Mapping Tree Canopy in Broward County, Florida

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Abstract:

Tree canopy is essential to environmental and economic health, providing additional cooling, reducing energy needs, increasing property values, improving air/water quality, reducing the cost of storm water control, and contributing to a more beautiful, friendlier, and livable community. Broward County Government recognizes the importance of gathering accurate information on the health and diversity of the community's urban forest. Despite having the expertise and the tools to acquire a total tree canopy, hardware/software issues and other unexpected hurdles made this endeavor problematic, yet in the end successful. This paper addresses the methodology used to create Broward County's tree canopy layer.

The Importance of Tree Canopy

Tree canopy is essential to environmental and economic health, providing additional cooling, reducing energy needs, increasing property values, improving air/water quality, reducing the cost of storm water control, and contributing to a more beautiful, friendlier, and livable community. "The benefits represent hefty dollar amounts, many millions to big cities even after the costs of tree management, which average less than 1 percent of municipal budgets. Psychological benefits, too, are worth plenty. People simply feel better and kinder around trees. Trees bring birdsong. They provide privacy and a sense of protection. Hospital patients exposed to trees heal faster, feeling less pain," (Plotnik, 2000).

The Broward County Board of Commissioners established the Broward Urban Forest Initiative in 1999 to stem the loss of tree canopy from Broward's urban landscape. One aspect of that initiative was to map and monitor the percentage of tree canopy county-wide. With that as a base line, urban foresters would be able to evaluate the present extent of tree canopy and monitor changes over time to ensure these goals were achieved.

Florida has the widest variety of tree species of any other state in the continental United States. Of the approximately 625 trees native to north America, at least 275 are found within the confines of Florida. Add to this an extensive list of introduced and naturalized species and Florida's tree flora becomes expansive indeed.

Three factors mostly define the nature of southern Florida's biodiversity: The recent origin of freshwater and terrestrial ecosystems; peninsula geography and habitat diversity; and subtropical wet/dry climate and productivity. Located along the southeastern perimeter of the North American continent and surrounded by vast expanses of ocean water, the state is strategically positioned to share in the flora of both the temperate and the tropical climate zones. Florida's subtropical location spanning 40 degrees - 42 degrees north latitude supports around half of its plant species which are of temperate origin, an extension of the flora of the Southeast coastal plain. The other half are members of the Caribbean tropical flora and reach their northernmost limit in South Florida. Water resources for this area are primarily available from rainfall and surface and groundwater storage systems such as shallow surface aquifers. The area between Boynton Beach and Miami receives the highest amount of rainfall in the State (163 cm or 63 in). Broward County is situated on the southeast coast of Florida between Miami-Dade and Palm Beach Counties. It has a total land area of 1,197 square miles; the western 787 square miles encompass the Conservation Area and the eastern 410 square miles include 30 municipalities and 23 miles of beachfront. Broward County is the second largest county in Florida with an estimated 1999 population of 1.5 million. Although the county is highly urbanized, many species of native flora continue to exist in the remnant patches of native vegetative communities. Ecological communities found in Broward County include beach dune, coastal strand, maritime and tropical hardwood hammocks, scrub, pine flatwoods, mangrove swamps, coastal saltmarsh, freshwater marsh, and wet prairie (Meyers and Ewel 1990, Science Subgroup 1996).

Potential Uses

Potential uses of a tree canopy coverage are numerous. It can be used to measure tree canopy over time and to determine where new trees should be planted. Tree shade and evaporation of water from the leaves (up to hundreds of gallons daily from a mature tree) cool hot city air and surfaces. Shade from trees can cut heat some 20 degrees, reducing energy costs. It can be used to monitor tree loss due to diseases such as the citrus canker that has devastated south Florida's citrus trees or to natural disasters like hurricanes or earthquakes. It can even be used to establish a debris management estimation model for hurricane preparedness and recovery. (Close to 40 million cubic yards of debris would be generated by a category 4 hurricane in Broward County, according to a preliminary estimate done for Broward County's Emergency Management Division.) Trees help cleanse the air, intercepting airborne particles and absorbing such pollutants as carbon monoxide, sulfur dioxide, and nitrogen dioxide. Trees stabilize soil, conserve rainwater, and reduce water runoff and sediment deposit after storms. Trees muffle urban noise almost as effectively as stone walls.

There has been shown a direct correlation between tree canopy and urban violence. A study by W.C. Sullivan and F.E. Kuo demonstrated that trees influenced attitude in a Chicago public housing project. "Residents of a building surrounded by trees experienced less aggression and violence in their homes than residents of a twin building without trees. They also got along better with their neighbors," (Plotnik, 2000). A tree canopy coverage also gives communities tools to measure success/failure of tree initiatives and a perceptual tool to decide how they want their communities to look and feel. Additionally it provides a means of measuring environmental health of a community (because of the correlation between ecology and tree canopy) as well as a way of identifying possible greenway linkages between urban forests.

