ASSESSING FOREST FRAGMENTATION IN CONNECTICUT USING MULTI-TEMPORAL LAND COVER

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ABSTRACT

Connecticut's Changing Landscape (CCL) is an ongoing project of the Center for Landuse Education and Research (CLEAR) at The University of Connecticut that currently consists of five dates of land cover (1985, 1990, 1995, 2002, and 2006) based on Landsat satellite imagery that spans a 21 year period for the state of Connecticut. This data has become a major resource for researchers, state agencies, regional and local planners, and the public to examine and assess land cover trends in the state.

Recently, CLEAR researchers have expanded the scope of the CCL project to look more closely at the impact of Connecticut's land cover patterns on the state's forest resources. The 2006 land cover map shows that Connecticut is approximately 60 percent forested (7,568 km^2) and has lost nearly 500 km^2 of tree cover since 1985. Yet Connecticut ranks fourth in highest population density (279 persons per km^2) of all the states in the United States. Since tree cover alone is not a complete indicator of the functional health of forested ecosystems, which can be impacted by proximity to non-forested areas, CLEAR has developed a landscape fragmentation tool that identifies and quantifies four types of forest fragmentation; core forest, edge forest, perforated forest, and patch forest. This tool was applied to the land cover information to show that there is a decline in overall forest cover and that existing forests are becoming more fragmented and isolated.

INTRODUCTION

Connecticut is part of the northeast United States megalopolis, and is located between the two major metropolitan centers of New York, NY and Boston, MA (Figure 1). As such, municipal and state officials are 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 (279 persons per square kilometer of land) yet has a tree canopy cover of nearly 60 percent. This juxtaposition of high population density and high forest cover presents the question of how intact is the forested landscape in Connecticut?

To examine this question, and assess the condition of forests in Connecticut, the University of Connecticut's Center for Landuse Education and Research (CLEAR) has applied a Landscape Fragmentation Tool to quantify internal and external fragmentation of the forests and to track changes over time. This project utilized five dates of land cover of Connecticut, spanning a 21 year period (1985, 1990, 1995, 2002, and 2006) that is the basis of CLEAR's *Connecticut's Changing Landscape*[1] (CCL) project. The CCL land cover data, derived from Landsat satellite imagery, provides a consistent representation of land cover and land cover change of the state from which other landscape analysis can be conducted, such as forest fragmentation.

Why be concerned with forests? Forests provide a wide variety of benefits that are important to the sustainability of a region's economies, communities, and natural environments. Benefits include providing habitat for wildlife, maintaining biodiversity, protecting water quality and quantity, reducing storm water run-off and erosion, improving air quality, regulating climate and carbon sequestration, providing a destination for recreation

[1] http://clear.uconn.edu/projects/landscape/index.htm

Figure 1. The northeast United States megalopolis (source: http://www.uta.fi/FAST/US2/REF/MAPS/reg-belt.html).

and tourism, and providing timber and non-timber resources (Barnes *et al.* 1998; Krieger 2001; BOA, 2008; Watson, 2008). 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 converting large tracts of forest into smaller isolated tracts (NCSSF, 2007). In Connecticut, this is overwhelmingly due to anthropogenic activities, originally through the clearing of forests for agricultural and industrial purposes, and more recently through urban expansion. 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. According to the Society of American Foresters, 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."

METHODS

At the end of 2008, CLEAR researchers completed an update to the *Connecticut's Changing Landscape* land cover data set (CCL v. 2.0). In addition to adding land cover for 2006, the previous four dates (1985, 1990, 1995, and 2002) of land cover were upgraded with other refinements to improve thematic quality. These data have proven to be a valuable resource and used by many in the state of Connecticut to track land cover change. The data also permit the analysis of other landscape wide phenomenon such as tracking the extent of forest fragmentation over time. To make forest fragmentation change most relevant, however, it is important to have a consistent set of land cover and land cover change information. The following sections will describe the generation of the multi-date land cover data set, the Landscape Fragmentation Tool (LFT), and the resulting forest fragmentation maps derived from the application of the LFT to the multi-date land cover.

Connecticut's Changing Landscape Land Cover

The initial land cover (CCL v. 1.0), completed in 2004, was developed using a cross-correlation analysis technique (Koeln and Bissonnette, 2000; Smith *et al.*, 2002). This began with the classification of Landsat imagery from 1985 using a two-step iterative ISODATA clustering technique. First, clusters were identified and labeled into one of eleven informational land cover categories: developed land, turf & grass, other grasses & agriculture, deciduous forest, coniferous forest, water, non-forested wetland, forested wetland, tidal wetland, barren land, and other. The "other" category contained clusters of pixels that were not readily identifiable as belonging to a single informational class. A second ISODATA clustering procedure was performed on these "other" pixels and the resulting clusters further identified and labeled into one of the final ten land cover categories. This was added to the first ISODATA classification result to create a single 10-category land cover image. Extensive on-screen digitizing was performed to eliminate apparent gross errors and to add isolated linear roads and also include utility corridors to the classification which were digitized from the forest categories. These linear features are important because they are considered fragmenting features in the forest landscape, yet the 30 meter pixel resolution of the Landsat Thematic Mapper image is not always capable of depicting these features using traditional classification techniques.

