Quantifying and Describing Urbanizing Landscapes in the Northeast United States

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Abstract

There is neither a single definition of nor a standardized process for performing landscape characterizations. For more than a decade, researchers at the University of Connecticut have used remote sensing technology to detect land-cover features and provide information to municipal land-use officials. Recent research has been directed at three dynamic elements of the landscape that are critically important to land use officials: impervious surfaces, forest fragmentation and urban growth. Techniques have been developed to extract impervious surface data directly from Landsat imagery to estimate non-point source pollution impacts on watersheds. A model has been created to quantify and describe forest fragmentation over various geographic areas and an urban growth model has been developed that quantifies and categorizes urban change. Both of these models use land-cover information as their source data. These tools and the derived information are important educational components of the University's recently created Center for Land use Education And Research.

Researching Landscapes to Improve Land-Use Decisions

Over the past decade, the University of Connecticut has initiated a series of projects that focus on land use and land cover as a research topic, and land-use decision makers as an outreach audience. This work is driven by the fact that land use is the common denominator underlying many of the issues that our communities face, from nonpoint source water pollution and open space preservation to sustainable economic development and community character. As America urbanizes, the role that land use plays in determining the quality of our water and air is of particular importance to our health and well-being as a nation, yet land use is a local affair, with limited mechanisms for federal and even state programs to influence local land-use decisions (GAO, 2001). Because land use is decided locally, in town and county commission meetings all over the country, the task of providing education and technical tools to local government officials is of critical importance (Arnold, 1999; Arnold and Schueler, 2001).

While always keeping in sight the ultimate goal of producing useful and accessible research-based information to local land-use decision makers in Connecticut's 169 municipalities, our work out of the College of Agriculture and Natural Resources has evolved over the past decade. The directions of this evolution, reported on in an earlier volume of this journal, have been toward better integration of research and outreach; toward development of more sophisticated analyses and ways of visualizing the results of those analyses; and toward demonstrating the utility and relevance of remote sensing information to support land-use planning at the local level (Arnold *et al.*, 2000).

Advances in remote sensing science, and in our ability to analyze temporal changes in our landscape, hold great promise for putting to rest any questions of the relevancy of remote sensing to local land-use decisions. This assumption was the foundation for the formation of the "NAUTILUS" Regional Earth Sciences Application Center (RESAC) at UConn, one of nine RESACs designated by NASA in 1999. The RESAC system was created with the goal of applying remote sensing research to pressing regional problems. In the case of the Northeast RESAC, this translated to a variety of landscape characterization techniques focused on providing information on the northeast's urbanizing landscape to local decision makers.

Research Overview

The research agenda of the Northeast RESAC has focused on improving information about and understanding of urban and suburban growth. Research needs are developed as part of an iterative process that follows both *pull-push* and *push-pull* models. On the one hand, the needs of our chief "clientele," local land-use decision makers, drive the development of educational outreach programs and technical applications, which in turn drive research needs. Conversely, discoveries made and new methods developed by the research team often result in new and innovative educational applications of geospatial data and information.

Three broad topical areas form the core of the Northeast RESAC research program: extraction of point-in-time land use and land cover and multitemporal (change) information from remote sensing data, development of improved methods to identify and quantify landscape elements of particular concern, and development of models and metrics to better characterize specific landscape trends. Each of these areas helps contribute to our understanding of the landscape dynamics in the Northeastern United States. Three measures of landscape characterization currently being investigated are highlighted in this paper:

- Direct impervious surface modeling,
- Forest fragmentation modeling and index, and
- Urban growth type modeling.

The following sections review our progress in each of these areas.

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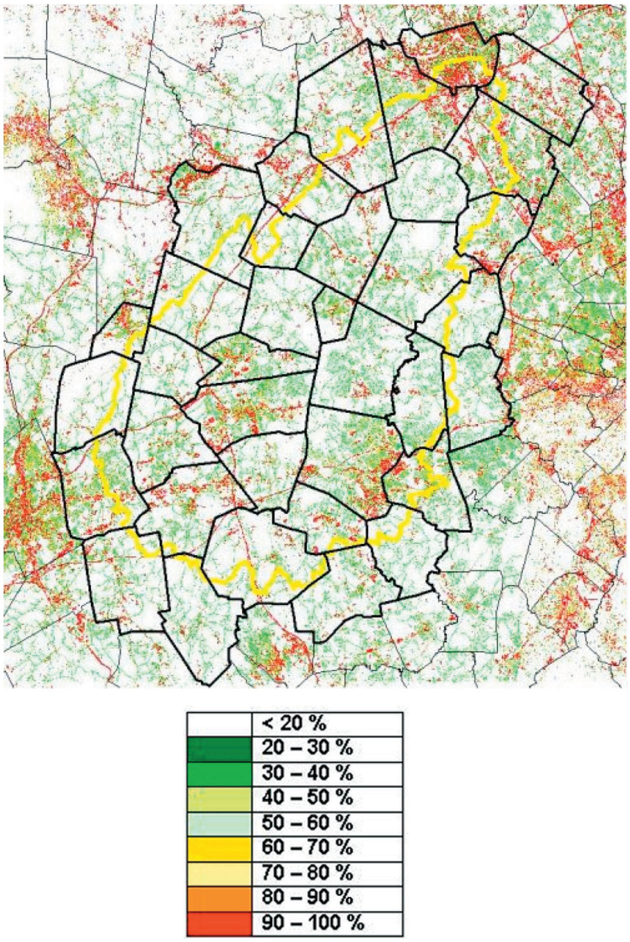

