Fragmentation regimes of Canada's forests

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Canada is a large nation, approximately 1 billion hectares in size, and until recently, no national assessment of forest fragmentation had been undertaken. To assess national level biodiversity and ecosystem condition, national drivers of forest fragmentation are identified as being either primarily natural (e.g., resulting from wildfires, water features, or topography), or primarily anthropogenic (e.g., resulting from urbanization or roads and associated activities such as forest harvesting and oil and gas exploration). The relative importance of each of these fragmentation drivers within Canada's ten forested ecozones, which occupy approximately 650 million ha, is assessed using ecozone summaries and standard scores. Forest pattern metrics were generated from a Landsat-derived land cover product and fragmentation drivers were characterized using available national datasets. Through this analysis, we combine and portray the relative importance of forest patches with spatial layers indicative of natural and anthropogenically induced conditions as driving various fragmentation regimes over the forested area of Canada. The forest fragmentation in Canada can be characterized primarily by natural drivers, whereas fragmentation regimes attributable to anthropogenic drivers are typically regionally located and related to industrial activities and access (i.e., roads). We identify three scenarios in our results that characterize forest fragmentation in Canada: ecozones with similar forest patterns but different drivers; ecozones with similar patterns and drivers; and finally, ecozones with both different patterns and different drivers. Our findings indicate that national assessments of forest fragmentation should account for both natural (and inherent) and anthropogenic sources of fragmentation.

Keywords: fragmentation, pattern, boreal, Landsat, forest, Canada, drivers

La fragmentation des régimes forestiers au Canada

Le Canada s'étend sur un vaste territoire d'une superficie totale d'environ 1 milliard d'hectares, et pourtant, l'évaluation des effets de la fragmentation du milieu forestier n'a été réalisée que très récemment. Les principaux facteurs déterminants de la fragmentation du milieu forestier à l'échelle nationale qui sont retenus dans la cadre des évaluations menées sur l'état de la biodiversité et des écosystèmes sont essentiellement d'ordre naturel (par exemple en raison de vastes incendies, de plans d'eau ou des caractéristiques topographiques) ou d'ordre anthropique (par exemple en raison de l'urbanisation ou de l'aménagement des voies de circulation et des activités connexes comme l'exploitation forestière ou l'exploration pétrolière et gazière). Dans les dix écozones forestières que compte le Canada et qui couvrent environ 650 millions ha, l'évaluation du poids relatif de chacun de ces facteurs déterminants de la fragmentation est réalisée à partir des informations contenues dans les capsules sur les écozones et des notes étalonnées (les cotes z). Les paramètres des structures forestières ont été définis par l'interprétation des images Landsat sur la couverture végétale et le portrait des facteurs déterminants de la fragmentation a été dressé à l'aide de bases de données nationales. De cette étude et à l'aide de couches spatiales révélatrices des effets des perturbations d'origine naturelle ou

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anthropique, il a été possible de mettre en rapport et d'établir un tableau illustrant l'importance relative des fragments forestiers comme facteur déterminant de la fragmentation des régimes forestiers dans les régions boisées du Canada. La fragmentation forestière au Canada se caractérise avant tout par des facteurs naturels, tandis que les facteurs anthropiques qui interviennent dans la fragmentation des régimes relèvent le plus souvent du niveau régional et sont liés à des activités industrielles et à l'accessibilité (par exemple, par les voies routières). Des résultats obtenus, il se dégage trois scénarios permettant d'envisager la fragmentation du milieu forestier au Canada sous trois angles différents. On identifie d'abord les écozones qui ont des structures forestières semblables, mais des facteurs déterminants différents; puis, les écozones semblables au niveau des structures forestières et des facteurs déterminants; et en dernier lieu, les écozones qui diffèrent sur les plans des structures forestières et des facteurs déterminants. À la lumière de ces conclusions, les évaluations réalisées à l'échelle nationale sur la fragmentation du milieu forestier doivent autant que possible tenir compte des sources naturelles (et donc intrinsèques) et des sources anthropiques de la fragmentation.

Mots clés : fragmentation, structure, boréal, Landsat, milieu forestier, Canada, facteurs déterminants

Introduction

Fragmentation is one of several criteria and indicators used to assess sustainable forest management practices; however, fragmentation lacks a commonly accepted definition and method of measurement (Kupfer 2006; Lindenmayer and Fischer 2006; Wijewardana 2008). Furthermore, although advances have been made in developing metrics and the associated computational software tools (Bogaert 2003), there is no consensus as to whether the loss of forest, the fragmentation of forest, or a combination thereof, has the greatest ecological impact (Fahrig 2003). Herein, we consider forest fragmentation as 'the state of being fragmented' (Franklin *et al.* 2002, 21), allowing for a broader context whereby fragmentation may be attributed to both natural and anthropogenic processes (Forman 1997), while at the same time acknowledging that in some contexts the phrase 'forest fragmentation' may have a negative connotation (Wiens 1995; Sallabanks *et al.* 1999).

