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Monitoring Canada's forests. Part 2: National forest fragmentation and pattern

Michael A. Wulder, Joanne C. White, Tian Han, Nicholas C. Coops, Jeffrey A. Cardille, Tara Holland, and Danny Grills

Abstract. Canada is one of the world's largest nations, with a land area of nearly one billion hectares. This vast area is home to a number of unique ecosystems, comprised of different climate, land cover, topography, and disturbance characteristics. Depiction of forest composition, based on satellite-derived land cover, is a common means to characterize and identify trends in forest conditions and land use. Forest pattern analyses that consider the size, distribution, and connectivity of forest patches can provide insights to land use, habitat, and biodiversity. In this communication, we present the pattern characteristics of Canada's forests as determined by the Earth Observation for Sustainable Development of Forests (EOSD) product, a new land cover classification of the forested area of Canada. The EOSD product (EOSD LC 2000) represents conditions circa the year 2000, mapping each 25 m × 25 m pixel into one of 23 categories. We used the EOSD data to assess forest patterns nationally at four spatial extents: level 1, 13 000 km^2 (corresponding to the area of a single 1:250 000 scale National Topographic System (NTS) map sheet); level 2, 800 km^2 (corresponding to the area of a single 1:50 000 scale NTS map sheet); level 3, 1 km^2; and level 4, 1 ha. For levels 1–3, a total of 95 landscape pattern metrics were calculated; for the 1 ha units, a subset of eight metrics were calculated. The results of this analysis indicate that Canada's forest pattern varies by ecozone, with some ecozones characterized by large areas of contiguous forest (i.e., Boreal Shield, Atlantic Maritime, and Montane Cordillera), while other ecozones have less forest and are characterized by large numbers of small forest patches, reflecting the complex mosaic of land cover types present (Taiga Shield, Taiga Cordillera). Trends for the subset of metrics used to characterize national conditions are relatively consistent across levels 1–3. Level 4 metrics, where the analysis extent is 1 ha, are well-suited to regional or local analyses. As the first regional assessments of the patterns contained in the EOSD LC 2000, these measures of Canada's forest landscape patterns add value to the national land cover baseline.

Résumé. Le Canada est l'un des plus grands pays du monde avec une superficie d'un milliard d'hectares. Ce vaste territoire est l'hôte de nombreux écosystèmes uniques comprenant différents climats, couverts, topographies et caractéristiques de perturbations. La description de la composition forestière basée sur le couvert dérivé des images satellitaires est une procédure courante pour caractériser et identifier les tendances dans les conditions de la forêt et l'utilisation du sol. Les analyses des patrons de forêts qui considèrent la dimension, la distribution et la connectivité des parcelles de forêt peuvent fournir une connaissance de l'utilisation du sol, des habitats et de la biodiversité. Dans cette communication, nous présentons les caractéristiques des patrons de forêts canadiennes tels que déterminés par le produit EOSD (Observation de la Terre pour le développement durable des forêts / « Earth Observation for Sustainable Development of Forests »), une nouvelle classification du couvert de la zone forestière du Canada. Le produit EOSD représente les conditions en date de l'an 2000, cartographiant chaque pixel de 25 m × 25 m en fonction d'une de 23 catégories. Nous avons utilisé les données de EOSD pour évaluer les patrons de la forêt pour quatre étendues spatiales différentes: niveau 1, 13 000 km^2 (correspondant à la superficie d'un feuillet cartographique du Système national de référence cartographique (SNRC) au 1:250 000; niveau 2, 800 km^2 (correspondant à la superficie d'un feuillet cartographique du SNRC au 1:50 000); niveau 3, 1 km^2; et niveau 4, 1 ha. Pour les niveaux 1–3, un total de 95 patrons différents du paysage ont été calculés; pour les unités de 1 ha, un sous-ensemble de huit patrons a été calculé. Les résultats de cette analyse indiquent que le patron des forêts canadiennes varie selon les écozones, avec certaines écozones qui sont caractérisées par de vastes étendues de forêt contiguë (c.-à-d. bouclier boréal, maritime de l'Atlantique, cordillère montagnarde), tandis que d'autres écozones ont moins de forêt et sont caractérisées par la présence d'un grand nombre de petites parcelles de forêt, reflétant ainsi la mosaïque complexe

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M.A. Wulder,[1] J.C. White, and D. Grills. Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, 506 West Burnside Road, Victoria, BC V8Z 1M5, Canada.

T. Han. Integrated Land Management Bureau, Ministry of Agriculture and Lands, PO Box 9355, STN PROV GOVT, Victoria, BC V8W 9M1, Canada.

N.C. Coops. Department of Forest Resource Management, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada.

J.A. Cardille and T. Holland. Département de Géographie, Université de Montréal, Montréal, QC H3C 3J7, Canada.

[1]Corresponding author (e-mail: mwulder@nrcan.gc.ca).

des types de couvert en présence (taïga du bouclier, taïga de la cordillère). Les tendances au niveau du sous-ensemble de valeurs utilisé pour caractériser les conditions au plan national sont relativement constantes pour les niveaux 1–3. Les valeurs de niveau 4, là où l'étendue de l'analyse est de 1 ha, sont plus appropriées pour les analyses régionales ou locales et seront prises en considération dans des projets futurs. À titre de premières évaluations régionales des patrons de forêt intégrés dans l'ensemble des données du couvert EOSD LC 2000, ces mesures des patrons de forêts à l'échelle nationale ajoutent de la valeur aux données de base du couvert national.
[Traduit par la Rédaction]

Introduction

Forests cover 30% of the total land area of the globe and fulfill important biologic, economic, cultural, and recreational functions (FAO, 2005). Forests are under increasing pressure from a range of factors, including agriculture, industrialization, climate change, and urbanization (FAO, 2007). It is not just the amount of forest that has been altered substantially, but also the composition and pattern of forests (Siry et al., 2005), posing a potential threat to biodiversity and the sustainable management of forests (Bishop, 1993; Fahrig, 2003; Kupfer, 2006). Landscape-level information about forest pattern can facilitate understanding of the processes that cause and (or) result from changes to forest patterns over time (Gustafson, 1998a) and inform management policies intended to reduce or mitigate potential negative consequences of increased forest fragmentation (Gustafson, 1998b).

At the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, world leaders acknowledged the role of forest management in supporting sustainable development. Scientists and policy-makers drew international attention to the importance of monitoring forest loss and fragmentation through a Statement of Forest Principles and the production of Agenda 21, a comprehensive plan of action to minimize human impact on the environment in the 21st century. The next stage of the process occurred in 1993, when Canada hosted an international seminar of experts on sustainable development of boreal and temperate forests from 12 nations (Argentina, Australia, Canada, Chile, China, Japan, Korea, Mexico, New Zealand, the Russian Federation, Uruguay, and USA) that together contained 90% of the planet's temperate and boreal forest area. The outcome of this meeting was the establishment of the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. By 1995, this working group had finalized the seven criteria and 65 indicators that make up the Montréal Process. These criteria and indicators were endorsed by the 12 participating nations as the Santiago Declaration (McDonald and Lane, 2004). The Santiago Declaration identifies fragmentation of forest types as one of nine indicators of biological diversity in terms of the disruption of ecological processes and availability of habitat, which can affect the viability of plant and animal populations.

Although included in the original criteria and indicators framework drawn up by the Canadian Council of Forest Ministers (CCFM, 1995), the "level of fragmentation and connectedness of forest ecosystem components (1.1.4)" has proven difficult to assess due to the lack of data suitable for national reporting (CCFM, 1997). Forest fragmentation was eventually dropped as an indicator when the criteria and indicators framework was reviewed in 2003 (CCFM, 2004) and has not been included in Canada's subsequent national reporting (CCFM, 2005). Wijewardana (2008) cited fragmentation as one of the concepts associated with criteria and indicators that required clarification and standardization. The first Montréal Process reports from participating nations (submitted in 1993) indicated that "there is little or no scientific understanding of how to measure forest fragmentation" (Montréal Process Working Group, 2003); moreover, there has been little consistency in how nations report on this indicator. Land cover maps developed from satellite imagery provide an opportunity for the large-area development of information on forest fragmentation (Riitters et al., 2004). Landscape pattern metrics have been implemented in the United States as an important indicator for sustainable forest management (Riitters et al., 2004), supported by large-area land cover products generated from Landsat Thematic Mapper (TM) imagery (Vogelmann et al., 2001). Similarly, the land cover product generated in Canada from the Earth Observation for Sustainable Development (EOSD) (Wulder et al., 2008) provides a heretofore unavailable information source from which an initial assessment of the fragmentation of Canada's forests can be made.

The EOSD land cover product provides a unique opportunity to quantify the forest patterns in Canada. The objectives of this communication are to characterize, for the first time, the spatial patterns of forests in Canada based on this EOSD product. We first review the data and methods used to generate selected landscape pattern metrics and then present the national and regional patterns both graphically and in tabular form.

Background

Forest fragmentation

Fragmentation is most commonly defined as the breaking apart of habitat (Fleishman and Mac Nally, 2007) and can be related to a variety of factors, including both natural processes, such as fires and insect infestations, and anthropogenic activities, such as logging or road building (Linke et al., 2007). In ecological literature, fragmentation can refer either to the entire process of forest loss and isolation (Wilcove et al., 1986) or specifically to the perforation of habitat (as distinct from total habitat loss) (Fahrig, 2003), which causes changes in the spatial configuration of forest remnants. The majority of current research employs the latter definition; however, it is important to remember that changes in spatial pattern cannot occur without corresponding changes in forest area. As such, landscape fragmentation is a function of both composition and configuration (Boots, 2003; 2006). Composition refers to the aspatial characteristics of the classes (e.g., the proportion of forest within the analysis unit), and configuration refers to the spatial distribution of classes (e.g., the number of forest/forest joins) (Boots, 2003).

Kupfer (2006) indicates that forest loss and fragmentation result in three distinct changes in forest pattern, namely reduced forest area, increased isolation of forest remnants, and creation of edges. Fahrig (2003) describes the changes in terms of habitat, specifically a reduction in habitat amount, an increase in number of habitat patches, a decrease in the size of habitat patches, and an increase in isolation of habitat patches. Although fragmentation occurs over many spatial scales and extents (Fleishman and Mac Nally, 2007), Kupfer notes that most landscape pattern metrics that measure fragmentation quantify the spatial arrangement of forested ecosystems at the landscape scale, and thus the metrics are useful quantifications of landscape pattern and may be represented by routinely used remotely sensed data sources such as Landsat (Gergel, 2007). In this paper we consider forest fragmentation as a condition of the landscape in the year 2000. Questions of fragmentation as a dynamic process are relegated to future consideration (Fortin and Dale, 2005; Wagner and Fortin, 2005).

A patch is defined as a relatively homogenous area that differs from its surroundings (Forman, 1995). The grain, minimum mapping unit, extent, and classification scheme used to generate the land cover product all influence landscape pattern metrics (Gergel, 2007). Grain size is analogous to pixel size and the grain size of the EOSD product is 25 m (the minimum mapping unit for the EOSD product is the same size). The extent of the area within which landscape pattern metrics are estimated (analysis unit) can also have an impact on the calculation of pattern metrics (Gergel, 2007). Some metrics (i.e., number of patches, mean patch size) are more sensitive than others to these factors.

When characterizing fragmentation through landscape pattern analysis, it is important to separate different types of fragmentation in the context of the land cover classification. In Canadian forested landscapes, fragmentation can be the result of various causes. First, anthropogenic disturbance such as timber harvesting (Hudak et al., 2007) and road building (Trombulak and Frissell, 2000) can result in the fragmentation of formerly forested areas (Heilman et al., 2002). Second, fragmentation may also be the result of natural processes: characteristics of different ecosystems could lead to areas of mixed land cover types being classified as fragmented. For instance, natural regions that are wetland- or alpine-dominated can be assessed as substantially fragmented based on measures of forest/nonforest juxtapositions (Boots, 2006). Third, fragmentation can be the result of, and also have impacts on, natural disturbances such as fire (Hudak et al., 2007), insect infestations (Hughes et al., 2006), and ice storms (Pasher and King, 2006). Fourth, different adjacent land uses can cause fragmentation effects by separating patches of a particular land cover type. Intense human activity, for example, can affect the shape of patches, usually resulting in simpler patch shapes (Forman, 1995). As a result, the simultaneous consideration of land cover with measures of landscape pattern is required. Typically, conventional forest management will impact the distribution of stand age and patch size, resulting in an increase in the number of smaller patches and younger age classes (Harris, 1984; Mladenoff et al., 1993; Radeloff et al., 2006). Lastly, forest pattern may also be considered somewhat ephemeral, as disturbed forested areas may ultimately return to forests over time, either through planned reforestation or through natural succession processes.

