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Dr. Sam Pearsall
Director of Science
Roanoke River Project Director
The Nature Conservancy
North Carolina Chapter
4705 University Drive, Suite 290
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Dear Sam:

Please find enclosed the proposal, "Revised Forest Map of the Roanoke River Floodplain," in which I will use multi-seasonal imagery to update the detailed vegetation classification of the Roanoke River floodplain that I previously developed for The Nature Conservancy. The plan is to use recent Landsat 5 imagery for the project, but if it becomes clear that Landsat 5 imagery are inappropriate, to then use alternate data sources. I look forward to our continued collaboration.

Sincerely,

Phil Townsend

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Associate Professor

attn:
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Revised Forest Map of Roanoke River Floodplain

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June 21, 2006

Overview

The original vegetation classification for the Roanoke River floodplain was developed by Townsend and Walsh (1997, 2001) using Landsat 5 satellite imagery primarily from 1993. The strength of the classification approach was that it used a total of eight images representing early spring leaf-off (March), early spring (April), late spring (May/June), and summer (July/August). Such a rich image time series facilitates the use of phenological information to map specific forest communities.

A revision of the map can take two approaches: (1) the development of a completely new vegetation classification using new field data and new imagery, and (2) use the original classification to stratify analyses of new imagery to identify areas of change. Option (1) is likely neither cost-efficient nor practical, and option (2) is viable only if the original classification has a very high accuracy if the forest changes are well-characterized and distinct (i.e., not subtle). A hybrid approach is warranted for several reasons:
(1) Vegetation communities on the Roanoke have undergone significant changes since 1993 due to a variety of factors, including logging, several hurricanes (including Floyd and Isabel), drought and the extended flooding of 2003.
(2) Because of the reasons cited above, the original vegetation data (collected in 1995) are no longer appropriate to mapping vegetation communities on the Roanoke. Some new vegetation data have been collected, but probably not of a spatial extent suitable for a complete re-mapping of communities.
(3) Landsat 7 (ETM+) experienced a scan-line corrector (SLC) error in 2003 and no longer provides spatially complete imagery. This necessitates mapping using new imagery from sensors other than Landsat 7.

Forest Communities. The following general approach will be employed to remap vegetation communities of the Lower Roanoke River floodplain. Recent multi-spectral imagery will be acquired for spring, summer and fall over the entire floodplain. The new image data will be stratified by the land cover classes in the original classification. Spectral signatures will be developed and evaluated for the original classes using the new image data. These new signatures will first be tested for internal homogeneity within a class and statistical differences between classes. "Cross-correlation" will then be used to identify pixels within a cover class whose spectral characteristics deviate substantially from the overall class spectral signature. "Cross-correlation" simply refers to establishing a threshold of difference from the original spectral signature (e.g., 1 or 2 standard deviations) and then determining which other class (if any) that pixel's signature is more closely correlated to. Pixels that do not clearly cross correlate with any class are evaluated to determine if a new class is warranted. Some of the largest changes that can be expected are among various classes of successional pines, shrub/brush, bare ground and/or clearcuts. However, forests that have experienced compositional changes due to other disturbances will also stand out. The fine discrimination of new classes in the new imagery will be limited because a recent image data set as rich as the original imagery is not likely to be available. In short, the quality of the new classification draws upon the quality of the original maps, extensive ground data on forest composition and the detection of changes in the original vegetation classes. The new classification will be evaluated for accuracy using field data that have been held aside from the analyses.

Forest Structure. Multi-spectral imagery from optical remote sensing sensors is best suited for mapping forest distribution and composition. However, forest structure is generally mapped with greater accuracy using active sensing data, such as from LIDAR (Light Detection and Ranging). Starting in 2000, the state of North Carolina has acquired airborne LIDAR data statewide for mapping elevation with 20-foot pixels. LIDAR works by transmitting laser pulses toward the ground, with as many as five returns per pulse measured back at the aircraft. The last return measured from a pulse is usually the bare earth, while any intermediate returns are from intervening features, e.g. a forest canopy. We have requested from the North Carolina Flood Mapping Program the full return LIDAR data for the five counties encompassing the Lower Roanoke River floodplain, and will explore the utility of using these data to map canopy height and canopy openness. These analyses will be conducted by simple difference of measured heights from bare earth heights. LIDAR posting are irregular (approximately 3 m), and a minimum of 50 measurements are usually required to estimate height with any confidence (yielding pixels with 20-30 m resolution).