The Montréal Process, a framework initiated in 1994 to develop internationally agreed criteria and indicators (C&I) for sustainable management of temperate and boreal forests (Brand 1997), includes fragmentation as one of nine indicators for the conservation of biological diversity (Riitters *et al.* 2004). When revising Canada's C&I framework in 2003, the Canadian Council of Forest Ministers dropped fragmentation as an indicator, citing the lack of a national dataset that would facilitate reporting as the reason for the omission (Canadian Council of Forest Ministers 2004). Other jurisdictions have encountered similar challenges in compiling appropriate datasets for national fragmentation assessments (Kupfer 2006). In addition to issues of data availability, there is no consensus on how best to measure fragmentation. To this end, the first reports submitted by member nations of the Montréal Process in 2003 indicated 'there is little or no scientific understanding of how to measure an indicator (e.g., forest fragmentation)' (Montréal Process Working Group 2003, 2). A review of scholarly literature indicates that there is a profusion of research on the subject of forest fragmentation (e.g., Riitters *et al.* 2000, 2002; D'eon and Glenn 2005; Wickham *et al.* 2007; Wulder *et al.* 2008b; Kupfer and Franklin 2009). The problem, therefore, does not seem to be one of a lack of scientific effort, but rather a lack of consensus in the scientific community as to the validity and utility of the metrics themselves (Tischendorf 2001; Li and Wu 2004; Dramstad 2009), as well as a problem of translating the science associated with the measurement of fragmentation into the realms of policy and management (Tabarelli and Gascon 2005; Lindenmayer *et al.* 2008; Dramstad 2009).

Canada's population is concentrated along its southern extent and 93 percent of its forest land is publicly owned (Power and Gillis 2006). Much of this forest land is far from major population centres, inaccessible by road, and not actively managed (Wulder *et al.* 2007). An assessment of Canada's forest conditions circa 2000 examined the size of contiguous blocks of remaining forest and reported that over 60 percent of Canada's forest was in very large (>10,000 km^2) unfragmented patches (Smith *et al.* 2000). Wade *et al.* (2003) found that globally, the boreal biome (of which 30 percent is contained in Canada) had a low level of fragmentation and little human influence; however, anthropogenic causes of fragmentation were at least three times more prevalent than natural sources of fragmentation (excluding natural water bodies).

National assessments of forest fragmentation should strive to achieve four objectives: (1) account for naturally fragmented landscapes; (2) provide a national baseline for monitoring changes in forest pattern through time; (3) broadly indicate the relative influence of fragmentation drivers in different regions of the country; and finally, (4) provide a broad ecological context for subsequent national assessments of fragmentation. Herein, we present such an assessment for the forested area of Canada.

Methods

Study area

Our analysis was confined to the forest-supporting ecosystems of Canada, as defined by those ecozones with a majority of forest vegetation and/or forestry land use (as opposed to areas that may support forests but are currently dominated by agricultural or other land uses, such as the Mixedwood Plains ecozone in southeastern Ontario) (Figure 1). An ecozone is 'an area of the earth's surface representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors' (Marshall and Schut 1999, 3). These forested ecozones of Canada occupy approximately 650 million ha (Wulder *et al.* 2008a), encompassing over 402 million ha of noncontiguous forests and other wooded land (Power and Gillis 2006). Representing 10 percent of the world's forests and 30 percent of the world's boreal forests, Canada's forests contribute $28.1 billion to the national balance of trade and provide an estimated 361,300 direct jobs annually. Canada's forests also support 180 different native species of trees and provide habitat for more than 93,000 species of plants, animals, and micro-organisms. Less than 1 percent of Canada's forests are harvested annually (Natural Resources Canada 2008).

Fragmentation metrics

To support monitoring of Canada's forests, the Earth Observation for Sustainable Developments of Forests (EOSD) project was initiated as a partnership between the Canadian Forest Service and the Canadian Space Agency with provincial and territorial participation and support. The EOSD project produced a 23-class land cover map (with a 25 m spatial resolution) of the forested ecozones of Canada, representing circa year 2000 conditions (Wulder *et al.* 2008a). Accounting for image overlap outside of the forested area of Canada, over 480 Landsat-7 ETM+ images were classified and more than 80 percent of Canada was mapped to uniform standards. The resulting land cover product is freely available to the public (Wulder *et al.* 2008a) and is the most detailed and comprehensive map of the forested area of Canada, enabling a spatially exhaustive assessment of national forest patterns.