Following the completion of the 1985 classification, cross-correlation analysis (CCA) was applied to 1990 Landsat imagery. The CCA works by using the land cover categories identified in the base land cover to derive an "expected" class average spectral response for each class from a subsequent Landsat image. A pixel that is spectrally far from the expected response for a given class is considered a changed pixel. Once the CCA process is complete, and all likely changed pixels are identified in the 1990 Landsat imagery, they are classified and identified using ISODATA and then embedded into the 1985 land cover to create an updated 1990 land cover. Using the updated 1990 land cover, CCA was again used to create a 1995 land cover, and then the 2002 land cover, and finally the 2006 land cover.

Additional processing was applied to all five dates to produce the current CCL v. 2 land cover. This included the extraction of an agricultural fields land cover category using other sources of land cover (*e.g.* NLCD 1992 and 2001 and GAP products) as a guide followed by extensive on-screen digitizing based on high resolution 2006 NAIP digital photography. Lastly, due to the assumption that developed land cover would not revert to another land cover type over time, it was found that the developed category was being over estimated, particularly in the highly urbanized areas. To reduce the amount of development classified, pixels identified as development from the most recent Landsat data (2006) were extracted and reclassified as either development, turf & grass, or deciduous forest. These were then embedded in each of the five dates of land cover (1985, 1990, 1995, 2002, 2006). The result was a better representation of the development and vegetative patterns in the land cover, particularly in the highly urbanized areas.

The final result is a consistent, five date, land cover data set that can be used to identify land cover change over the 21-year sampling period. Examples of each of the land cover dates are presented in Figure 2. Resulting change products that show the increase in development during each time period and from which land cover type the developed category has removed are shown in Figure 3. CLEAR educators have found retrospective data on land cover change to be a powerful tool to help decision makers analyze the ultimate landscape results of their past land use decisions, and to begin to grasp what future changes their current land use policies may produce. In addition to the data, the land cover imagery displayed via simple animated sequences, is a striking educational tool that can help underscore more technical points about the impacts of land use regulations.

Landscape Fragmentation Tool

The Landscape Fragmentation Tool[2] (LFT v2.0) was developed by CLEAR researchers to identify internal and external fragmentation categories for a specified land cover feature. In the case of this paper, the LFT was applied to forest land cover (which consists of the deciduous, coniferous, and forest wetland categories) to assess forest fragmentation within the state. The concept for this model came from a paper authored by Vogt *et al.* (2007) who developed a method for identifying types of fragmentation based on image morphology. Their approach used a sequence of logical operations applied with structuring elements (SE) of two pre-defined shapes and dimensions. One of these being an eight-pixel neighborhood around the center pixel, and the second being a four pixel neighborhood, in the cardinal directions, around the center pixel. Erosion and dilation operations were applied using each SE to shrink and expand the connectivity of pixels to derive a fragmentation result. The LFT uses a different procedure that derives an equivalent result, but takes advantage of the capabilities of ESRI's ArcGIS software. As a result, the LFT v2.0 is able to perform the fragmentation analysis in a more efficient and intuitive manner.

The LFT classifies a land cover type of interest, such as forest, into four main categories - *patch, edge, perforated, and core.* The core category is further divided into small core, medium core, and large core based on the area of the core tract. These are described in Table 1, as applied to forest cover. The main fragmentation categories are defined based on an edge width parameter. Many studies have documented the degradation of forests or grasslands along the edges of disturbances (Forman, 2000; Forman and Deblinger, 2000; Harper *et al.*, 2000; Riitters and Wickham, 2003). The edge width indicates the distance over which a fragmenting land cover (*i.e.* urban or agriculture) can degrade the land cover of interest (*i.e.* forest). The width of the 'edge effect' varies depending on the species or issue being studied. Fore example, pasture adjacent to a forest may have an edge influence of 100 meters into the forest whereas a two lane highway may have an edge influence up to 200 meters into the forest and a four lane highway up to 300 meters. The sub-classification of core pixels is based on studies of forest ecology (Andren, 1996; Villard *et al.*, 1999; Mortberg, 2001; Lee *et al.*, 2002; Environment Canada, 2004). These studies have found that the area of a forest tract impacts its viability in terms of supporting wildlife. Larger forest patches are more likely to support greater numbers of interior forest species.

