FOREST FRAGMENTATION DUE TO LAND PARCELIZATION AND SUBDIVISION: A REMOTE SENSING AND GIS ANALYSIS

Brian M. Holdt, Graduate Research Assistant
Daniel L. Civco, Associate Professor
James D. Hurd, Research Assistant
Department of Natural Resource Management and Engineering
College of Agriculture and Natural Resources
University of Connecticut
Box U-4087, Room 308, 1376 Storrs Road
Storrs, CT 06269-4087
bholdt@canr.uconn.edu
dcivco@canr.uconn.edu
jhurd@canr.uconn.edu

ABSTRACT

The parcelization of single-owner tracts of land has been the primary cause of forest fragmentation in Connecticut over the past forty years. As the parcel size decreases, and the number of landowners increases, the manageability of the forest as a resource is also greatly affected. The purpose of this study was to examine these interactions in a six- town area located in the Salmon River watershed in eastern Connecticut. The relationship between the parcelization and the forest fragmentation is actively tracked through time using GIS; data include town parcels, land cover, soils, and terrain. The physical changes in the forest are characterized and measured using a variety of remote sensing data sources and techniques, using primarily 30-meter Landsat satellite imagery. Finally, municipal factors including zoning, conservation plans, taxation, and property owner rights are evaluated to understand better the impact of local government and community decisions. By combining the temporal evaluation of satellite imagery, the GIS discovery of parcelization trends, and the socio-economic impact of community government, a set of land use decision support models and visualizations are created. These tools will help future landowners and community governments control the fragmentation and guide the community development in more sustainable processes, to ensure the long-term successful management of forest resources.

INTRODUCTION

The combination of high population density and forestland ownership puts the Connecticut's forest resource at risk and places a premium on understanding the relationship of development patterns, especially forest fragmentation and landscape parcelization, to the physical changes in the landscape. Forest extent and fragmentation will be mapped for a 40-year period. The relationship between land subdivision and forest fragmentation will be examined. Correlations of these trends will be made with observable trends in regulatory and policy decisions and characteristics of the landscape.

LAND COVER CLASSIFICATION

The primary data source for this research was a land cover classification conducted by researchers at the University of Connecticut's Center for Land use Education and Research (CLEAR). This classification map of Connecticut was derived for four dates over a 17-year period using 30-meter Landsat imagery. This imagery was processed using sub-pixel classification, supervised and unsupervised classification, and cross-correlation analysis. The resulting land cover map divided the landscape into a variety of urban and forest categories, accurately quantifying the land cover and the changes to the land cover through time (Hurd *et al* 2003).

Based upon this land cover classification map, a forest fragmentation map was created (Hurd *et al* 2003). The categories chosen were based upon the Riitters *et al* (2000) fragmentation model, and include interior, perforated, edge, transition, and patch. These categories are defined as follows:

- Interior forest – all pixels in the surrounding area are forest
- Perforated forest - most of the pixels in the surrounding area 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.
- Edge forest - most of the pixels in the surrounding area 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.
- 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.
- 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.

These five categories were supplemented with four additional non-forest categories: Water, Urban, Agriculture, and Barren. By default, a No Data category was also used to classify the pixels outside of the study area.

The Connecticut landscape was classified according to these categories for four dates: 1985, 1990, 1995, and 2002. These land cover maps clearly illustrate the changes to the landscape, and how forest integrity has diminished through time. A chief cause of the change is assumed to be urban growth, and the spread of urban areas into surrounding towns. However, there has been no clear manner in which to quantify the impact of residential development on the forest change.

FRAGMENTATION

Habitat fragmentation is defined as the process of dissecting large and contiguous areas of similar native vegetation types into smaller units separated by different vegetation types and/or areas of intensive human activity (Saunders *et al* 1991). Such habitat disturbance is estimated by the USDA Forest Service to affect habitat quality for over 80% of all mammal, reptile, bird, and amphibian species found in forest habitat (USDA Forest Service 1997). The fragmentation of habitat has been cited as the primary cause of rapid species extinction, and the loss of native species (Wilcox and Murphy 1985). These species declines due to fragmentation have been extensively documented for many species, including birds, small mammals, and invertebrates.

