A PRELIMINARY ASSESSMENT OF MONTRÉAL PROCESS INDICATORS OF FOREST FRAGMENTATION FOR THE UNITED STATES*

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Abstract. As part of the U.S. 2003 National Report on Sustainable Forests, four metrics of forest fragmentation – patch size, edge amount, inter-patch distance, and patch contrast – were measured within 137 744 non-overlapping 5625 ha analysis units on land-cover maps derived from satellite imagery for the 48 conterminous States. The perimeter of a typical forest patch is about 100 m from the perimeter of its nearest neighbor, except when there is not much forest, in which case that distance is 200 to 300 m. A typical analysis unit has from 10 to 40% as much forest edge as it could possibly have, given the amount of forest present. Most analysis units contain a large number of patches that are less than one hectare in size, and about 10% contain one or more 2000 to 5000 ha patches. Forest often defines the background landscape, and patch contrast is generally either very high or very low in eastern regions and intermediate in western regions. Many research needs were identified by this experimental analysis of available data and metrics.

Keywords: fragmentation, land cover, Montréal Process, national assessment, spatial pattern

1. Introduction

Pursuant to the Santiago Declaration and the Montréal Process, analyses of forest fragmentation are needed to assess progress towards sustainable forest management. As part of the United States 2003 National Report on Sustainable Forests, four metrics of fragmentation – patch size, edge amount, inter-patch distance, and patch contrast – were measured on land-cover maps derived from satellite imagery. This paper summarizes the results of that analysis and identifies research needed to better address the Montréal Process.

The Montréal Process (Montréal Process Liaison Office, 2000) is an international framework for assessing progress towards sustainable forest management. Seven criteria represented by 67 indicators address forest conditions, attributes, and functions associated with the environmental and socio-economic values that forests

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provide, and the policy and institutions that enable efforts to achieve sustainable forest management. 'Fragmentation of forest types' is one of nine indicators of the criterion 'conservation of biological diversity'. It refers to the extent to which forests are distributed as large blocks of habitat conducive to the maintenance of viable populations of flora and fauna. Other biodiversity indicators describe the amount of forest and its protected status, and the population characteristics of forest-dependent species (USDA Forest Service, 2003).

The U.S. 2003 National Report on Sustainable Forests ('2003 Report') is part of the Montréal Process. Together with the Sustainable Forest Data Working Group of the Federal Geographic Data Committee, the Roundtable on Sustainable Forests ('Roundtable') convened public and expert workshops to reach agreement on how to evaluate sustainability (USDA Forest Service, 2003). The Roundtable evaluated the data and information requirements for assessing forest fragmentation, and made recommendations that were the point of departure for the research described in this paper.

2. Methods

The Roundtable recommended using three metrics (average patch size, amount of edge, and inter-patch distance) to describe forest fragmentation, and one metric (patch contrast) to describe the landscape context of forest patches. The Roundtable further recommended that the measurements be made on land-cover maps derived from satellite imagery, recognizing that available maps were adequate for characterizing 'forest' fragmentation but not 'forest type' fragmentation. Finally, the Roundtable recommended a grid system such that metrics computed within each grid cell could be summarized for national reports. This section describes the implementation of the Roundtable recommendations.

2.1. Land-cover maps

We used the land-cover maps for the lower 48 States from the National Land Cover Data (NLCD) database. The NLCD land-cover mapping project (Vogelmann *et al.*, 2001) used Landsat Thematic Mapper (TM) data (ca. 1992) to map 21 classes of land cover (Table I) at a spatial resolution of 0.09 ha per pixel. There are about 8×10^9 pixels on the NLCD map, of which about 2.8×10^9 pixels are forest. The TM data were mapped into the land-cover classes using a combination of digital image processing techniques and logical modeling with ancillary data (Vogelmann *et al.*, 1998). The forest versus non-forest classification accuracy of the NLCD map is 86% (based on omission error), and 94% (based on commission error) for the eastern seaboard (Yang *et al.*, 2001).

The 21-class NLCD map legend was aggregated to eight land-cover types including water, developed/urban, barren/disturbed, forest, shrubland, agriculture,

TABLE I

Aggregation of the 21 NLCD land-cover types for the fragmentation analysis

NLCD categories	Aggregated category
Open water, perennial ice/snow	Water
Low intensity residential, high intensity residential, commercial/industrial/transportation, urban/recreational grasses	Developed/urban
Bare rock/sand/clay, quarries/mines, transitional	Barren/disturbed
Deciduous forest, evergreen forest, mixed forest, woody wetlands	Forest
Shrubland	Shrubland
Orchards/vineyards, pasture/hay, row crops, small grains, fallow	Agriculture
Grasslands/herbaceous	Grassland
Emergent herbaceous wetlands	Wetland

grassland, and wetland (Table I). Four of the original NLCD types (deciduous forest, evergreen forest, mixed forest, and woody wetlands) were included in the aggregated forest class. The NLCD ‘transitional’ class includes forestland that is only temporarily cleared (e.g., timber harvest, wildfire), but it was included with the barren/disturbed class because it also includes permanent (e.g., urban development) and semi-permanent (e.g., agricultural clearing) forest conversion. The aggregation yielded a legend that is appropriate for coarse-scale analysis of fragmentation over large regions. When calculating fragmentation metrics, no distinction was made between fragmentation by anthropogenic classes (e.g., agriculture) and semi-natural classes (e.g., water).

