNSHEND, J. R. G.; VERMONTE, E. F.; MASUOKA, E.; WOLFE, R. E.; SALEOUS, N.; ROY, D. P., AND MORISETTE, J. T. 2002. An Overview of MODIS Land Data Processing and Product Status. *Remote Sensing of Environment.* 83:3-15.

LEFSKY, M. A.; COHEN, W. B., PARKER, G. G., AND HARDING, D. J. 2002. LIDAR remote sensing for ecosystem studies. *BioScience.* 52(1):19-30.

LIM, K.; TREITZ, P.; WULDER, M.; ST-ONGE, B., AND FLOOD, M. LIDAR remote sensing of forest structure. *Progress in Physical Geography.* 2003; 27(1):88-106.

MCDERMID, G. J.; FRANKLIN, S. E., AND LEDREW, E. F. 2002. Remote Sensing for Large-Area Habitat Mapping. *Progress in Physical Geography.*29(4):449-474.

NELSON, R.; VALENTI, M.; SHORT, A., AND KELLER, C. 2003. A multiple resource inventory of Delaware using airborne laser data. *BioScience*. 53(10):981-992.

NIELSEN, S.E., BOYCE, M.S., STENHOUSE, G.B. AND MUNRO, R.H.M. 2003: Development and testing of phonologically driven grizzly bear habitat models. *Ecoscience* 10, 1-10.

NIELSEN, S. E.; MUNRO, R. H. M.; BAINBRIDGE, E. L.; STENHOUSE, G. B., AND BOYCE, M. S. 2004. Grizzly Bears and Forestry II. Distribution of Grizzly Bear Foods in Clearcuts of West-Central Alberta, Canada. *Forest Ecology and Management.* 199:67-82.

SHORE, T. AND SAFRANYIK, L. 1992. Susceptibility and risk rating systems for the mountain pine beetle in lodgepole pine stands. Forestry Canada, Pacific and Yukon Region, Pacific Forestry Centre; BC-X-336. 12p.

SKAKUN, R.; WULDER, M., AND FRANKLIN, S. 2003. Sensitivity of the thematic mapper enhanced wetness difference index to detect mountain pine beetle red-attack damage. *Remote Sensing of Environment.* 86:433-443.

WESTFALL, J. AND EBATA, T. 2007. (Ministry of Forests and Range, Forest Practices Branch). 2007 Summary of Forest Health Conditions in British Columbia.

WHITE, J.; WULDER, M.; BROOKS, D.; REICH, R., AND WHEATE, R. 2005. Detection of red attack stage mountain pine beetle infestation with high spatial resolution satellite imagery. *Remote Sensing of Environment*. 96:340-351.

WHITE, J. C.; COOPS, N. C.; HILKER, T.; WULDER, M. A., AND CARROLL, A. L. 2007. Detecting Mountain Pine Beetle Red Attack Damage with EO-1 Hyperion Moisture Indices. *International Journal of Remote Sensing.* 28(10):2111-2121.

WULDER, M. A. AND SEEMANN, D. 2003. Forest inventory height update through the integration of LIDAR data with segmented Landsat imagery. *Canadian Journal of Remote Sensing.* 29(5):536-543.

WULDER, M.; SEEMANN, D.; DYMOND, C.; SHORE, T., AND RIEL, B. 2004. Arc/Info Macro Language (AML) scripts for mapping susceptibility and risk of volume losses to mountain pine beetle in British Columbia. Technology Transfer Note, Forestry Research Applications, Pacific Forestry Centre. Victoria, British Columbia, Canada: Natural Resources Canada, Canadian Forest Service; Apr; Number 33.

WULDER, M. A.; DYMOND, C. C.; WHITE, J. C.; LECKIE, D. G., AND CARROLL, A. L. 2006a. Surveying mountain pine beetle damage of forests:A review of remote sensing opportunities. *Forest Ecology and Management.* 221:27-41.

WULDER, M. A.; WHITE, J. C.; BENTZ, B.; ALVAREZ, M. F. , AND COOPS, N. C. 2006b. Estimating the probability of mountain pine beetle red-attack damage. *Remote Sensing of Environment.* 101:150-166.

WULDER, M. A.; WHITE, J. C.; COOPS, N. C., AND BUTSON, C. R. 2008a. Multi-Temporal Analysis of High Spatial Resolution Imagery for Disturbance Monitoring. *Remote Sensing of Environment*. 2008; 112:2729-2740.

WULDER, M. A.; WHITE, J. C.; GOWARD, S. N.; MASEK, J. G.; IRONS, J. R.; HEROLD, M.; COHEN, W. B.; LOVELAND, T. R., AND WOODCOCK, C. E. 2008b. Landsat Coninuity: Issues and Opportunites for Land Cover Monitoring. *Remote Sensing of Environment*. 112:955-969.