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[2] http://clear.uconn.edu/tools/lft/lft2/index.htm

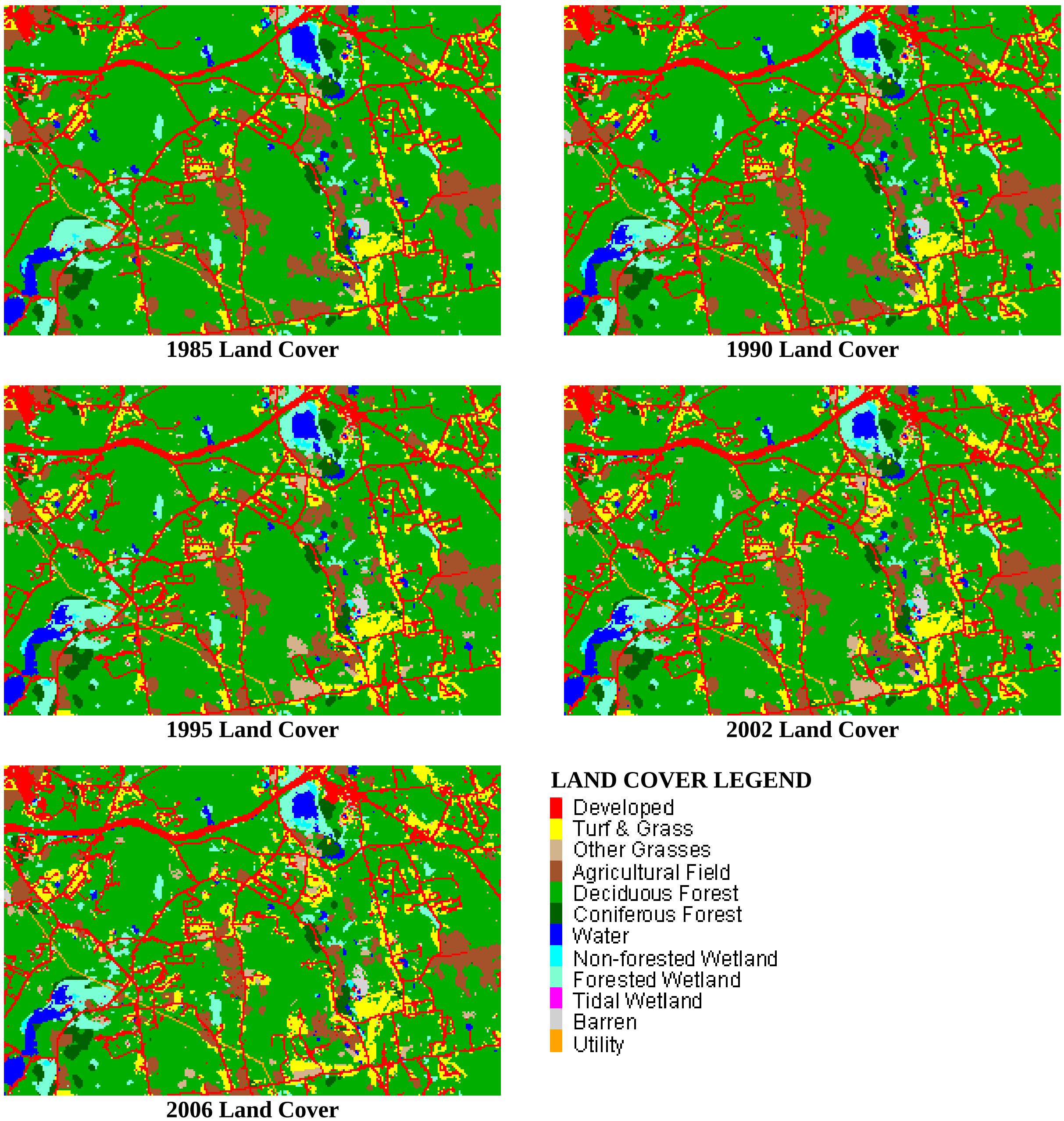


Figure 2. Examples of the Connecticut's Changing Landscape land cover for each of the five dates for a portion of Connecticut.