Methods

Data

EOSD land cover

The EOSD project culminated in the production of a land cover map of the forested ecozones of Canada using Landsat satellite data representing circa year 2000 conditions (hereafter referred to as EOSD LC 2000). The EOSD product represents 23 unique land cover classes mapped at a spatial resolution of 0.0625 ha (equivalent to a 25 m × 25 m pixel) (described in more detail in Wulder et al., 2008). There are approximately 10 billion pixels found within the forested ecozones of Canada, with about 50% of these pixels being a forest class. The EOSD classification was produced using an unsupervised hyperclustering approach (Wulder et al., 2008). The accuracy of the EOSD product on Vancouver Island, British Columbia, was found to be 77% for level 4 of the classification hierarchy (achieving the target accuracy of 80%, with a 90% confidence interval of 74%–80%) (Wulder et al., 2007). EOSD LC 2000 is delivered as 1:250 000 scale National Topographic System (NTS) map sheets (bundled by province) and as Universal Transverse Mercator (UTM) zone mosaics and is a free and publicly available data source (www4.saforah.org/eosdlcp/nts_prov.html). The products are available in a Paletted GeoTIFF format, with a disabled TIFF world file, and bilingual Federal Geographic Data Committee compliant metadata. Details on the methodology used to produce the EOSD product are described in Wulder et al. (2008).

Ecological mapping zones

The Ecological Stratification Working Group (1996) established the *National Ecological Framework for Canada*, partitioning the country into 15 broad terrestrial ecozones (**Figure 1**). An ecozone is defined as "an area of the earth's surface representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors" (Ecological Stratification Working Group, 1996). On a subcontinental scale, these ecozones depict the broad mosaics formed by the interaction of macroscale climate, human activity, vegetation, soil, geological, and physiographic features (Marshall and Schut, 1999). These ecozones are commonly used as a framework for national reporting (CCFM, 2005; Power and Gillis, 2006). Ten of the 15 terrestrial ecozones contain the majority of Canada's forested and other wooded land, and these ecozones formed the EOSD project area. In this communication, ecozones enable meaningful generalization of the landscape patterns found, offer a linkage to other national reporting activities, and provide an ecologically meaningful context. Such a context is useful for understanding landscape patterns that result from land cover characteristics and dominant disturbance regimes (such as large and frequent fires in the northern boreal forest and industrial forestry activities in more southerly or accessible locations).

Data processing and generation of landscape pattern metrics

Preprocessing

Landscape pattern metrics were calculated for each 1:250 000 EOSD LC 2000 map sheet. First, the EOSD product was reclassified from 23 classes to three classes, namely forest, nonforest, and other (**Figure 1**) (see Figure 3 in Wulder et al., 2008). Second, patches consisting of a single pixel were replaced by assigning them the majority land cover class (forest, nonforest, or other) of their surrounding 3 × 3 pixel neighbourhood. If there was no majority class, single pixel patches remained, retaining their original class. Lastly, analysis units (i.e., arrays of appropriately sized grid cells) were generated to facilitate calculation of the landscape pattern metrics. Riitters et al. (2004) define an analysis unit as the spatial extent over which the landscape pattern metrics are calculated and saved. The Landsat-based EOSD classification (products with a 25 m grain) and the seamless large-area coverage provide opportunities using different extents for metric calculation. Larger extents will allow for representation of regional to national trends, with smaller extents conferring information regarding more local characteristics. We selected four different spatial extents that either conformed to existing spatial mapping conventions and nomenclatures (levels 1 and 2) or are commonly used for mapping and modeling (levels 3 and 4). Accordingly, the EOSD landscape pattern metrics were then calculated over each of these four different spatial extents (i.e., levels 1–4) (**Figure 2**): (1) 13 000 km^2 (corresponding to the area of a single 1:250 000 NTS map sheet); (2) 800 km^2 (corresponding to the area of a single 1:50 000 NTS map sheet); (3) 1 km^2; and (4) 1 ha.

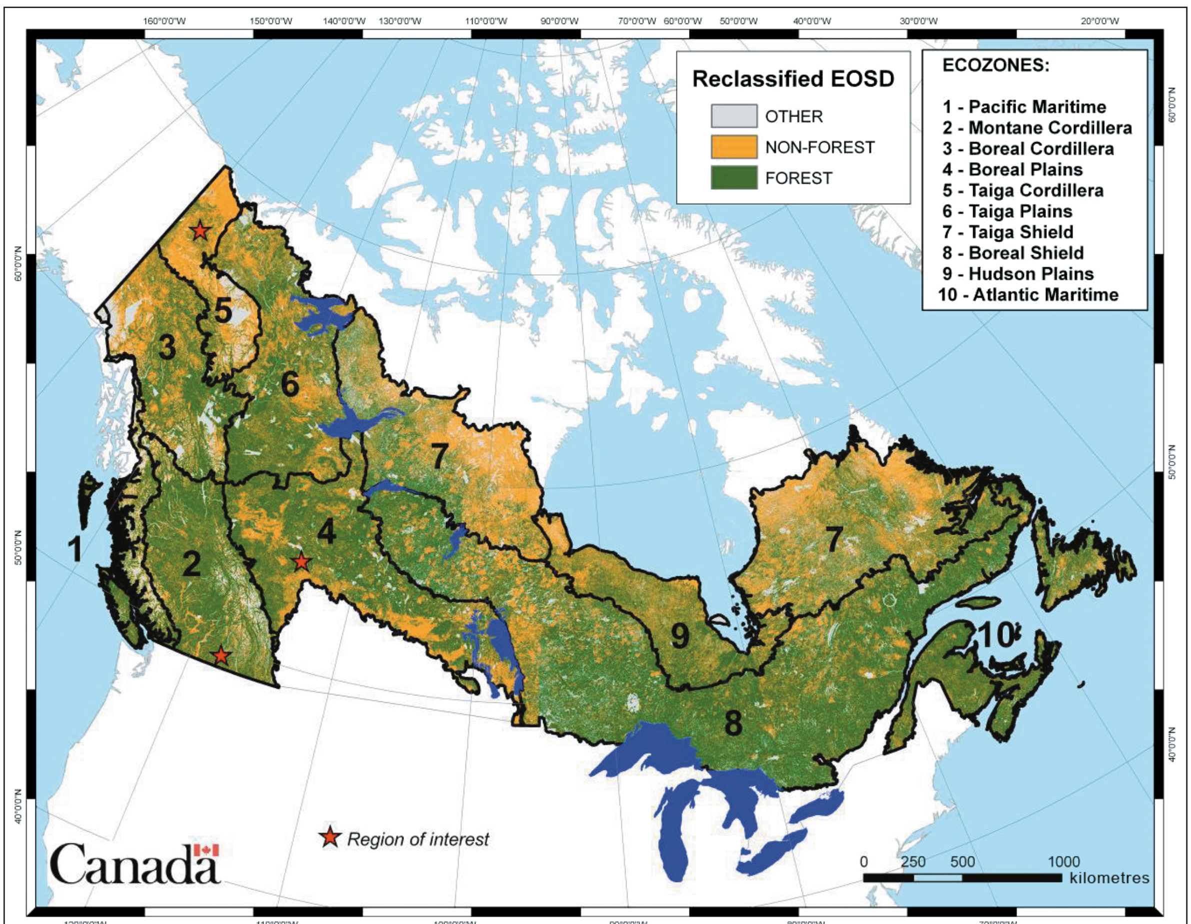

Figure 1. The distribution of EOSD forest, nonforest, and other classes used to calculate landscape pattern metrics. Also shown are the forested ecozones of Canada used as the assessment units in this study and specific regions of interest, which are shown in **Figure 5**.

All analysis units have the same geographical extent corresponding to the 1:250 000 EOSD LC 2000 product and the spatial referencing of the Canadian National Topographic Data Base (NTDB). In the example presented in **Figure 2**, forest, nonforest, and other categories are shaded for NTS map sheet 093F. The number of forest patches is indicated within each analysis unit for each of the four aforementioned analysis levels. Landscape pattern metrics were calculated for 630 1:250 000 NTS map sheets, 9450 1:50 000 map sheets, approximately 1.07 million 1 km × 1 km cells, and more than one billion 1 ha cells. The 1 ha cells are more useful for capturing local and (or) regional conditions and as such are not considered appropriate for national reporting.

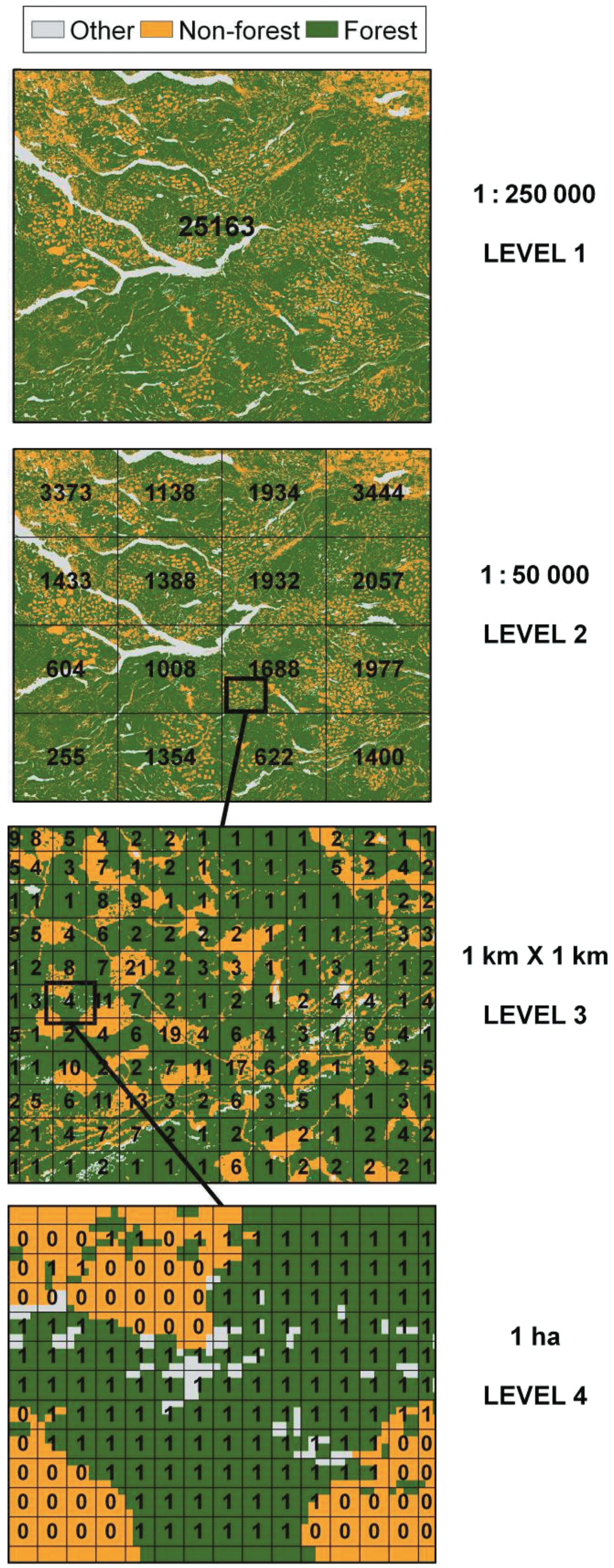

Figure 2. Illustration of the four analysis units used to calculate the EOSD landscape pattern metrics. The number of patches within each analysis unit is indicated.