2.2. Analysis units and assessment units

An analysis unit defines a spatial extent over which the metrics are calculated and saved, and an assessment unit defines a spatial extent over which the analysis unit calculations are summarized and reported. Analysis units were defined by a grid of 137 744 non-overlapping 5625 ha (7.5 $\times$ 7.5 km, or 250 $\times$ 250 pixels) squares that tiled the NLCD land-cover map from a random starting point. For consistency when calculating metrics, we excluded squares that were completely water (large inland lakes and estuaries), or that contained missing values (near international borders). To facilitate association with assessment units, the metrics that were calculated for a given analysis unit were assigned to the center point of that analysis unit.

The assessment units were taken to be the RPA (Resource Planning Act) reporting regions (Figure 1; USDA Forest Service, 2001), excluding Alaska, Hawaii, and Puerto Rico. The following acronyms were used for RPA regions in this report: NO = North; PC = Pacific Coast; RM = Rocky Mountains, and; SO = South. All of the fragmentation metrics that were calculated within analysis units were summarized to the level of those four administrative regions. The summary statistics for an assessment unit represent an 'average analysis unit' for that region.

2.3. Fragmentation Metrics

The operational definitions of 'patch' and 'edge' were as follows. A 'patch' was defined as a block of contiguous pixels of forest land-cover, where contiguity was evaluated in four cardinal directions. Individual patches were truncated at the boundaries of analysis units even if they continued into an adjacent analysis unit. Thus, the upper size limit of individual patches is the size of the analysis unit (5625 ha). Inter-patch distance calculations only considered patches within a given analysis unit.

'Edge' refers to the imaginary line that separates any two adjacent pixels on the land-cover map. 'Forest edge' specifically refers to edge that separates a forest pixel from a non-forest pixel. The outside edges of analysis units were considered to be missing values, and the total number of edges in an analysis unit is 124 500.

2.3.1. *Inter-Patch Distance*

Inter-patch distance was taken to be the average nearest neighbor distance among forest patches on a perimeter-to-perimeter basis. After individual patches were delineated within an analysis unit, every pair of patches within the analysis unit was examined to determine the minimum distance between the perimeters. For consistency with patch definition by the four-neighbor rule, the distances were measured from the center points (not the edges) of the perimeter pixels.

The minimum spanning tree (e.g., Hillier and Lieberman, 1990) was then constructed from the minimum inter-patch distances. The minimum spanning tree has two key properties: (1) each patch is connected to another patch by the shortest possible distance, and; (2) the total length of all connections is minimized. If M is the total length of all connections on a minimum spanning tree, and N is the number of patches, then the quantity M/(N–1) is the average nearest neighbor distance that was used as the metric of inter-patch distance in this study.

2.3.2. *Edge Amount*

The measure of forest edge was taken to be the number of forest edges divided by the number of forest pixels in an analysis unit. The maximum possible value is four because an isolated forest pixel has four forest edges. Physical packing constraints necessarily reduce the maximum attainable value in analysis units that are more than half forested. The metric is interpretable as the overall perimeter-to-area ratio for all forest pixels in the analysis unit.