Plate 1. Percent impervious surface layer for the SuAsCo Watershed in Massachusetts. The watershed boundary is shown in yellow. The borders of towns falling wholly or partially within the watershed are shown in black, and those of other towns in gray.

Impervious Surface Characterization

UConn researchers have been long involved in investigating ways to measure impervious surfaces (IS), and to use these data in educational programs such as the *Nonpoint Education for Municipal Officials* (NEMO) Project (Arnold *et al.*, 1993; Stocker *et al.*, 1999). Impervious surface is widely accepted as a reliable indicator of urbanization and its impacts on natural resources, particularly water resources (Schueler, 1994; Arnold and Gibbons, 1996). RESAC's research results have continued to improve upon a traditional assignment of percent IS coefficients as a function of land-use/land-cover (LULC) type (Prisloe *et al.*, 2000; Sleavin *et al.*, 2000). However, substantial effort also has been directed towards direct subpixel percent IS modeling from Landsat TM data themselves (Civco and Hurd, 1997; Flanagan and Civco, 2001). The results of several pilot project studies indicate that methods being developed have improved both accuracy and greater geographic extensibility.

One of the most promising methods of modeling percent IS has been the application of the ERDAS Imagine SubPixel Classifier™ (SPC) to Landsat TM and ETM+ data. The SPC, engineered by Applied Analysis Inc. (AAI), is a supervised classifier that enables the detection of materials of interest (MOIs) as whole or fractional pixel composition, with a minimum detectable threshold of 20 percent and in increments of 10 percent (*i.e.*, 20 to 30%, 30 to 40%, . . . , 90 to 100%). Because of tonal variations in the built landscape, MOIs representing different brightness classes of IS are typically selected to be mapped. It should be noted that these are not representative of functional classes of IS, but simply spectral subclasses. An IS layer for the entire state of Connecticut has been produced from spring 1995 Landsat TM imagery.

Subpixel percent imperviousness has been modeled for the SuAsCo watershed (a major watershed in Massachusetts that contains the Sudbury, Assabet, and Concord rivers), one of the RESAC's Partner Watersheds (Plate 1).

The procedures used in the SuAsCo Direct Impervious Surface (DIS) mapping were augmented to include a water mask, to eliminate the possible confusion with dark impervious surfaces, and a rasterized version of the MassGIS roads layer. Further detail on the methodology of the SuAsCo IS mapping project can be found on NAUTILUS's website (http://resac.uconn.edu/research/impervious__surfaces/suasco__imperv.htm; date last accessed 10 June 2002).

The accuracy of the percent IS estimates has been determined by comparison with planimetric data. Examples are presented for the Town of Bedford, Massachusetts, located on the northeasterly fringe of the SuAsCo (Plate 2). The percent IS for six validation sites were compared with the DIS estimates from the SPC applied to Landsat data (Table 1). These results indicate that the SPC DIS method produces estimates of percent imperviousness very close to those provided by the validation planimetric data, especially compared to the data used by MassGIS, which are LULC-based %IS coefficients, where a difference as great as 25 percent for one test site was observed. Examination of the six test sites (Plate 3), in which the planimetric layer is shown in black and the SPC DIS predictions are shown in a color gradient, reveals a high degree of agreement, with few errors of omission and commission.

