ASSESSING THE IMPACT OF LAND COVER SPATIAL RESOLUTION ON FOREST FRAGMENTATION MODELING

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ABSTRACT

Researchers at the University of Connecticut's Center for Landuse Education and Research (CLEAR) have been utilizing a raster based image convolution forest fragmentation model developed by Riitters *et al.* (2000) to assess the impact of landscape change on forest resources in the State of Connecticut. The model calculates Pf (forest proportion) and Pff (forest connectivity or adjacency) values based on a roving window analysis. These values are used to assign, to the center forest pixel of the analysis window, one of five possible forest fragmentation categories of core, perforated, edge, transition, and patch forest. Within CLEAR, this work had been applied exclusively to 30-meter land cover maps derived from Landsat satellite imagery. Recently, CLEAR researchers have begun to assess the application of the forest fragmentation model to land cover of higher spatial resolution. In comparing the results with 30-meter land cover, it was found that there were significant differences in the forest fragmentation maps, particularly among the perforated and edge forest categories. This paper discusses the issues involved with forest fragmentation modeling using land cover of different spatial resolutions and how the model has been refined to provide a consistent result regardless of the spatial resolution of the land cover used.

INTRODUCTION

Forests provide many important benefits to society in terms of the timber resources and the ecosystem services they provide. These benefits include maintaining water quality, reducing storm water run-off and erosion, improving air quality, regulating climate and carbon sequestration, providing habitat for wildlife, maintaining biodiversity, and providing a destination for recreation and tourism in addition to providing timber and non-timber resources (Barnes *et al.* 1998; Krieger 2001). The ability of forests to provide timber products and ecosystem services may be compromised by a loss of forest quality (SAF 1998; Lovejoy *et al.* 1986; Howarth *et al.* 1996). The fragmentation of the forested landscape is a major contributor to declines in forest quality. Forest fragmentation, in this context, refers to the process of dividing large tracts of forest into smaller isolated tracts surrounded by human-modified environments (SAF 1998). Fragmentation can lead to a reduction in habitat quality and loss of biodiversity for interior forest species (Barnes *et al.* 1998). Forest health may be reduced along the perimeters due to changes in microclimate and increased susceptibility to edge predators, parasites, and invasive species (Barnes *et al.* 1998). According to the Society of American Foresters (1998), there is concern that "…continued declines and fragmentation of the forestland base may lead to the impairment of our forest ecosystems' ability to protect water flow and quality, to provide healthy and diverse forest habitat, and to remain a viable economic resource that provides recreation, timber, and other forest products."

Connecticut is located between the two major metropolitan centers of New York and Boston and is continuously faced with the difficult challenge of balancing natural resource protection with economic growth and development. As a state, Connecticut ranks fifth in the nation for population density (703 persons per square mile of land) yet has a tree canopy cover of about 60 percent. This presents the question of how intact is the forested landscape in Connecticut?

To assess the condition of forests in Connecticut and to quantify forest fragmentation, The University of Connecticut's Center for Landuse Edaucation and Research (CLEAR) has been applying a forest fragmentation This project currently consists of five dates of land cover spanning a 21 year period (1985, 1990, 1995, 2002, and 2006)

model developed by Riitters *et al.* (2000) as part of CLEAR's Connecticut's Changing Landscape (CCL) project.derived from Landsat satellite imagery and provides a consistent representation of land cover and land cover change of the state from which other analysis can be conducted including urban growth, impervious surfaces and forest fragmentation. The results of the forest fragmentation analysis applied to the CCL land cover show that within Connecticut there exist very few large intact forested areas and those that are present are being eroded away due to development and urban growth.

Having successfully applied the forest fragmentation model to 30-meter spatial resolution land cover, CLEAR researchers were curious how the model would perform on higher spatial resolution land cover. With the increased availability of high resolution aerial and satellite digital imagery, and the development and improvement of image processing algorithms and techniques, the ability to more derive effectively, increased spatial detailed land cover products has emerged. The question is, how would the forest fragmentation model handle higher resolution land cover?

FOREST FRAGMENTATION MODEL BACKGROUND

The purpose of the forest fragmentation model is to generate a map that would allow a user to visualize and quantify the extent of forest fragmentation and track any change in fragmentation over time. The basis of this model comes from a forest fragmentation model developed by Riitters *et al.* (2000). Their model, which was originally developed to assess forest fragmentation at the global level using 1-km land cover information, is based on image convolution where a fixed area, roving 'analysis window', or kernel, is centered over a forest pixel identified by a raster land cover map (Riitters *et al.*, 2000; Riitters *et al.*, 2002; Vogt *et al.*, 2007). An index that identifies the amount (Pf) and connectivity or adjacency (Pff) of forest pixels in the analysis window is then calculated and the center forest pixel is assigned to a forest fragmentation category based on Figure 1. The resulting fragmentation categories are described in Table 1.