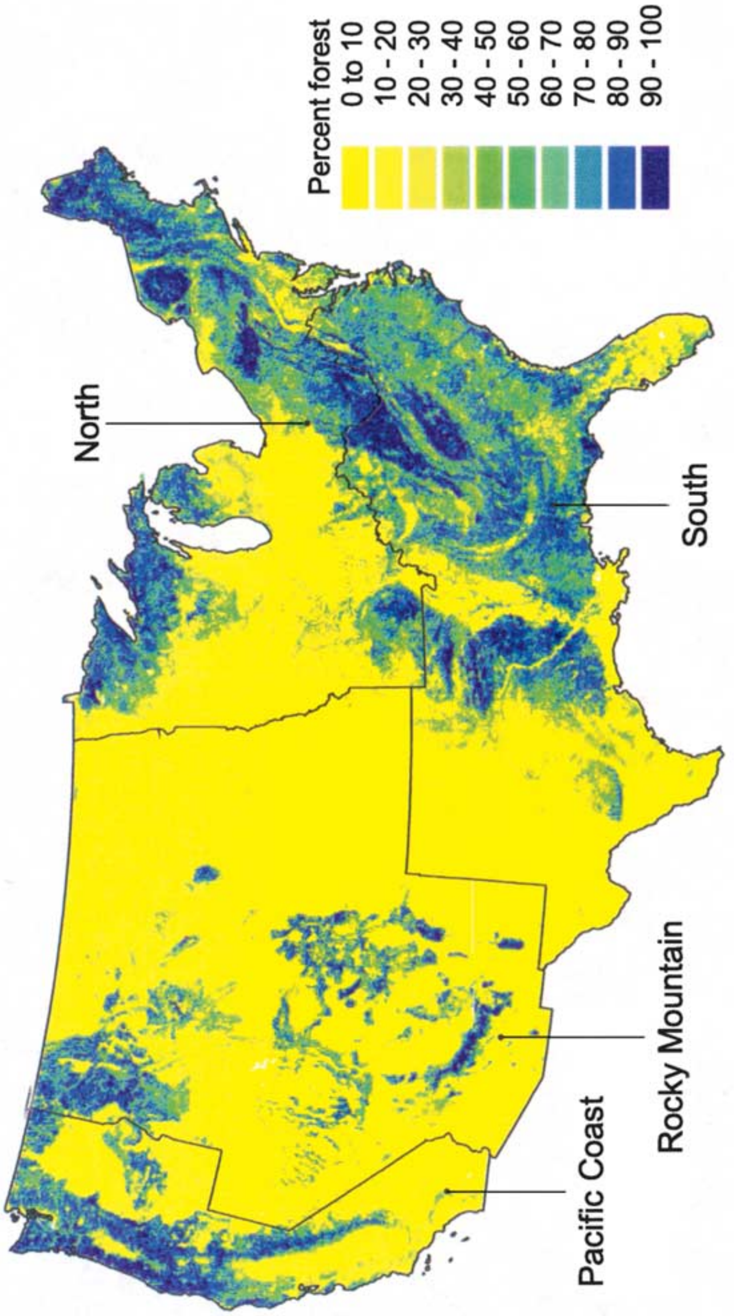

Figure 1. Percent forest land-cover within 5625 ha analysis units. Assessment regions are shown for comparison.

2.3.3. *Average Patch Size*

This metric was taken to be the area-weighted average patch size, in this case equal to the sum of squared forest patch sizes divided by the total number of forest pixels in an analysis unit. The focus was on forest habitat and an area-weighted average may better characterize how an organism perceives the existence of large patches. The maximum possible value depends on the amount of forest present in an analysis unit. For a given amount of forest, the maximum is obtained if there is only one forest patch.

2.3.4. *Patch Contrast*

The patch contrast metric requires substantially more definition here because there was no standard formula. Patch contrast is intended to reflect the idea that a patch may be in physiognomic structure quite similar to, or very different from, that of the landscape matrix in which it is embedded. A patch contrast index should characterize the physiognomic structures of patch and matrix and express the contrast as the relative difference between the two (USDA Forest Service, 2003).

Physiognomy generally refers to the structure and life form of a plant community, and physiognomic class is ‘a level in the classification hierarchy defined by the relative percent canopy cover of the tree, shrub, dwarf shrub, herb, and non-vascular life form in the uppermost strata during the peak of the growing season’ (FGDC, 1997). It is plausible that the physiognomic class of a pixel can be approximated with the 8-class land-cover map. However, the problem is more complicated because the contrast index should express differences between forest patches and the background matrix. It is tenuous to assume that there is an identifiable background matrix, upon which forest patches appear as distinct entities (Wickham and Norton, 1994). Forest very often forms the background matrix and does not appear as distinct patches (Riitters *et al*., 2002).

An approximate approach based on the concept of ‘landscape pattern types’ (Wickham and Norton, 1994; Jones *et al*., 1997) was used. The background matrix was characterized in terms of the relative percentages of different land-cover types within an analysis unit. Contrast coefficients were then defined for forest in the analysis unit, based on assumed physiognomic classes for non-forest land.

The first step condensed the land-cover legend to four categories – forest, grassland, shrubland, and other (including water, developed/urban, barren/disturbed, agriculture, and wetland). The rationale was that physiognomic class and contrast coefficients are easier to guess for forest, shrubland, and grassland in comparison to the other land-cover types. Physiognomic class probably has little meaning for some of the ‘other’ land-cover types (e.g., developed/urban) but they cannot simply be ignored since in many cases they constitute the background matrix. The percentages of the four land-cover types were then measured within each analysis unit.