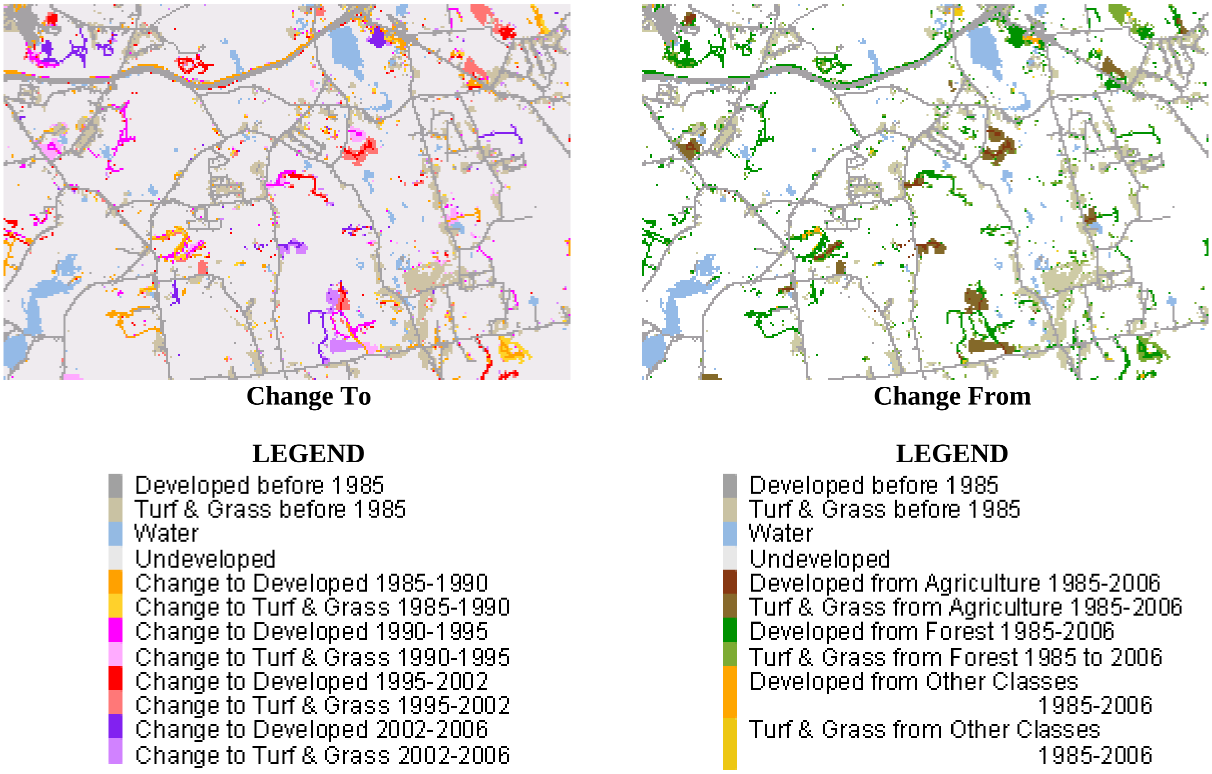


Figure 3. Examples of the Change To and Change From land cover maps based on the five date Connecticut's Changing Landscape land cover data set.

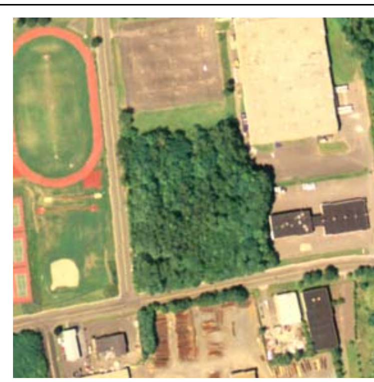
The Landscape Fragmentation Tool v2.0 is a python script that runs out of ArcToolbox and requires ArcGIS 9.3 (an ArcGIS 9.2 version is also available). An example of the GUI is provided in Figure 4. Requirements for running the tool is an input raster land cover reclassified so a value of 1 is given to the land cover categories that are causing the fragmentation, a value of 2 for the land cover category being fragmented (typically the land cover category of interest), and a NoData value given to any category that is not analyzed, or does not influence fragmentation. An edge width must also be specified. This is the distance from the land cover boundary (*e.g.* the forest non-forest land cover boundary) into the fragmented land cover category (*e.g.* forest) that determines the width of the edge and perforated categories. The units will be the same as the input land cover, and the distance must be greater than the size of the land cover pixel. Lastly, an output raster name must be specified.

Connecticut's Changing Landscape Forest Fragmentation Analysis

The forest fragmentation maps[3] which identify patch, perforated, edge, and three sizes of core forest were generated using the LFT applied to the CCL land cover. As required by the LFT, the land cover was reclassified to identify the non-forest, forest, and not analyzed categories. The reclassification of the land cover is shown in Table 2. Water, non-forested wetland, and tidal wetland were excluded from the analysis since these are considered natural features in the landscape and thus do not contribute to anthropogenic caused fragmentation, represented by the remaining categories. By excluding these categories from analysis, forest will remain as core forest up to the edge of water, non-forested wetland and tidal wetland features, thereby not creating an edge or perforated forest category along a natural boundary.