When using the forest fragmentation model, there are essentially two conditions that must be considered. First is the spatial resolution of the input land cover information. Second is the desired width of the edge/perforated category. Both of these conditions are related when it comes to creating the forest fragmentation map and are used to determine the size of the analysis window. To do so, the following equation is used:
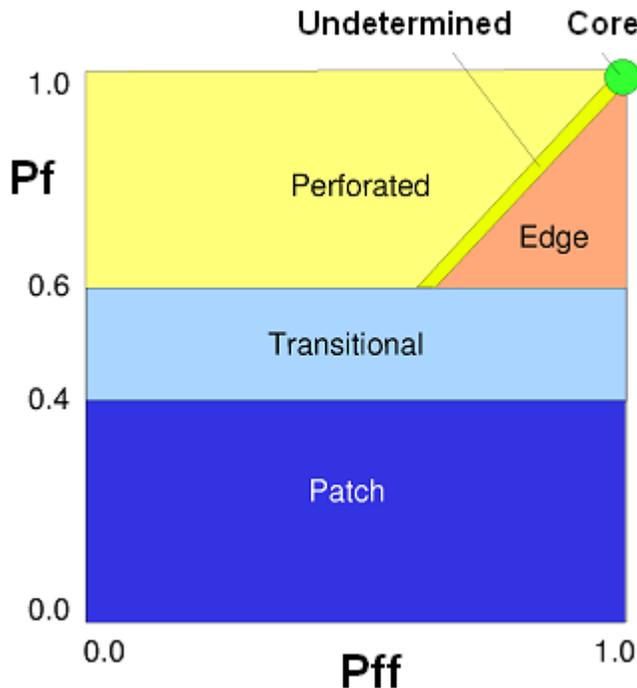
$$n \equiv [(w/r)2] + 1$$

where *n* is the pixel size of the analysis window (rounded to the nearest odd integer), *w* is the desired width of the edge or perforated forest, and *r* is the spatial resolution of the land cover. Looking at it from a different perspective, the minimum distance from the edge of a core forest pixel to the nearest edge of a non-forest pixel is defined by the largest analysis window size for which that pixel is core (Riitters *et al.*, 2002). For an *n* X *n* pixel analysis window with *n* odd, the minimum distance is (n - 1) / 2 pixels. The corresponding linear distance is that number times the nominal side length of a pixel. Take, for example, a land cover map based on a 30-meter spatial resolution Landsat image. Let us say that we want the width of the edge/perforated forest to be 60 meters, that is to say the edge of a core forest pixel is 60 meters from the edge of the closest non-forested pixel. Based on the first equation, an analysis window size of 5 X 5 pixels should be used. An example of using a 5 X 5 analysis window on 30-meter land cover is provided in Figure 2.

Figure 1. Graphical representation of the model used to assign forest fragmentation categories based on the calculations of Pf and Pff (adapted from Riitters *et al.* 2000).

Table 1. Definition of forest fragmentation categories.

Core forest - all pixels within the analysis window are forest.	$Pf = 1.0$
Perforated forest - most of the pixels within the analysis window are forested, but some appear to be part of the inside edge of a forest patch, such as would occur if a small clearing was made within a patch of forest.	$Pf > 0.6$ and $Pf - Pff > 0$
Edge forest - most of the pixels within the analysis window are forested, but some appear to be part of the outside edge of forest, such as would occur along the boundary of a large urban area, or agricultural field.	$Pf > 0.6$ and $Pf - Pff < 0$
Transitional forest - about half of the cells in the surrounding area are forested and these may appear to be part of a patch, edge, or perforation depending on the local forest pattern.	$Pf > 0.4$ and $Pf < 0.6$
Patch forest – very few forest pixels that are part of a forest patch on a non-forest background, such as a small wooded lot within an urbanized region.	$Pf < 0.4$
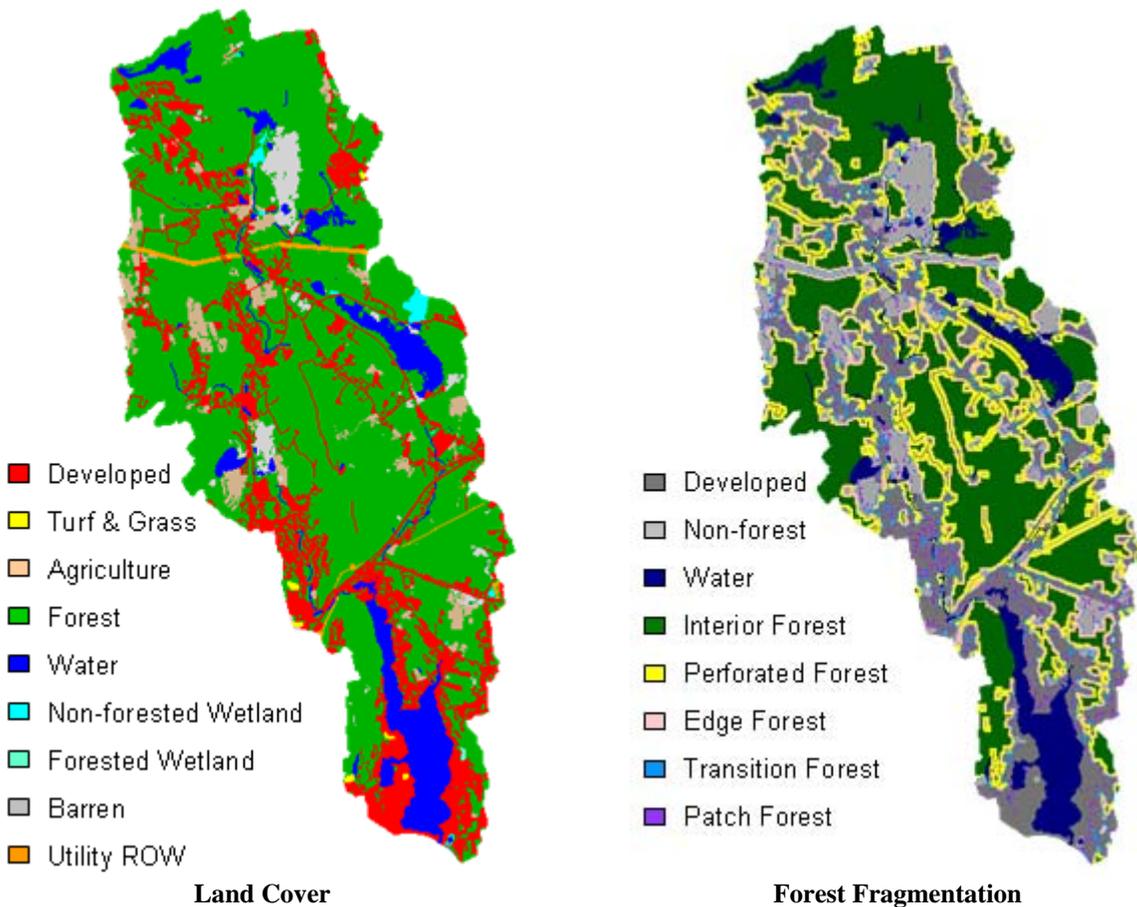
Figure 2. General 30-meter land cover and derived forest fragmentation map based on a 5x5 pixel (2.25 hectare) analysis window for the Niantic watershed, Connecticut.