Landscape pattern metrics

To characterize the fragmentation of Canada's forested land, it is necessary to select a set of landscape metrics that are appropriate for national reporting. Ninety-six landscape pattern metrics (**Table 1**) were calculated for analysis levels 1–3 (**Tables 1, 2**), and nine were computed for analysis level 4 (**Table 2**) using APACK (version 2.23) (Mladenoff and DeZonia, 2004) and IDL (IDL, version 6.4.1; ITT Visual Information Solutions, 2007). The APACK parameters and analysis assumptions were the same for all analysis levels and are summarized in **Table 1**. The background value was no data, the class of interest was forest, the number of neighbouring cells was eight, and the borders of the analysis units were not included in the analysis (i.e., were not considered edges). This implies that roads that were resolvable in the Landsat data were classified as exposed land, reclassified as nonforest, and were considered in metric calculation. Conversely, water was reclassified as no data and was considered background by APACK, and therefore was not included in calculation of the metrics. The parameters and assumptions associated with the Boots metrics (**Table 2**) were different. No data and nonforest were recombined into a single class, so the Boots metrics assume two classes (forest and nonforest).

Metrics were considered appropriate if they depicted fragmentation as a condition of the landscape; captured the different types of fragmentation, as caused by natural and anthropogenic disturbances, ecosystem characteristics, and land use activities; were minimally redundant; and were readily interpretable and easy to understand when reported nationally. **Table 3** includes a list of those metrics that emerged from our review of the literature as being particularly well suited to characterizing forest fragmentation over large areas (e.g., Riitters et al., 2002; Kupfer, 2006) and that also meet the criteria indicated previously. The rationale behind the selection of each of these metrics is described in the following sections. Formulas for calculating these landscape pattern metrics are provided in Mladenoff and DeZonia (2004).

Proportion forested area

Proportion, or class area proportion, describes the proportion of the landscape composed of a given land cover type. Calculated for each class, it is a measure of landscape

Table 1. List of 87 landscape pattern metrics generated using APACK software (Mladenoff and DeZonia, 2004).

APACK parameters
Background value = 1 (no data)
Class of interest = 3 (forest)
No. of neighbouring cells = 8
Do not include map borders
Areal units = hectares; linear units = metres
Landscape metrics
Total no. of cells (without background)
Total area (without background) (ha)
Total perimeter (m)
No. of patches
Mean patch size (ha)
Standard deviation of patch size (ha)
Area of smallest patch (ha)
Area of largest patch (ha)
No. of patches between 0 and 10 ha
No. of patches between 10 and 100 ha
No. of patches between 100 and 500 ha
No. of patches between 500 and 1000 ha
No. of patches between 1000 and 5000 ha
No. of patches between 5000 and 10 000 ha
No. of patches larger than 10 000 ha
Normalized mean patch size (ha)
Mean patch perimeter (m)
Mean patch perimeter to area ratio (m/ha)
Corrected mean perimeter to area ratio (m/ha)
Edge density (m/ha)
Fractal dimension (box)
Shannon–Weaver diversity
Shannon–Weaver evenness
Dominance
Dominance (relative)
Contagion
Contagion (relative)
Edge distribution evenness
Angular second moment
Inverse difference moment
Aggregation index
Forest metrics
Total no. of cells
Total area (ha)
Total perimeter (m)
Relative area (%)
No. of patches
Proportion of all patches (%)
Mean patch size (ha)
Standard deviation of patch size (ha)
Area of smallest patch (ha)
Area of largest patch (ha)
No. of patches between 0 and 10 ha
No. of patches between 10 and 100 ha
No. of patches between 100 and 500 ha
No. of patches between 500 and 1000 ha
No. of patches between 1000 and 5000 ha
No. of patches between 5000 and 10 000 ha
No. of patches larger than 10 000 ha

Table 1 (*concluded*).

Normalized mean patch size (ha)
Mean patch perimeter (m)
Mean patch perimeter to area ratio (m/ha)
Corrected mean perimeter to area ratio (m/ha)
Edge density (m/ha)
Fractal dimension (box)
Connectivity (centroid)
Aggregation index
No. of patches between 1000 and 5000 ha
Nonforest metrics
Total no. of cells
Total area (ha)
Total perimeter (m)
Relative area (%)
No. of patches
Proportion of all patches (%)
Mean patch size (ha)
Standard deviation of patch size (ha)
Area of smallest patch (ha)
Area of largest patch (ha)
No. of patches between 0 and 10 ha
No. of patches between 10 and 100 ha
No. of patches between 100 and 500 ha
No. of patches between 500 and 1000 ha
No. of patches between 1000 and 5000 ha
No. of patches between 5000 and 10 000 ha
No. of patches larger than 10 000 ha
Normalized mean patch size (ha)
Mean patch perimeter (m)
Mean patch perimeter to area ratio (m/ha)
Corrected mean perimeter to area ratio (m/ha)
Edge density (m/ha)
Fractal dimension (box)
Connectivity (centroid)
Aggregation index
Between-class metrics
Shared perimeter forest and nonforest classes (m)
Adjacency probability to forest with forest class
Adjacency probability to forest with nonforest class
Shared perimeter nonforest and forest classes (m)
Adjacency probability to nonforest with forest class
Adjacency probability to nonforest with nonforest class

Table 2. List of additional eight landscape pattern metrics adapted from Boots (2003; 2006).

Proportion of forest area (%) (composition)
Forest/nonforest join count (configuration)
Forest/forest join count (configuration)
Nonforest/nonforest join count (configuration)
No. of forest patches (configuration)
Sum of squared forest patch area (m^2) (configuration)
No. of nonforest patches (configuration)
Sum of squared nonforest area (m^2) (configuration)

Table 3. Selected metrics used to characterize Canada's forest fragmentation.

Metric	Indicates	Name	Reference
Proportion forested area	Proportion of analysis unit that is occupied by forest	f_rarea	Turner et al. (2001)
No. of forest patches	Count of the number of forest patches found within the analysis unit; the more forest patches there are, the more fragmented the forest is considered to be	f_patch	Li et al. (2005)
Proportion of patches that are forested (%)	The proportion of all landscape patches that are forest; this metric links fragmentation with cover type	f_prop	
Mean forest patch size	The average size of a forest patch within the analysis unit; a smaller than average forest patch size is considered indicative of a more fragmented forest	f_marea	McGarigal et al. (2002)
Forest patch size standard deviation	A measure of the absolute variation in patch size for the analysis unit; the mean patch size can obscure the presence of very large or very small patches	f_sarea	Cumming and Vervier (2002)
Amount of forest edge	Sum of the perimeter of forest patches; larger values indicate more edge habitat, more fragmentation	f_peri	McGarigal et al. (2002)
Forest edge density	Higher values indicate more edge habitat, more fragmentation	f_dense	Li et al. (2005)
Forest/forest join count	Indicative of the configuration of unfragmented forests	b_ff_count	Boots (2006)
Forest/nonforest join count	Indicative of the configuration of fragmented forests	b_fn_count	Boots (2006)

composition, ignoring the spatial arrangement of the patch types within the landscape. By quantifying the extent of each land cover type, it is possible to discern the presence of a matrix and characterize overall evenness (or dominance) of a landscape (Botequilha Leitao et al., 2006). This metric provides basic information about the landscape that can be useful in a variety of applications, including natural resource planning and wildlife management (Gustafson, 1998a). The proportion of area that is forest is also easy to calculate and interpret, making it useful for national reporting purposes.

Total number of forest patches

Total number of forest patches has been found to successfully reflect pattern changes in landscapes at both the landscape level and the class level (Li et al., 2005). Since the number of patches represents the spatial characteristics of a class or landscape, this metric can be used to indicate the fragmentation level of a landscape (Botequilha Leitao et al., 2006). Fragmentation results in the subdivision of large continuous patches into smaller remnant patches, which is reflected by this metric. Fragmentation as indexed by the number of patches has been shown to have both potential benefits and negative effects with regard to the propagation of disturbances across a landscape. Saunders at al. (1991) suggest that if a class is divided into a large number of patches, it could be more resistant to disturbances such as fire or pests. Conversely, fragmentation of forests into more patches has been found to increase the incidence of ice storm damage (Pasher and King, 2006). Forest loss has been also shown to be significantly reflected by this metric (Trani and Giles, 1999). Although total number of patches is simple and easy to understand, it should be used in concert with other patch-level metrics to more fully describe the spatial complexity of the landscape (Botequilha Leitao et al., 2006). If the analysis unit over which the metric is calculated is constant, then the number of patches will convey the same information as patch density or mean patch size (McGarigal and Marks, 1995).

Proportion of patches that are forest

The proportion of patches in a specific class of interest (forest) provides some additional context for the analysis unit as a whole. For example, one analysis unit could have a greater number of forest patches relative to another analysis unit (of the same size), but the proportion of the patches that are forested could be relatively low, suggesting that the landscape is very fragmented (i.e., it has a large number of patches) but is not necessarily fragmented forest.

Mean and standard deviation of forest patch size

Mean patch size is the average size of patches of a particular category (class level) or across the entire landscape (landscape level) (Botequilha Leitao et al., 2006). McGarigal and Marks (1995) suggest that patch size is the most important and useful measure that can be obtained from a landscape analysis. Mean patch size is an ecologically important measure because it not only quantifies the fragmentation level of the landscape (Trani and Giles, 1999), but also can be used to compare measurements of different classes (Li et al., 2005). This metric has been shown to vary for different types of fragmentation (Hudak et al., 2007) and, although some studies have found mean patch size to be an ambiguous measure of fragmentation (Fahrig, 2003), this is not typically a problem with map extents greater than 100×100 cells (Li et al., 2005). Mean patch size is a fairly intuitive measure of landscape structure and has many potential applications (Botequilha Leitao et al., 2006).

Patch size standard deviation is a measure of the absolute variation in patch sizes (Botequilha Leitao et al., 2006). Along with mean patch size, patch size standard deviation has been shown to be useful in assessing forest fragmentation over large areas (Cumming and Vervier, 2002). Measuring variability in patch size may capture phenomena such as an occurrence of very small or large patches in the landscape (Botequilha Leitao et al., 2006), which may be important when considering the different types of forest fragmentation represented in Canada's forested land area.

Amount of forest edge and forest edge density

The presence and amount of patch edge have ecological significance, since many forms of wildlife will either preferentially seek edges out or avoid edges (Murcia, 1995; Lahti, 2001; Boudreault et al., 2008; Li et al., 2007; Hinam and St. Clair, 2008). Li et al. (2005) found that total edge density is a useful index for representing different landscape patterns across spatial scales. Edge-based metrics have been shown to capture important aspects of landscape fragmentation not captured by patch-based metrics (Zeng and Wu, 2005). Using edge measures in conjunction with patch measures gives a broader view of forest fragmentation patterns. The total amount of forest edge in an analysis unit is determined by summing the perimeter of all forest patches within the unit. Forest edge density (metres per hectare) is estimated by dividing the sum of the forest patch perimeter by the area of the analysis unit.

Forest/forest join counts

Join counts are a statistical method used to characterize spatial patterns (Upton and Fingleton, 1985; Boots, 2006) frequently employed in raster datasets having two categories. Join-count measures differ from the other landscape pattern calculations in this study in that they explicitly assess the configuration of cover (Hargis et al., 1998) and thus can quantify the relative dispersion or aggregation of forests. To facilitate the calculation of join counts, the EOSD land cover was further simplified from the three-class generalization of forest, nonforest, and other classes used to calculate the pattern metrics listed in **Table 1** to forest and nonforest (the "other" class was grouped with nonforest). A large number of forest/forest joins are considered indicative of contiguous forest, and a large number of forest/nonforest joins are indicative of more fragmented forests. In this communication, we focus only on forest/forest join counts because we are interested in reporting on the contiguity of Canadian forests; however, an analysis of forest/nonforest join counts (which were also generated; **Table 2**) could provide useful information on the forest/nonforest interface if the information need was focused on the interface between these two categories.

When there are only two classes (i.e., forest and nonforest), the null hypothesis is that adjacent pixels are more likely to be from the same class (Fortin et al., 2002). Since the spatial extents and grain are of known and regular sizes, we can estimate an expected number of forest/forest joins $E(\mathrm{BB})$, following a rook's case definition of neighbourhood, and using the following equation (Cliff and Ord, 1981):

$$E(\mathrm{BB}) = 2b(b-1)/c(c+1) \quad (1)$$

where b is the count of the number of forest pixels within the analysis unit (i.e., a maximum of 1600 pixels for a 1 km analysis unit or 16 pixels for a 1 ha analysis unit; pixels are 25 m × 25 m), and c is the number of columns (i.e., $c = 40$ for a 1 km analysis unit and $c = 4$ for a 1 ha analysis unit).