Our results hold great promise for improved accessibility and accuracy of this important urban indicator at the local and state level. A decade of experience through the NEMO project in Connecticut, and increasing experience with NEMO Network projects in 23 states, indicates that imperviousness is a tangible landscape element that can be understood—and thus used—by community land-use decision makers as they craft their

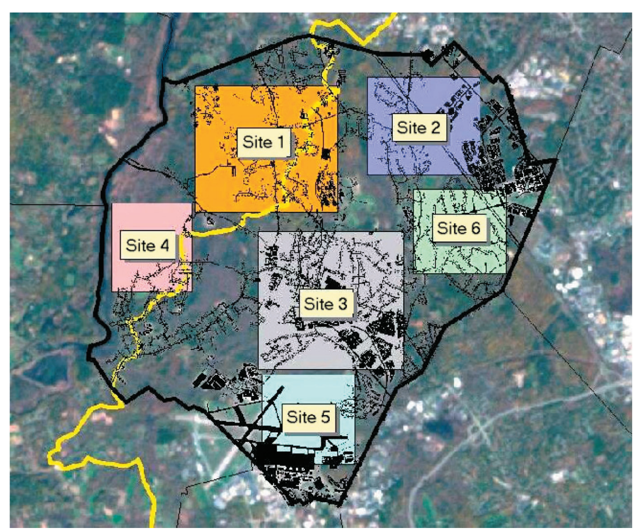

Plate 2. Bedford, Massachusetts impervious surface test sites. Planimetric vector layer overlain on Landsat ETM+ image.

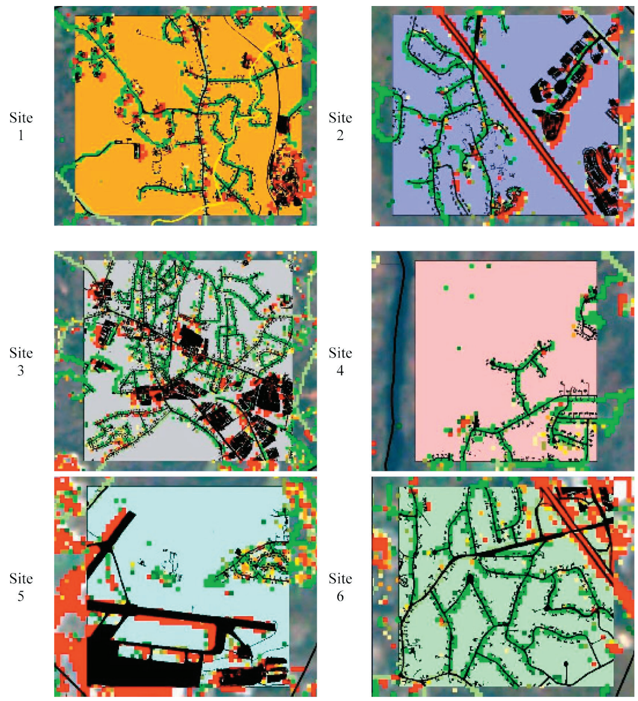

Plate 3. Detail of calibration sites 1 through 6 shown in Plate 2. Planimetric data are shown in black. Subpixel percent impervious estimates are depicted in the color gradient shown in Plate 1. Apparent omissions are due to the planimetric data being more recent (year 2000 update) than the Landsat ETM+ data (11 and 27 October 1999).

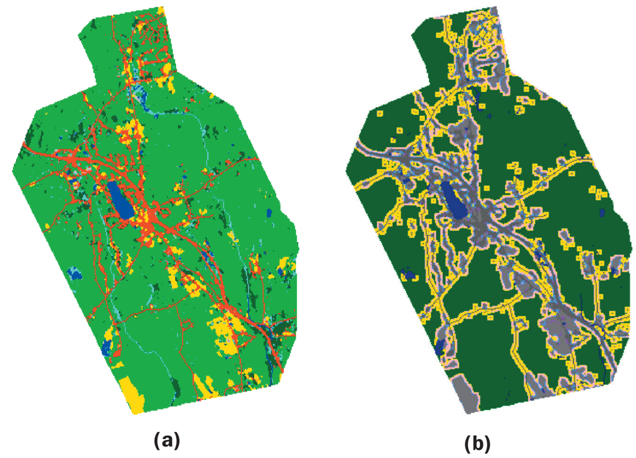

Plate 4. Result of applying the forest fragmentation model to a 1985 land-cover map of Marlborough, Connecticut. (a) 1985 land-cover map. Red is urban, yellow is non-woody vegetation, green is deciduous forest, dark green is coniferous forest, blue is water, cyan is wetland, and gray is barren. (b) 1985 fragmentation map. Dark gray is urban, gray is non-woody vegetation, dark green is interior forest, yellow is perforated forest, pink is edge forest, light blue is transition forest, purple is patch forest, and dark blue is water.

land-use regulations and development design requirements. An improved subpixel IS map for the entire state of Connecticut, using more recent Landsat 7 ETM+ data and the techniques refined for the SuAsCo project, is available from the RESAC web site, as well as having been incorporated into the ongoing NEMO Project educational programs.

Forest Fragmentation Characterization

In addition to a focus on particular elements of concern, such as impervious cover, RESAC researchers investigated combining landscape analysis and land-cover change data to model specific change processes of the Connecticut landscape. One of these is forest fragmentation.