APPLICATION TO HIGH SPATIAL RESOLUTION LAND COVER

Following the application of the forest fragmentation model to 30-meter spatial resolution land cover, it was assessed on land cover of higher spatial resolutions. The analysis consisted of two parts. The first looked at applying analysis windows using the same number of pixels (*e.g.* 5 X 5 pixels) to four land cover datasets of different spatial resolutions (1-meter, 4-meter, 10-meter, and 30-meter respectively). Examples of applying 5 X 5 pixel and 81 X 81 pixel analysis windows are provided in Figure 3. As would be expected, the amount of core forest was found to be
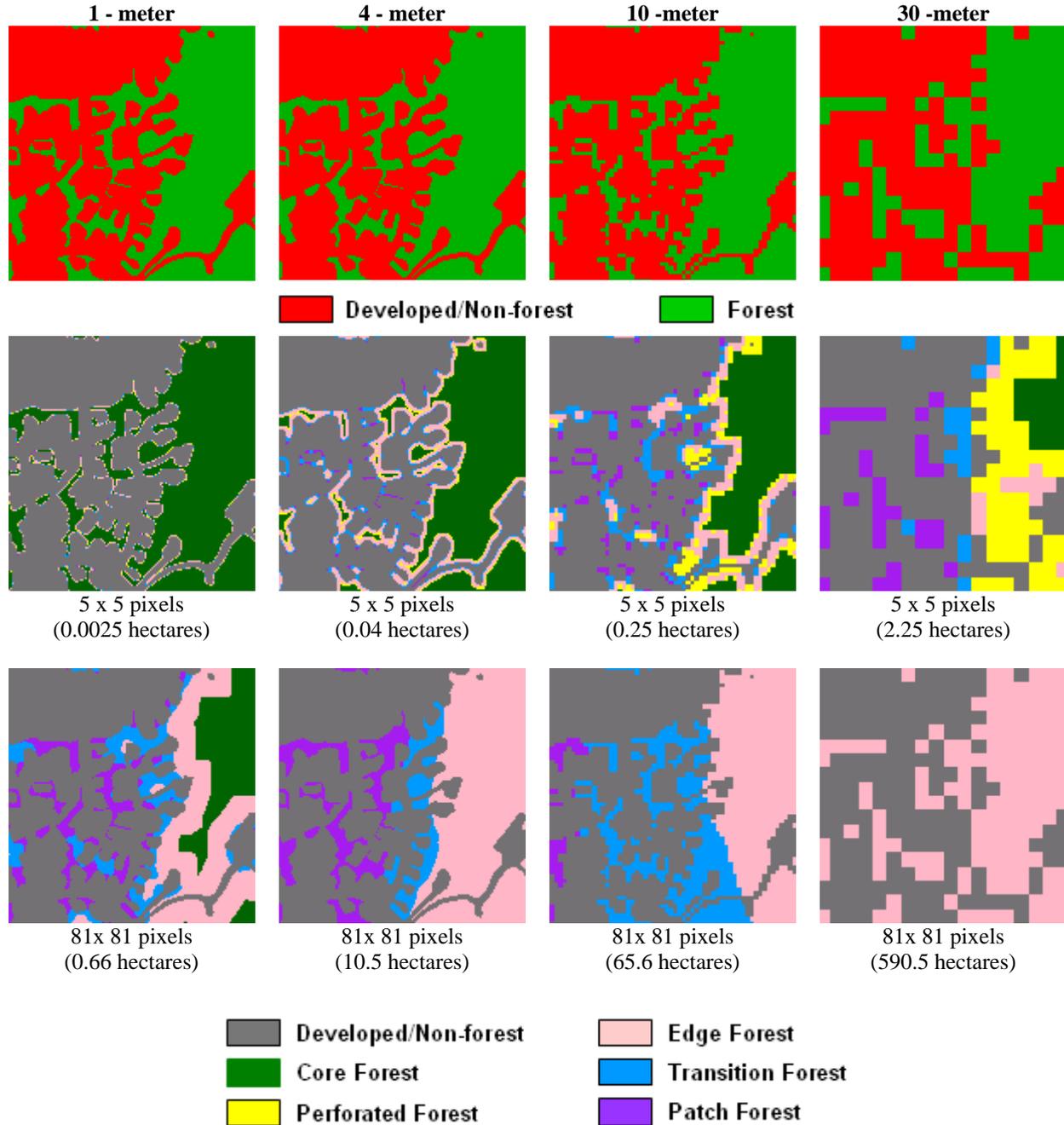
Figure 3. Examples of applying analysis windows of the same number of pixels for land cover of different spatial resolutions. Land cover is shown in the top row with results of the forest fragmentation model provided in the center and bottom rows.