The second step employed a rule set (Table II) to define ‘matrix types’ in terms of those percentages. This step labeled each analysis unit by a matrix type representing the background matrix. For example, an analysis unit with 46% forest land-cover and 30% grassland cover has the 'Forest-Grassland' matrix type (symbolized as 'FG').

The third step defined a set of contrast coefficients (Table II) that specify the contrast between forest and each of the possible matrix types that might contain forest. For three of the simple matrix types (F, S, G), the contrast coefficients are based on physiognomic class as defined by height of the dominant vegetation (forest is taller than shrubland, and shrubland is taller than grassland). The coefficient for the 'Other' (O) matrix type assumes that the contrast with forest is greater than for the other three simple matrix types. For six of the seven complex matrix types (FS, FG, FO, SG, SO, GO), the coefficient is simply the average of the applicable simple matrix types (e.g., FS uses the average of F and S). For the seventh complex matrix type (M), an arbitrary coefficient was assigned.

The contrast coefficient was taken as a categorical metric of forest patch contrast for each analysis unit. This metric is best interpreted as representing potential forest patch contrast because it is defined for all analysis units whether or not there is forest present in every one. However, this analysis will focus on those analysis units that actually contain forest.

2.3.5. *Supplemental Metrics*

Two supplemental metrics were calculated to enable better interpretation of the four primary metrics. 'Amount of forest' is simply the proportion of pixels in an analysis unit that were of the forest land-cover type. 'Matrix type' is a categorical metric that was obtained as an intermediate step in the computation of the patch contrast metric (Table II).

3. Results

3.1. Amount of Forest

The geographic pattern of the amount of forest (Figure 1) reflects what is generally known about forest distribution across the lower 48 States. There is some forest nearly everywhere, but forest is less common in the Great Plains and Intermountain West. Predominantly agricultural and urban areas also have less forest. Forest is more evenly distributed in the East than in the West, and is more common in mountains and remote areas.

The range of percent forest was from 0.0 to 1.0 in all RPA regions. The mean and the median values varied from 0.01 to 0.46 (Table III), but those values were sensitive to analysis units with little or no forest. For example, 66% of the analysis units in the RM region contained less than 5% forest, and the median metric value there was only 0.01. In contrast, only 13% of analysis units in the NO region contained less than 5% forest and the median value in that region was 0.39 (Table III).

TABLE II

Rule set used to define the matrix type and forest patch contrast metric. P_f, P_s, P_g, and P_o are the area percentages of forest, shrubland, grassland, and other land-cover types, respectively

Rule set	Matrix type	Forest contrast metric
Rule 1. If any one of the four land-cover types occupies more than half of the analysis unit, then the matrix type is that land-cover type.		
If $P_f > 50\%$	Forest (F)	1.0
Else if $P_s > 50\%$	Shrubland (S)	2.0
Else if $P_g > 50\%$	Grassland (G)	3.0
Else if $P_o > 50\%$	Other (O)	4.0
Rule 2. Otherwise, if any two occupy more than three-fourths of the analysis unit, then the matrix type is a combination of those two land-cover types.		
Else if $P_f + P_s > 75\%$	Forest-Shrubland (FS)	1.5
Else if $P_f + P_g > 75\%$	Forest-Grassland (FG)	2.0
Else if $P_f + P_o > 75\%$	Forest-Other (FO)	2.5
Else if $P_s + P_g > 75\%$	Shrubland-Grassland (SG)	2.5
Else if $P_s + P_o > 75\%$	Shrubland-Other (SO)	3.0
Else if $P_g + P_o > 75\%$	Grassland-Other (GO)	3.5
Rule 3. Otherwise, at least three land-cover types are needed to occupy three-fourths of the analysis unit and the matrix type is not well defined.	Mixed (M)	2.0

Relatively few analysis units in any region had more than 95% forest (Table III). Except for analysis units with less than 5% forest, the frequency distributions of the metric were roughly uniform in each region (results not shown). Some parts of the analysis as noted below used only analysis units with at least 5% forest, or excluded analysis units with no forest.

3.2. Inter-patch distance

Of the 127 012 analysis units with at least some forest, 124 843 contained at least two patches of forest as required to estimate the inter-patch distance metric. Average minimum inter-patch distance was very sensitive to the amount of forest present. Analysis units with very little forest exhibited a wide range of metric values, whereas those with more than about 5% forest exhibited a much narrower

TABLE III

Characterization of the amount of forest within 5625 ha analysis units, by RPA assessment region

