Localizing National Fragmentation Statistics *with Forest Type Maps*

Kurt H. Riitters, John W. Coulston, and James D. Wickham

ABSTRACT

Fragmentation of forest types is an indicator of biodiversity in the Montreal Process, but the available national data permit assessment of only overall forestland fragmentation, not forest type fragmentation. Here we illustrate how to localize national statistics from the 2003 *National Report* on *Sustainable* Forests by combining state vegetation maps with national forestland fragmentation maps. The degree and scale of fragmentation of diff erent forest types can be gauged from the amount of forestland that meets certain fragmentation thresholds at multiple scales of analysis.

Keywords: biodiversity; GIS; Montreal Process

Fragmentation of forest types" is an indicator of biodiversity in the Montreal Process for assessing sustainable forest management (Montreal Process Liaison Office 2000). The Montreal Process is one of several groups of regional governments-in this case, the United States, Canada, and 10 other countries with temperate and boreal forests-that have adopted criteria and indicators for sustainable forestry. Conservation of biological diversity is one of its seven national-level criteria.

In the United States, fragmentation is interpreted as the spatial arrangement of forest and the degree to which continuous forest cover has been broken up into smaller pieces. Together with indicators of the total area and protected status of forests, it describes habitat capacity, which is of interest as a leading indicator of change in biodiversity (USDA-FS 2003).

Maps of forest types and other habitat classes are available for conducting assessments in some states (e.g., Scott et al. 1996) and for most federal lands and some private lands. However, detailed maps are not available everywhere, and different mapping rules are used in different places. As a result, it is not feasible to aggregate local forest type fragmentation statistics to national scale. In contrast, the national land cover map (Vogelmann et al. 2001) that was used to assess fragmentation in the ***Sustainable Forests*** (USDA-FS 2003) provides national comparability but does not resolve many forest types. As a result, the national statistics refer to fragmentation of "forestland," not "forest types." Toward the goal of using all available data to meet both national and local assessment requirements in a consistent fashion, this article illustrates how to combine national information with local vegetation maps to improve the interpretation of national statistics.

Methods

The national assessment used the National Land Cover Database (NLCD), a land cover map that was derived from satellite imagery for the 48 conterminous states (Vogelmann et al. 1998, 200 1). The NLCD has a spatial resolution of 0.09 hectare/pixel and distinguishes 21 land cover types, four of which were combined into one "forestland" class. We conducted an analysis to characterize each of the ~2.8×10^9 forestland pixels in terms of fragmentation in the surrounding landscape, for five landscape sizes up to 5,000 ha (Riitters et al. 2002). Each forestland pixel appeared at the center of its own set of five landscapes, such that the fragmentation context for each forestland pixel was characterized at five scales. The national assessment showed that forestland generally appears in close proximity over large regions but also that fragmentation is pervasive: There are many small patches, and edge effects potentially influence more than half of the total forestland area.

The present analysis illustrates one way to disaggregate the pixel-level national statistics according to local maps of forest types or vegetation classes. GAP Analysis Program (GAP; Scott et al. 1996) maps from Oregon (Kagan et al. 1999) and New York (Smith et al. 2001) were used for this illustration because they exemplify two approaches to vegetation mapping. The New York GAP map is a land cover type map that was created by labeling relatively small groups of pixels; it has 29 land cover classes, including 10 forest types. In contrast, the Oregon GAP map is a vegetation zone map that was made by delineating relatively large regions corresponding to 62 vegetation classes defined by dominant vegetation (Jennings 1993), including approximately 30 classes with a significant forest component.

The corresponding fragmentation maps were obtained from the National Land-Cover Pattern Database (Riitters et al. 2002). We used the forest area density index (P,, defined as the proportion of the landscape that is forestland) for landscape sizes of 2.25 ha, 65.61 ha, and 5,314.41 ha for this illustration. The fragmentation maps were segmented to remove all pixels that were not labeled as forestland in the original NLCD land cover map, and then overlaid on the GAP vegetation maps. The resulting maps show, for each NLCD forestland pixel, a forest or vegetation type for that pixel, and the values of forest area density at three scales. The pixel-level values of forest area density were then summarized by forest type (New York) or vegetation zone (Oregon).