significantly larger using the higher resolution land cover since the width of the edge/perforated forest would decrease with increasing land cover spatial resolution. The amounts of transition and patch forest also differ depending on the spatial pattern of the forests being analyzed and is directly related to the number of forest pixels contained in the analysis window.

The second part of the assessment examined the use of analysis windows of near equal spatial extent, but using a different number of pixels depending on the spatial resolution of the land cover. That is, a land cover image with coarser spatial resolution (*e.g.* 30 meters) would use an analysis window of fewer pixels (*e.g.* a 9 x 9 pixel analysis window would contain 81 pixels) than a higher spatial resolution land cover (*e.g.* 10 meters) that would require more pixels (*e.g.* a 27 x 27 pixel analysis window would contain 729 pixels) to make up an analysis window of similar spatial extent. An example of the results is provided in Figure 4. The areal extent of each analysis window for a given land cover spatial resolution size differs slightly due to the spatial resolution of the land cover map and the center pixel being analyzed. For a 30 meter resolution land cover, the center pixel will have an area of 900
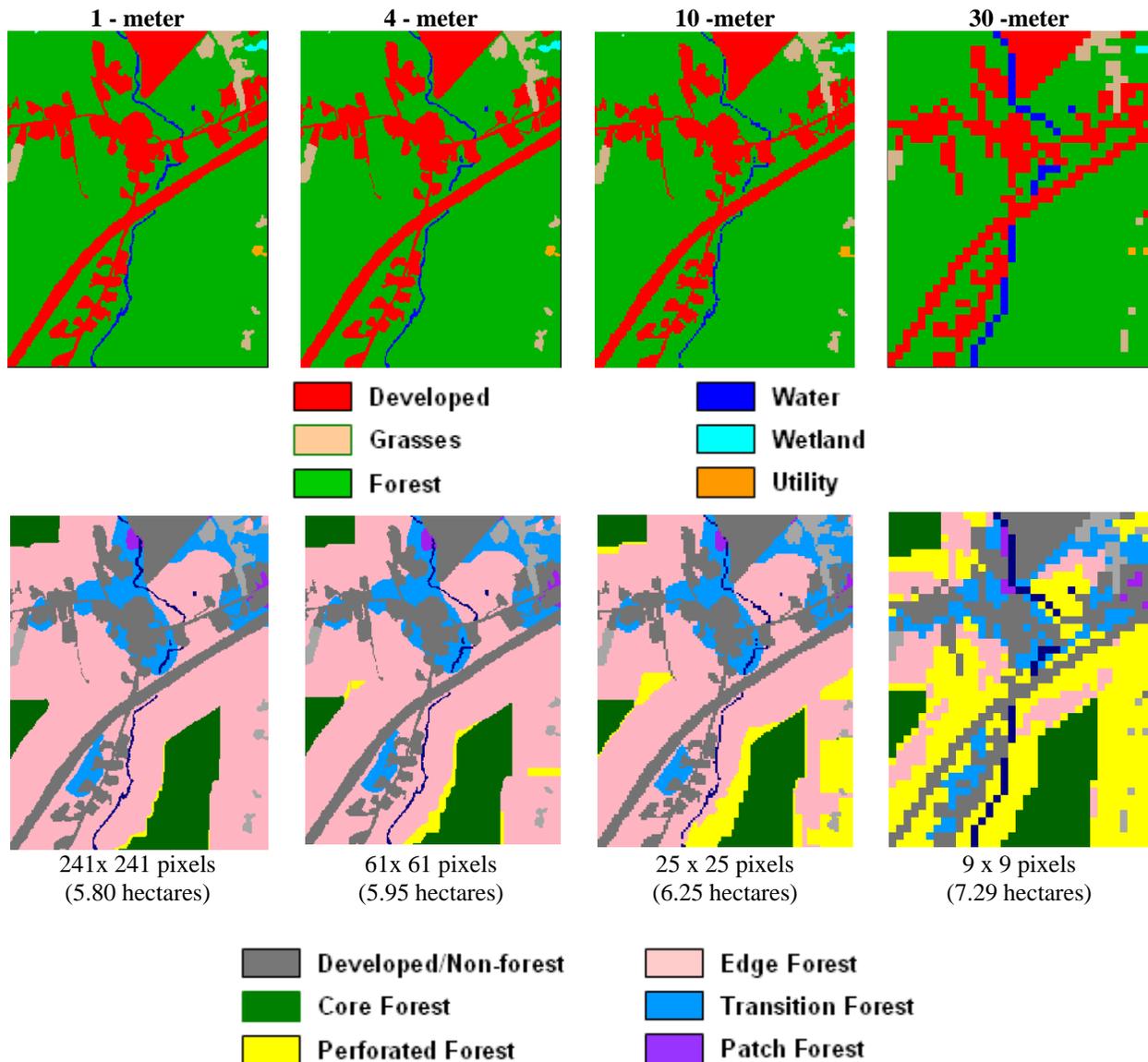
Figure 4. Examples of applying analysis windows of similar spatial extent but different numbers of pixels on land cover of different spatial resolutions. Land cover is shown in the top row with results of the forest fragmentation model provided in the bottom row.