[3] http://clear.uconn.edu/projects/landscape/forestfrag/index.htm

Table 1. Definition of forest fragmentation categories as applied to the Connecticut's Changing Landscape Forest Fragmentation Analysis, with representative examples from aerial imagery

Core forest - Forest areas that are relatively far from the forest/non-forest boundary. Essentially these are forested areas surrounded by more forested areas. In the case of the forest fragmentation results presented in this paper, the core forest will be further than 100 meters from the forest/non-forest boundary. **Sub-categories** • **Small Core Forest –** Less than 100 hectares (approximately 250 acres). • **Medium Core Forest** – Between 100 and 200 hectares (approximately 250 – 500 acres). • **Large Core Forest** – Larger than 20 hectares (approximately 500 acres).	
Perforated forest - Forest areas that define the boundary or transition zone between core forest and relatively small clearings (perforations) within the forested landscape. In the case of the forest fragmentation results presented in this paper, the perforated forest will be within 100 meters of a relatively small forest clearing and adjacent to core forest.	
Edge forest - Forest areas that define the boundary or transition zone between core forest and large non-forested land cover features. In the case of the forest fragmentation results presented in this paper, the edge forest will be within 100 meters of a large non-forest land cover feature and adjacent to core forest	
Patch forest – A small forested or treed area surrounded by non-forested land cover. The patch forest cannot be adjacent to any core forest areas, that is, a patch forest must be completely isolated from other forested areas. In the case of the forest fragmentation results presented in this paper, a patch forest must be within 100 meters from a non-forest land cover feature.	

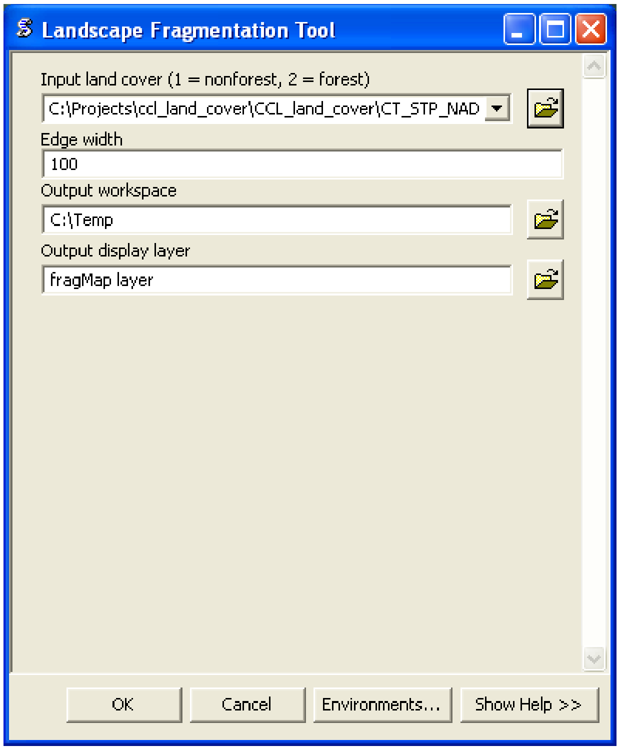


Figure 4. Graphical User Interface (GUI) of the Landscape Fragmentation Tool (LFT).

Table 2. Reclassification of the 12 land cover categories into the three categories require to run the LFT