To illustrate a way to interpret the results, we defined three threshold values for the P_f statistic corresponding to 60 percent, 90 percent, and 100 percent forestland cover in the surrounding landscape (Heinz Center 2002). Recognizing that such thresholds are arbitrary unless set by specific ecological or policy rationale, we adopt the following terminology. If a forestland pixel meets the 60 percent criterion, it is said to reside in a landscape where forestland is the *dominant* land cover. Pixels that meet the 90 percent criterion are termed *interior* forestland, and those that meet the 100 percent criterion are called core forestland. Pixels meeting the core criterion also meet the other two criteria, and interior pixels meet the dominant criterion. The minimum distance from a core forest pixel to the nearest nonforest pixel can be inferred from the largest landscape size for which that pixel is core (Riitters et al. 2002). For the landscape sizes used here, these distances are 90, 420, and 3,660 meters.

After overlaying with GAP maps, consider the proportion of all pixels of a given forest type that meet or exceed each of the three threshold P_f values, at each of three scales or landscape sizes. If there is a high proportion of core forest at all three scales, the implication is that a high proportion of that forest type exists in unfragmented forestland patches that are larger than the largest landscape tested. If there is a high proportion of dominant pixels at all three scales, the implication is that a high proportion of that forest type exists in landscapes that are mostly forested. Typically, the proportion of core forest decreases rapidly with increasing landscape size because most forests are fragmented; the proportion of dominant forest decreases much less rapidly because forest tends to be the dominant land cover type where it occurs (Riitters et al. 2002). We will demonstrate how the differences among forest types in the proportion of forestland that meets those thresholds, over a range of scales, offer insights into landscape-scale spatial patterns.

Results

Figures 1 (Oregon) *and 2 (New* York) (p. 20-2 1) show the proportions of total NLCD forest area in selected GAP forest type or vegetation classes meeting national criteria for core, interior, and dominant forestland for three landscape sizes. Within-state comparisons among the selected classes are possible, but comparisons of similar classes between states are not valid because of differences in the GAP maps. The proportions are based on class total numbers of NLCD pixels ranging from 300,000 to 16 million in Oregon, and from 600,000 to 30 million in *New* York. In *figures I and* 2, the forest and vegetation classes have been sorted in ascending order of proportion of interior forest at each scale.

In both states, the lines representing core forestland shift to the left with increasing landscape size because it is increasingly difficult to meet the criterion of 100 percent forest in a large landscape. Some classes shift more than other classes, indicating that core areas are typically smaller. The proportion of core forest is near zero when the landscape size reaches 5,314.41 ha, implying that very little forest of any class is more than 3,660 m away from a nonforest pixel (i.e., a forest edge). For some naturally fragmented classes (e.g., Oregon white oak forest), the observed proportion of core forest for 2.24-ha landscapes indicates that most of those classes are within 90 m of a forest edge. With one exception in each state, at least 60 percent of the total forestland in all classes was within 420 m of forest edge (i.e., the proportion of core forest was less than 40 percent for those classes).

The lines representing interior forest also shift to the left with increasing landscape size, and differences among classes are more evident for interior forest than for core forest. Forestland pixels that reside in landscapes that are at least 90 percent forested are almost certainly part of a forest patch that is larger than the landscape size, and fragmentation is usually associated with "perforations" in that patch (Riitters et al. 2000, 2002). Compared with other classes, the interior statistics indicate that spruce-fir and evergreen wetland in New York and the Douglas-fir-Port Orford cedar forest in Oregon are typically the least fragmented over relatively large areas.

Because the classes were sorted at each scale, the movement of a class up or down in the list indicates a change in the local-to-regional spatial pattern of that class, relative to other classes. For example, the evergreen plantation class in New York is ranked fourth for interior forest at the 2.25-ha scale but drops to seventh rank at the 5,314.41-ha scale. One interpretation is that evergreen plantations are less fragmented at local scale, but the landscapes containing them are more fragmented at larger scales, relative to other forest types in New York. This is plausible because evergreen plantations should be well stocked at the local scale and appear in landscapes that contain roads and other nonforest land-cover types.