meters squared verses 100 meters square for a 10 meter land cover and so forth, thus reducing the linear distance from the edge of the center forest pixel and the nearest non-forest pixel edge resulting in a slightly smaller overall aerial extent of the analysis window yet still maintaining the desired edge/perforated forest width (Figure 5).

What becomes apparent from Figure 4, is the decrease in perforated forest and increase in edge forest identified as the land cover spatial resolution progressively gets higher. The cause has to do with the definition of perforated and edge forests using Pf and Pff (see Table 1), the number of pixels used in the analysis window, and the representation and pattern of forested and non-forested features in each land cover. Since the definition of an edge forest requires that the Pf value (proportion of forest in the analysis window) be smaller then the Pff value (how adjacent are forest pixels in the analysis window), it would be expected that the forest pixels would become more adjacent for a given landscape pattern as the land cover spatial resolution increased (*i.e.* more forest pixels are connected resulting in a higher Pff value) whereas the Pf value would remain similar between differing land cover spatial resolutions. To correct this problem, the definition between perforated and edge must be dynamically modified as land cover resolution changes.
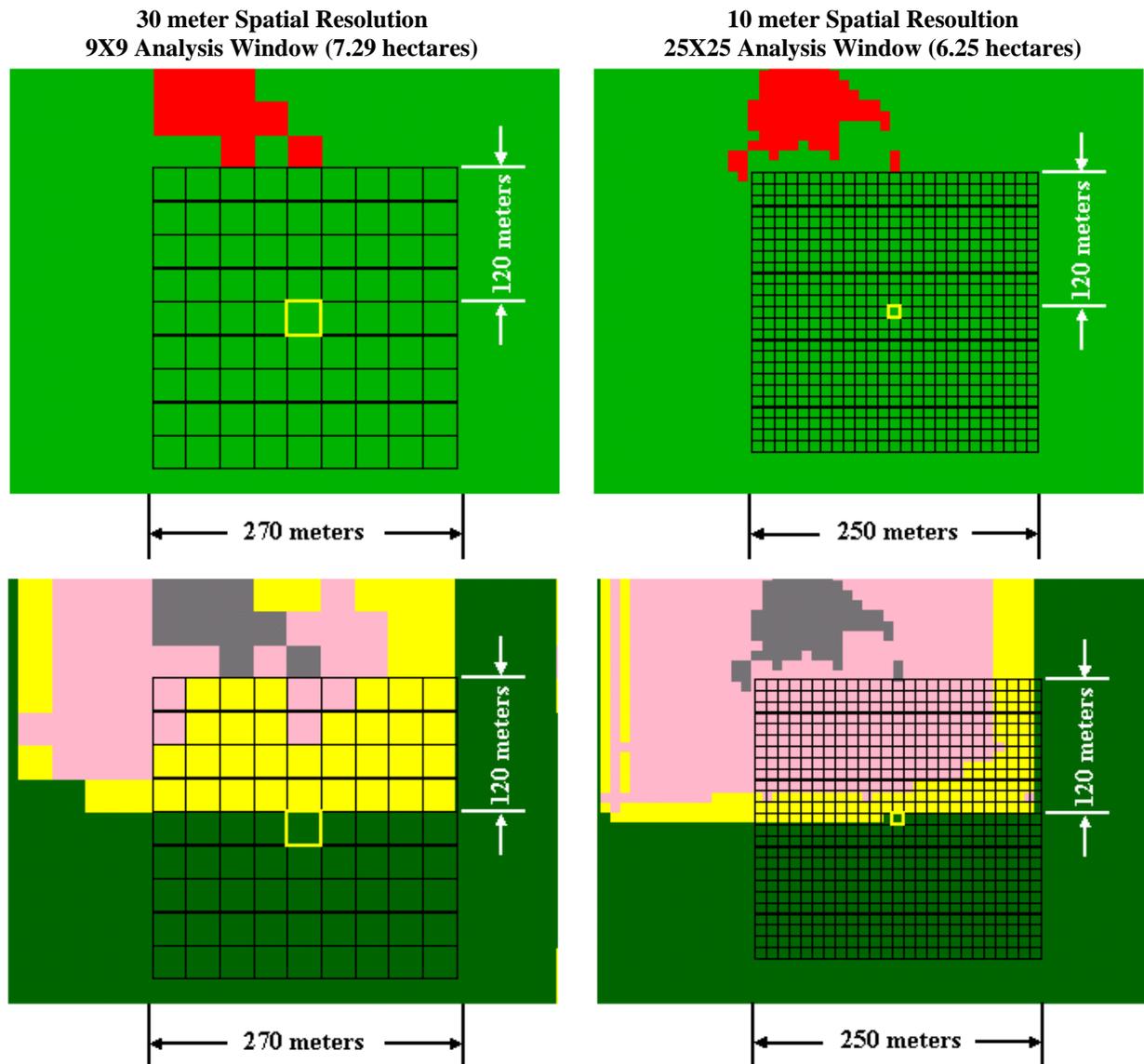
Figure 5. Comparison of the application of the forest fragmentation model on two land cover datasets of different spatial resolutions (top) and the resulting forest fragmentation maps and analysis window sizes needed to produce an edge/perforated width of equal linear distance of 120 meters (bottom). The yellow square represents the forest pixel being analyzed located at the center of the analysis window.