The fragmentation of the forest causes a number of changes to the habitat; aside from the loss of continuous acreage, changes in spatial patterns, species movement, and competitive advantages also occur. The introduction of exotic species also changes the communities and the relative advantages within. For example, fragmentation causes an increase in the amount of edge per acre of forest, thereby improving habitat for species that are best adapted to edge environments, while degrading the area for those species that are best suited for interior areas.

PARCELIZATION

Parecelization is defined as the process by which large tracts of single owner land are subdivided into many small parcels with multiple owners. This shift occurs for a number of reasons, including increasing real estate values, urbanization, and landowner age.

In order to quantify the impact of parcelization on forested areas, it is vital first to determine exactly where and when this parcelization is occurring. When this information is available, the forest fragmentation levels for the region can be compared to the forest fragmentation levels for the recently parcelized areas. This comparison will quantify the impact of parcelization, thereby further defining the true impacts of urban growth and subdivision of land.

STUDY AREA

The rural study area (Figure 1) is contained within the Salmon River watershed, which covers roughly 150 square miles of eastern Connecticut. The Salmon River and the surrounding watershed drain directly into the Connecticut River. Six towns cover the majority of this watershed, including Bolton, Colchester, East Haddam, East Hampton, Hebron, and Marlborough. The study area for this research was chosen for three main reasons:

- The area has undergone extensive development over the past several decades, with an average population growth rate of 172% over the past forty years (Table 1);
- The area has shifted from being a largely agricultural area to a residential zone, acting as a bedroom community for the city of Hartford, located approximately thirty miles to the northwest;
- This study area is also significant for geographic reasons, as the six towns cover over 93% of the Salmon River watershed. This congruence of political boundary and the physical watershed boundary allows the results of the study to be interpreted on both human and ecosystem levels.

Table 1. Population Change 1960-2000

Town	1960	1970	1980	1990	2000	growth
Bolton	2,933	3,691	3,951	4,575	5,017	71%
Colchester	4,648	6,603	7,761	10,980	14,551	213%
East Haddam	3,637	4,676	5,621	6,676	8,333	129%
East Hampton	5,403	7,078	8,572	10,428	13,352	147%
Hebron	1,819	3,815	5,453	7,079	8,610	373%
Marlborough	1,961	2,991	4,746	5,513	5,709	191%
region total	20,401	28,854	36,104	45,251	55,572	172%

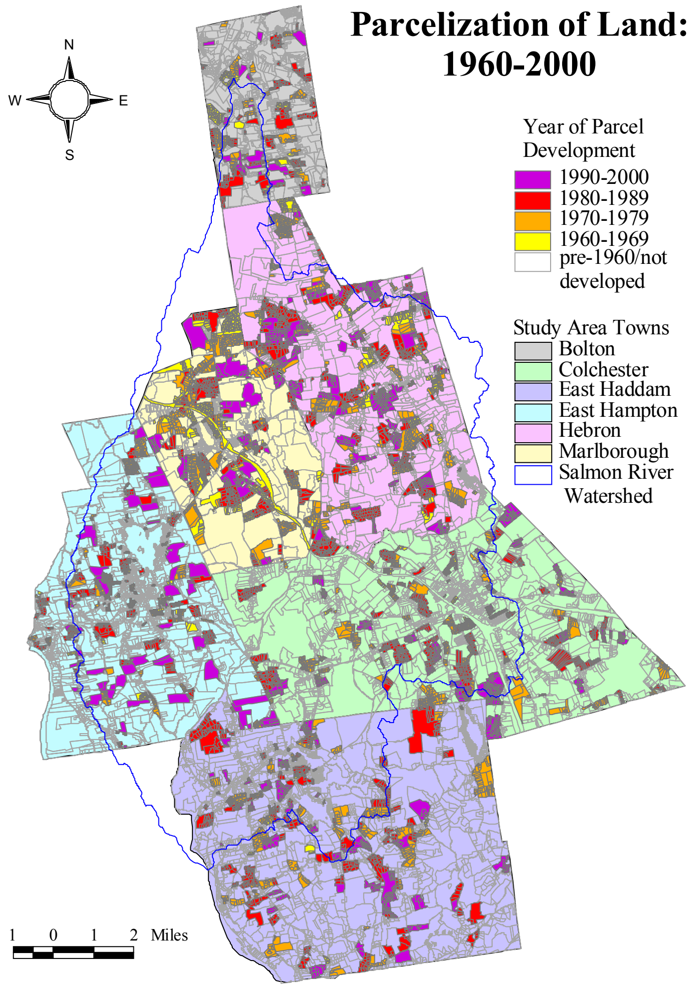

Figure 1. The Salmon River Watershed study area, and the six towns that encompass 93% of the watershed area.

