MAPPING FOREST INVENTORY ATTRIBUTES ACROSS CONIFEROUS, DECIDUOUS AND MIXEDWOOD STAND TYPES IN THE NORTHWEST TERRITORIES FROM HIGH SPATIAL RESOLUTION QUICKBIRD SATELLITE IMAGERY

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ABSTRACT

Conducting vegetation inventories that describe the state of forests in the Northwest Territories (NWT) is challenging due to the large geographic extent of forest resources that are not easily accessible. The federal (Natural Resources Canada, Canadian Space Agency) and territorial (Government of NWT) governments recently completed a satellite-based land cover map of the forested areas of the NWT in the Earth Observation for the Sustainable Development of Forests (EOSD) project with Landsat Thematic Mapper data. Within the framework of the EOSD land cover map, this project is modeling and mapping four forest inventory attributes (stand height, crown closure, stand volume and aboveground biomass) from panchromatic and multispectral Quickbird satellite imagery. The image derivatives from Quickbird used to derive inventory attributes depends on whether the stand types were predominately comprised of coniferous, deciduous or mixedwood species. For coniferous species, image tree shadows derived from the panchromatic Quickbird image were used to compute the shadow fraction, of which image estimates of the four inventory attributes were within 10 to 15 percent of independent field measurements. Due to differences in crown morphology between coniferous and deciduous stands, image shadow fraction was not a good predictor of the forest inventory attributes for deciduous and mixedwood species. A first-order texture measure based on variance from the panchromatic image resulted in image models for deciduous species with adjusted R^2 values that ranged from 0.50 to 0.62. Estimating forest structure from mixedwood stands were more difficult, and required a combination of both panchromatic and multispectral image bands as estimators of the forest inventory variables.

INTRODUCTION

The intent of the Government of Northwest Territories Department of Environment and Natural Resources (GNWT-ENR) Forest Inventory Strategic Plan is to achieve accurate and timely information on the state of the forest resource that is consistent over time and which can be used at local, regional and territorial scales (Smith, 2002). The forested area of the Northwest Territories (NWT) is a widely distributed land mass 33 million ha in size (Natural Resources Canada, 2006), much of which is inaccessible and costly to survey. While conventional air photo-based forest inventories are being undertaken in the NWT, they represent only 17 percent of its forested area[*]. To complement existing forest inventory information, the federal (Natural Resources Canada, Canadian Space Agency) and territorial (GNWT-ENR) governments recently completed a satellite-based land cover map of the NWT under a project called the Earth Observation for the Sustainable Development of Forests (EOSD) (Wulder et al., 2003). To improve its informational value, particularly for forest inventory, there is the need to derive additional attributes of forest structure as value added products to the land cover map.

[*] Mindus, K. August 2007. Personal communications. Department of Environment and Natural Resources, Government of Northwest Territories, Hay River, NWT.

The estimation of forest attributes and in particular, stand volume, has been of considerable interest to those working in satellite remote sensing (Franklin, 2001). The accuracy by which these attributes have been estimated has been variable, and attributed, in part, to the spatial resolution and limited dynamic range of sensors such as the Landsat Thematic Mapper (Landsat TM) (Salvador and Pons, 1998; Hyyppä et al., 2000). Key to the use of satellite imagery is some degree of areal stratification, such as from a land cover map, which would improve the relationship between satellite spectral response and elements of stand structure. The sensitivity of Landsat TM data to stand characteristics, for example, was improved when undertaken within spatially homogeneous Landsat TM data (Gemmell, 1995). Previous forest inventory research in the NWT with Landsat Thematic Mapper data explored empirical relations between forest stand attributes of stand height, age, and crown closure for dominant stands of jack pine, white spruce and trembling aspen (Gerylo et al., 2002). Classification of these attributes into relatively broad categories was possible within these species groups (Franklin et al., 2003) although there is a desire for more continuous estimates to meet inventory information needs (Smith, 2002). While implementing a continuous variable model approach has seen some success from Landsat Thematic Mapper data (Cohen and Spies, 1992; Hall et al., 2006), a limitation in the NWT is the availability of field information from which such models could be developed.