METHODS

Since the model was originally developed for coarser resolution land cover, an assumption was made that the 30-meter spatial resolution forest fragmentation map represented the correct distribution of forest fragmentation categories. It was then necessary to determine the value needed to identify the threshold (other than Pf-Pff < 0 or Pf-Pff > 0) between edge and perforated forests for higher spatial resolution forest fragmentation maps that would produce a result similar to the 30-meter spatial resolution forest fragmentation map. This threshold value is called the *Class Edge Bias*. To accomplish this, four land cover datasets with different spatial resolutions were created. The first was a 1-meter spatial resolution land cover based on 1-meter resolution imagery that was degraded to 4-meter, 10-meter, and 30-meter land cover respectively. The forest fragmentation model was then applied to each of these using the standard edge and perforated definitions to derive the forest fragmentation maps shown in Figure 4. Subsequent runs of the model were performed, with each run altering the Class Edge Bias value (*i.e.* Pf-Pff < -0.1 and Pf-Pff > -0.1). Based on visual analysis and graphing the areal extent of each forest fragmentation category, it was found that the higher the spatial resolution of the land cover, the more negative the Class Edge Bias value had to be to approximate the results of the 30-meter forest fragmentation analysis. These values were ultimately plotted against the spatial resolution of the land cover (Figure 6) to generate the following regression equation:

$$\text{Class Edge Bias} = 0.0488 * \ln(r) - 0.1601$$

where r is the land cover spatial resolution (meters) and ln(r) is the natural log of r. Further tests have found that using this equation on other higher spatial resolution land cover has derived forest fragmentation maps that approximate the 30-meter derived forest fragmentation maps (Figure 7).
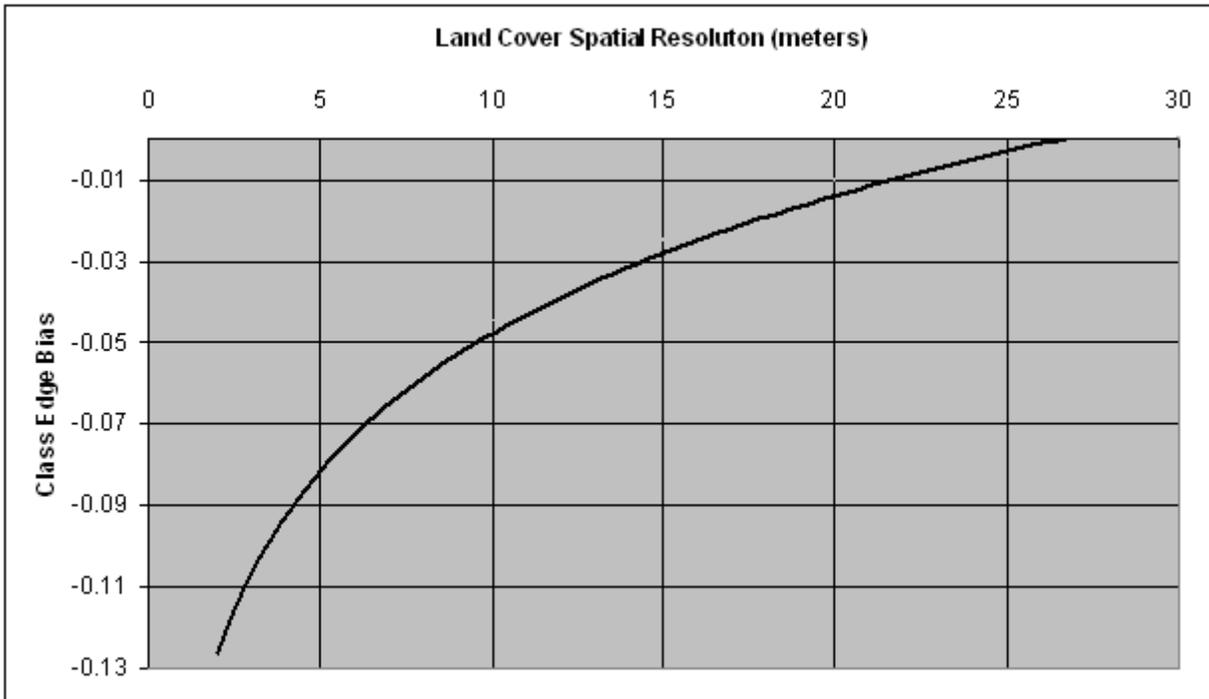
Figure 6. Resulting logarithmic regression trend line based on the alteration of the Class Edge Bias value for higher spatial resolution land cover to approximate the 30-meter forest fragmentation result (R^2 = 0.9904).
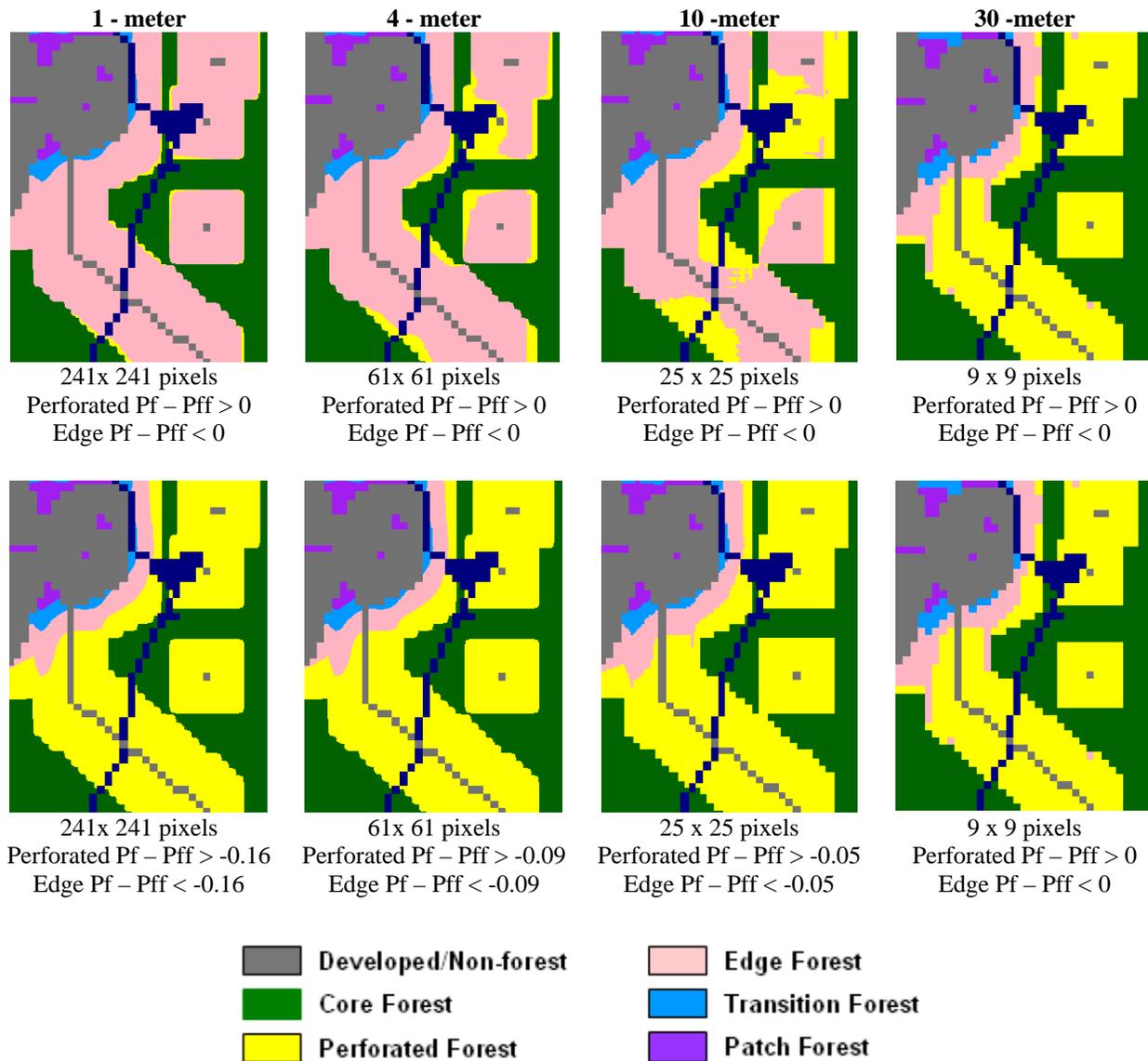
Figure 7. Examples of applying the forest fragmentation model to land cover of different spatial resolutions using analysis windows of similar spatial extent with the top row showing results where the Class Edge Bias values remained at zero and the bottom row showing altered Class Edge Bias values appropriate to the spatial resolution of the land cover to produce a result that approximates the 30-meter spatial resolution forest fragmentation map.

DISCUSSION

The creation of land cover maps of different spatial resolutions for the same area result in land cover maps of differing landscape patterns. With coarser resolution land cover, a given feature might be represented as a single pixel whereas the same feature might be represented by numerous pixels depending on the spatial resolution of the land cover and the size of the feature. Additionally, thin linear features and other small features may not even be detected with coarse resolution land cover. Based on this issue alone, the potential for differences in forest fragmentation maps based on image convolution using different spatial resolution land cover is highly probable.