Using the EOSD data and APACK 2.23 analysis software (Mladenoff and DeZonia 2004), selected fragmentation metrics were generated for a national tessellation of analysis units. Riitters *et al.* (2004) define an analysis unit as the spatial extent over which the landscape pattern metrics are calculated and saved. For this study, each analysis unit was 1 km × 1 km in size. Following common nomenclature, the 1 km × 1 km units are the extent, while the 25 m classified pixels are the grain (e.g., Gergel 2007). Wulder *et al.* (2008a, 2008b) provide additional details on the land cover product and methodology used to generate the fragmentation metrics.

Objective and consistent characterization of forest fragmentation status and dynamics are important elements of ecosystem monitoring (Carpenter *et al.* 2006); therefore, we selected a subset of metrics that are intuitive and interpretable in a national context: number of forest patches, proportion of patches that are forested, mean forest patch size, standard deviation of forest patch size, number of forest–forest joins, and number of forest–nonforest joins (Table 1). To provide regional context for the interpretation

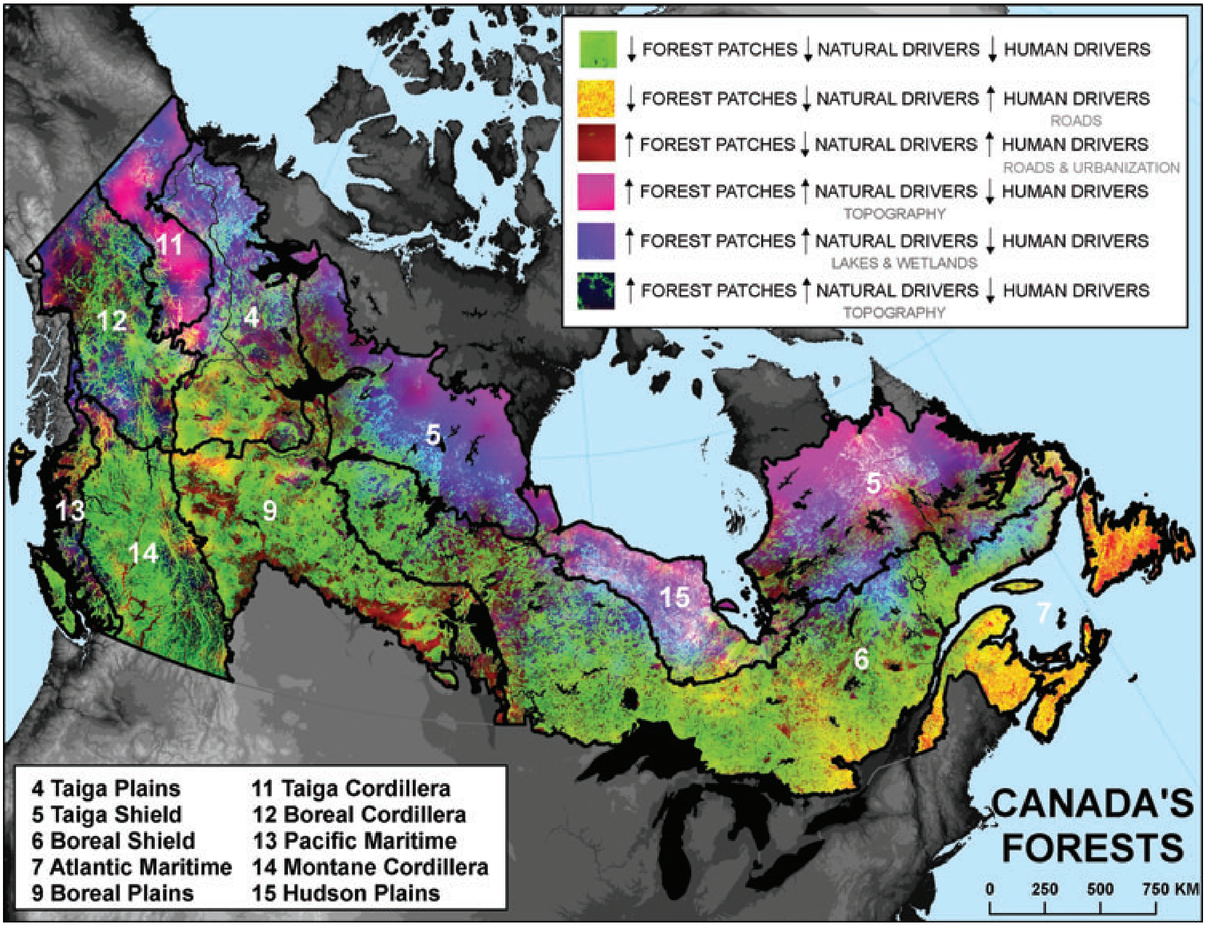

Figure 1
Canada's forested area superimposed with forested ecozone boundaries. This figure captures spatial information relating forest fragmentation to natural and anthropogenic disturbance drivers and conditions. Using additive colour theory, the map enables the combined interpretation of a number of attributes. Natural drivers of forest fragmentation—distance to water, distance to wildfire, and the inverse of elevation—are shown in red. Forest fragmentation (measured using forest–forest joins) is shown in green. Anthropogenic drivers—distance to road and distance to human settlement—are shown in blue. The result, as demonstrated in the interpretation key, indicates the relative contribution of these three components for each 1 × 1 km unit over Canada's forested area

of the spatial variability in forest fragmentation across the country, metrics were summarized by ecozone (see Figure 1).

Fragmentation drivers