Finding an alternative means of scaling stand attribute estimates from relatively few field plots to satellite data is a problem that has been investigated with high spatial resolution Quickbird satellite imagery (Beaudoin et al., 2005). High spatial resolution images such as Quickbird panchromatic will have a pixel size at or near the size of an average individual tree crown. The range in spectral response from such data will vary greatly due to pixel responses that may represent sunlit, shaded and tree shadow objects. The way such data are processed requires a paradigm shift in how image pixels are often analyzed. While per pixel classification methods predominate with medium resolution sensors such as Landsat TM (Franklin, 2001), they do not operate well at high spatial resolution (Wulder et al., 2004). Aside from methods that function within the auspices of an individual tree crown (Leckie et al., 2003), methods based on the spatial domain such as image texture may hold greater promise in its relationship to forest attributes. One approach to information extraction is the use of image texture and vegetation indices from different band combinations. Past studies have reported improved accuracies in the estimation of forest structure from combining the per pixel approach with texture processing (Wulder et al., 1998). The utility of such an approach with high spatial resolution satellite data to northern boreal forests in the NWT is relatively unknown and merits further investigation.

The objective of this study is to evaluate the use of Quickbird high spatial resolution imagery to estimate forest attributes of stand height, crown closure, stand volume and aboveground biomass across forested areas classified as coniferous, deciduous and mixedwood. Mapping these attributes across a high spatial resolution image is part of an approach being developed to scale these attributes to larger areas with Landsat TM and SPOT images (Beaudoin et al., 2005; Guindon et al., 2005).

STUDY AREA

The study area consists of two Quickbird panchromatic and multispectral satellite images that are located within the Mackenzie and Slave Lowlands of the Mid-Boreal Ecoregion within the Taiga Plains Ecozone (Ecosystem Classification Group, 2007). The area is characterized by variable forest stands interspersed with large fens and bogs with discontinuous permafrost. The study focused on the three primary forest stand types mapped during the EOSD land cover project as defined by coniferous, deciduous and mixedwood. Coniferous species mainly consisted of jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill) B.B.P.), and white spruce (*Picea glauca* (Moench) Voss). Deciduous species consisted primarily of trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.) and white birch (*Betula papyrifera* Marsh.)**,** and areas classified as mixedwood contained a mixture of coniferous and deciduous species in varying proportions (Wulder et al., 2003).

DATA COLLECTION

Field Sampling

Field data was collected during July 2005 and 2006 within the Quickbird footprints located near Fort Providence and Fort Simpson, NWT. Over the two years, a total of 94 plots, $400m^2$ in size, were distributed in stands of jack pine, white spruce, black spruce, trembling aspen and mixedwoods. Tree selection included every tree that was at least 1.3 m in height and at least 5 cm at diameter breast height, from which species, tree height (m), diameter at breast height (cm), tree status (dead or alive), crown closure measurements, and a differentially corrected GPS coordinate at plot centre were collected.

Stand estimates of height, crown closure, volume, and aboveground biomass were computed from the field data. Plot crown closure was derived from the average of nine spherical densiometer measurements taken within the plot boundary. Estimates of stand volume were generated by summing the computed individual tree volumes (Huang, 1994), divided by the plot area and scaled to a total volume density measurement (m^3/ha). A generalized, allometric tree biomass equation (AGB = aDBH^b) was used to generate tree level biomass*, which was then summed for each tree and converted to a stand-level total aboveground biomass density (tonnes/ha).

Satellite Imagery

Quickbird panchromatic and multispectral high spatial resolution satellite images were acquired on August 30, 2003 near Fort Providence, and on July 22, 2006 near Fort Simpson, NWT. The panchromatic and multispectral images had a spatial resolution of 0.6m, and 2.44m, respectively, with a spatial extent of approximately 17 km (West-East) by 19 km (North-South). The images were orthorectified to ground control points collected along main roads through the image area. Canadian Digital Elevation Data at a scale of 1:250k was used for the elevation model. A first-order polynomial correction applied to 22 ground control points in each image resulted in an average positional root mean square error (RMSE) of approximately 0.75m.