METHODS

The overall procedure for extracting forest fragmentation by land parcel required several processing steps (Figure 2). Parcel maps were obtained for the six towns in the study area. The parcelization history for the 40-year period of 1960 to 2000 was manually recorded using the property maps at each town hall, with a specific year of subdivision recorded for each parcel polygon. These data were attributed to digital parcel maps using ESRI ArcView. The digital parcel maps for the six towns were merged into a master coverage illustrating the subdivision history across the study area.

The date of subdivision data was segmented into five-year increments to illustrate the subdivision trends, graphically illustrated with an animation of the parcelization over the forty-year period. These grouped shapefiles were then converted into grid format using ERDAS Imagine; these grids were used to create mask layers. When applied to the watershed level fragmentation maps, the resulting coverage defines the fragmentation levels only for those parcels, which had been developed in the previous five-year period. The number of pixels per category was recorded, and converted to a percentage. These percentages were then compared to the watershed level statistics (Table 2) using Microsoft Excel. The process was repeated with parcels grouped into ten-year increments to determine longer-term effects.

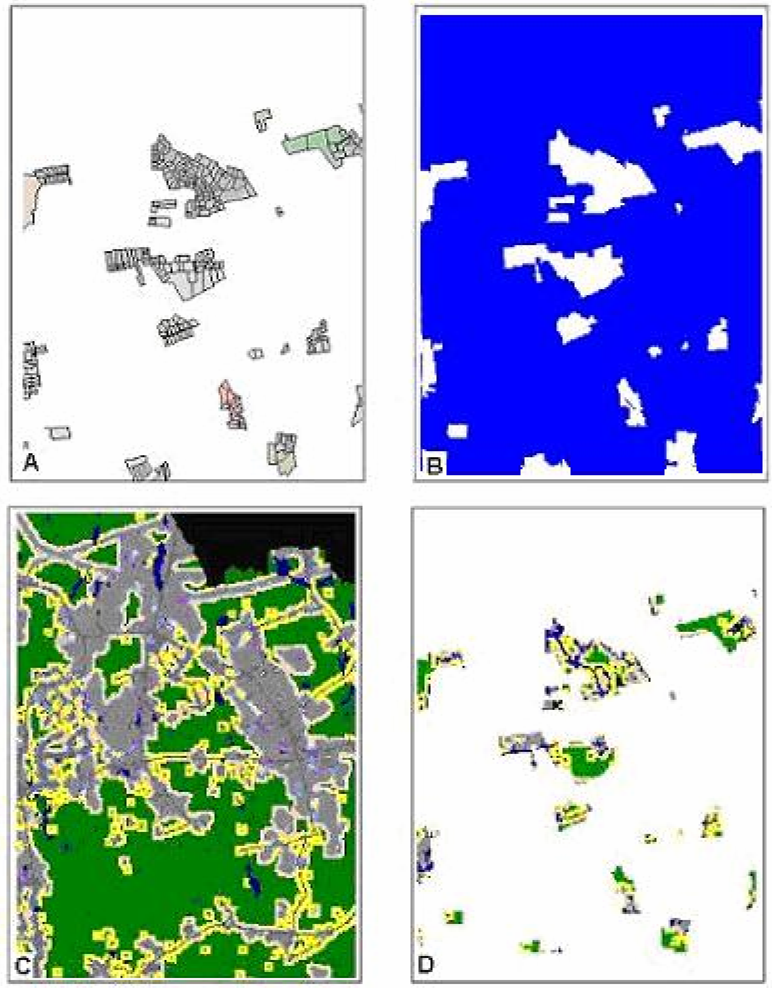

Figure 2. The steps involved in extracting the fragmentation information for the parcels: First, the parcel map (A) for each town is attributed so that each parcel is dated. Then, the parcel data are grouped by year of parcelization, converted into a grid, and used as a mask (B) for the forest fragmentation map (C). The resulting map (D) illustrates the forest fragmentation just for the parcelized areas.