Driving forces are defined as 'the influential processes in the evolutionary trajectory of the landscape' (Bürgi *et al.* 2004, 858). We identified five such drivers that have influenced forest pattern in Canada and grouped them as being either inherent factors or process-based forces and, further, as being either primarily natural or anthropogenic (Figure 2). Natural drivers include wildfires (distance to nearest wildfire event), water features (distance to nearest water feature), and topographic features (mean elevation). Anthropogenic drivers include roads (distance to nearest road) and human settlements (distance to nearest human settlement). Use of

Table 1
Fragmentation metrics

Metric	Indicates	Reference
Number 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.	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.	
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.	McGarigal and Marks (1995)
Standard deviation of forest patch size	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.	Cumming and Vervier (2002)
Number of forest–forest joins	Indicative of the configuration of unfragmented forests.	Boots (2006)
Number of forest–non-forest joins	Indicative of the configuration of fragmented forests.	Boots (2006)

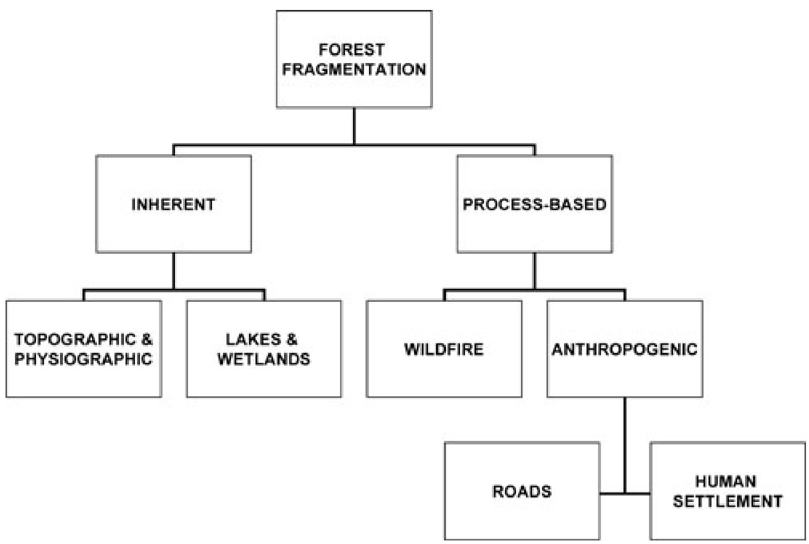

Figure 2
Drivers of forest fragmentation in Canada

'distance-to' conversions of the driving variables (excluding elevation) allows for standardization of measures, spatially extensive coverage, and improved comparability of drivers (Bürgi *et al.* 2004). Our intent was to identify broad trends, acknowledging that there are often complex interactions amongst drivers and that drivers may exert a strong influence on forest fragmentation at a regional scale but are less influential when considered nationally. Data for characterizing fragmentation drivers were compiled using ESRI's ArcGIS 9.2 software (2009) and projected to ensure proper spatial alignment with the 2000 EOSD land cover product. Data came from a variety of sources and were pre-processed and rasterized as described in Table 2.

Analysis

National averages were generated for the selected fragmentation metrics and drivers. These national averages were then used as the