Ideally a complete tree inventory would be beneficial to planning a green environment, but logistically that's not feasible. The manpower and cost required to undertake such a task would be prohibitive, particularly in a local government setting. GIS and remote sensing techniques offered a more cost-effective way of generating the information. As with any technological solution, there are limitations, but overall, extracting tree canopy from digital aerial photographs is a viable alternative.

Initial Stages

During the inception of the project, the County reorganized and two large departments, Strategic Planning & Growth Management and Natural Resource Protection were merged into the Department of Planning and Environmental Protection (DPEP). The Tree Canopy Project was seen as a way to integrate the Department's multiple GIS staff into a department-wide resource sharing venture. While it was a good idea on paper, in reality, it didn't work. Staff was too busy with their own divisions' projects to devote any serious time to learning to classify trees. Therefore, it was determined that the Tree Canopy Project would be done primarily by the Planning Services Division GIS staff, a contingent of two, because they were the only staff with any expertise in digital image processing and remote sensing principles.

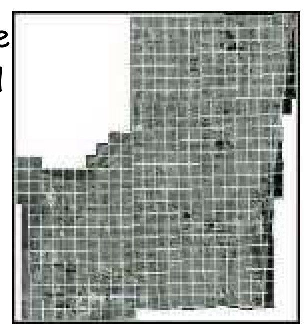
The imagery used for this project were taken in January 1996, prior to the inception of this project. They were color infrared scanned photographs with no georeferencing and no fiducial marks on the photography. Although new photography was flown in January 2000, it was decided that the 1996 imagery would be mapped and classified as a baseline for tree canopy in Broward County. Figure 2

Initially the first iteration was to be done using the most recent photography, but due to delays by the vendor (the 2000 photos were not delivered until August 2000), it was decided to move ahead with classifying the 1996 images. First step was to generate fiduciary marks on the photos, then to georeference the photos using 1997 black and white orthorectified aerial photographs. This was done in PCI's OrthoEngine by an intern initially and later completed by staff. This software was chosen particularly because of its ability to generate 'tie points' between images, a way of generating additional control points "on the fly." Essentially we used image-to-image rectification, based on 1997 black and white aerial photos which were georeferenced.

One of the first questions addressed by staff was, 'Would it be better to digitize the tree canopy or use digital image processing techniques to generate the canopy coverage?' To determine the scope of time and work involved, a test area of a one-mile section was generated. One staff member was assigned to digitize the pilot area while other staff worked out the methodology to perform image processing. It took one staff member approximately 4 weeks to digitize the tree polygons in a one-mile section. (See Figure 2.)

Once the methodology was established, it took 4 hours to create a coverage for the same area using the digital image processing techniques. Considering this process needed to be repeated 440 times, the image processing methodology was by far more practical.

Early on it was apparent that existing hardware and software would have to be updated in order to complete the project. The image processing software, ERDAS Imagine 8.4 required NT as an operating platform. As it happened, plans had already been made to upgrade workstations from UNIX to NT throughout the department and to upgrade existing software to the latest versions, which required NT to run; this project merely sped up the replacement process. This also provided us with more processing power and storage capacity than was available on our existing UNIX Alpha workstations. However, we still had the problem of our classification processes exceeding the limits of the software.



It was initially suggested that one way to cut down on the scope of the work was to mosaic the photos together and then one classification be run over the entire image. There were several problems with this: First, the mosaicked images were well over 16 gigabytes and well beyond the capabilities of the software to process. Secondly, the differences in color even across individual photographs made a single classification impossible. Thus, an answer to both these issues was to clip the photos to smaller areas for processing and classification. Since the final coverages were to be kept in Arc/Info's Map Librarian, which tiled the information by one-mile sections, it made sense to clip the images to that size.

Reducing the size of the images also worked well with our plan to keep the coverages county-wide in Arc/Info Map Librarian. Other large coverages such as future land use and existing land use were stored by section, township, and range, so it made sense to store the tree canopy as another layer in that library. We clipped the images by section to process them. This method also helped to fine-tune the classifications because the color differences in the photographs were less of a hindrance in the smaller images.

One of the initial questions was what constitutes a tree. There is no generally accepted and botanically precise definition of the constellation of characters that constitutes a tree. This is not to say that definitions have never been advanced nor general rule of thumb adopted.

Figure 4

It is the distinction between what constitutes a shrub and what constitutes a tree that is at the heart of this definitional dilemma.