Forest Fragmentation Modeling

Forest fragmentation is having an adverse impact on the ecological and economic viability of the northeast landscape. Many of the remaining large parcels of forestland in this region are being converted for anthropogenic uses, primarily residential, resulting in decreased forest health and forest sustainability.

TABLE 1. ACTUAL PERCENT IMPERVIOUS SURFACE FOR SIX TEST SITES, THE ESTIMATES FROM THE SUBPIXEL CLASSIFIER (SPC) DIRECT IMPERVIOUS SURFACE (DIS) MODEL, AND THE %IS BASED ON MASSGIS LAND-COVER-SPECIFIC COEFFICIENTS

Test Site	1	2	3	4	5	6
Actual IS	13.3	19.0	28.6	7.0	25.0	19.5
SPC DIS	11.3	18.7	23.8	5.3	26.5	17.8
MassGIS IS	8.3	20.8	19.3	4.2	48.4	16.0

NAUTILUS research focused on development of a forest fragmentation index to be used in the identification and comparison of the condition of forest fragmentation within a given area. The primary objective was to develop a tool that would allow a user to visualize easily the extent of forest fragmentation and track the change in fragmentation over time. The basis for the index is a forest fragmentation model developed by Riitters *et al.* (2000). This model was designed to identify patterns of forest fragmentation at a global scale using 1-km resolution land-cover information. The model generates two values that characterize a forest pixel located at the center of a sliding window of fixed size, Pf and Pff. Pf and Pff are defined by

$$\mathrm{Pf} = \frac{\text{\# of forest pixels}}{\text{\# of all non-water pixels}}$$

$$\mathrm{Pff} = \frac{\text{\# of pixel pairs with both pixels forest}}{\text{\# of pixels pairs with at least one pixel forest}} \quad (1)$$

Pff looks at pixel pairs only in cardinal directions. Because they are proportions, both Pf and Pff range from 0 to 1. Figure 1 illustrates the procedure for calculating the Pf and Pff values of a forest pixel within a 5 by 5 window.

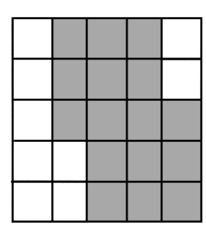

Figure 1. Illustration of the computation of Pf and Pff within a 5 by 5 grid of pixels. Gray represents forest pixels, white represents non-forest pixels. Of the 25 pixels, 16 are forest pixels (none are water). Pf therefore equals 16/25 = 0.64. Considering pairs of pixels in cardinal directions, the total number of adjacent pixel pairs is 40. Of these, 32 pixel pairs contain at least one forest pixel, and of those, 23 pairs contain two forest pixels. Pff therefore equals 23/32 = 0.72. (adapted from Riitters *et al.* (2000)).

From Pf and Pff values, the following six fragmentation categories are derived (Riitters *et al.*, 2000). Figure 2 identifies how the Pf and Pff values were used to assign pixels to the six fragmentation categories.

- *Interior Forest*. All of the pixels surrounding the center pixel are forest. Pf = 1.0
- *Perforated Forest*. Most of the pixels in the surrounding area are forested, but the center pixel appears 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 in the surrounding area are forested, but the center pixel appears 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 the center forest pixel may appear to be part of a patch, edge, or perforation depending on the local forest pattern. 0.4 < Pf < 0.6.
- *Patch Forest*. Pixel is part of a forest patch on a non-forest background, such as a small wooded lot within an urban region. Pf < 0.4.
- *Undetermined Forest*. Most of the pixels in the surrounding area are forested, but this center forest pixel could not be classified as being either perforated or edge. Pf > 0.6 and Pf = Pff.

To implement the process, the size of the analysis window had to be determined. After considering the resolution of the data, the size of the smallest forest feature of interest, and practicality of various window sizes, a 5 by 5 window was utilized to maintain an adequate representation of the proportion (Pf) of pixels in the window and also maintain interior forest at an appropriate level. The result of applying the forest fragmentation model to 30-meter resolution land-cover information is illustrated in Plate 4.

State of Forest Fragmentation Index

Using the results from the forest fragmentation model, further research was conducted to produce maps that identify the state of forest fragmentation of a specified region. The premise was that, while the forest fragmentation map produced valuable information, it was difficult to visualize easily the state of forest fragmentation for an area, to track trends in forest fragmentation, and to identify areas where forest restoration might prove appropriate to reduce the impact of forest fragmentation. RESAC investigators developed a model that uses quantitative values to produce a simplistic map that identifies the state of forest fragmentation for a given area.