Table 2
Fragmentation drivers

Driver	Data	Source	Description
Distance to road	2008 Road Network File	Statistics Canada (2008)	The 2008 Road Network File was selected for its completeness and positional fidelity. Released annually, the Road Network File is constantly being improved, particularly with regards to adding road features outside of urban centres (Statistics Canada 2008). All of the road vectors contained in the file were rasterized to a 1 km spatial resolution. The Euclidean distance from each 1 km cell to the nearest 1 km cell with roads was calculated.
Distance to human settlement	Circa 2000 Version 2 DMSP-OLS Nighttime Lights Time Series	NOAA (2000)	Commonly known as 'city lights', these data are cloud free composites of nighttime imagery acquired from the Defence Meteorological Survey Program (DMSP) Operation Linescan System (OLS). These data are useful for mapping human settlement patterns (Elvidge *et al.* 1997) and were used in this analysis because they represent year 2000 conditions, which correspond to the land cover data used to generate the fragmentation metrics (Wulder *et al.* 2008b). As per Milesi *et al.* (2003), DN values >50 were used to identify human settlements. The appropriateness of this threshold was calibrated using a sample of populated places data from the *Atlas of Canada* (Natural Resources Canada 2003). The Euclidean distance from each 1 km cell to the nearest 1 km cell with human settlement was calculated.
Distance to wildfire	National Fire Database	Stocks *et al.* (2003)	The National Fire Database (which now includes the Large Fire Database) contains polygon and point data representing wildfire locations from 1917 to 2007. Fire data for each year were rasterized to a 25 m spatial resolution. From these data the proportion of each 1 km cell that had been burned was calculated, as was the number of years each 1 km cell had experienced fire. Only those 1 km cells that had been 100 percent burned *and* were burned in more than one year were selected for analysis. A 3 × 3 pixel majority filter was applied to this output to remove any single 25 m pixels. This data was then used to calculate the Euclidean distance from each 1 km cell to the nearest 1 km cell with wildfire.
Distance to water	Canada-wide 1-km Water Fraction Data	Fernandes *et al.* (2001)	This is a raster dataset representing the fraction of each 1 km cell over Canada's landmass that is covered with water bodies in the National Topographic Database (version 3.1). Only those 1 km cells that were more than 25 percent water were included in our analysis. This data was then used to calculate the Euclidean distance from each 1 km cell to the nearest 1 km cell with water.
Elevation	GTOPO30	Hastings and Dunbar (1999)	GTOPO30 is a digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately 1 km). The elevation of each 1 km grid cell was used in our analysis.

reference group for calculating standard scores for each metric, by ecozone. Standard scores were calculated by subtracting the national average from the ecozone average and then dividing by the ecozone standard deviation. The relative importance of each of the fragmentation drivers within Canada's 10 forested ecozones was then assessed based on these standard scores. Using additive colour theory we created a colour composite map to enable the combined interpretation of a number of attributes (see Figure 1). Natural drivers (distance to water, distance to wildfire, and the inverse of elevation), were scaled to the range 0–255, combined (summed), and re-scaled to 0–255 for display purposes (red). To represent forest fragmentation, we used number of forest–forest joins, scaled to the range 0–255 (green). Finally, anthropogenic drivers (distance to road and distance to human settlement) were similarly scaled to the range 0–255, summed, and then re-scaled to 0–255 (blue).

Results and Discussion

Using standard scores for each metric and driver (Figure 3A and B), in conjunction with summary