RPA region	Number of analysis units (percent of all regions)	Proportion of analysis unit that is forest		Analysis units with no forest		Analysis units with less than 5% forest		Analysis units with more than 95% forest	
		Mean	Median	Number	Percent of region	Number	Percent of region	Number	Percent of region
NO	30261 (22)	0.44	0.39	1	<1	4063	13.4	1432	4.7
PC	14786 (11)	0.37	0.24	816	5.5	5644	38.2	655	4.4
RM	53639 (39)	0.15	0.01	7492	14.0	35392	66.0	401	0.7
SO	39058 (28)	0.44	0.46	2423	6.2	8327	21.3	1453	3.7
All regions	137744 (100)	0.32	0.17	10732	7.8	53426	38.8	3941	2.9

range (Table IV). As a result, this metric was separately summarized for analysis units with less than 5% forest. As expected, distances were smaller in units with more forest (Table IV). The distributions of analysis units were lognormal in all regions (results not shown), and the regional values do not reflect local conditions. However, the median values suggest that a typical forest patch is about 100 m from its nearest neighbor, except when there is not much forest, in which case that distance is 200 to 300 m depending on the region (Table IV).

3.3. Edge amount

For the 127 012 analysis units with forest, the maximum observed value of the edge amount metric was related to the amount of forest present (results not shown). Except for analysis units with extremely high or low amounts of forest, the observed maximum values were not near the maximum value for a given amount of forest. The implication is that over-dispersed patterns such as checkerboards never span entire analysis units. Using mean or median values as a guide, typical analysis units roughly have from 10 to 40% as much edge per unit forest area as they could have, depending on the region (Table V). Regional values do not reflect local conditions everywhere. For example, the standard deviations of the metric indicate that values commonly approach 40 to 90% of maximum for individual analysis units depending on the region.

The edge amount metric is typically highest in the Great Plains and intermountain West (Figure 2). Forests are not naturally abundant over much of the Great Plains, and most of the fragmentation is associated with small parcels of artificial forests such as windbreaks, shelterbelts, and urban trees. Areas of high fragmentation on the east coast identify major urban and agricultural areas. High fragmentation on the west coast is associated with both human and natural features.

3.4. Average patch size

For the 127 012 analysis units containing at least some forest, the area-weighted average patch size metric was also dependent on the amount of forest present (results not shown). The median value of the average patch size metric varied among RPA regions from 3 ha in the RM region to 1126 ha in the SO region (Table V). At least 30% of the analysis units in each region (up to 70% in the RM region) had metric values less than 10 ha (results not shown). The average patch size metric is typically highest in areas that are mostly forested and relatively remote (see Figure 1).

Additional insight can be gained by adjusting patch size for the amount of forest present in each analysis unit (Wickham *et al.*, 1999). Here, the metric values were divided by the maximum possible value for the given amount of forest in each analysis unit. The frequency distributions of the 'standardized' metric are bi-modal in all regions (Figure 3). After adjusting for the actual forest amount, typical analysis units in all regions have either relatively large or relatively small area-weighted

TABLE IV

Summary statistics for the average minimum inter-patch distance for forest patches within 5625 ha analysis units that contained at least two forest patches, by RPA assessment region

RPA region	Analysis units with less than 5% forest					Analysis units with at least 5% forest				
	Number of analysis units	Mean distance (m)	Range (m)	Standard deviation (m)	Median distance (m)	Number of analysis units	Mean distance (m)	Range (m)	Standard deviation (m)	Median distance (m)
NO	4059	219	51–2591	121	189	26130	90	42–636	29	82
PC	4573	577	42–8783	799	310	9128	87	42–392	28	79
RM	26526	512	42–9518	749	256	18245	90	42–704	27	84
SO	5556	493	42–8323	723	239	30621	86	42–503	23	81
All regions	40714					84124				

TABLE V

Summary statistics for the edge amount and weighted average patch size metrics within 5625 ha analysis units that contained forest, by RPA assessment region

RPA region	Number of analysis units	Edge amount (number of forest edges per unit forest area)				Area-weighted average patch size (hectares)			
		Mean	Range	Standard deviation	Median	Mean	Range	Standard deviation	Median
NO	30260	0.81	0.001–4.00	0.69	0.64	1687	0.09–5623	1977	495
PC	13970	1.42	0.002–4.00	1.24	1.04	1737	0.09–5620	2094	235
RM	46147	1.81	0.004–4.00	1.11	1.82	676	0.09–5617	1426	3
SO	36635	0.86	0.0000–04.00	0.91	0.48	1893	0.09–5625	1932	1126
All regions	127012								