Using analysis window sizes of similar areal extent, it would be expected that the results from applying the forest fragmentation model to land cover of different spatial resolutions would be similar. This was found not to be the case. The cause appears to be with the calculation of the Pf and the Pff values which represent the proportion of

forest pixels within an analysis window of a given size and the connectivity or adjacency of those forest pixels within the analysis respectively. With forest fragmentation maps derived from coarser resolution land cover the connectivity of forest pixels is lower than for forest fragmentation maps derived from higher spatial resolution land cover. Essentially there are fewer forest pixels to be connected for a given area with coarser land cover than for a similar area of higher spatial resolution land cover. The result in terms of the function of the forest fragmentation model is to over estimate the amount of edge forest compared to perforated forest due to the higher Pff values being calculated from higher spatial resolution land cover. If the definition of edge and perforated forest remain the same (Pf-Pff > 0 for perforated and Pf-Pff < 0 for edge) then edge forest is likely to be identified, again dependent on the landscape patterns identified in the land cover. To correct for this, it is necessary to alter the Class Edge Bias value for higher spatial resolution land cover to produce a result similar to a coarser resolution forest fragmentation map.

Because of the variability of landscape patterns among various land cover maps due to spatial resolution and the distribution of landscape features, there may be instances where it is not appropriate to alter the Class Edge Bias for higher spatial resolution land cover. In fact, the assumed correct 30-meter resolution result may not even be considered correct in all cases. As such, CLEAR, in partnership with Placeways LLC (http://placeways.com/), developed a toolbox[1] (Figure 8) for use in ESRI's ArcGIS 9.2 geographic information system software to provide users with the ability to customize the forest fragmentation model inputs to satisfy their needs. Required inputs include a raster land cover map of any spatial resolution, the size of the analysis window in terms of pixels, and an appropriate Class Edge Bias value. Output options include the forest fragmentation map and optional images that show the results of Pf and Pff.
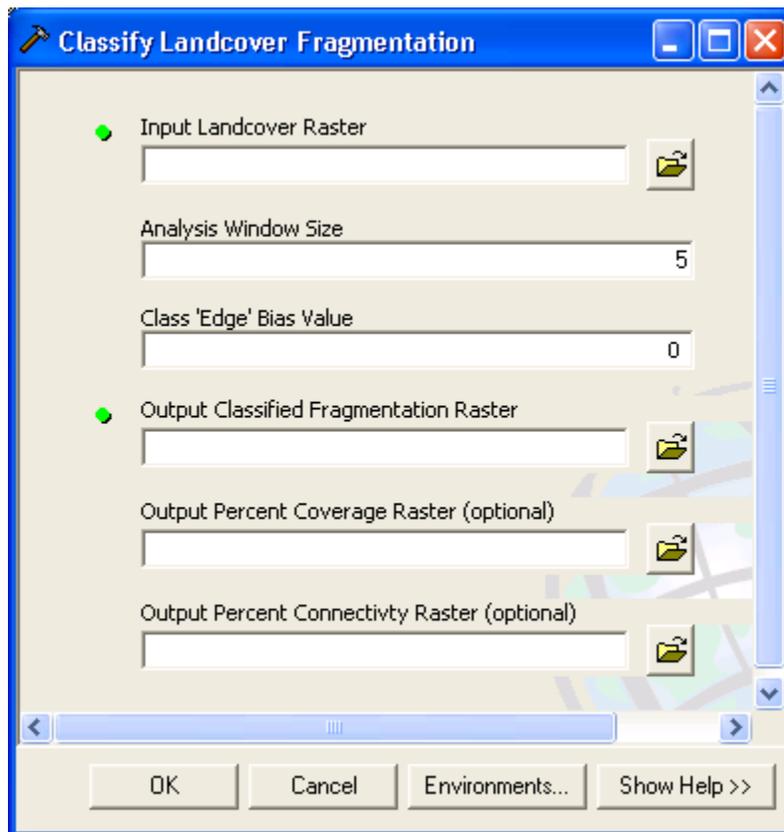
Figure 8. Graphical user interface of the forest fragmentation model as implemented in ESRI's ArcGIS 9.2 GIS software.

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[1] This toolbox may be downloaded at http://clear.uconn.edu/projects/landscape/forestfrag/ff_tool.htm.

CONCLUSION

The forest fragmentation model described is based on image convolution whereas a roving analysis window of fixed size is used to calculate values of Pf (forest proportion) and Pff (forest connectivity or adjacency) which are then used to describe five categories of fragmentation. Using this model, a user is able to quantify the type of fragmentation occurring within an area and can further track changes in each of these categories over time given appropriate, consistent, land cover data. It is important to note that the model itself is only approximate, and when comparing among land cover maps of different spatial resolution land cover is dependent on the characteristics and patterns of the input land cover map. It is also important to note that no single size analysis window will be correct for all purposes. Ultimately the size of the analysis window used will be based on the spatial resolution of the land cover and desired width of the edge/perforated fragmentation category. As shown in this paper, land cover of different spatial resolutions produce different forest fragmentation results when the same definition for edge and perforated forests are used. Adjusting the Class Edge Bias value will allow the user to produce a fragmentation map that is similar across land cover of different spatial resolutions.

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