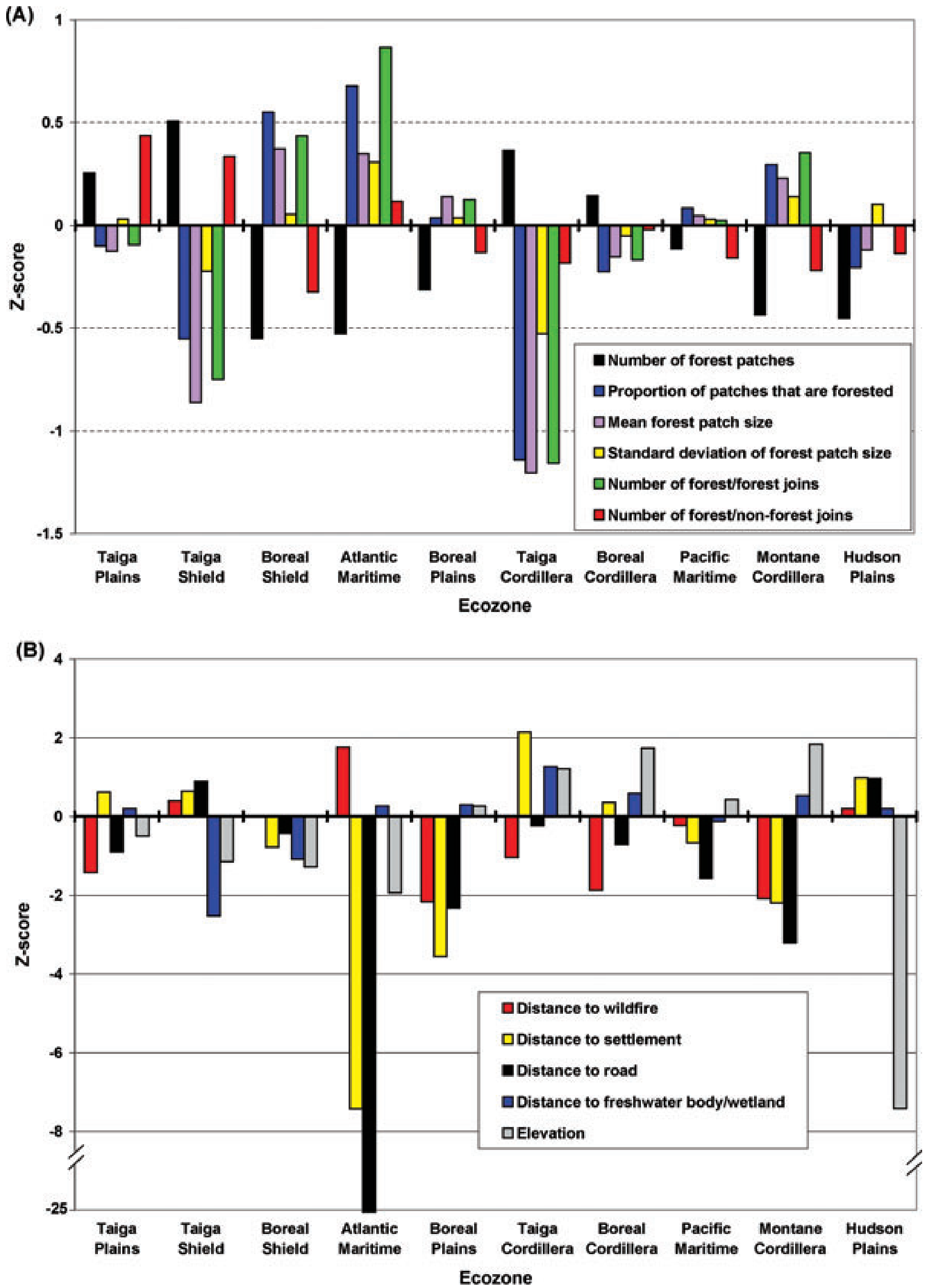

Figure 3
Standard scores for fragmentation metrics (A) and drivers (B) in the forested ecozones of Canada. Scores are calculated using national averages as the reference group

statistics for each of the ecozones (Wulder *et al.* 2008a), we identified three scenarios that characterize forest fragmentation in Canada: ecozones with similar forest patterns but different drivers; ecozones with similar patterns and drivers; and finally, ecozones with both different patterns and different drivers. Figure 1 combines the influence of natural drivers (red), fragmentation (forest–forest joins, green), and anthropogenic drivers (blue). As indicated in the interpretation key for Figure 1, the resulting colour combinations provide a visual representation of the relative amount of fragmentation and the influence of natural and anthropogenic drivers for each 1 km unit over Canada's forested area.

Similar forest pattern, different drivers

The Taiga Shield and Taiga Cordillera are the most fragmented ecozones in Canada and exemplify the scenario where ecozones have similar forest patterns, but different fragmentation drivers (see Figure 3A). The Taiga Shield is an area of transition from the forest-dominated Boreal Shield to the south to the open Arctic tundra of the north. A mosaic of wetlands, lakes, and forest, the Taiga Shield is spatially disjointed (located on either side of Hudson Bay, see Figure 1) and is the second largest forested ecozone in Canada with an area of 1.1 million km^2 and a total population of less than 42,000 (~0.03 persons/km^2) (Trant and Filoso 2008). The Taiga Cordillera, one of the most northern forested ecozones, is remote and sparsely populated (0.002 persons/km^2), located at the northern extent of the Rocky Mountains and dominated by rugged topography. These two ecozones have similar proportions of forest area (32 percent in the Taiga Shield and 22 percent in the Taiga Cordillera) and the greatest mean number of forest patches, the lowest mean patch size, and the lowest mean number of forest–forest joins relative to the other forested ecozones of Canada. Both of these ecozones are inherently fragmented, either due to a proliferation of water features (Taiga Shield) or due to extreme topography (Taiga Cordillera). The remoteness of the Taiga Cordillera is further evidenced by it having the largest mean distance to human settlements and water features, and one of the largest average distances to road (Figure 3B).

The Boreal Shield and Atlantic Maritime ecozones also exemplify the scenario of ecozones with similar forest patterns, but different fragmentation drivers. The Boreal Shield is the largest ecozone in Canada (1.6 million km^2) with a population density of 1.76 persons/km^2. The Boreal Shield is the ecozone with the largest proportion of forest area, volume, and biomass (Power and Gillis 2006). In contrast, the Atlantic Maritime ecozone, which is a mosaic of managed forest, urban, and industrial landscapes, has an area of only 192,017 km^2 and a population density of 13.30 persons/km^2.