Forest Fragmentation and Land Cover Classes	
	Interior forest
	Perforated forest
	Edge forest
	Transitional forest
	Patch Forest
	Water
	Urban
	Agriculture
	Barren
	No Data

CONCLUSIONS

The initial stages of research confirm that parcelization of land has a great impact on forest continuity. Specifically, as land is subdivided, the amount of interior forest decreases greatly, while amounts of urban area and non-continuous forest types increase.

When comparing the watershed fragmentation maps over the 15-year period, the following trends were observed:

- The amount of urban area increased from 9% overall to 13% overall;
- The amount of interior forest decreased substantially from 1985 to 1999, with the lowest period of change between 1995 and 1999;
- As the interior forest levels decrease, the amount of perforated forest increased, while the edge, patch, and transitional areas remained fairly constant;
- The total amount of forest decreased from 75% to 68%, with the lowest period of change between 1995 and 1999.
- When comparing the landcover of just those parcels that have been subdivided in the previous five or ten-year increments to the landcover of the watershed as a whole, the following trends are observed:
- The percentage of interior forest is significantly lower in the parcelized areas than in the watershed as a whole;
- The amount of interior forest was less after ten years of potential development than after the five-year period, indicating that while most development occurs within five years of parcelization, additional development will occur beyond the five-year period;

- Despite the dramatic decrease in interior forests due to parcelization, the percentage of total forest classes was relatively consistent. This was due to increased levels of perforated forest, and a slight increase in the transitional forest. Patch forest areas remained constant at 1% throughout the time period.
-

FUTURE RESEARCH

The forest change over time will be analyzed further by grouping the parcels into 15-year and 20-year increments. It is expected that the longer term results will continue the trends shown by the five-year and ten-year statistics, though some increase in non-interior forest levels is likely to occur, as previously cleared areas begin to grow young forests. There will also likely be some variance as land shifts fluctuate over the years between agriculture and forest, depending upon economic conditions.

It is very likely that the interior forest levels will continue to drop; once an interior forest area is disturbed, only removal of development and extensive regrowth time can restore the forested area. Even if such conditions occur, the biodiversity and forest health have been compromised, and a return to pre-disturbance conditions would typically require many decades to several hundred years, depending upon the forest conditions and species mix.

Additional future research will focus on the risk of parcelization to additional forest areas, including the proximity to roads, forest edge, and urban centers, and physical conditions such as aspect, slope, and soil conditions. These findings will be presented at the 2004 ASPRS Conference in Denver, and will be included in the senior author's Masters Thesis at the University of Connecticut.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Storrs Agricultural Experiment Station, Hatch project CONS00750 "Remote Sensing and GIS Analysis of Landscape Parcelization and Forest Fragmentation". [CLEAR Publication 040227.3]

REFERENCES

Best, C. (2002). America's Private Forests: Challenges for Conservation. *Journal of Forestry*, 100(3); 14-17.

Hurd, J.D., D.L. Civco, E.H. Wilson, S. Prisloe, and C. Arnold. (2003). Temporal Characterization of Connecticut's Landscape: Methods, Results, and Applications. Proc. 2003 ASPRS Annual Convention, Anchorage. AK. 12 p.

Hurd, J.D., E.H. Wilson, and D.L. Civco. (2002). Development of a Forest Fragmentation Index to Quantify the Rate of Forest Change. Proc. 2002 ASPRS-ACSM Annual Convention, Washington, DC. 10 p.

Mehmood, S.R., and Zhang, D. (2001). Forest Parcelization in the United States: A Study of Contributing Factors. *Journal of Forestry*, 99(4); 30-34.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. (2000). Global-scale Patterns of Forest Fragmentation. *Conservation Ecology*, **4**(2): 3. [online] URL: http://www.consecol.org/vol4/iss2/art3.

Saunders, D.A, R.J. Hobbs, and C.R. Margules. (1991). Biological Consequences of Ecosystem Fragmentation: A review. *Conservation Biology*, (5)1; 18-32.

USDA Forest Service. (1987). Report of the United States on the Criteria and Indicators for the Sustainable Management of Temperate and Boreal Forests. Washington, DC: US Department of Agriculture, Forest Service.

Wilcox, B.A., and D.D, Murphy. (1985). Conservation Strategy: The Effects of Fragmentation on Extinction. *American Naturalist*, (125); 879-887.