The variance of the forest/forest joins can be determined using the following equation (Cliff and Ord, 1981):

$$\mathrm{var}(\mathrm{BB}) = S_1T_1/2n^{(2)} + (S_2 - 2S_1)(T_2 - 2T_1)/4n^{(3)} + (S_0^2 + S_1 - S_2)(T_0^2 + T_1 - T_2)/n^{(4)} - [E(\mathrm{BB})]^2 \quad (2)$$

where $T_0 = b(b-1)$; $T_1 = 2T_0$; $T_2 = 4b(b-1)^2$; $S_0 = 4c(c-1)$; $S_1 = 2S_0$; $S_2 = 16(4c^2 - 7c + 2)$; n is the number of grid cells, which is 1600 (for a 1 km analysis unit); $n^{(2)} = n(n-1)$; $n^{(3)} = n(n-1)(n-2)$; and $n^{(4)} = n(n-1)(n-2)(n-3)$.

A Z score can be calculated for the forest/forest joins using the following equation (Cliff and Ord, 1981):

$$Z = [\mathrm{BB} - E(\mathrm{BB})]/\mathrm{var}(\mathrm{BB})^{1/2} \quad (3)$$

Therefore, we can examine join counts in two different ways: we can enumerate the total number of forest/forest join counts by analysis unit, and we can examine the Z scores by analysis units to look at areas with statistically significant forest/forest joins or, alternatively, calculate specific percentiles of the Z scores.

Results

Proportion of analysis unit that is forested

Figure 3A shows the proportion of analysis units that are forested as calculated for level 2 analysis units, and the median values range from 22.10% to 82.17% (**Table 4**). Similarly, the median values for this metric for level 3 analysis units range from 19.83% to 92.38% (**Table 4**). Only two ecozones have a median proportion of forest that is less than 50% (Taiga Cordillera and Taiga Shield); in the Taiga Cordillera ecozone, approximately 23% of level 3 analysis units contained no forest, and 43% of level 3 analysis units had less than 5% forest. Three ecozones have a median proportion of forest greater than 80% (Boreal Shield, Atlantic Maritime, and Montane Cordillera); 42% of the level 3 analysis units in the Boreal Shield contained more than 95% forest, followed by 25% of units in the Atlantic Maritime and Montane Cordillera. The median values for the level 1 and level 2 analysis units reflect similar trends in the proportion of the unit that is forested (**Table 4**). Generally, the median value for proportion of forest decreases from level 3 to level 1, with the exception of the Taiga Cordillera, where the median value for proportion forested increases from 19% at level 3 to 27% at level 1 (**Figure 4**). **Figure 3B** shows the proportion of patches in the analysis unit that are forested and indicates that those areas that have a low proportion forest are the same areas where the majority of the patches are forested. This result is not surprising as areas with low amounts of forest typically have a dispersed and patchy forest distribution.

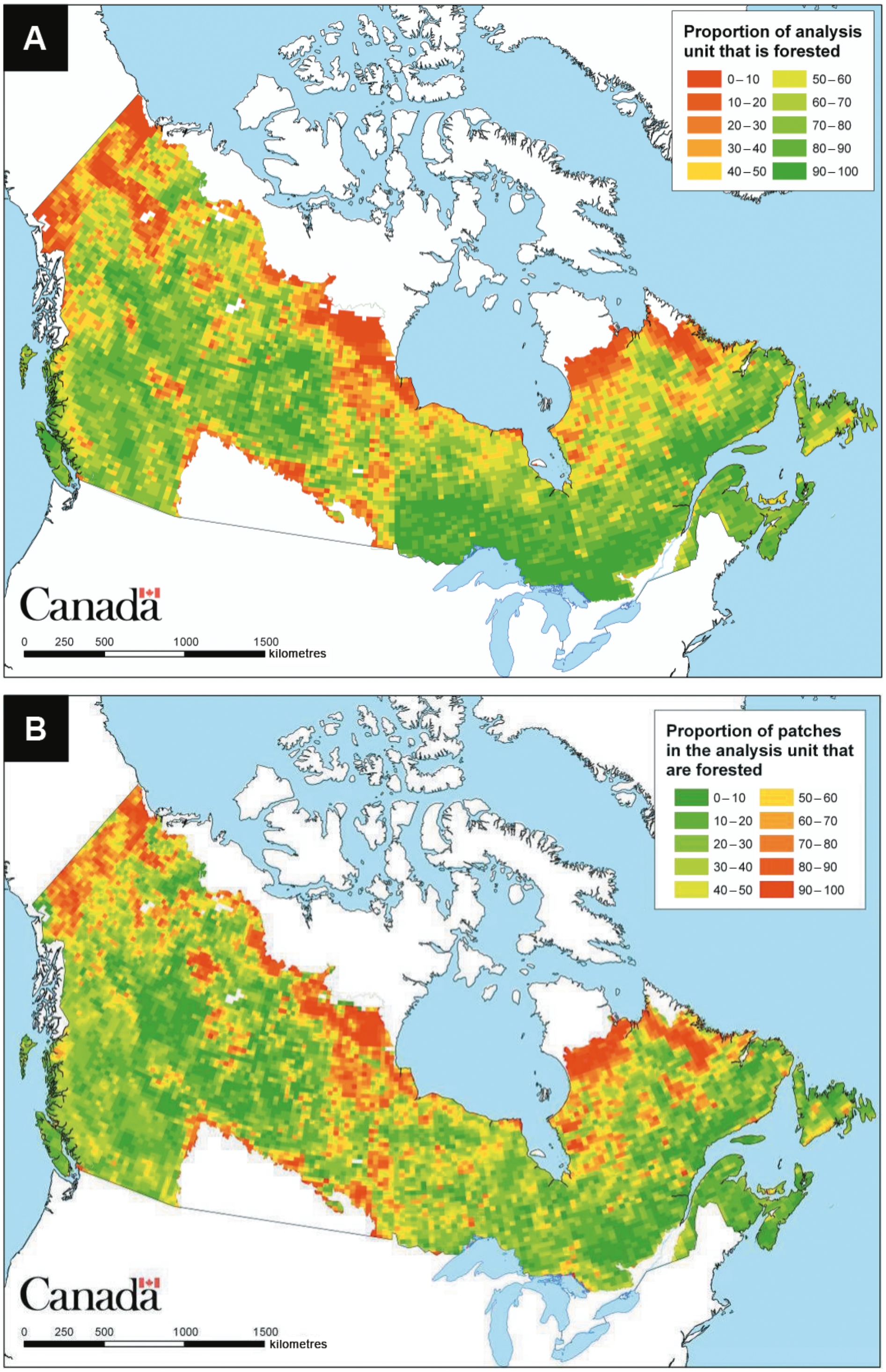

Figure 3. National representation of level 2 analysis units showing (A) the median value for proportion forested and (B) the median value for the proportion of patches in the analysis unit that are forested.

Number of forest patches and proportion of patches that are forested

The total number of forest patches within level 3 analysis units across all ecozones ranged from 0 to 70 (**Table 4**). The Taiga Shield ecozone had the largest median (9) number of forest patches, followed by the Taiga Cordillera (7) (**Table 4**). The Taiga Shield also had the second lowest median proportion of forest (level 3) at 47%, indicating that the small amount of forest present is part of a patchwork of wetland, shrub, and forest that is typical of this ecozone (Marshall and Schut,

Table 4. Landscape pattern metrics for forest patch size and proportion by ecozone.

Proportion of analysis unit that is forested (%)			No. of forest patches			Proportion of patches in the analysis unit that are forested (%)			Mean forest patch size (ha)			Standard deviation (SD) of forest patch size		
Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Pacific Maritime														
67.93	79.39	31.29	5.52	3.00	5.97	33.19	25.01	28.05	36.42	18.17	38.09	15.16	4.23	19.73
65.34	71.41	24.02	2 220.33	1 914.21	1 829.12	28.01	28.12	14.06	33.01	17.91	40.21	750.01	562.01	765.01
70.02	70.22	17.31	24 600.41	17 739.01	3 918.01	26.33	28.33	9.01	30.21	23.01	23.97	1798.22	1294.44	1472.22
Montane Cordillera														
72.84	83.56	28.28	4.29	2.00	4.62	35.22	28.57	27.05	43.39	28.38	38.85	16.43	5.48	20.54
73.31	76.00	14.00	2 041.23	1 804.00	1 058.00	26.41	24.32	12.41	45.32	34.04	40.01	1379.43	1175.00	862.00
70.09	75.00	18.00	32 425.01	30 393.34	11 956.86	30.22	26.15	16.61	34.87	33.21	17.44	4226.01	4310.16	2074.62
Boreal Cordillera														
56.80	62.63	34.10	7.33	5.00	7.18	40.26	33.33	31.86	28.88	8.31	36.67	13.53	3.89	18.48
53.32	55.00	24.04	3 296.45	3 092.91	1 967.88	43.31	41.28	21.31	24.06	11.01	45.01	671.00	477.00	763.00
51.12	55.00	21.32	50 419.01	49 307.61	22 391.01	44.49	43.31	18.12	15.31	10.83	15.78	1791.02	1390.02	1743.41
Boreal Plains														
65.62	76.76	31.70	4.61	2.00	5.42	36.96	29.91	29.87	39.86	23.19	38.51	14.74	3.81	19.62
61.89	69.00	25.00	2 100.00	1 408.03	2 132.12	35.34	28.16	26.41	72.70	34.81	123.01	1413.41	1009.89	1470.22
57.01	63.04	24.01	35 267.78	23 613.26	30 156.31	38.26	30.74	24.31	37.12	28.01	33.07	3435.11	2662.34	3000.31
Taiga Cordillera														
30.51	19.83	29.77	8.82	7.00	6.92	43.20	46.15	33.83	9.22	1.41	20.96	8.17	1.91	13.47
26.21	22.10	19.22	3 506.12	3 287.45	1 700.41	56.16	57.06	21.33	5.75	3.32	6.89	150.21	56.76	225.43
29.37	27.09	18.45	51 626.34	54 934.82	20 607.71	56.41	53.12	16.01	5.81	4.46	4.01	580.75	186.91	783.11
Taiga Plains														
61.56	67.89	29.28	8.58	5.00	8.93	34.99	23.33	31.99	30.01	10.67	35.85	14.67	5.43	18.59
60.24	62.11	21.55	3 877.71	3 163.12	3 273.12	35.21	32.91	25.41	42.65	11.44	193.72	874.01	504.31	1197.31
58.11	60.47	17.01	63 347.33	55 196.77	39 769.41	38.78	35.41	21.01	16.11	8.11	17.48	1964.31	149.00	1759.01
Taiga Shield														
47.16	45.16	31.33	10.89	9.00	9.08	48.27	50.13	31.77	13.58	2.59	24.24	10.33	3.03	14.82
42.18	43.54	25.01	5 884.17	4 916.08	4 414.31	53.94	53.41	27.22	13.04	4.01	39.01	351.51	118.21	628.01
39.67	42.78	23.44	85 162.11	79 367.83	58 525.87	54.31	55.85	23.43	8.76	4.32	17.61	820.01	314.89	1508.41
Boreal Shield														
79.30	92.38	26.96	3.68	2.00	4.76	49.54	45.45	34.02	48.83	40.41	38.69	14.42	2.02	19.94
77.01	82.17	18.08	1 525.49	799.41	1 967.01	31.78	27.12	20.24	218.01	70.01	544.44	2676.49	1770.81	2781.31
77.27	79.02	13.54	21 781.22	16 941.00	19 936.32	31.02	29.04	14.21	128.31	49.43	195.33	7587.12	5185.10	6973.42
Hudson Plains														
58.59	60.85	28.73	4.54	3.00	3.86	46.24	44.44	26.65	30.45	14.05	34.01	15.10	7.92	17.52
52.20	56.33	23.48	1 566.38	1 183.71	1 485.09	39.33	38.89	20.01	87.01	31.45	210.11	1425.31	889.31	1696.89
51.01	53.56	22.01	20 652.12	16 333.47	19 846.01	51.02	53.04	22.31	56.43	29.01	74.08	3790.41	2871.01	4027.34
Atlantic Maritime														
78.63	85.69	21.29	3.97	2.00	4.44	29.87	21.05	24.83	47.26	38.38	37.48	19.74	11.20	21.96
73.09	79.08	18.02	1 419.17	1 239.45	1 184.34	21.16	17.22	15.49	61.01	43.43	68.31	1538.01	1410.41	1214.16
68.13	80.01	27.45	13 237.98	8 617.53	14 483.71	68.02	19.98	16.01	42.31	33.01	44.21	3225.04	2996.03	3257.31

Note: Values are reported for level 3 (top value for each ecozone), level 2 (middle value), and level 1 (bottom value) analysis units.