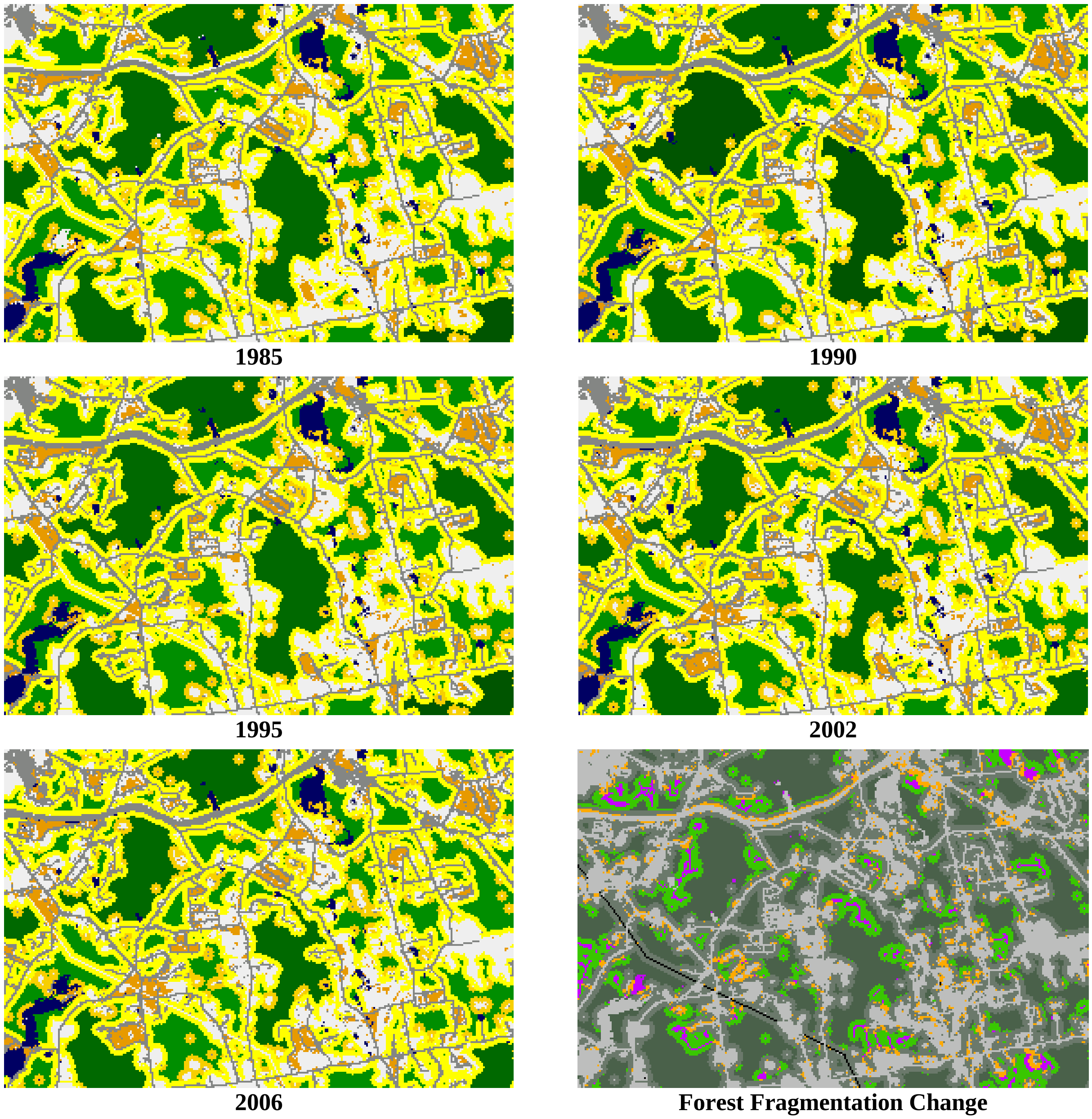
Original Category	Reclassified Category
1. Developed	1. Non-forest
2. Turf & Grass	1. Non-forest
3. Other Grasses	1. Non-forest
4. Agricultural Field	1. Non-forest
5. Deciduous Forest	2. Forest
6. Coniferous Forest	2. Forest
7. Water	NoData
8. Non-forested Wetland	NoData
9. Forested wetland	2. Forest
10. Tidal Wetland	NoData
11. Barren Land	1. Non-forest
12. Utility Corridor	1. Non-forest

To produce a general representation of forest fragmentation for Connecticut, a value of 100-meters was used for the edge width parameter in the LFT. As mentioned in the previous section, several studies have been conducted to examine the influence of various land cover features on forests and grasslands edges. Based on these studies, and understanding the complexities of potential edge influence from various land cover features, CLEAR researchers decided an edge width of 100-meters would produce a reasonable, albeit conservative, assessment of the average edge influence of non-forested land cover features to the forest edge. A sample of the forest fragmentation maps resulting from the application of the LFT to each date of the CCL forest land cover using a 100-meter edge width are provided in Figure 5. Additionally, an image showing change in forest fragmentation categories is provided.

DISCUSSION

Typically when we study the impact of development on forests, we quantify only the amount of forest that has been lost through removal. With the results of applying the LFT to assess forest fragmentation, we can clearly see that the impact to forest habitat and quality is much greater than just forest removal, since now forest edge effects have been introduced (compare images in Figure 2 with Figure 5). Based on this analysis, what can we say about how intact is the forested landscape in Connecticut?