Wilson, E.H., J. D. Hurd, D.L. Civco, S. Prisloe, and C. Arnold (2003). Development of a Geospatial Model to Quantify, Describe and Map Urban Growth. Special Issue of *Remote Sensing of Environment*: *Remote Sensing for Urban Planning and Urban Ecology*, 86(3): 275-285.

Table 2. Watershed Landcover Changes

Landcover Changes 1985 to 1999	1985 percentage	1999 percentage	change
NoData	0%	0%	no change
Water	4%	4%	no change
Urban	9%	13%	**4% increase**
Agriculture	11%	13%	2% increase
Barren	1%	1%	no change
Interior Forest	47%	36%	**11% decrease**
Patch Forest	1%	1%	no change
Transitional Forest	4%	5%	1% increase
Perforated Forest	13%	16%	3% increase
Edge Forest	9%	9%	no change
Total	100%	100%	no change
Total Forest	75%	68%	**7% decrease**

Table 3. Parcelized Areas vs. Entire Watershed Images

1985 Image	pixels	percentage		1980-1984 pixels	1980-1984 percentage		1975-1984 pixels	1975-1984 percentage
Water	17538	4%		47	0%		197	1%
Urban	39574	9%		1869	15%		3271	15%
Agriculture	48665	11%		1065	8%		2160	10%
Barren	2800	1%		72	1%		155	1%
Interior Forest	**204129**	**47%**		**4456**	**35%**		**7418**	**33%**
Patch Forest	3845	1%		114	1%		229	1%
Transitional Forest	18077	4%		730	6%		1368	6%
Perforated Forest	58059	13%		2813	22%		4977	22%
Edge Forest	38074	9%		1604	13%		2760	12%
total	430761	100%		12770	100%		22535	100%
total forest	322184	75%		9717	76%		16752	74%

1990 Image	pixels	percentage		1985-1989 pixels	1985-1989 percentage		1975-1984 pixels	1975-1984 percentage
Water	18270	4%		128	1%		192	1%
Urban	49248	11%		2958	16%		5382	17%
Agriculture	50131	12%		1878	10%		2996	10%
Barren	3286	1%		180	1%		281	1%
Interior Forest	**182130**	**42%**		**4759**	**26%**		**8045**	**26%**
Patch Forest	4911	1%		195	1%		367	1%
Transitional Forest	20632	5%		1331	7%		2299	7%
Perforated Forest	64074	15%		4402	24%		7525	24%
Edge Forest	38079	9%		2474	14%		4004	13%
total	430761	100%		18305	100%		31091	100%
total forest	309826	72%		13161	72%		22240	72%

1995 Image	pixels	percentage		1990-1994 pixels	1990-1994 percentage		1985-1994 pixels	1985-1994 percentage
Water	18270	4%		136	2%		267	1%
Urban	54191	13%		962	11%		4560	17%
Agriculture	56800	13%		983	12%		3280	12%
Barren	2437	1%		11	0%		158	1%
Interior Forest	**163388**	**38%**		**3047**	**36%**		**6504**	**24%**
Patch Forest	5730	1%		68	1%		356	1%
Transitional Forest	22369	5%		515	6%		2144	8%
Perforated Forest	68032	16%		1737	21%		5955	22%
Edge Forest	39544	9%		1004	12%		3534	13%
total	430761	100%		8463	100%		26758	100%
total forest	299063	69%		6371	75%		18493	69%

1999 Image	pixels	1999 Image		1995-1999 parcels	1995-1999 parcels		1990-1999 parcels	1990-1999 parcels
Water	18270	4%		157	1%		302	2%
Urban	57583	13%		1321	12%		2570	13%
Agriculture	57671	13%		1286	12%		2268	12%
Barren	2439	1%		61	1%		76	0%
Interior Forest	**156581**	**36%**		**3667**	**34%**		**6123**	**32%**
Patch Forest	6093	1%		129	1%		227	1%
Transitional Forest	23198	5%		577	5%		1209	6%
Perforated Forest	68846	16%		2530	23%		4393	23%
Edge Forest	40080	9%		1195	11%		2190	11%
total	430761	100%		10923	100%		19358	100%
total forest	294798	68%		8098	74%		14142	73%