Notwithstanding these differences, the Boreal Shield and Atlantic Maritime ecozones both have the smallest mean number of forest patches (3.68 and 3.96, respectively), the largest mean patch size (48.84 and 47.54 ha, respectively), the largest mean proportion of patches that are forested (both 79 percent), and more forest–forest joins than the other forested ecozones. In the complex mosaic of land use that is the Atlantic Maritime ecozone, roads are the primary driver of forest fragmentation, followed by the presence of human settlements. In the forest-dominated Boreal Shield ecozone, the primary drivers of fragmentation are water features, followed by human settlement; however, in contrast to the other forested ecozones where a primary (and secondary, in some cases) driver exerts more influence over forest pattern, the Boreal Shield's forest pattern is influenced by an amalgam of several natural and anthropogenic drivers (see Figure 3B).

The Atlantic Maritime ecozone possesses a fine-scale network of roads that provides access for forest harvesting and other land uses but that are not readily captured with the spatial resolution of Landsat TM or ETM+ imagery. Hence, depending on road width and spectral contrast with surrounding land cover types, some roads may not have been mapped in the EOSD product. As a result, the amount of forest fragmentation in the Atlantic Maritime may be underestimated and this may also explain why this ecozone, despite its relatively small area, has the greatest standard deviation in forest patch size.

The inclusion of roads and measurement of their impact in the assessment of forest fragmentation has been debated in the literature (e.g., Riitters *et al.* 2004; Kupfer 2006; Girvetz *et al.* 2007). In a national assessment of fragmentation in the United States, Riitters *et al.* (2004) found that the inclusion of roads increased the overall amount of forest fragmentation and reduced the estimated amount of forest area by approximately 9 percent; however, >80 percent of the forest edge and >88 percent of the fragmentation of core forest areas was detected without the inclusion of roads since roads were often adjacent to other nonforest land cover types. The authors concluded that the inclusion of roads should be dependent upon the objective of the assessment and that 'unless road-caused fragmentation is of special interest, land-cover maps alone may provide an adequate representation of the geography of forest fragmentation' (Riitters *et al.* 2004, 1).

Similar forest pattern, similar drivers

The second scenario we examined was that of ecozones with both similar forest patterns and drivers. The Taiga Plains and Boreal Cordillera ecozones are the third and fourth least fragmented forest ecozones in Canada in terms of number of forest patches and are similar in all other metrics we considered with the exception of the number of forest–nonforest joins: the Taiga Plains is the ecozone with the largest number of forest–nonforest joins of all the forested ecozones. The Taiga Plains are characterized by slow-growing open forests and shrub-lands containing 9 percent of Canada's forested area but accounting for only 5 percent of wood volume while the Boreal Cordillera, located in the middle of the Rocky Mountains, is dominated by topography, with forests on south-facing slopes and grasslands on north-facing slopes. Both the Boreal Cordillera and Taiga Plains have a similar amount of forest (approximately 46 percent of the ecozone area) and similar fragmentation drivers—with the exception of topography (see Figure 3B). The Boreal Cordillera has the second-largest mean elevation and snow/ice and rock/rubble land cover classes are more prevalent in this ecozone (accounting for 6 percent of ecozone area vs. <1 percent in the Taiga Plains). The Boreal Cordillera and Taiga Plains have similar areas of non-forest (approximately 38 percent of the ecozone area); however, the distribution of this non-forest differs, with the open-forested Taiga Plains having more water features by area (30 percent vs. 3 percent in the Boreal Cordillera) and a larger-than-average number of forest–non-forest joins. Both ecozones have smaller-than-average distance to wildfires and distance to roads, indicating that these drivers influence the forest patterns found in these ecosystems. Furthermore, both ecozones have a larger-than-average distance to human settlement (both ecozones have population densities <0.08 persons/km^2) and water bodies.

Another example of ecozones with similar patterns and drivers is the Boreal Plains and Montane Cordillera. These two ecozones are spatially adjacent (Figure 1), of comparable size and population density (1.21 persons/km^2 in Boreal; 1.84 persons/km^2 in Montane), and have a similar proportion of area that is forested (46 percent); however, the Montane Cordillera has a larger proportion of patches that are forested as well as a larger mean forest patch size and a larger number of forest–forest joins. Encompassing the southern portion of the Rocky Mountains in Canada, the Montane Cordillera is dominated by topography, with extensive areas of very productive forests, lakes, and grasslands. The Boreal Plains ecozone is characterized by areas of mixed forest, with urban and industrial activities more prevalent in the south. Although the Montane Cordillera contains only 9 percent of Canada's forested area, forests in this ecozone account for 20 percent of total wood volume and 19 percent of total forest biomass (Power and Gillis 2006). In contrast, the Boreal Plains accounts for 12 percent of forest area but only 11 percent of volume and biomass. Distance to wildfire, settlement, and roads all play a role in determining forest pattern in these two ecozones, with distance to settlement having a more prominent role in the Boreal Plains and distance to roads (and topography) a more prominent role in the Montane Cordillera.