To compound this, in South Florida, many of the hedge species are actually tree species which have been planted and trimmed as hedges. These hedges have the same spectral characteristics as the full blown trees. Therefore the computer classifies them as trees. The only indication of them being a hedge is their geometric shape: long and linear, which the computer cannot detect. One species in particular, *Ficus sp.*, was favored by developers because of its thick lush speedy growth. These hedges block traffic noise and provide privacy screens from adjacent developments. In some cases these hedges exceed 12 feet in height. (See Figure 4.) Height would not be a good identifier because it is nearly impossible to tell height with any reliability on an aerial photograph using digital image analysis techniques unless ancillary information such LIDAR (Light Detection and Ranging) or photogrammatry is used. For this project, it was determined to use an area greater than 4.5 square feet, using LIDAR to refine the coverages as it becomes available. In this way single shrubs and small grassy patches would be eliminated from the coverage.

Special care was taken to gather multiple training fields for golf courses. In particular, training fields were taken of greens, roughs, fairways, and shrubbery, in addition to the trees. While this improved classification results, these areas still required additional editing work to eliminate grass polygons. This was also true of highly irrigated and fertilized lawns, prevalent in the more exclusive developments.

Color differences, reflected in the original color infrared image and in the Normalized Difference Vegetation. Index (NDVI) masked image, are thought to be scanner effects. Color differences were rampant in the photography, even across the same image. At first it was thought that the color differences were merely random effects, but after the Normalized Difference Vegetation Index (NDVI) was performed, these differences were easily recognizable as regularly occurring phenomena. Such a pattern in the colors of the images were determined to be scanning effects caused by the scanner used to create the digital version of the photographs.

Figures 5 & 6

File sizes were a continuing problem throughout the project life cycle, beginning with the size of the images and continuing with the resultant Arc/Info coverages. Once the coverages were inserted into Librarian and managed by section, township and range, it was assumed that extraction of information and analysis of information would be easier. To a certain extent, this was true, but even the extraction of tree canopy by city has been problematic. A single request to extract tree canopy by the city boundaries of Fort Lauderdale (33.5 square miles) took 25 hours on an NT server with dual 1 gigahertz processors and 1 gigabyte of RAM. The resultant coverage was 1.16 gigabytes in size.

Methodology

The original raw data was delivered as color infrared TIFF files. Because it was saved in the color infrared format, this meant that the infrared band was located in band position 1, while the red was in band 2 position and the green was in band 3 position. The ERDAS software, in generating the NDVI, needed the infrared band in band 3 position. This meant that as we were clipping the imagery, we also had to reorder the sequence of the bands.

Even with the clipping of the images to one-mile sections, the files were still large, with many different classes that would have to have Figure 7. Brightness values used to separate vegetation from non-vegetation in the Normalized Difference Vegetation Index show the breakpoint.training fields to use in the classification. By reducing the three band image to a single 256 scale band image, the NDVI allowed us to separate out vegetation from non-vegetation classes. (See Figure 7.) It even allowed us to remove some of the grass classes from consideration in the classification process.

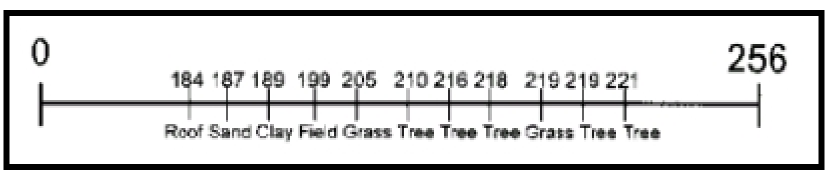
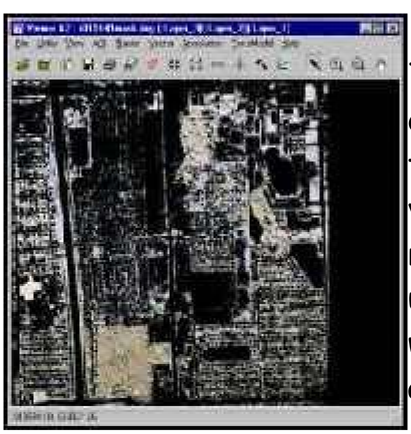


Figure 7

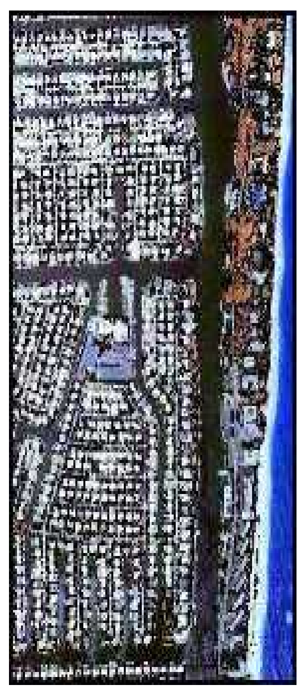


The image resulting from the NDVI mask overlaid on the original 3-band image was used to take training fields. The normalized difference vegetation index (NDVI) is a standard image ratioing technique that has been around and in use since 1974, when it was developed for use with the Landsat Multispectral Scanner (Rouse et al., 1974).