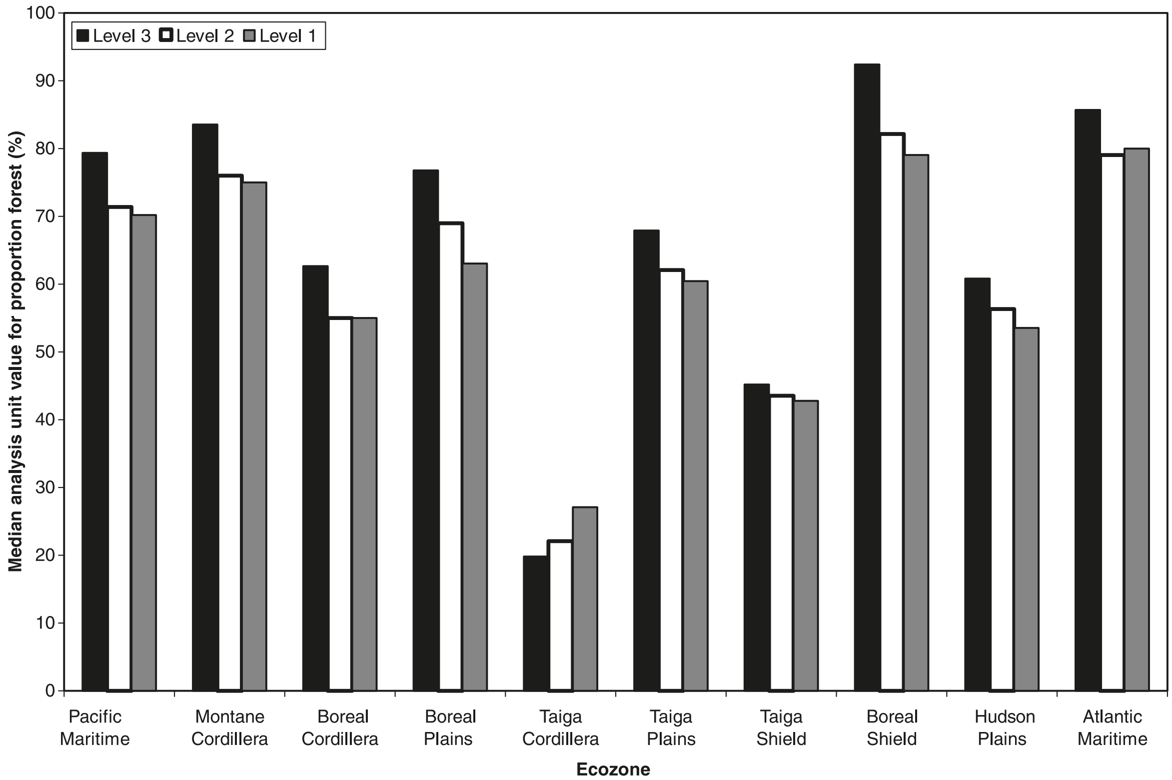

Figure 4. Distributions of median value for proportion forested for levels 1–3 analysis units.

1999). The distribution of EOSD land cover in the Taiga Shield ecozone confirms this: there are three dominant EOSD land cover types in the Taiga Shield (not including water) that represent 76% of the ecozones area, namely coniferous forest (33%), wetland (22%), and shrub (21%) (Wulder et al., 2008).

The Taiga Cordillera ecozone has the lowest median proportion of forest (20%) and, unlike the Taiga Shield, is dominated by mountainous terrain and alpine environments, as opposed to water and wetlands (Marshall and Schut, 1999). The area of the Taiga Cordillera ecozone is dominated by shrub (24%), coniferous forest (19%), herbs (17%), and exposed and barren land (13%) (Wulder et al., 2008). As indicated in **Table 4**, the lowest average number of patches (level 3) was found in the Boreal Shield ecozone, which also has the greatest median value for proportion forested (92%) and the largest area of forest and other wooded land (36% of Canada's total) (Power and Gillis, 2006). The trends in the number of forest patches described previously are also consistent for level 2 and level 1 analysis units.

Figure 5 shows subareas of the Montane Cordillera, Boreal Plains, and Taiga Cordillera ecozones. The number of forest patches (level 3) is divided into quantiles, with the same colour mapping for each subarea. This part of the Montane Cordillera in southern British Columbia is dominated by forest harvesting and agricultural activities; the influence of roads and urban development on the number of forest patches is evident. Large forest fires (overlaid in black) from 1995 to 1999 are shown in the Boreal Plains subarea; fires increase the number of patches on the landscape. Lastly, the large number of patches of the Taiga Cordillera relative to the other examples indicates the difference in forest pattern in this very northern area of Canada. This area is dominated by a complex assemblage of nonforest classes, such as herb, shrub, and exposed land.

The proportion of the patches in the analysis unit that are forested (level 3) is shown in **Figure 3B** and represents different patterns from those shown in **Figure 3A**. The Taiga Shield and Taiga Cordillera had the largest median value (level 3) for proportion of patches in the analysis unit that were forested, at 50% and 45%, respectively, followed closely by the Boreal Shield (45%) and Hudson Plains (44%) ecozones. The Taiga Plains (23%) and Atlantic Maritime (21%) ecozones had the smallest median value (level 3) (**Table 4**). For the Montane Cordillera, Boreal Plains, Boreal Shield, and Hudson Plains, the median proportion of forested patches actually decreased at level 2 and then increased again at level 1.

Mean forest patch size

The median value of average forest patch size (level 3) ranged from a low of 1.41 ha in the Taiga Cordillera to a high of 40.41 ha in the Boreal Shield (**Table 4**). More than 50% of the level 3 analysis units across all ecozones had a mean patch size less than 10 ha, 29% of the analysis units in the Boreal Shield ecozone had a mean patch size less than 10 ha, and only 3% of analysis units in the Pacific Maritime and Atlantic Maritime ecozones had a mean patch size less than 10 ha (results not shown). In the Taiga Cordillera, 92% of the analysis units had a mean patch size less than 25 ha, and 42% of the forest patches

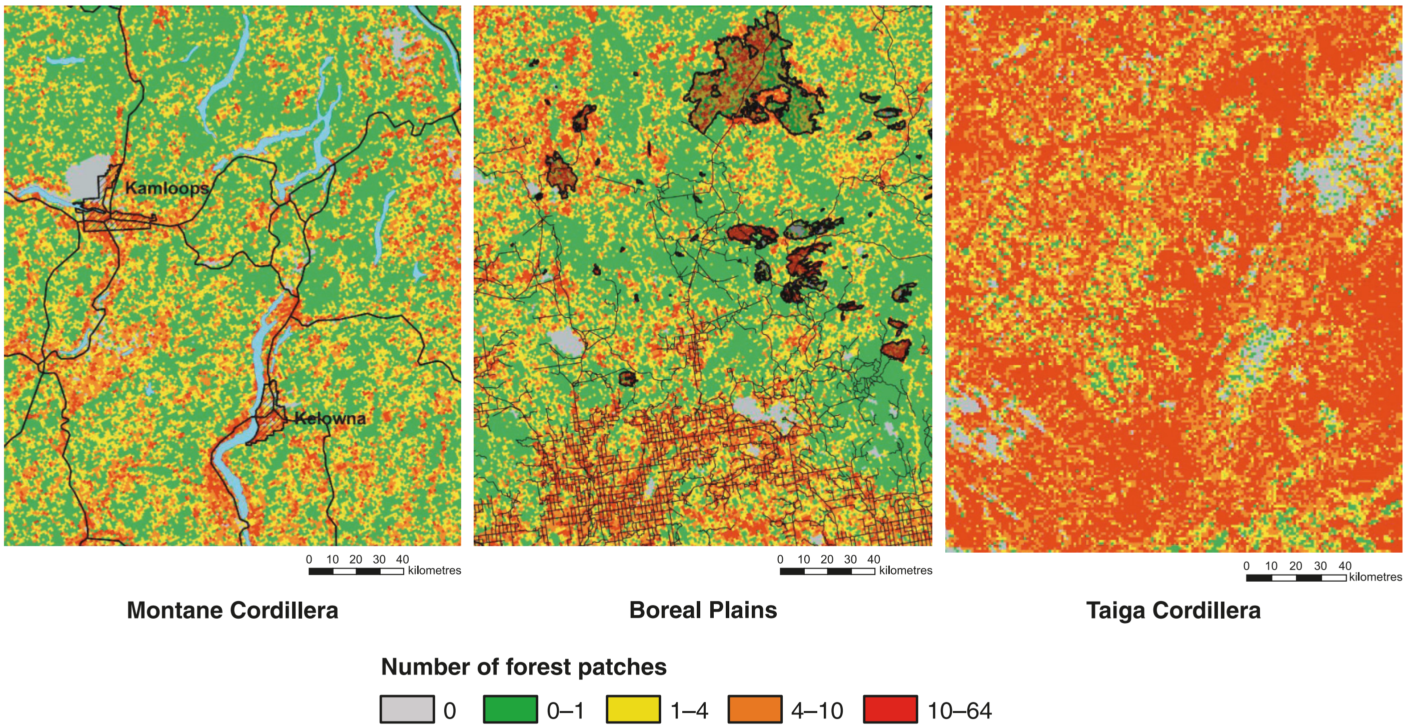

Figure 5. Large-scale views of level 3 analysis units showing number of forest patches for three regions of interest, namely Montane Cordillera, Boreal Plains, and Taiga Cordillera.

in the Boreal Shield and Atlantic Maritime had a mean patch size less than 25 ha. Once again, trends for the other levels of analysis units were similar, with Boreal Shield consistently having the largest median value for mean patch size at levels 1–3 and the Taiga Cordillera and Taiga Shield having the smallest (**Table 4**).

Forest patch size standard deviation

The standard deviation in forest patch size gives a useful indication of the uniformity of patch size. The Taiga Cordillera and Taiga Shield consistently had the smallest median value for patch size standard deviation for analysis units at levels 1–3. The Atlantic Maritime had the largest median value for patch size standard deviation (11 ha); however, the Boreal Shield had the largest median value for forest patch size standard deviation at levels 1 and 2 (**Table 4**). This suggests that there is variability in forest patch size in the Boreal Shield that is not fully captured with the level 3 analysis units.

Total edge, mean patch edge, and edge density of forest patches

The Taiga Plains ecozone has the largest median value (level 3) for total forest edge (10 475 m), and the Taiga Shield ecozone had the largest median value (level 3) for total forest patch edge density (117 m/ha) (**Table 5**). The trends in edge amount are similar across analysis levels 1–3 (**Figure 6**). The Taiga Shield had the highest edge density (level 3) at 121 m/ha, followed by the Taiga Plains with an edge density of 107 m/ha. The smallest median value for total edge was found in the Boreal Shield (4025 m) and Montane Cordillera (5400 m). The smallest median value for forest edge density was found in the Taiga Cordillera at 45 m/ha, followed by the Boreal Shield at 49 m/ha; these results were supported by the calculated ecozone forest edge density values.

Join counts

The distribution of forest/forest join counts (level 3) by ecozone is shown in **Figure 7** and summarized in **Table 6**. The difference in the distribution of forest/forest join counts between the Taiga Shield and Boreal Shield is very pronounced. The largest median forest/forest join count (level 3) was found in the Atlantic Maritime (2416), followed by that in the Boreal Shield (2322). The smallest median number of forest/forest join counts was found in the Taiga Cordillera (366). The largest median number of forest/nonforest join counts was found in the Taiga Plains (425), followed by that in the Taiga Shield (370). The lowest median forest/nonforest join count was found in the Boreal Shield (173) ecozone. The top 5% of forest/forest join counts (level 3) are indicated in blue in **Figure 8** and represent areas where forest is aggregated on the landscape, and the bottom 5% are indicated in red and represent areas where forests are dispersed. The inset map in **Figure 8** shows that these extreme values are clustered on the landscape and that for this area (southern British Columbia, Montane Cordillera ecozone) the bottom 5% of forest/forest joins are located primarily in valley bottoms.