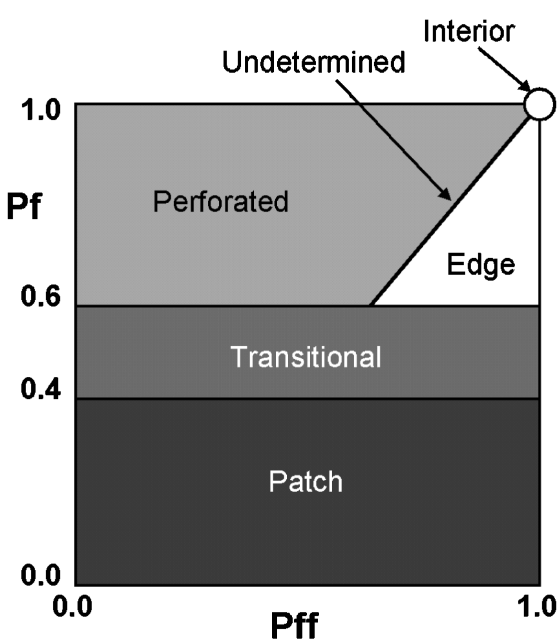

Figure 2. Graphic used to identify forest fragmentation categories from local measurements of Pf and Pff. (adapted from Riitters *et al.* (2000)).

The state of forest fragmentation index is comprised of two parts. The first is the total forest proportion (TFP): i.e.,

$$\text{TFP} = \frac{\text{total forest area}}{\text{total non-water area}}. \quad (2)$$

The TFP is a general value used by many investigators to provide a basic assessment of forest cover in a region, and many investigations have identified a non-linear relationship between the amount of forest in a region and the level of forest fragmentation (Volgelmann, 1995; Wickham *et al.*, 1999). The TFP ranges from 0 to 1.

The second component of the index is a measure of forest continuity (FC) within the region. The FC value examines only the forested areas within the analysis region: i.e.,

$$\text{FC} = \frac{\text{weighted forest area}}{\text{total forest area}} * \frac{\text{area of largest interior forest patch}}{\text{total forest area}}. \quad (3)$$

The FC measure specifically utilizes the results from the forest fragmentation model. Weighting values for the weighted forest area (WFA) were derived from the median Pf value for each fragmentation class as shown by the equation below. The area of each fragmentation class was then multiplied by the weight.

$$\text{WFA} = (1.0 * \text{inerior}) + (0.8 * (\text{perforated} + \text{edge} + \text{undeter.}) + (0.5 + \text{transitional}) + 0.2 * \text{patch}) \quad (3)$$

The rationale is that, given two regions of equal forest cover, the one with more interior forest would have a higher weighted area, and thus be less fragmented. To separate further regions based on the level of fragmentation, the weighted area ratio is multiplied by the ratio of the largest interior forest patch to total forest area for the region. FC ranges from 0 to 1.

The values of TFP and FC calculated for a region are plotted on a graph that specifies six conditions of forest fragmentation as shown in Plate 5. The TFP designations were determined based on the results of both Vogelmann (1995) and Wickham *et al.* (1999). They found that forest fragmentation becomes more severe as forest cover decreases from 100 percent cover towards 80 percent. Between 60 and 80 percent forest cover, the opportunity for re-introduction of forest to connect forest patches is greatest, and below 60 percent, forest patches become small and more fragmented. The FC regions were evenly split and designated high forest continuity (above 0.5) or low forest continuity (below 0.5).

Applying both the forest fragmentation model and state of forest fragmentation index to a time series of land-cover data provides a quantitative assessment of the pattern of forest fragmentation at each date and provides a means for tracking trends in forest fragmentation. This is illustrated in Plate 6 for the town of Marlborough, Connecticut. The forest fragmentation images (Plate 6) provide a visual representation of the changes occurring in the forested landscape of the town, while Table 2 provides quantitative information concerning these changes. Comparing the values of TFP and FC for the Town of Marlborough (Table 3) to the graph (Plate 5) indicates that the

Table 2. Hectares Occurring in Each Class of the 1985 and 1999 Marlborough, Connecticut Forest Fragmentation Images

	Non-Forest	Total Forest	Interior Forest	Perforated Forest	Edge Forest	Transitional Forest	Patch Forest
1985 Frag.	952	5080	3446	878	482	238	36
1999 Frag.	1302	4721	2797	1001	525	330	68

town would fall in the dark green region (high forest proportion and low forest continuity) in 1985 and the dark yellow region (moderate forest proportion and low forest continuity) in 1999. This example demonstrates how the color for each of the six state of forest fragmentation conditions is assigned to a given region. Furthermore, these values quantify changes in forest fragmentation for a given region and identify whether forest fragmentation is increasing or decreasing. Applying the index to discrete areas, such as uniformly sized grids or local watersheds, generates an informative, yet simple assessment of the changes in forest fragmentation within a region (Plate 6).