Figure 8

The end result is an image where all vegetation, which has high reflectance in the infrared relative to red, is one side of the data set, and all non-vegetation is on the other side.

This produces a known boundary for pixels whose reflection is uninfluenced by vegetation. Then it is possible to perform a piecewise stretch, and recode every non-vegetation pixel to 0 and every vegetation pixel to 1, which allows the ratio image to be used as a mask, combined with the original raw data to mask out every non-vegetation pixel in the county. The resulting image contains only vegetation reflectance information (Rouse, et al., 1974). In ERDAS, this function essentially takes the Infrared Band - Red Band divided by the Infrared Band + Red Band. Once the breakpoint between vegetation and non-vegetation was determined, all non-vegetation classes were recoded to zero and the NDVI was then used as a mask on the original image so that only vegetation classes would be classified. (See Figure 8.)



Training fields were taken on trees and non-tree classes (grass, hedges, algae-laden water, etc.). A supervised maximum likelihood classification was used because we wanted everything in the image, excluding zeros, to be classified. Once the classification was acceptable, these classes were recoded to 1 and 0, ones being trees and 0 being anything that was non-tree. The recoded image was then converted from raster to vector with one of the attribute fields identified as grid_code, which represented the tree or non-tree classification.

In order to have a coverage which for the most part only delineated trees, the coverages were brought into

ArcView, selecting only the tree polygons and putting them into a new shapefile. (See Figure 9.)

Figure 9

This effectively reduced the size of the coverage when we converted it back into an Arc/Info coverage and clipped it by section. The second clipping was necessary because in clipping the image, which results in a square or rectangular shape, extra pixels outside the section boundaries were retained. Clipping the coverage a second time eliminated the extra pixels and allowed the coverages to be placed in the Map Librarian grid. The major reason for using ArcView at this stage is that it allowed us to quickly edit and query the data; the process in Arc/Info took hours for a simple query opposed to mere minutes in ArcView.

Initial calculations show that Broward County has a tree canopy of approximately 13 percent, which falls short of the recommendation by the American Forests which stresses that a 40 percent tree canopy is essential to sustain the ecological, environmental and social health of a community. (American Forest, 2001) Individual cities have canopy percentages as high as 45 percent (Lazy Lake) and as low as 11.5 percent (Hallandale Beach).

Lessons Learned

An issue to be wary of in considering such a project is the imagery itself. The person in charge of purchasing the imagery should be well-versed in remote sensing techniques and imagery types and limitations. With the cost of imagery dropping drastically as more and more vendors offer this service, it can be difficult to keep abreast of which imagery is best for a particular project. As resolution gets smaller and smaller, enabling researchers to measure things like the canopy of a single tree, file sizes get bigger and bigger. Storage and retrieval become significant factors in managing the database once it is generated.

Knowing when and how the imagery was generated and what processes were done on it prior to delivery can save a lot of headaches later on. Metadata on the imagery should be kept just as would be done on GIS coverages. This is particularly important if plans include time series or change detection studies, because in order for comparisons to be valid, measurements and methodology need to be consistent. The time of year that the imagery is flown can be significant in regard to cloud cover or whether trees are in leaf-on or leaf-off mode. The classifications should be done as soon as possible after the delivery of the imagery. Even in the span of one year, significant change can occur on the ground that will affect ground-truthing and subsequent accuracy assessments.

As mentioned earlier, sufficient staff and resources need to be allocated to a project such as this. Hardware and software need to be sufficient to handle processing and storage demands and ideally should be in place in advance of the production schedule. Staff needs to be well-versed in remote sensing principles and techniques, as well as GIS. Mere training on the software packages is not sufficient. Documentation of processes and procedures is vital in the event of staff turn-over during the life of the project. Additionally, upper management support of the project is imperative in providing staff and resources.

Perhaps the most significant lesson we learned in creating the Tree Canopy Coverage is that in the future we should hire outside consultants to do the work. Attempting to complete such a large scale project using our limited staff resources while continuing to keep up with regular work, proved to be unrealistic and moved the project beyond its initial time line considerably. Hiring a consultant would alleviate the drain on staff time. Even so, one of the significant benefits from doing the first phase of this project in-house is that now staff has the skill and expertise to prepare technical requirements for the project and monitor progress and quality of deliverables.

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