Table 5. Landscape pattern metrics for assessing the amount of forest edge by ecozone.

Forest patch edge (m)			Forest patch edge density (m/ha)		
Mean	Median	SD	Mean	Median	SD
Pacific Maritime					
6 615.02	6 075.02	4 684.67	73.48	65.00	66.07
4 480 416.31	4 914 600.33	2 573 871.22	80.02	79.03	33.04
52 649 954.01	51 004 300.41	35 202 073.83	83.05	88.14	26.31
Montane Cordillera					
6 032.79	5 400.03	4 369.11	67.35	57.00	60.53
5 744 481.65	5 482 750.21	1 861 261.26	68.04	65.04	22.41
88 665 215.12	89 373 564.34	27 066 603.50	65.30	63.87	19.07
Boreal Cordillera					
7 604.92	7 050.65	5 338.06	71.79	65.00	60.62
5 475 625.11	5 756 675.71	2 259 856.31	78.03	81.42	27.13
82 596 912.76	81 800 988.01	29 549 809.06	78.01	79.98	19.41
Boreal Plains					
6 592.25	5 675.06	4 955.77	64.75	54.00	57.49
5 638 687.12	5 361 075.41	2 768 919.12	67.01	61.32	31.42
85 192 263.34	84 679 528.33	35 144 109.04	62.51	61.02	26.41
Taiga Cordillera					
7 495.21	6 800.45	5 736.22	62.05	45.00	62.92
4 303 085.65	4 296 125.24	2 530 251.90	73.31	75.06	38.09
68 682 012.01	71 973 104.01	34 997 267.11	72.05	75.14	32.04
Taiga Plains					
10 641.70	10 475.91	6 136.41	107.22	106.00	74.73
7 541 624.41	7 464 850.77	3 095 739.01	120.19	119.34	41.06
118 018 792.31	12 011 670.92	39 349 727.99	121.07	121.09	28.14
Taiga Shield					
9 608.89	9 250.31	5 763.55	121.30	117.00	87.21
7 351 142.01	7 597 825.76	4 096 522.31	118.06	120.64	61.03
102 761 533.12	10 949 120.41	63 043 320.34	112.98	119.54	56.89
Boreal Shield					
5 282.05	4 025.11	4 625.21	65.29	49.00	67.83
5 057 680.41	4 357 625.21	3 061 425.74	65.07	57.06	38.25
73 170 302.37	71 447 696.87	39 370 760.63	67.01	58.46	26.03
Hudson Plains					
6 306.96	6 450.01	3 719.96	67.02	68.00	45.16
5 454 967.81	60 002 788.41	2 747 642.12	64.31	69.03	30.74
71 412 185.12	84 307 672.63	42 271 450.08	62.81	67.04	25.12
Atlantic Maritime					
7 254.97	6 800.04	4 617.78	77.33	71.00	52.72
5 836 806.81	6 130 725.31	3 541 189.44	82.04	80.31	30.47
52 527 193.01	46 150 752.73	52 364 454.98	73.99	80.11	34.13

Note: Values are reported for level 3 (top value for each ecozone), level 2 (middle value), and level 1 (bottom value) analysis units.

Discussion

Redundancy among landscape metrics is well documented in the literature (Riitters et al., 1995; Li et al., 2005; Cushman et al., 2008); however, the use of a particular metric should be dictated more by its biological relevance to a given research question or application rather than by its relative statistical properties (Bogaert, 2003). Ultimately, the end user should decide which metric is most useful for capturing the information required to satisfy their particular need or test a specific hypothesis in advance of analysis (Gergel, 2007).

When the metrics listed in **Table 3** are examined collectively, trends emerge that allow us to characterize forest patterns in Canada; generally, these trends are consistent across the three different spatial extents we examined. **Figure 9** demonstrates the relationship between the median number of forest patches

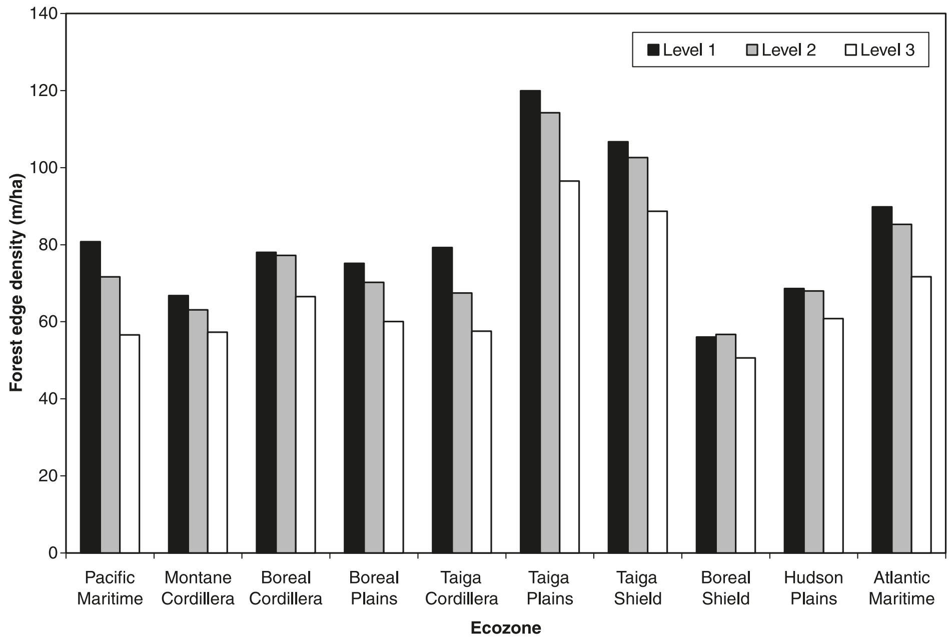

Figure 6. Trends in forest edge density (levels 1–3) by ecozone.

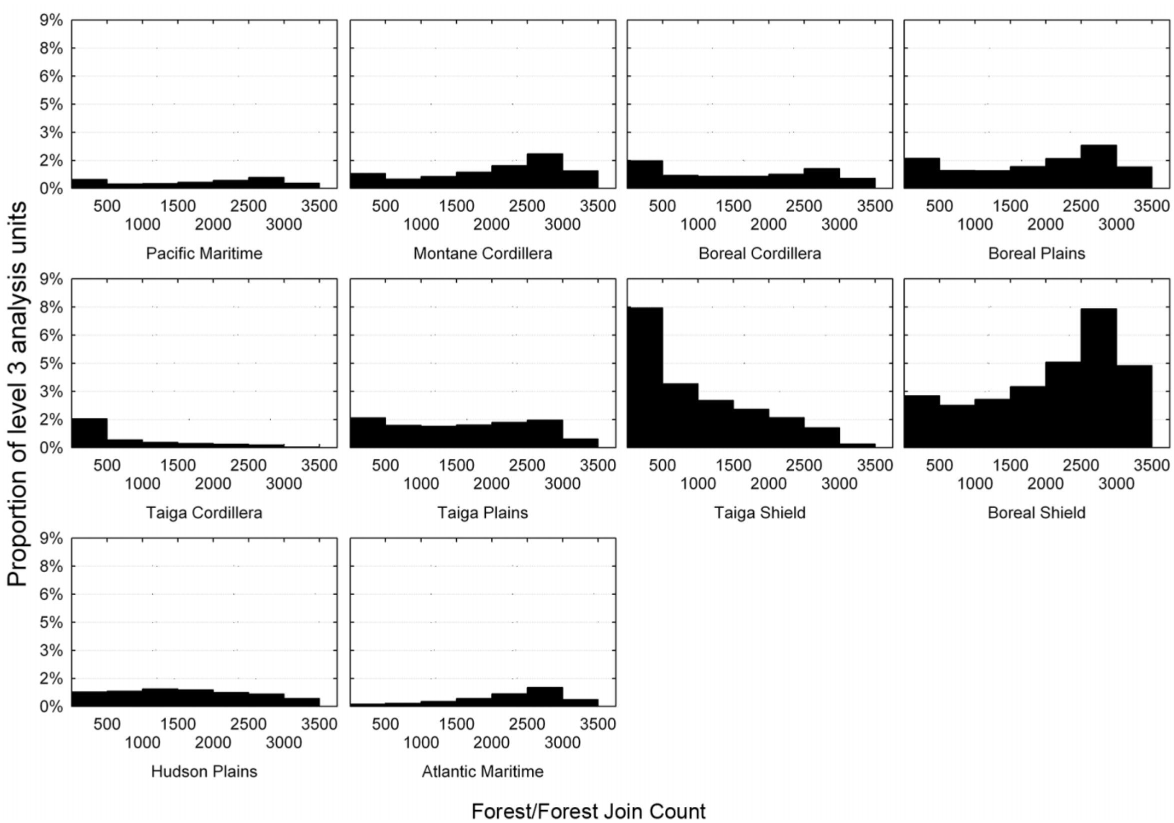

Figure 7. Distribution of forest/forest join counts (level 3) by ecozone.

Table 6. Landscape pattern metrics for forest and nonforest configuration by ecozone.

Forest/forest join count			Forest/nonforest join count		
Mean	Median	SD	Mean	Median	SD
Pacific Maritime					
1 751.46	1 972.00	273.25	252.00	191.89	1 039.49
1 147 400.23	1 142 341.45	763 751.11	178 613.02	193 543.23	102 814.15
1 340 219.91	12 101 116.12	1 656 722.09	2 100 500.06	1 974 651.41	1 409 527.31
Montane Cordillera					
1 994.26	2 266.00	247.95	224.00	178.29	963.46
1 895 989.14	2 001 255.87	548 388.12	227 176.89	217 398.98	73 881.02
28 924 580.12	31 348 604.66	8 762 417.41	3 517 037.71	3 519 706.07	1 080 447.89
Boreal Cordillera					
1 531.39	1 552.00	308.79	288.00	215.76	1 076.17
1 103 561.61	1 128 427.12	618 158.31	216 054.23	227 164.56	89 326.41
16 253 388.78	16 910 482.47	8 666 841.00	3 263 370.41	3 211 220.98	1 168 081.04
Boreal Plains					
1 823.00	2 061.25	271.36	237.00	200.80	1 019.44
1 525 896.41	1 691 694.23	730 213.33	224 478.05	213 103.12	109 822.12
22 700 268.01	24 756 752.77	9 918 646.01	3 398 043.08	3 349 555.31	1 389 892.98
Taiga Cordillera					
753.27	366.00	301.12	272.00	232.07	864.11
430 200.02	301 379.01	404 053.41	168 786.09	169 000.41	99 690.11
2 701 629.31	2 853 520.38	1 383 759.62	2 701 629.21	2 853 520.98	1 383 759.32
Taiga Plains					
1 578.15	1 618.00	431.59	425.00	248.19	961.59
1 100 548.88	1 060 527.02	575 049.31	299 848.99	296 801.01	123 837.51
16 351 264.21	15 398 605.19	7 919 126.34	4 703 014.02	4 825 569.31	1 579 332.33
Taiga Shield					
958.63	713.00	385.51	370.00	230.55	851.14
725 043.41	651 883.09	562 662.75	288 069.03	297 280.02	160 934.05
9 991 415.01	9 132 762.11	8 098 929.89	4 035 464.01	4 260 021.43	2 478 650.98
Boreal Shield					
2 044.07	2 322.00	222.02	173.00	189.84	945.86
1 919 949.75	2 026 250.21	761 415.01	203 362.88	176 279.02	123 603.07
27 652 310.03	28 861 968.89	11 927 303.09	2 948 774.79	2 856 020.07	1 591 411.02
Hudson Plains					
1 586.57	1 557.00	262.38	270.00	152.81	921.58
1 377 713.11	1 402 121.67	761 319.23	216 796.41	240 519.05	109 315.09
18 748 500.09	18 231 744.33	12 915 130.45	2 846 105.02	3 283 011.03	1 689 454.14
Atlantic Maritime					
2 206.69	2 416.00	299.53	282.00	189.08	769.83
1 737 239.01	2 080 461.48	1 027 360.02	234 146.31	247 715.80	142 088.31
15 570 253.12	11 238 322.31	15 028 086.00	2 112 190.27	1 853 363.27	2 102 013.21

Note: Values are reported for level 3 (top value for each ecozone), level 2 (middle), and level 1 (bottom) analysis units.

and the median patch size, by ecozone. The size of the spheres representing each of the ecozones is proportional to the standard deviation of patch size within the ecozone. The relative positions of the ecozones remain similar as each level of analysis is considered, but there is greater variability in patch size at level 3 (**Figure 9C**). When the proportion of the level 3 analysis units that are forested is also considered, we can examine the relative positions of the ecozones in three dimensions (**Figure 10**).