The proportions residing in landscapes where forestland is dominant are of interest because mostly forested landscapes probably contain well-con-

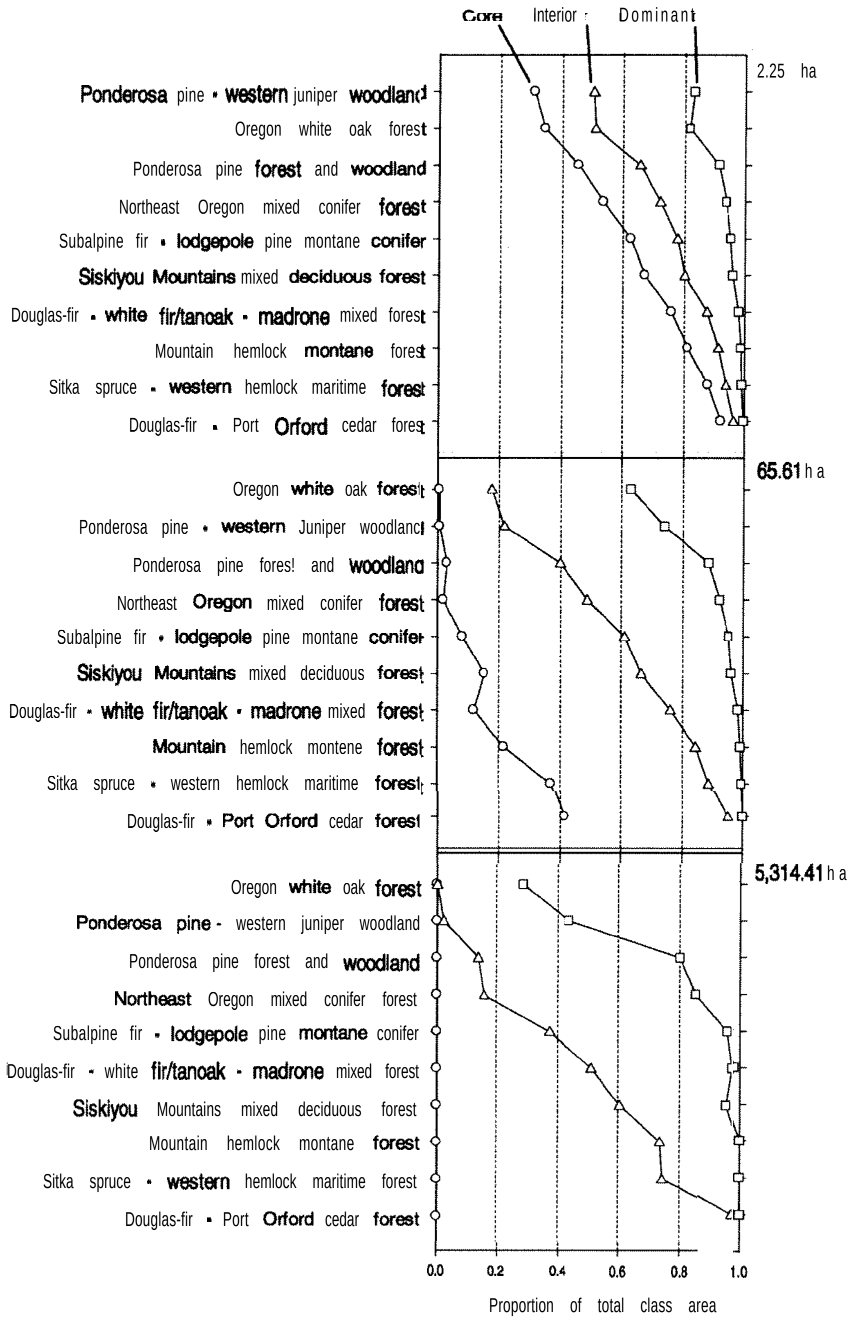

Figure 1. **Forestland fragmentation statistics for selected forest-dominated vegetation classes in Oregon. The proportions of total NLCD forest area in 10 Oregon GAP vegetation classes meeting national criteria for core, interior, and dominant forestland are shown for three landscape sizes. The vegetation classes (from Kagan et al. 1999) have been sorted according to the proportion of interior forest for each landscape size.**