First, the multi-date land cover data set provides the ability to track change in land cover over time. Statewide land cover statistics provided in Table 3, which shows the areal extent of land cover and percent cover statewide for each land cover and forest fragmentation category, for each year, identify the developed, turf & grass, other grasses and utility corridor categories (the four land cover categories considered to be most related to the built environment) have increased at the expense of the deciduous and coniferous forest and also agricultural land cover. This is evident in the change maps provided in Figure3. Further, Table 4 displays statistics identifying the change for each land cover and forest fragmentation category over the 1985 through 2006 period. Statistics provided are the increase or decrease in areal extent, the percent relative change which represents the difference between the 1985 and 2006 percent coverage, and the percent rate of change which represents how quickly a category is changing relative to the 1985 baseline. As shown in Table 4, the developed and turf & grass categories are increasing at a faster rate than the deciduous and coniferous forest are decreasing. This is due to the amount of developed and turf & grass in existence in 1985, proportionally more of these land cover types have been added to the landscape than removal of deciduous and coniferous forest due to these latter categories occupying a much greater percentage of the Connecticut landscape. Factor in other grasses and utility corridor with the developed and turf & grass categories and agriculture with the deciduous and coniferous categories, the amount of new land cover created (617 sq. km.) is near reciprocal to the amount of land cover removed (612 sq. km.).



FOREST FRAGMENTATION LEGEND

- Developed
- Undeveloped
- Water
- Patch Forest
- Edge Forest
- Perforated Forest
- Small Core Forest (< 100 ha.)
- Medium Core Forest (> 100 ha. and < 200 ha.)
- Large Core Forest (> 200 ha.)

CHANGE LEGEND

- Non-forest, No Change
- Fragmented Forest, No Change
- Core Forest, No Change
- Fragmented to Non-forest
- Core Forest to Fragmented Forest
- Core Forest to Non-forest

*Fragmented forest in the above legend includes patch, perforated and edge.

Figure 5. Examples of the application of the landscape Fragmentation Tool (LFT) to the Connecticut's Changing Landscape land cover for each of the five dates, and a forest fragmentation change map for a portion of Connecticut.

Table 3. Statistics identifying the aerial extent and percent cover of each land cover category and forest fragmentation category for Connecticut

	1985		1990		1995		2002		2006	
	sq. km	% of State	sq. km	% of State	sq. km	% of State	sq. km	% of State	sq. km	% of State
Developed	2065	16.05%	2233	17.35%	2293	17.82%	2390	18.57%	2440	18.96%
Turf & Grass	800	6.22%	844	6.56%	885	6.88%	939	7.30%	989	7.68%
Other Grasses	169	1.31%	178	1.38%	197	1.53%	213	1.66%	223	1.73%
Agricultural Field	1101	8.56%	1046	8.13%	1015	7.88%	963	7.48%	941	7.31%
Deciduous Forest	6390	49.65%	6243	48.51%	6163	47.89%	6056	47.06%	5976	46.43%
Coniferous Forest	1181	9.17%	1172	9.10%	1164	9.05%	1153	8.96%	1142	8.88%
Water	448	3.48%	437	3.40%	425	3.30%	417	3.24%	418	3.24%
Non-forest Wetland	52	0.41%	55	0.43%	55	0.43%	56	0.44%	55	0.42%
Forested Wetland	476	3.70%	460	3.58%	453	3.52%	450	3.50%	450	3.50%
Tidal Wetland	59	0.45%	59	0.46%	60	0.46%	60	0.47%	59	0.46%
Barren	83	0.65%	97	0.75%	115	0.89%	127	0.99%	133	1.03%
Utility Corridor	46	0.35%	45	0.35%	45	0.35%	44	0.34%	44	0.34%
Total Forest[1]	**8046**	**62.53%**	**7875**	**61.21%**	**7781**	**60.47%**	**7659**	**59.52%**	**7568**	**58.80%**
Patch Forest	603	4.69%	616	4.79%	629	4.89%	650	5.05%	668	5.19%
Edge Forest	2872	22.32%	2875	22.34%	2872	22.32%	2877	22.35%	2867	22.28%
Perforated Forest	376	2.92%	396	3.08%	443	3.44%	487	3.78%	521	4.05%
Small Core Forest	1121	8.71%	1116	8.68%	1106	8.60%	1075	8.35%	1064	8.27%
Medium Core Forest	769	5.98%	702	5.45%	679	5.27%	637	4.95%	606	4.71%
Large Core Forest	2305	17.91%	2168	16.85%	2049	15.92%	1935	15.03%	1841	14.31%
Total Core Forest[2]	*4196*	*32.60%*	*3989*	*31.00%*	*3836*	*29.81%*	*3644*	*28.31%*	*3512*	*27.29%*

[1] Sum total of the forest categories: Deciduous Forest, Coniferous Forest, and Forested Wetland.
[2] Sum total of the core forest categories: Small Core Forest, Medium Core Forest, and Small Core Forest.