The Boreal Shield is the largest ecozone and has the greatest proportion of forest area per analysis unit, the smallest number of forest patches, and the largest mean patch size. In addition, the Boreal Shield has the lowest total forest patch edge amount, the second largest number of forest/forest joint counts, and the

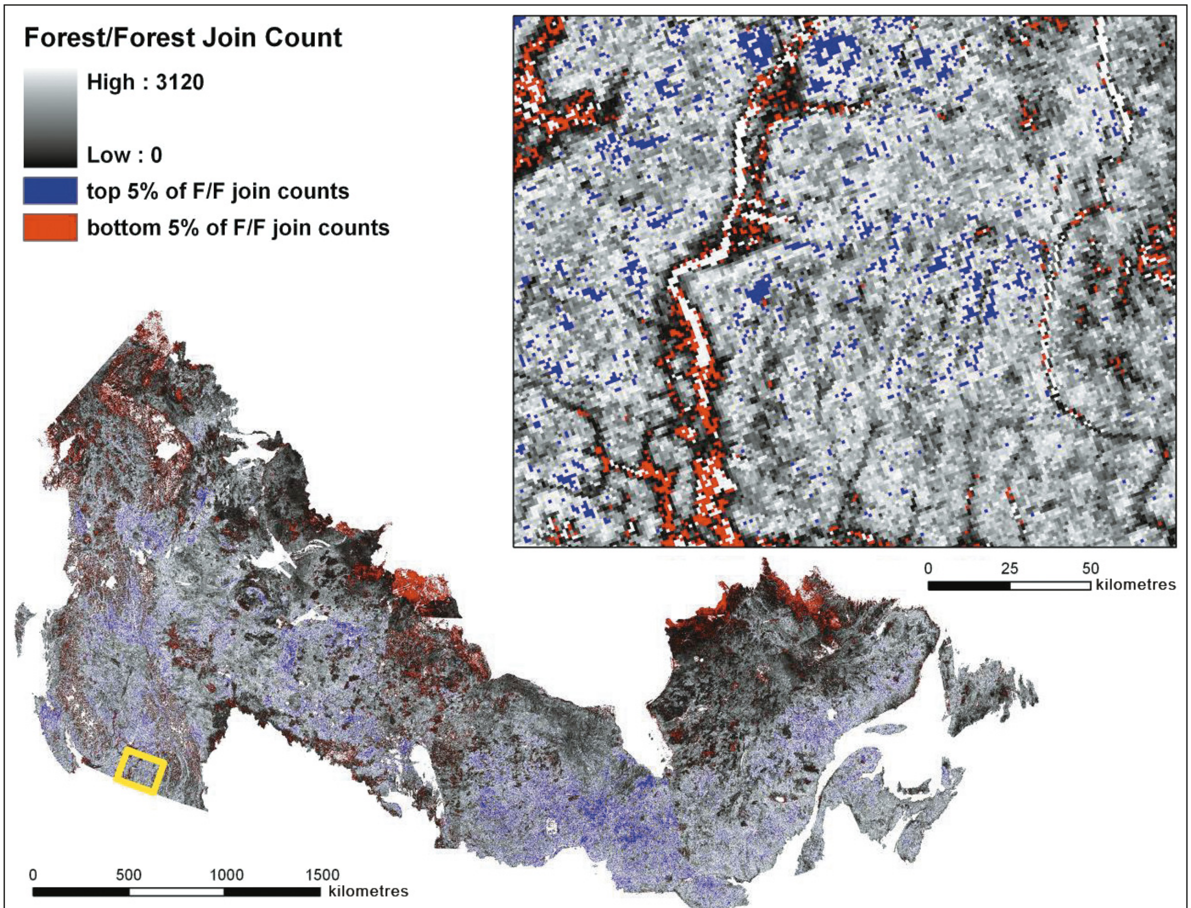

Figure 8. National distribution of forest/forest join counts, showing top 5% (blue) and bottom 5% (red) of forest/forest joins. The inset is from southern British Columbia (Montane Cordillera) and shows the clustering of these top and bottom values on the landscape.

smallest number of forest/nonforest join counts. All of these factors suggest that the Boreal Shield ecozone has a low level of forest fragmentation relative to other forested ecozones in Canada. The Boreal Shield ecozone is dominated by mixedwood forest and contains 36% of Canada's forest and other wooded land and supports 37% of the country's total wood volume (Power and Gillis, 2006). Forest harvesting and urban development are concentrated primarily in the southern portion of this ecozone; however, the edge density of this ecozone is low relative to that of the other ecozones. Fire is also a dominant disturbance regime in this ecozone, with 2177 large fires (>200 ha in size) between 1980 and 1999 (Parisien et al., 2006). The size of this ecozone and the large tracts of contiguous forests contained therein act to moderate the impact that disturbances may have over a smaller spatial unit, indicating the need for focused regional analyses or smaller spatial extents for generalizations.

Conversely, the Taiga Cordillera ecozone has the lowest proportion of forest area, the second largest number of forest patches, the smallest mean patch size, and the largest amount of total forest patch edge. Furthermore, this ecozone has the smallest average standard deviation of forest patch size and the lowest number of forest/forest join counts. These results suggest that this ecozone is more fragmented relative to other ecozones in Canada; however, since this ecozone is dominated by shrub and herb, which occupy 42% of the area of the Taiga Cordillera ecozone, it may be assumed that this is primarily fragmentation resulting from a natural mosaic of cover types. For example, the forest edge density of the Taiga Cordillera is similar to that of the Boreal Shield (**Figure 6**). The Taiga Cordillera contains the least amount of Canada's forest and other wooded land (only 2%) and supports less than 0.1% of Canada's total wood volume (Power and Gillis, 2007).

The Taiga Shield ecozone contains the second largest area of forest and wooded land (12%), yet supports only 2.3% of Canada's wood volume (Power and Gillis, 2007). The median proportion of forest (level 3) for this ecozone is the second lowest at 45%, suggesting the large amount of forest found in this area is dispersed rather than aggregated. This is confirmed by the high forest edge density in the Taiga Shield relative to other ecozones (**Figure 6**). The Taiga Shield also has the highest median number of forest patches, the second lowest median value for mean patch size (2.59 ha), and the second lowest number of forest/forest joins. This ecozone is characterized by a dispersed mosaic of lakes, wetlands, and open forests (Marshall and Schut, 1999), and fresh water covers

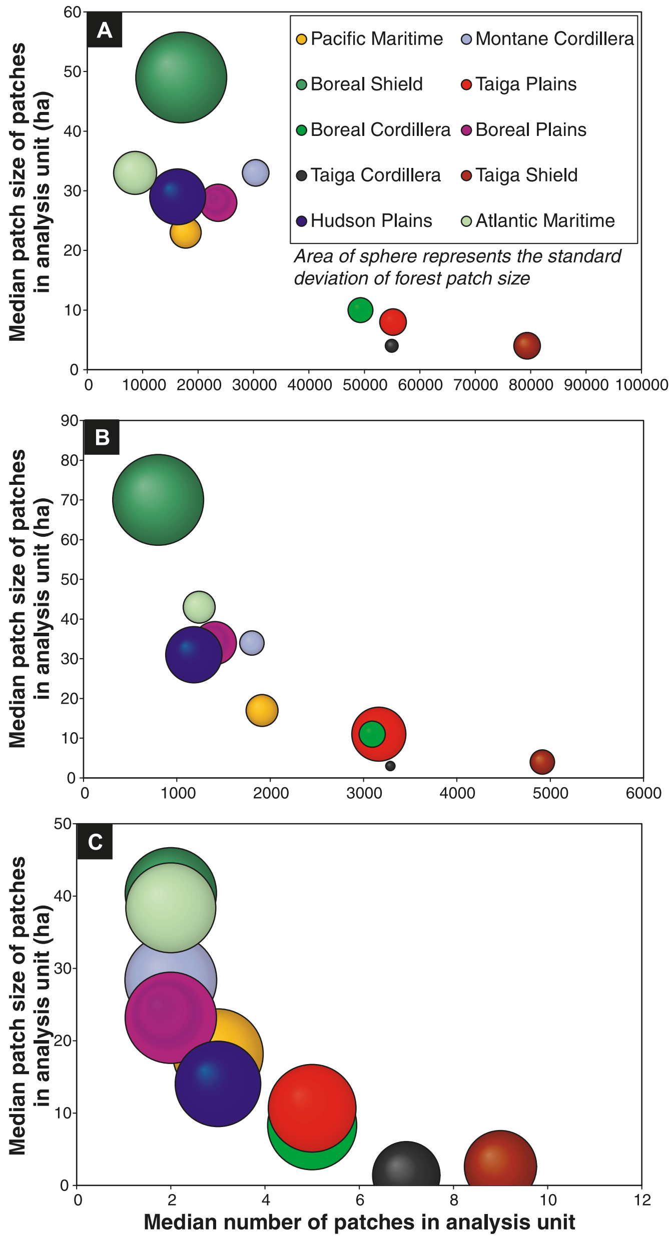

Figure 9. Median number of forest patches versus mean patch size for (A) level 1, (B) level 2, and (C) level 3. The size of the spheres is determined by the standard deviation in median patch size. Note that the relative distributions of ecozones for these two attributes remain relatively unchanged.

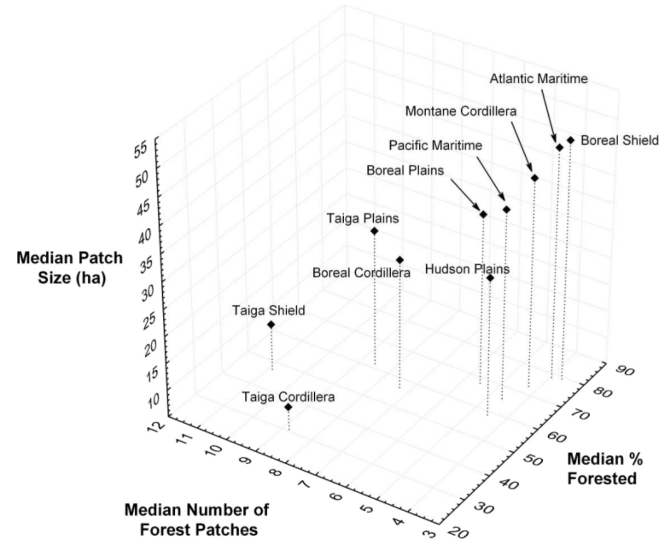

Figure 10. A three-dimensional representation of the ecozones as measured by median patch size (ha), median number of forest patches, and median percent forested.

15% of the area of this ecozone (Power and Gillis, 2007). Forest fires are the primary disturbance agent in this ecozone, with a total of 959 large forest fires (>200 ha) between 1980 and 1999 (Parisien et al., 2006).

Canada's commercial forest industry is primarily located in four ecozones, namely the Boreal Shield, Atlantic Maritime, Pacific Maritime, and Montane Cordillera (Canadian Council on Ecological Areas Database, 2002). The amount of strictly protected forest area in these four ecozones increased by an average of 5% between 1970 and 2001, with the Atlantic Maritime ecozone having the smallest increase (2.3%) and the Montane Cordillera having the largest increase (7.7%) in protected area (Canadian Council on Ecological Areas Database, 2002).