Urban Growth Characterization

Another change process being investigated is the continuing development of the northeast landscape, often called urban/suburban sprawl. The impacts of sprawl and its economic, social, and environmental impacts on America's communities is evidenced in studies ranging from The Nature Conservancy and The Sierra Club to the Bank of America (Bank of America, 1995; Sorensen *et al.*, 1997; Sierra Club, 2000). However, the term "*sprawl*" has many definitions. The first step in successfully assessing urban sprawl is to define what exactly urban sprawl ***is***. This is not a trivial task and many definitions involve the use of subjective and qualitative terms. Because of this, the RESAC has developed an urban *growth* model to provide a quantitative and objective analysis to better understand where, how much, and what kind of development has occurred in the Northeast.

Many criteria that define a good urban sprawl model are met by the methodology presented here, and many of the characteristics have not been implemented together before. Some criteria that define a good urban sprawl model are: has spatially detailed data with fine spatial grain, examines the whole landscape, is broadly available to allow for regional planning, assesses urban growth in all areas, avoids spatial averaging, maintains spatial pattern and configuration, has historical depth, and is consistent over time (Theobald, 2001). Utilization of multiple dates of spatially registered Landsat data in conjunction with an objective and repeatable model, provides an urban growth map that characterizes where and what type of growth has occurred over time.

The urban growth model is based on a modified forest fragmentation model developed by Riitters *et al.* (2000) and described in the preceding section of this paper on *Forest Fragmentation Modeling*. Input data consist of two dates of Landsat-derived land cover with a minimum of three classes: urban (developed), non-urban (non-developed), and water. Instead of using a forest *versus* non-forest binary image to create a forest fragmentation map, the first step of the urban growth model uses a non-developed *versus* developed image to create a "non-developed" fragmentation image. The single-date fragmentation maps consist of three "fragmented" classes that are combinations of the five classes previously described. The first is interior, which occurs when all pixels in a 5 by 5 window are non-developed. The second class is perforated, which occurs when between 60 percent and less than 100 percent of pixels in a 5 by 5 window are non-developed. The final class is patch, which occurs when fewer than 60 percent of pixels in a 5 by 5 window are non-developed.

The next step in the urban growth model is to use both dates of fragmentation maps to create a change map. There are three types of change classes. The first type consists of no change classes, including developed, water, and interior. The second type includes improbable changes, likely due to classification error, and the third type consists of classes that represent urban growth. The classes that indicate urban growth are outlined in Table 4, along with their corresponding urban growth classes.

The change classes determine the type of urban growth. *Infill* is defined as the development of a small area surrounded by existing developed land. *Expansion* is defined as the spreading out of urban land cover from existing developed land. *Outlying growth* is defined as an interior pixel that changes to developed, and is further classified as either isolated, linear branching, or clustered branching. Their distinction is made using a set of rules. An isolated growth is defined as a new, small area of construction surrounded by non-urban land and some distance from other developed areas. A linear branching growth is a road, corridor, or linear development surrounded by non-urban land and some distance from other urban areas. And a clustered branching growth is indicative of a new, large, and dense development in a previously undeveloped area. The urban growth model produces an urban growth map, which consists of five types of growth as well as developed land, water, and non-developed land. Examples of each of the five types of growth, along with a high-resolution image for reference, are displayed in Plate 7.

The urban growth model successfully combines spatially detailed and widely available multi-temporal satellite imagery with a model that creates a map of urban growth. Combining urban growth maps over several time periods creates an informative picture of the dynamics and changes that have occurred in an area. Local decision makers can see the results of past decisions and policies, and begin to incorporate the lessons into future land use policies.

Table 3. The TFP and FC Values in 1985 and 1999 for Marlborough, Connecticut

	1985 State of Fragmentation	1999 State of Fragmentation
Total Forest Proportion	0.842	0.784
Forest Continuity	0.121	0.109

Table 4. Change Classes that Represent Urban Growth and the Corresponding Urban Growth Types

Significant Change Classes	Type of Growth
Patch to Developed	Infill Growth
Perforated to Developed	Expansion Growth
Interior to Developed	Outlying Growth: Isolated Growth Linear Branching Growth Clustered Branching Growth

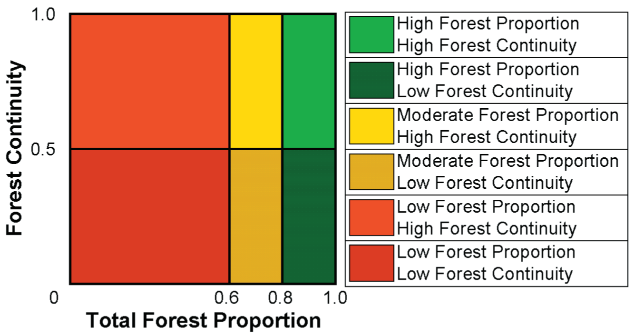

Plate 5. Graph identifying the six forest fragmentation conditions based on values of TFP and FC calculated for a region.