METHODS

Three approaches were employed in the association of image to stand attributes. The first approach entailed an image shadow fraction method described by Beaudoin et al. (2005) and Lebouef et al. (*in press*). A threshold mask was initially employed to isolate image tree shadows from other image objects. Sampling areas that represent the size of a 30m by 30m Landsat TM pixel (50 by 50 Quickbird panchromatic pixels) were centered on each of the plot locations on the Quickbird panchromatic image. These sampling areas were then superimposed onto the tree shadow threshold layer to determine the proportion of tree shadow pixels at each plot location. Simple linear and Theil-Sen regression models (Fernandes and Leblanc, 2005) were employed to relate the plot shadow fraction for each stand attribute across the coniferous species groups.

The second approach employed first (variance)- and second (homogeneity)- order image texture measures that were computed with window sizes ranging from 3x3 to 15x15 pixels, and averaged over a 30m window to emulate the pixel size of a Landsat TM image. As well, a larger 50x50 pixel window was used to compute the image texture values of the full Landsat pixel size. These image texture values were subsequently associated to each stand attribute across the three species groups using linear regression procedures from which model adjusted R^2 values were obtained.

The third approach employed a stepwise multiple regression procedure based on both image texture and the average image spectral response from the panchromatic and multispectral image bands over a 30m pixel window. Combinations of first order and second order image texture and average image spectral response were used as input variables to a forward stepwise regression for the mixedwood species group.

RESULTS AND DISCUSSION

Shadow fraction generated from the Quickbird panchromatic image was statistically correlated with all stand attributes for conifer (R values >=0.80, p = 0.001) and poorly correlated for the deciduous and mixed species groups (unpublished data). Forest stands in the NWT tend to be relatively open and the crown morphology of conifers where leaf area is concentrated tends to result in darker, more intense shadows than for deciduous and mixed species. Deciduous stands will transmit more light through the canopy than conifers, and light penetration in

* Case B.S. and R.J. Hall. Assessing prediction errors of generalized tree biomass and volume equations for the boreal forest region of west-Central Canada. Natural Resources Canada, Canadian Forest Service. *Manuscript under review*.

mixedwood canopies increases as the deciduous component increases (Lieffers et al., 1999). As a result, it was not possible to implement a shadow fraction approach to deciduous and mixedwood stands.

Regression models between shadow fraction and stand attributes were only developed for conifer, with adjusted R^2 values that were all greater than 0.70 (Table 1). The model coefficients from Theil-sen regression were similar but the regression slope was larger, resulting in larger values of the stand attributes at the upper end, and smaller values at the lower end of the data range across all variables. Outliers tend to occur at the upper and lower ends of the data range, and these were addressed, in part, by the insensitivity of Theil-sen to approximately 30% of outliers (Fernandes and Leblanc, 2005). With limited independent validation data, all stand attributes generated by the Theil-sen regression for conifer were within 10 to 15 percent of field measured values (unpublished data).

A first order variance texture variable was associated to varying degrees with deciduous stand height, volume and biomass with the largest value occurring with the largest window size based on single variable linear regression models (Table 1). Crown closure was not statistically correlated to any of the two texture measures, and the second order homogeneity texture measure was not able to predict any of the stand attributes across all window sizes (unpublished data). While texture measures derived from the grey-level co-occurrence matrix predominates in the remote sensing literature, previous studies have reported classification accuracies from high spatial resolution image data may be higher with local variance than from second order texture measures (Coburn and Roberts, 2004). In this context, study results were consistent with those of Coburn and Roberts (2004). The observed improvement in empirical relationships at larger window sizes was also consistent with previous studies that reported separability of forest age class from IKONOS panchromatic data was more effective at larger window sizes (Franklin et al., 2001). For the deciduous species group, reasonable predictions of the stand attributes could be attained from the use of image texture alone based on a first order variance measure.