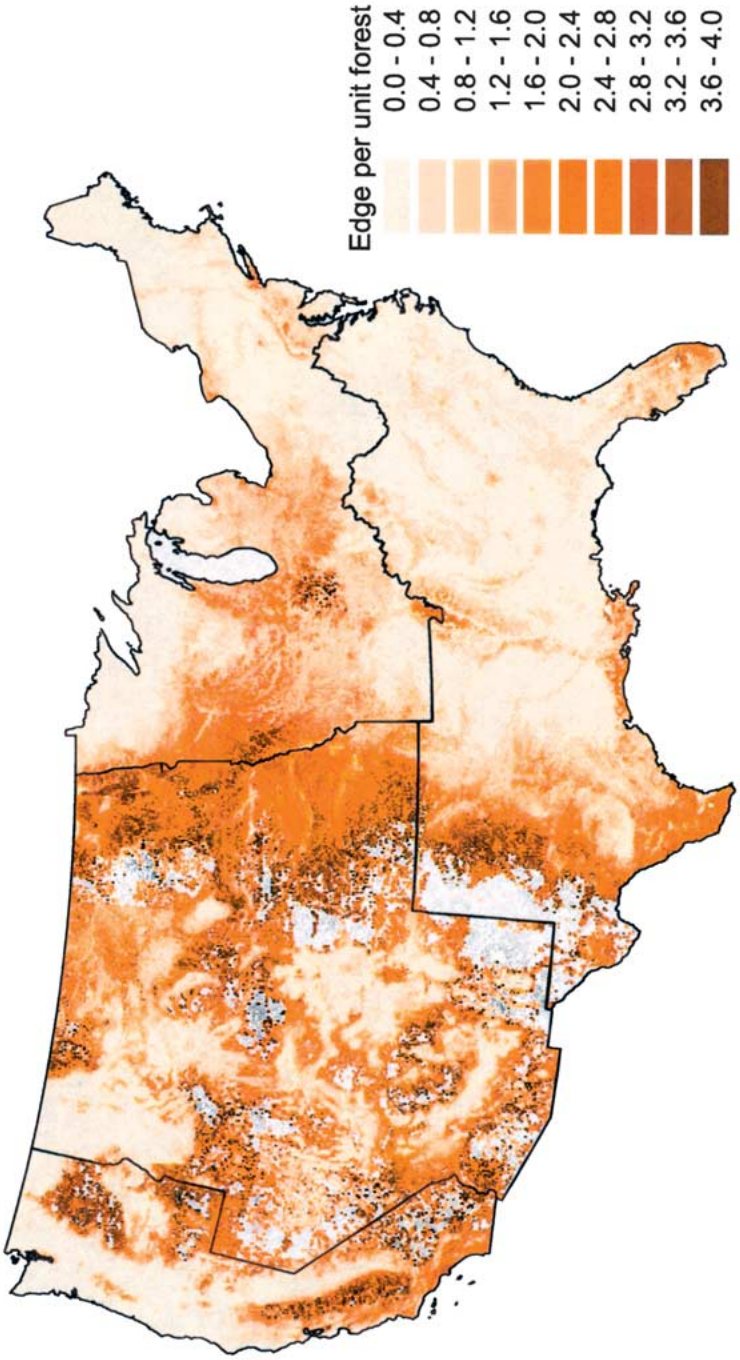

Figure 2. Number of forest edges per unit forest area within 5625 ha analysis units. Assessment regions are shown for comparison.

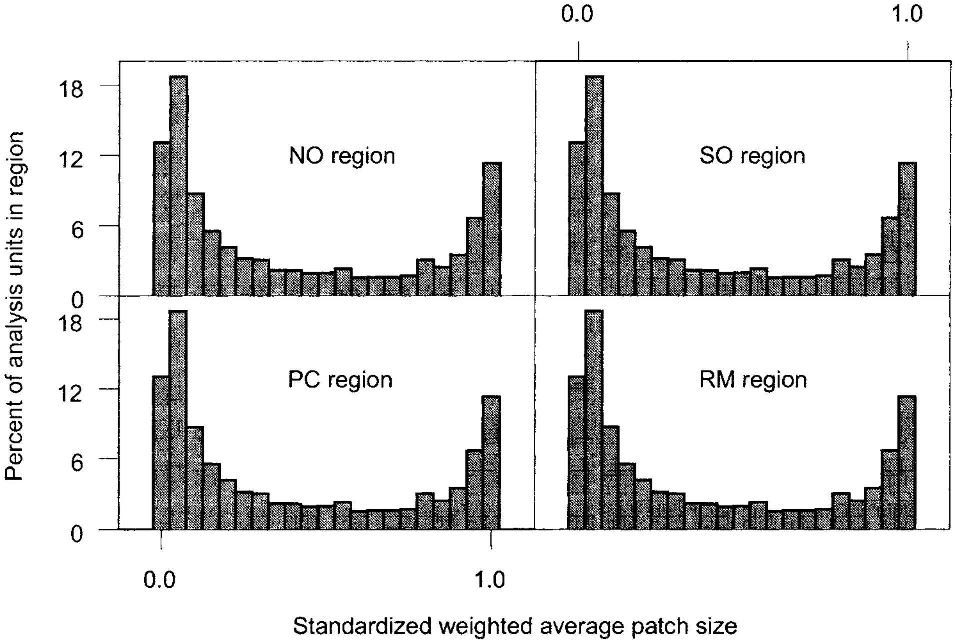

Figure 3. Relative frequency of adjusted area-weighted average patch size within 5625 ha analysis units for four assessment regions.

average patch size. The implication is that a given amount of forest tends to be arranged either as compactly as possible (large standardized metric value) or as dispersed as possible (small standardized metric value).