Future Work

The research completed as part of the NAUTILUS RESAC is the starting point for a long list of new initiatives at UConn. The research presented in this paper has become an important part of the foundation for the University of Connecticut's new *Center for Land use Education And Research* (CLEAR), a collaboration of the USDA Land Grant, NOAA Sea Grant, and NASA Space Grant programs at the University.

"Applications" meetings between the CLEAR research and outreach teams have been conducted, focused on the urban growth, forest fragmentation, and subpixel impervious surface analyses. The meetings are an important part in the iterative development process described in the beginning of this paper, in which outreach applications make use of research, but in turn help to redefine future research directions based on needs identified by the outreach professionals and their clientele of community decision makers. From these meetings, the team has decided to create Northeast-wide sets of the subpixel IS data and the land-cover change data (1985 to 2000).

This information will be incorporated into a number of ongoing land-use education projects in the state, including the NEMO Project and the Extension Forestry program. It will also be made available in an interactive tutorial form over the Web. Finally, because UConn serves as the communications "Hub" of the National NEMO Network (a group of projects in 23 states patterned after our Connecticut work), both new remote sensing techniques and ideas for incorporating these data into outreach projects have the potential for national dissemination. To this end, CLEAR staff are working with remote sensing and GIS colleagues at the NOAA Coastal Services Center in Charleston, South Carolina, on ways to apply UConn-developed impervious surface characterization techniques to widely available land-cover datasets, such as the Interagency Multi-Resolution Land Characteristics (MRLC) and the NOAA CoastWatch Change Analysis Program (C-CAP) data.

Another future initiative involves refinement and wider spatial and temporal application of the forest fragmentation and urban growth models. The goal is to have 15-year change data displayed and analyzed for the Northeast United States, using both models, which have been designed to run in ERDAS Imagine® using a series of menus and dialogue boxes (Figure 3).

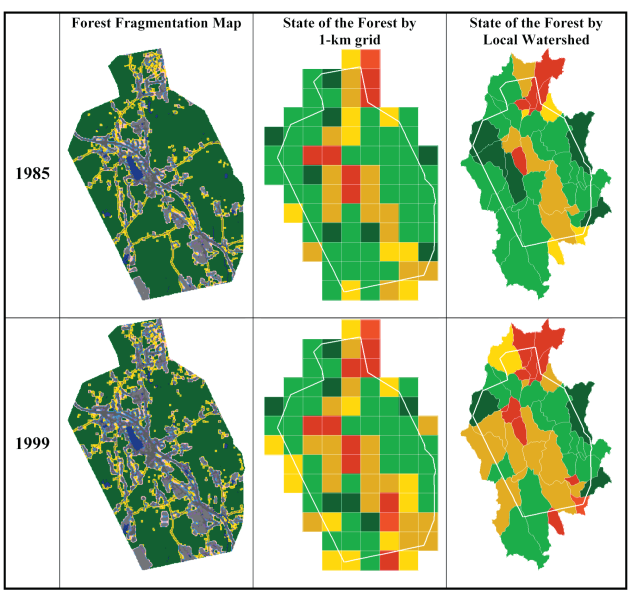

Plate 6. Results of applying the forest fragmentation model to two dates of land-cover data for the Town of Marlborough, Connecticut and results of applying the state of forest fragmentation index to a 1-kilometer grid and local watersheds for the same two dates.