The most challenging problem was the estimation of stand structure for the mixedwood species. Both shadow fraction and image texture were poor predictors of stand structure (unpublished data). Image texture variance and average image spectral response from Quickbird image channel 2 (e.g., 520 – 600 nm) emerged from a stepwise regression process that resulted in relatively poor to modest predictions of stand attributes (Table 1). Based on the image attributes evaluated, it was not possible to estimate crown closure. Mixedwood stands tend to be more complex in stand composition due to their variability in species composition, density and occurrence of understory (Hall et al., 2000). As a result, additional attributes that can further stratify mixedwood areas may hold promise through its reduction in textural and spectral variability. Further investigations are underway to address this problem.

CONCLUSIONS

This study is examining the use of Quickbird panchromatic and multispectral images to model and map four forest inventory attributes (stand height, crown closure, stand volume, biomass) across coniferous, deciduous and mixedwood species in a northern boreal region of the Northwest Territories. The method used to estimate these attributes varied by species group. The shadow fraction on Quickbird panchromatic images could be used to estimate inventory attributes for conifers, but this approach was ineffective for deciduous and mixedwoods. A first-order variance texture measure alone was able to estimate all stand attributes with the exception of crown closure for deciduous species. Estimating inventory attributes for mixedwoods proved most difficult with only modest prediction models based on a combination of texture variance and average spectral response from Quickbird channel 2 representing the 520 – 600 nm portion of the electromagnetic spectrum. Current work involves methods to improve estimation of inventory attributes from Quickbird imagery and approaches to scale these Quickbird estimates over larger areas.

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Table 1. Adjusted R^2 values from simple linear regression across 4 inventory attributes for coniferous, deciduous, and mixedwood land covers. The approaches employed are highlighted in gray.

Inventory Attribute	Coniferous	Deciduous								Mixedwood
	Shadow Fraction	Variance Texture (pixel window sizes)								Stepwise Regression
		3x3	5x5	7x7	9x9	11x11	13x13	15x15	50x50	
Height	0.71	0.18	0.29	0.36	0.39	0.40	0.40	0.42	0.62	0.23
Crown cls.	0.73	0.22	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02
Volume	0.76	0.39	0.46	0.46	0.44	0.41	0.40	0.40	0.50	0.50
Biomass	0.72	0.28	0.41	0.47	0.49	0.49	0.51	0.53	0.54	0.62

* Adjusted R^2 values for deciduous based on the average variance texture value within a 30 x 30m pixel window
** Units: Height (m); Crown closure (%); Volume (m^3/ha); Biomass (tonnes/ha)

REFERENCES

Beaudoin, A., A. Leboeuf, L. Guindon, R. A. Fournier, J. E. Luther, and M.-C. Lambert (2005). Mapping of Canadian northern boreal forest biomass using QuickBird high spatial resolution imagery. Proceeding from the ForestSat 2005 workshop, May 31 - June 3 2005, Borås, Sweden, Vol. 8b, pp. 66-70.

Coburn, C. A., and A. C. B. Roberts (2004). A multiscale texture analysis procedure for improved forest stand classification. *International Journal of Remote Sensing, 25*:4287-4308.

Cohen, W. B., and T. A. Spies (1992). Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and Spot imagery. *Remote Sensing of Environment, 41*:1-17.

Ecosystem Classification Group (2007). Ecological Regions of the Northwest Territories – Taiga Plains. Department of Environment and Natural Resources, Government of Northwest Territories, Yellowknife, NT, Canada. Vii + 209 pp. + folded insert poster map.

Fernandes R., and S. G. Leblanc (2005). Parametric (modified least squares) and non-parametric (Theil-sen) linear regressions for predicting biophysical parameters in the presence of measurement errors. *Remote Sensing of Environment, 95*:303-316.

Franklin, S. E. (2001). *Remote Sensing for Sustainable Forest Management*. Lewis Publishers, New York, N.Y.

Franklin, S. E., R. J. Hall, L. Smith, and G. R. Gerylo (2003). Discrimination of conifer height, age, and crown closure classes using Landsat-5 TM imagery in the Canadian Northwest Territories. *International Journal of Remote Sensing, 24*:1823–1834.