Different forest pattern, different drivers

The third and final scenario is characterized by different patterns and different drivers as exemplified by the Pacific Maritime and Hudson Plains ecozones. The Pacific Maritime ecozone, located on Canada's west coast, has one of the wettest and mildest climates in Canada, encompassing 3 percent of Canada's forested area, and accounting for 12 percent of total wood volume and 10 percent of total biomass (Power and Gillis 2006). Relative to other ecozones, fragmentation patterns in the Pacific Maritime ecozone do not vary notably from national averages, with slightly fewer patches, a slightly larger proportion of patches that are forested, and a smaller than average number of forest–non-forest joins. As one of the largest contiguous wetland ecosystems on Earth, the Hudson Plains ecozone is characterized by a smaller-than-average number of patches, fewer patches that are forested, and a smaller mean patch size. Distance to roads is the most prominent driver in the Pacific Maritime, followed by distance to settlement. Mean elevation in this ecozone is larger than average, and topography plays a small role (through limits to vegetation establishment and growth) in driving fragmentation patterns. The Hudson Plains has a mean elevation that is markedly less than the national average, the smallest proportion of forest, and distance-to metrics that are all larger than the national average. Encompassing 5 percent of Canada's forest area, the Hudson Plains ecozone accounts for only 2 percent of Canada's total wood volume and 3 percent of Canada's total biomass and is dominated by wetlands (60 percent by area), exemplifying an inherently fragmented forested landscape composed of a mosaic of wetlands and forests (Wulder *et al.* 2008b).

Inherent forest fragmentation

Wade *et al.* (2003) suggest that since anthropogenic agents of fragmentation tend to increase over time, areas that are currently experiencing anthropogenically driven fragmentation are more likely to be areas of changing forest patterns in the future. Others have suggested that the effects of anthropogenic fragmentation in forests that are already naturally fragmented may be substantially different from the effects in naturally contiguous forests (Tewksbury *et al.* 1998). Indeed, many of the theoretical and empirical underpinnings of the effects of forest fragmentation on bird populations are based on research conducted in the eastern forests of the United States (Sallabanks *et al.* 1999; George and Dobkin 2002) which at one time were relatively homogenous, contiguous forests. It has been suggested that species of birds that have evolved in naturally fragmented forests (e.g., western forests of the United States, boreal forests) may be more resilient to further fragmentation (Schmiegelow *et al.* 1997; Kremsater and Bunnell 1999; Whitaker *et al.* 2008). We posit that a suitable baseline for future monitoring of forest pattern requires both a consistent national dataset to facilitate analysis and reporting as well as an understanding of the inherent variability in forest pattern and the relative influence of various fragmentation drivers.

Conclusion

Kupfer argues that the goal of a national assessment of forest fragmentation should be 'to characterize and monitor changes in the structural pattern and connectivity of forests without concern for how such values relate to specific aspects of biodiversity or ecological pattern and process' (Kupfer 2006, 81). While we concur with Kupfer's notion that the goal of a national assessment of fragmentation should be intrinsically different from that of a more detailed landscape-level assessment, we emphasize the importance of understanding the context within which forest fragmentation varies at the national level, especially for larger countries. In this study, we aimed to provide context for characterizing Canada's forest fragmentation by using broad ecological units to summarize fragmentation metrics and by likewise summarizing the relative influence of fragmentation drivers within each of these same ecozones. We have shown—through the use of readily interpretable pattern metrics generated from a consistent and detailed national land cover product—that similar forest fragmentation regimes can emerge as the result of different drivers and conversely, that differing fragmentation regimes can emerge from similar drivers.

A national assessment of forest fragmentation, particularly in a very large country such as Canada, must take into account a broader ecological context and also consider the influence of inherent forest fragmentation. Large tracts of the

Canadian boreal forest remain subject to a predominantly natural disturbance regime (such as wildfire) whereas an abundance of water features drives forest fragmentation in other areas of Canada's boreal zone. Anthropogenic drivers, as represented by road networks and the location of human settlements, influence the fragmentation characteristics present in ecozones that contain urban and industrial developments. A baseline of forest fragmentation conditions and an understanding of the drivers shaping these conditions, such as that presented in this article, is particularly important for monitoring forest fragmentation through time and for assessing the changes in forest pattern that are observed. Furthermore, this broad characterization of forest patterns can inform more detailed landscape-level assessments of fragmentation and help serve as a bridge between science and policy.

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