nected forest, whereas forestland in landscapes with $P_f < 60$ percent is more likely to appear in identifiable patches (Riitters et al. 2000). The location and scale of nondominant forestland indicate where fragmentation statistics such as patch shape and interpatch distance may be needed and suggest the size of the analysis units to use. The national assessment estimated that about three-fourths of all forestland nationwide was dominant within 5,314.41-ha landscapes and thus probably well connected over areas at least that large (Riitters et al. 2002). Classes that are exceptions in New York (successional hardwoods, deciduous wetlands, and pitch pine-oak) and Oregon (Oregon white oak forest, ponderosa pine-western juniper woodland) are probably not as well connected over areas of that size.

Discussion

From this analysis we can infer the forestland fragmentation context within which a typical pixel of a given forest type resides, not the fragmentation of that forest type per se. This distinction is less meaningful when coarser-scale vegetation maps or maps with less geographic variation of forest types are used (Riitters et al. 2000). Furthermore, like the underlying land cover maps, the inferences refer to typical pixels in general locations. Nevertheless, large-area planning and management could benefit from maps that show concentrations of typical forest pixels meeting certain fragmentation thresholds at different scales. Such concentrations could also be analyzed using traditional patch-based measures (e.g., Riitters et al. 1997).

The general approach presented here can be modified in many ways because the fragmentation statistics are available for all possible 0.09-ha locations, whether the NLCD considered them forested or not. For example, we could have used the GAP maps instead of the NLCD maps to define where the forest was. The NLCD maps allow comparability with national statistics; the GAP maps would permit comparability with other state-level statistics. It is also possible to summarize forest fragmentation surrounding nonforest classes, such as urban and agricultural regions, and examine the fragmenting effects of those land uses. Forest inventory plot locations could be overlaid on the national fragmentation maps, and the plot data could then be used to summarize fragmentation statistics by forest age, size, and stand origin classes.

Additional research is needed to fully implement the Montreal Process fragmentation indicators. Two important issues are parcelization (Sampson and DeCoster 2000) and roads. Parcelization of forestland ownership is an issue because virtual fragmentation is a precursor to actual physical fragmentation in urbanizing regions; at present, there are no suitable maps for performing a geographic analysis at national scale. Roads are important fragmenting agents (Forman and Alexander 1998; Trombulak and Frissell 2000), and national road maps have been incorporated in some assessments (e.g., Heilman et al. 2002). The national fragmentation maps that we analyzed have now been updated to include roads as fragmenting agents. Research is also needed to interpret the observed fragmentation in terms of normal or historical patterns, to select the most useful indices and measurement scales for quantifying habitat suitability, and to understand how forest patterns relate to other assessment criteria besides biodiversity.

Conclusion

With digital maps and computers, it is now feasible to measure the fragmentation of forestland in a consistent fashion nationwide. We expect that future national mapping efforts will focus on temporal trends in forestland for inventory purposes, with less emphasis on increasing the thematic resolution of the maps for assessment purposes. We also expect that local mapping efforts will not always adhere to national classification standards (FGDC 1997), so national aggregation of local statistics will continue to be problematic. Therefore, the challenge of localizing national statistics is likely to remain, and it is important to develop and test new applications using all available data to meet both national and local assessment requirements in a consistent fashion. National statistics