Second, in terms of the forest fragmentation categories, perforated forest is increasing at the fastest rate followed by patch forest as shown in Table 4. Again, it is important to note the overall areal extent is smaller for these forest types than the remaining forest fragmentation categories (see Table 3) so small conversions can increase the rate of change more dramatically. The continued increase of perforated forest is indicative of more sprawling type development as these areas are punched out core forest regions creating forest perforations. The increase in patch forest is indicative of the continued disconnect of forest in primarily urbanized areas. In this case, small tracts of core forest surrounded by edge forest is broken apart into small patches, or as the urban area expands outward, forest is broken off from larger tracts of forests leaving small forest remnants as patch forest. A surprising finding is how little edge forest has changed during the 1985 through 2006 time period. This is likely due to removal of edge forest and conversion of core forest to edge forest as development extends outward from already developed areas. Animated sequences of the forest fragmentation maps have shown this to be true. Total core forest is decreasing, with each of the sub-categories of core forest decreasing at different rates. As shown in Table 3, large core forest still remains the largest in area of the three core forest categories, but has also decreased the most in area. More core forest appears to have been lost than total forest since all three core forest categories are changing whereas some of the other forest fragmentation categories making up the total forest values are actually increasing.

To expand on the purpose of having three core forest sizes. In the development of the LFT, the core forest was divided into three categories to indicate the viability of the core patches with respect to the size of the patch. These three categories – small, medium, and large - are based on the literature. All because it is classified as core forest, is it really productive core forest? Research suggests that total forest cover within a landscape has a greater role in maintaining biodiversity than forest patch size (Lee *et al.* 2002). However, the importance of forest patch size is still clearly significant for certain species (Lee *et al.* 2002; Mortberg, 2001; Villard *et al.* 1999; Andren 1996). It is recommended that 100 hectares should be considered the *absolute minimum* forest patch size needed to support area-sensitive edge-intolerant species. The *recommended minimum* forest patch size is 200 hectares, as this is likely to provide enough suitable habitat to support increased diversity of interior forest species. These two guidelines are reflected in the medium and large core categories in this study. The smallest core size in this study is smaller than these habitat-based guidelines. While not suitable for interior habitat, these smaller core forest areas are still valuable from forestry and other perspectives.

Table 4. Statistics identifying the aerial extent, relative percent change, and percent rate of change of each land cover category and forest fragmentation category for Connecticut

	Change 1985 - 2006		
	sq. km.	**% Relative Change**	**% Rate of Change**
Developed	375	2.91%	18.15%
Turf & Grass	189	1.46%	23.57%
Other Grasses	54	0.42%	31.70%
Agricultural Field	-160	-1.25%	-14.53%
Deciduous Forest	-414	-3.22%	-6.47%
Coniferous Forest	-38	-0.29%	-3.25%
Water	-31	-0.24%	-6.87%
Non-forest Wetland	3	0.01%	4.46%
Forested Wetland	-26	-0.20%	-5.50%
Tidal Wetland	1	0.01%	1.33%
Barren	50	0.38%	60.12%
Utility Corridor	-1	-0.01%	-2.84%
Total Forest[1]	**-479**	**-3.73%**	**-5.95%**
Patch Forest	67	0.50%	10.73%
Edge Forest	-8	-0.04%	-0.18%
Perforated Forest	145	1.13%	38.62%
Small Core Forest	-57	-0.44%	-5.08%
Medium Core Forest	-166	-1.27%	-21.21%
Large Core Forest	-464	-3.60%	-20.11%
Total Core Forest[2]	*-684*	*-5.31%*	*-16.30%*

[1] Sum total of the forest categories: Deciduous Forest, Coniferous Forest, and Forested Wetland.
[2] Sum total of the core forest categories: Small Core Forest, Medium Core Forest, and Small Core Forest.

CONCLUSION

Connecticut has clearly lost forest land cover over the 21 year period of this analysis. Further, based on the results of the application of the Landscape Fragmentation Tool to the forest categories, we can better understand the impact of land use decisions on the forest environment. It is evident that the forest in Connecticut is becoming increasingly disconnected due primarily to increased development. This is identified through continued increase in perforated forest, an indicator of sprawl like development patterns and patch forest, the continued division of larger forest tracts into smaller and thus less viable forest. Additionally, the decrease in all three core forest categories indicates the expansion of development to all reaches of Connecticut.

It is expected that the Connecticut landscape will continue to urbanize, resulting in increased pressure on the natural forested ecosystem. The results of the CCL land cover and associated forest fragmentation analysis will allow municipal and state land use decision makers to review past development patterns within the state and help them place their decisions within a broader spatial and temporal context. Connecticut remains heavily forested although over half of that forest is no longer functioning as core forest. It is, therefore, important that Connecticut land use decision makers work to protect the last remnants of core forest to maintain a semblance of a healthy working forest within Connecticut's borders.

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