Franklin, S. E., M. A. Wulder, and G. R. Gerylo (2001). Texture analysis of IKONOS panchromatic data for Douglas-fir forest age class separability in British Columbia. *International Journal of Remote Sensing, 22*:2627-2632.

Gemmell, F. M. (1995). Effects of forest cover, terrain, and scale on timber volume estimation with Thematic Mapper data in a Rocky Mountain site. *Remote Sensing of Environment, 51*:291-305.

Gerylo, G. R., R. J. Hall, S. E. Franklin, and L. Smith (2002). Empirical relations between Landsat TM spectral response and forest stands near Fort Simpson, Northwest Territories, Canada. *Canadian Journal of Remote Sensing, 28*:68–79.

Guindon, L., A. Beaudoin, A. Leboeuf, C.-H. Ung, J. E. Luther, S. Côté, and M.-C. Lambert (2005). Regional mapping of Canadian subarctic forest biomass using a scaling-up method combining QuickBird and Landsat imagery. Proceedings from the ForestSat 2005 Workshop, May 31-June 3 2005, Borås, Sweden,

Vol. 8b, pp. 71-75.
Hall, R.J., D. R. Peddle, and D. L. Klita (2000). Mapping conifer understory within boreal mixedwoods from Landsat TM satellite images. *The Forestry Chronicle, 76*:75-90.
Hall, R. J., R. S. Skakun, and E. J. Arsenault (2006). Modeling forest stand structure attributes using Landsat ETM+ data: application to mapping of aboveground biomass and stand volume. *Forest Ecology and Management, 225*:378-390.
Huang, S. (1994). Individual tree volume estimation Procedures for Alberta: Methods of Formulation and Statistical Foundations. Land and Forest Service, Alberta Environmental Protection, Tech. Rep. Pub. No. T/288, Edmonton, Alta., 80 pp.
Hyyppä, J., H. Hyyppä, M. Inkinen, M. Enghahl, S. Linko, Y.-H. Zhy (2000). Accuracy comparison of various remote sensing data sources in the retrieval of forest stand attributes. *Forest Ecology and Management*, *128*:109-120.
Leboeuf, A., A. Beaudoin, R. A. Fournier, L. Guindon, J. E. Luther and M.-C. Lambert. A shadow fraction method for mapping biomass of northern boreal black spruce forests using Quickbird imagery. *Remote Sensing of Environment, in press*.
Leckie, D. G., F. A. Gougeon, N. Walsworth, D. Paradine (2003). Stand delineation and composition using semi-automated individual tree crown analysis. *Remote Sensing of Environment*, *85*:355-369.
Lieffers, V. J., C. Messier, K. J. Stadt, F. Gendron, and P. G. Comeau (1999). Predicting and managing light in the understory of boreal forests. *Canadian Journal of Forest Research, 29*:796-811.
Natural Resources Canada (2006). The state of Canada's forests 2005-06. Natural Resources Canada, Canadian Forest Service, Ottawa, Ont.
Salvador, R., and X. Pons (1998). On the reliability of Landsat TM for estimating forest variables by regression techniques: a methodological analysis. *IEEE Transactions on Geoscience and Remote Sensing, 36*:1888–1897.
Smith, L. (2002). Forest resource inventory and analysis strategic plan. Government of Northwest Territories, Resources, Wildlife and Economic Development, Forest Management Division, Hay River, NWT.
Wulder, M. A., J. Dechka, M. Gillis, J. Luther, R. J. Hall, A. Beaudoin, and S. E. Franklin (2003). Operational mapping of the land cover of the forested area of Canada with Landsat data: EOSD land cover program. *The Forestry Chronicle, 79*(6):1075-1083.
Wulder, M. A., R. J. Hall, N. C. Coops, and S. E. Franklin (2004). High spatial resolution remotely sensed data for ecosystem characterization. *BioScience, 54*(6):511-521.
Wulder, M. A., E. F. Ledrew, M. Lavigne, and S. E. Franklin (1998). Aerial image texture information in the estimation of deciduous and mixed forest LAI. *Remote Sensing of Environment, 64*:64-76.