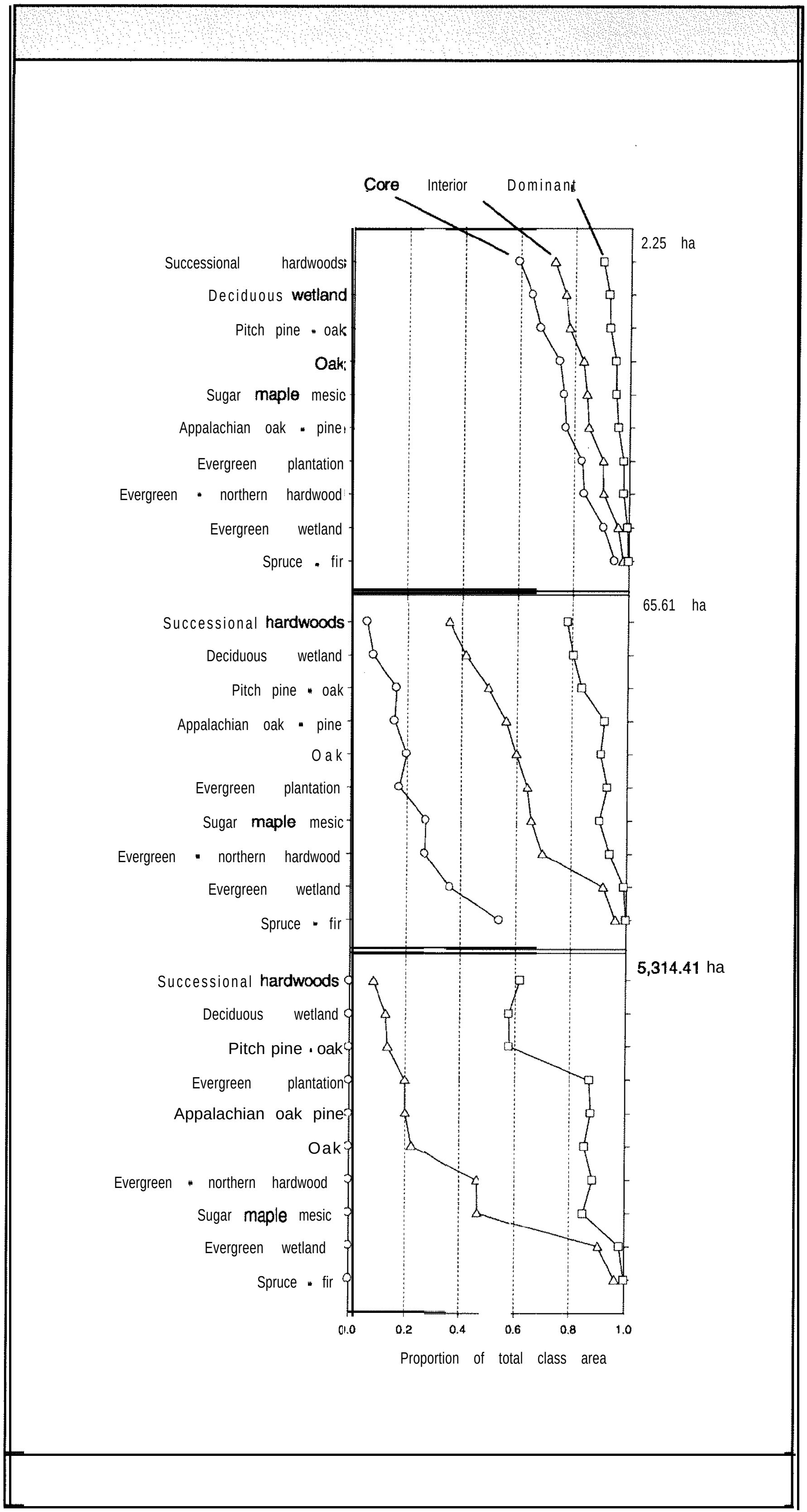

***Figure* 2. Forestland fragmentation statistics for forest type classes in New York. The proportions of total NLCD forest area in 10 New York GAP forest type classes meeting national criteria for core, interior, and dominant forestland are shown for three landscape sizes. The forest type classes have been sorted according to the proportion of interior forest for each landscape size. Forest types are from Smith et al. (2001).**

will never be as detailed as local statistics. From a local perspective, one advantage of using national statistics is that they permit comparisons with locations for which there are no local data. From an assessment perspective, even though consistent fragmentation statistics will not guarantee successful integration of information across criteria, experience has shown that, if the data are disparate, integration is usually more difficult.

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