The Atlantic Maritime ecozone represents 4% of Canada's forest and other wooded land and 3% of the total wood volume (Power and Gillis, 2007). The median values (level 3) for proportion forested and mean patch size are large and second only to those of the Boreal Shield ecozone; however, the median value for level 3 analysis unit standard deviation of patch size is markedly larger in this ecozone (11 ha) relative to that of all other ecozones, suggesting that patch sizes within this ecozone are highly variable. The Atlantic Maritime ecozone has the largest median value (level 3) for average amount of forest patch edge but the highest median value for forest/forest join counts. Forests in this ecozone are dominated by mixed stands of coniferous and deciduous species, and the majority of forest has been harvested or burnt at least once in the past 200 years (Marshall and Schut, 1999).

The Pacific Maritime ecozone spans the mainland Pacific coast and offshore islands of British Columbia. This ecozone contains only 3% of Canada's area of forest and other wooded land, yet accounts for 12% of Canada's wood volume (Power and Gillis, 2007). The Montane Cordillera spans most of southern British Columbia and southwestern Alberta and is the most diverse ecozone in terms of topography, climate, and vegetation; this ecozone represents 9% of Canada's forest and other wooded land and accounts for 20% of Canada's wood volume. As a consequence of the high level of forest productivity in these ecozones, commercial forestry has become a dominant economic activity in this ecozone. In terms of landscape pattern metrics, the Pacific Maritime and Montane Cordillera ecozones are characteristically middling relative to other ecozones, having no extremely high or low values for any of the metrics considered.

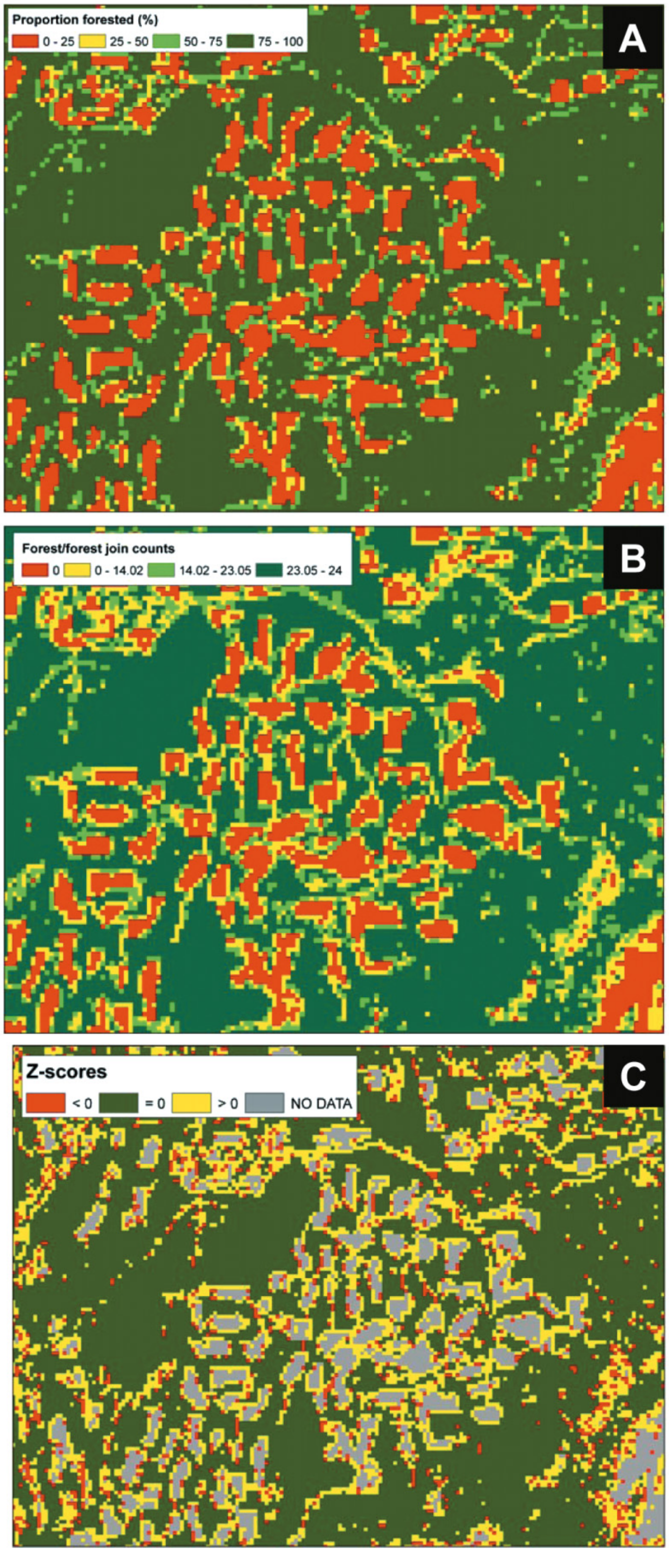

Figure 11. An example of the utility of the level 4 analysis units in an area with active forest harvesting: (A) proportion forested; (B) relative number of forest/forest joins; (C) *Z* scores for the join counts.

Compositional and configurational metrics provide complementary information. A portion of NTS map sheet 082E in the Okanagan Valley, British Columbia, is shown in **Figure 11**. The data shown are for the level 4 analysis units (1 ha) over which a subset of pattern metrics were calculated (**Table 2**) to demonstrate the utility of the 1 ha data for local or regional analyses. There is active forest harvesting in this area, and in **Figure 11A** we show the proportion of forest within each level 4 analysis unit. The harvested patches (red) have no forest or a low proportion of forest, whereas the majority of the analysis units in this area have more than 75% forest (green). In **Figure 11B**, the number of forest/forest joins are shaded with the joins partitioned into quantiles; the patterns are similar to those in **Figure 11A**, with generally more forest/forest joins where there is more forest and fewer forest/forest joins in areas where there is less forest. Lastly, the *Z* scores of the forest/forest join counts are illustrated in **Figure 11C**, with negative *Z* scores shown in red and positive *Z* scores shown in yellow.

Negative *Z* scores represent areas where, given a known amount of forest (composition), the number of forest/forest joins is less than expected (**Figure 11C**, in red), whereas positive *Z* scores indicate areas where the number of forest/forest joins is greater than expected, given the proportion of forest present (**Figure 11C**, in yellow). Both the forest/forest join *Z* scores and the raw counts can be used to provide information on the pattern of forests, depending on the information need (**Figure 12**). For example, if one is interested in identifying forest areas that are highly aggregated, one could select areas where the top 5% of raw forest/forest join counts are located (shown in red in **Figure 12A**, with EOSD LC 2000 in the background). Conversely, if one wanted to identify areas where the number of forest/forest joins is high relative to the proportion of forest present (i.e., leave patches, forest edges), one could select the top 5% of forest/forest join count *Z* scores (shown in red in **Figure 12B**, with EOSD LC 2000 in the background). One could also select statistically significant forest/forest joins, as identified by *Z* scores >1.96 ($\alpha = 0.05$); once again, the information need would identify the appropriateness of selecting these statistically significant locations.

The terrestrial ecozones used as the assessment units in this study vary in size, with the larger ecozones containing more classes and more patch configurations. When generalized, the subset of ecozone conditions may be masked by these generalizations, highlighting the importance of separate and more detailed regional analyses for information needs other than broad-scale national reporting of trends in forest patterns.

Conclusion

The Earth Observation for Sustainable Development of Forests (EOSD) LC 2000 land cover product provides a unique and new information source suitable for characterizing the fragmentation of Canada's forests at multiple spatial scales. In this communication, we have focussed on reporting national

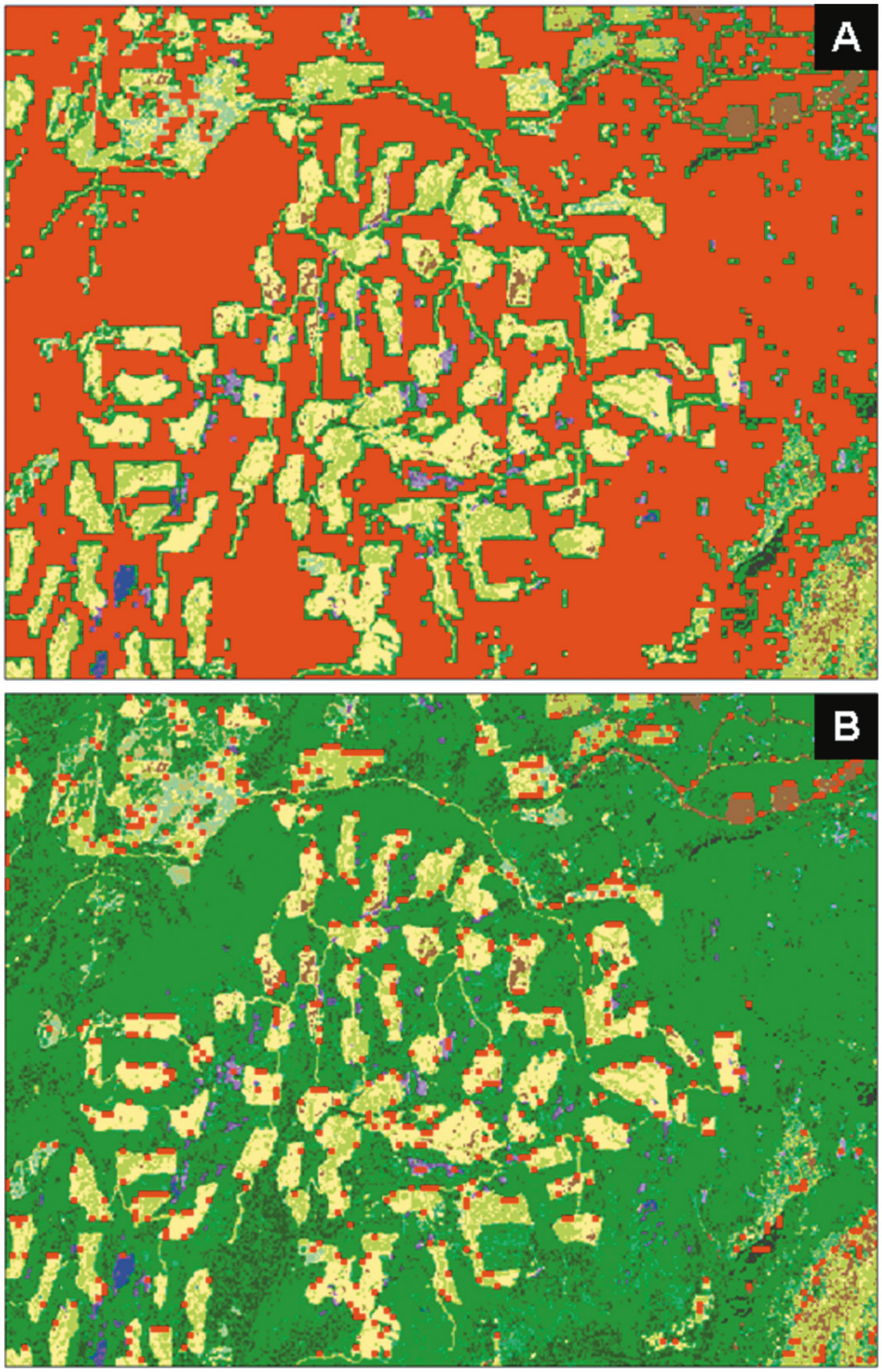

Figure 12. Both raw forest/forest join counts and *Z* scores can be used to characterize forest patterns. The top 5% of raw counts (A; shown in red) indicates areas of relatively contiguous forest, whereas the top 5% of *Z* scores (B; shown in red) indicates areas where forest/forest join counts are greater than expected relative to the amount of forest found within the analysis unit.

trends and variability in landscape pattern metrics, by ecozone. A variety of metrics have been produced to meet foreseen and unforeseen user needs. The national database of landscape pattern metrics, computed at four different spatial extents, affords many opportunities for further analyses and will be useful for meeting a wide range of outstanding information needs, especially when combined with local knowledge, ancillary spatial data, and (or) species data. Such analyses can support a broad range of national reporting and natural resource management applications. Although we have reported broad national trends in landscape pattern metrics by ecozone, more detailed regional analyses may be required to identify and characterize the underlying causes and landscape processes that have resulted in the patterns observed.

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