3.5. Patch contrast

A brief characterization of matrix types for all analysis units will provide information to help interpret the patch contrast metric. Analysis units are typically dominated by one of the four condensed land-cover types (Table VI). In the NO region, nearly all analysis units were either 'Forest' or 'Other' matrix types, and the 'Other' matrix type is associated with agricultural and urban land-cover types because shrubland and grassland land-cover were not very common in that region. In contrast, the other regions all contained significant percentages of 'Shrubland', 'Grassland', and 'Other' matrix types because of the different land-cover types present in those regions. The 'Forest' matrix type characterized about 40 to 50% of the analysis units except in the RM region where about 15% of the analysis units were the 'Forest' matrix type. Forest land-cover is often the dominant land-cover type, and the concept of forest patches on a background of some other land-cover type may not be an appropriate model in those instances.

The analysis of the patch contrast metric was limited to the 127 012 analysis units that contained forest. Patch contrast values are either very low or very high

TABLE VI

Percent of 5625 ha analysis units with different matrix type designations, by RPA assessment region. See text for explanation of matrix types

RPA region	Number of analysis units	Percent of analysis units in a region having the given value of matrix type										
		F Forest	G Grassland	S Shrubland	O Other	FS Forest-Shrubland	FG Forest-Grassland	FO Forest-Other	GS Grassland-Shrubland	GO Grassland-Other	SO Shrubland-Other	M Mixed
NO	30261	43.2	0.0	0.0	56.3	0.0	0.0	0.5	0.0	0.0	0.0	0.0
PC	14786	38.8	4.6	29.0	16.3	2.0	0.9	0.8	0.7	0.5	1.6	4.8
RM	53639	14.3	27.0	29.9	20.7	1.1	0.9	0.2	1.1	1.4	0.8	2.5
SO	39058	46.9	5.5	8.8	30.0	0.3	0.5	1.2	0.8	1.6	0.6	3.9
All regions	137744	32.5	12.6	17.3	30.7	0.7	0.6	0.6	0.7	1.0	0.6	2.6

TABLE VII

Percent of 5625 ha analysis units with different values of the forest contrast metric, for analysis units that contain forest, by RPA assessment region. See text for explanation of the forest contrast metric

RPA region	Number of analysis units	Percent of analysis units in a region having the given value of the forest contrast metric						
		1	1.5	2	2.5	3	3.5	4
NO	30260	43.2	0.0	0.0	0.5	0.0	0.0	56.3
PC	13970	41.1	2.2	32.5	1.5	6.4	0.5	15.8
RM	46147	16.6	1.3	31.1	1.4	26.8	1.5	21.2
SO	36635	50.0	0.3	11.7	2.0	4.9	1.5	29.5
All regions	127012	35.3	0.8	18.3	1.4	11.9	1.0	31.4

in the NO region where forest tends to appear either as part of the background matrix, or in combination with dominant agriculture and/or urban land-cover types (Table VII). In the PC region, patch contrast was 2.0 or less for about 75% of the analysis units. The RM region was unique among RPA regions in that intermediate metric values were more common than extreme metric values. The SO region was similar to the NO region but had more intermediate metric values and fewer high values.

3.6. Summary of Results

The key points that emerged from the analysis can be summarized as follows. There is at least some forest land-cover nearly everywhere in the lower 48 States. Large areas on the Great Plains and in the Intermountain West, and additional smaller areas in predominantly agricultural and urban settings have less than 5% forest. The results for the inter-patch distance metric suggested that a typical forest patch is about 100 m from its nearest neighbor, except when there is not much forest, in which case that distance is 200 to 300 m. According to the edge amount metric, a typical analysis unit roughly has from 10 to 40% as much edge per unit forest area as it could possibly have, based on the amount of forest present. The results for the average patch size metric suggested that most analysis units contain a large number of small patches, and that about 10% of analysis units contain at least one large (i.e., >2000 ha) patch. The patch contrast metric suggested that forest is a common component of the background matrix. Where that is not the case, forest patches are likely to occur on a background matrix of urban or agricultural land-cover types in eastern regions, or on a background matrix of shrubland or grassland land-cover types in western regions. As a result, patch contrast is generally either very high or very low in eastern regions and intermediate in western regions. Fragmentation metrics within individual analysis units can be an order of magnitude different from a regional average value.