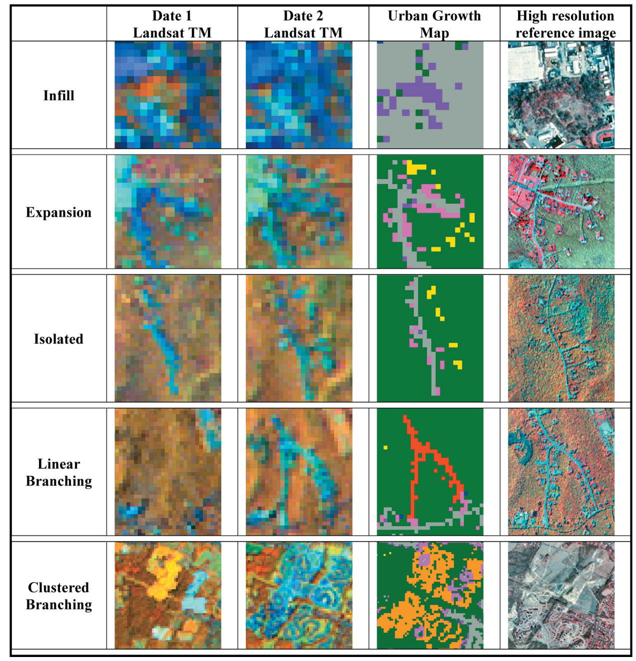

Plate 7. Examples of each type of urban growth are shown. Because two dates are inherently necessary for urban growth, the first and second dates of the original Landsat TM (used to create LULC maps) are shown along with the urban growth map where gray is developed, green is non-developed, blue is water, purple is infill growth, magenta is expansion growth, yellow is isolated growth, red is linear branching growth and orange is clustered branching growth. A high-resolution image of the same area is shown for reference and validation only. The expansion, isolated, and linear branching examples show a 1999 4-meter multispectral Ikonos image and the infill and clustered branching examples show a 1995 digital orthophotograph where, in both cases, the development had either not yet started or not yet finished. All Landsat images were captured before 1999.

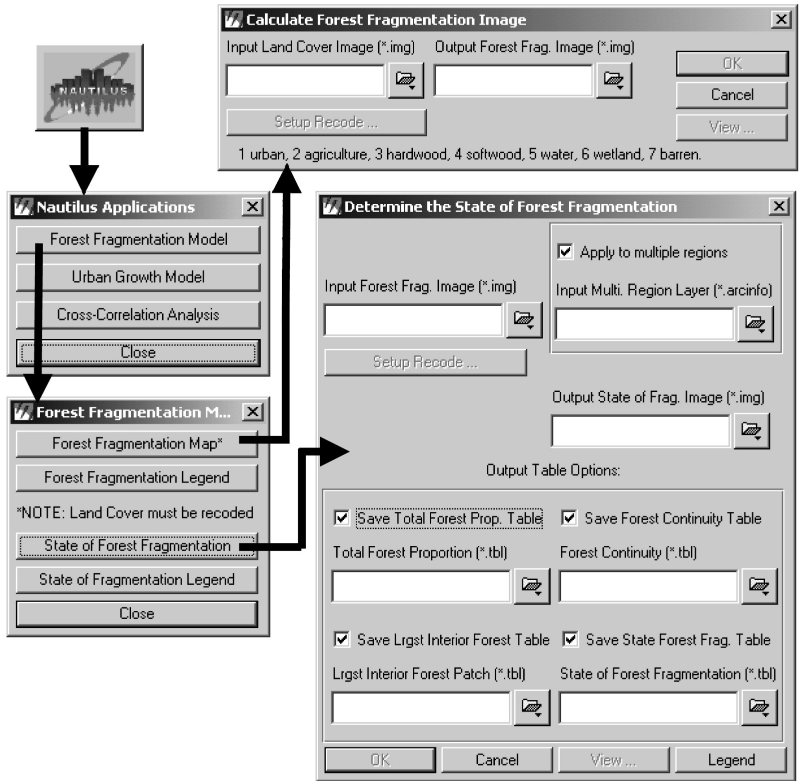

Figure 3. Example of the NAUTILUS button available on the ERDAS Imagine toolbar, along with some example menus and dialogue boxes for the forest fragmentation model and index.

Future work includes improving the interface, allowing the ability for other kernel sizes to be used, assessing the model on different resolutions of data, and in different regions. A third, parallel analysis modeling the loss of farmland in the state is also being considered.

In addition to consolidating the research gains made by NAUTILUS, further land-use/land-cover research is planned that focuses on techniques to discriminate landscape elements of particular interest. These areas include bedrock outcrops, upland meadows, vernal pools, and other habitat areas that have been identified by state and regional ecologists as significant. One method of improved land-cover mapping being explored is object-oriented segmentation and classification, using a software package named ***eCognition***®, developed by Definiens Imaging GmbH (Trappentreustrasse 1, 80339 München, Germany). These investigators have had a great deal of success in extracting land use information from 30-meter resolution Landsat and 4-meter resolution Ikonos remote sensing data.

America's landscape will continue to urbanize, and as it does, our communities will continue to struggle with ways to accommodate economic growth while protecting natural resources and community character. Community officials need all the education, (accessible) data, and technical tools that they can get, to enable them to get a handle on their changing landscape, and the relationship of these changes to their daily land-use decisions. CLEAR, founded on collaboration between the USDA Land Grant, NOAA Sea Grant, and NASA Space Grant programs at the University, has been created to enable the University to expand and improve its work in providing these data, tools, and education.

NAUTILUS research gains take us one step closer to our goal of providing timely and relevant remote-sensing-based information to community decision makers. And, as the research evolves, so too will the educational approaches and tools developed to make this information truly accessible and understandable. We are confident that our target audience of local land-use decision makers will continue to be a critical user group for landscape characterization and change information.

Acknowledgments

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