Considering all four metrics together, the general picture of forest fragmentation has two parts. First, in places where forest is generally dominant, the background matrix is formed by very large (i.e., >5625 ha) regional forest patches that are probably defined by moisture and temperature constraints. These regional patches are fragmented by perforations that increase edge amount, and they are usually associated with a large number of very small forest patches in close proximity. Second, in regions where forest is not generally dominant, the forest appears as a patchy, highly fragmented land-cover type set against a background of other land-cover types.

4. Discussion

The 'First Approximation Report' for the Montréal Process (USDA Forest Service, 1997) did not assess forest fragmentation because there was no agreement on metrics and no national database. Since then, several national land-cover maps have been prepared from satellite imagery, and there has been a substantial effort to critically evaluate the candidate fragmentation metrics and available data. Based on Roundtable recommendations from the Montréal Process, this preliminary assessment of fragmentation from land-cover maps might be termed a 'second approximation', and the lessons learned here will help to guide future research.

There have been three parallel efforts to produce and assess national databases of fragmentation metrics from remotely sensed information. Riitters *et al*. (2000) analyzed fragmentation on global land-cover maps of much coarser resolution, and those results help to put U.S. forest patterns into a global perspective. Using the NLCD land-cover maps, Heilman *et al*. (2002) incorporated maps of roads and humans, and used naturally defined analysis and assessment units. Riitters *et al*. (2002) used a multiple-scale approach that unified the analysis of fine-scale patterns such as distance from forest edge and large-scale patterns such as regional patches. That information should be evaluated together with this report to help guide future assessments in the Montréal Process.

RPA regions contain so much variation among landscapes that an 'average analysis unit' is rarely applicable to a particular landscape within a region. For the same reason, RPA regions are also much too large to serve as analysis units for computing fragmentation metrics. While a systematic grid of fixed-area analysis units preserves flexibility for re-aggregation later, better regional estimates could probably be obtained by grouping analysis units according to natural features such as ecoregions, prior to further aggregation to administratively defined assessment units such as RPA regions. Variation of fragmentation within analysis units could be addressed by either improving the metrics to account for the variation, or by adopting some type of naturally defined analysis units. If fixed-area analysis units are used, then several sizes could be employed depending on the metric that is computed.

Considering patch size metrics, median values may be more informative than averages, and if minimum patch size requirements are at issue, then percentiles of the patch size frequency distribution should be reported. Considering edge amount, the alternate metric recommended by the Roundtable (i.e., the absolute amount of forest edge) can be obtained by multiplying the relative measure reported here by the amount of forest in an analysis unit. The relative measure is more useful for characterizing forest pattern, and the absolute measure is more useful for evaluating specific habitat requirements. Considering inter-patch distances, the alternate metric suggested by the Roundtable (i.e., the average minimum patch centroid-to-centroid distance) would not be very useful when applied to the data used in this study. The reason is that inter-patch distances are small relative to patch size and, as a result, centroid distances will tend to overestimate distance between patches.

When the objective is to assess 'fragmentation of forest types', there are limitations when using the available land-cover maps. Leaving aside the problem of interpreting fragmentation metrics, there are at least five research needs. First, to achieve the literal interpretation of the Montréal indicator, it is necessary to improve the definition and mapping of forest cover types at multiple scales in a consistent fashion nationwide. Second, procedures are needed to incorporate information from road maps and other ancillary data sources, to better define forest patches and other features (e.g., corridors) at multiple scales. Third, there has to a better accounting of 'natural' patterns of forest fragmentation, particularly in the western U.S., and of the proximate 'causes' of fragmentation, because not all fragmentation has the same effect on forest values. Fourth, conceptual and technical approaches are needed for assessing the risk of future fragmentation in rapidly changing landscapes, including information about patterns of human population, infrastructure, and land ownership. Finally, the patch contrast metric needs more conceptual development, testing of alternate metrics, and evaluation of other databases.

The fragmentation metrics can be interpreted in terms of what they say about forest patterns, irrespective of any impacts on forest values such as biological diversity. However, they should be combined with information from other criteria and indicators to evaluate possible associations, because most people care more about the effects of fragmentation than knowing how fragmented the forests are. Many research questions must be answered before detailed national assessments of fragmentation impacts on biological diversity can be made. For example, at local scales and for particular species and processes, it is necessary to know 'thresholds' of fragmentation (e.g., minimum patch size to sustain a population), 'limiting distances' (e.g., dispersal distance from forest edge), and 'context' (e.g., movement cost between patches). In the meantime, forest spatial pattern cannot be ignored and coarse-scale national assessments will be a necessary step towards assessing the possible impacts of forest fragmentation on the sustainability of biological diversity.

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http://www.srs.fs.usda.gov/4803/landscapes.

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