Data Acquisition

Five satellite data sources exist for mapping vegetation composition at the 10-30m resolution: Landsat 7 (ETM+), Landsat 5, SPOT, ALI and Aster. Landsat ETM+ images with 30m pixels (multispectral data) for 180 km swaths are available through spring of 2003 when the Landsat 7 satellite experienced a scan line corrector error. Landsat 5 images are available for the entire study area since 1984 (indeed the original classification was developed using Landsat 5 data). All Landsat scenes contain 4 multispectral (or visible-near infrared, VNIR) bands and 2 shortwave infrared (SWIR) bands. Landsat also has one thermal IR band (TIR) that is not usually used for vegetation studies. ETM+ images can be acquired for $625 per scene and Landsat 5 images can be acquired for $450. Most of the Roanoke floodplain is contained in one scene, although additional images are need to cover the far eastern portion of the study area (from Plymouth to the Albemarle Sound). A large number of Landsat 5 scenes capturing Roanoke River phenology for the period 2003-present are available for the study area. Although Landsat 5 data has experienced considerable degradation over its 23-year lifespan (especially in the visible wavelengths), the large number of recent images (> 10) that capture subtle differences in spring/fall phenology are hypothesized to more than compensate for the degraded signal-to-noise ratio of Landsat 5 in contrast to ETM+ and other sensors.

Data from four other sensors will be explored for use in case issues with Landsat 5 data arise. SPOT imagery has 10-20m pixels and 60-km swaths, with image data collected in 3 VNIR bands and one SWIR band. Maximum commercial prices range between $1900-$3375 per scene, which for four scenes covering the lower Roanoke floodplain during two seasons would amount to a total cost as high as $13,500. Additional charges of $1000-$4875 for programming new acquisitions may also apply. The SPOT satellite is pointable. SPOT data will only be used as a last resort if Landsat 5 data prove unavailable.

ALI (Advanced Land Imager) data from the EO-1 satellite are available from NASA at a cost of $625 per scene. ALI data have one 10m panchromatic band plus 5 30m VNIR and 3 30m SWIR bands. The spectral quality of ALI data is extremely high. Because I am a science team member for the EO-1 satellite, I should be able to get priority acquisitions from ALI. However, because the ALI path is on the same path as Washington metro area, the possibility of conflicts in pointing the satellite exists. ALI scenes have a 37-km swath width, meaning that depending on satellite pointing 2-3 acquisitions per season would be required (4-6 images total). A small amount of non-optimal ALI imagery is available if needed.

Aster data can be acquired from NASA at a cost of $625 per scene. ASTER has 4 15m VNIR bands and 5 30m SWIR bands, with a swatch width of 60-km. The VNIR bands are acquired stereoscopically, allowing some detection of vegetation structure. Aster also has 5 TIR bands. Aster data may be the most promising data source for this project, but also will require the most processing to be used. A number of recent (but non-optimal) images from ASTER are available at no cost, and will be acquired in case of issues with Landsat 5 data. Four new spring/summer Aster acquisitions have been requested (at no cost) for 2006 2007. ASTER is the primary option in case Landsat 5 data prove problematic.

Data Processing

In cooperation with TNC, I will attempt to acquire the most recent and highest quality satellite imagery that can be purchased at an affordable price. The primary focus will be on acquiring images over the Roanoke River floodplain corresponding to the 2004-2006 growing seasons, with new or archived data from ASTER, ALI or SPOT used as fallback. Some archived Landsat imagery from 2003 or earlier may be used if needed, but we will try to avoid this because of the disturbances that occurred in 2003.

All images will be atmospherically and geometrically corrected following standard procedures. The images will be referenced to the existing classification, and spectral signatures derived for each class on the existing map.

Spectral Separability within and among Classes

Spectral separability between classes will be carried out using standard methods in remote sensing (i.e., Transformed Divergence Index) and statistics (Analysis of

Variance). Image data may be transformed using principal components analysis to reduce data volume. Deviation within a class will be assessed using the Z-score, a measure of the deviation of a pixel from the mean of the entire class. Different Z-scores (e.g., 1 standard deviation, 2 standard deviations, etc.) will be evaluated on a per-class basis to detect the threshold that represents a distinction from the class mean. The field data of vegetation composition will be used to determine the differences. Townsend & Walsh (2001) report overall species composition by class, and Townsend (2000) outlines the method for evaluating the deviation in species composition by class.

Field Data Support

Field data from 400 point locations along transects established for the NSF sediments project will be used as preliminary data to assess forest composition. These data include visual assessments of cover by species and an evaluation of the probability of membership in all vegetation classes on the original map. This data set will be split with 2/3 used for making the new map and 1/3 used for evaluation. Field data from the original project (~700 points and/or plots collected 1995-1997) will be used only for those pixel locations that do not exhibit high deviation from class means. Additional field data will be collected in 2006-2007 using the original method described by Townsend & Walsh (2001). Those data will be targeted to areas with: (1) poor spatial representation in the database, (2) demonstrable or known changes, or (3) possible classes not represented in the original database. It is expected that in 2 weeks of sampling, data from an additional 60 plots can be acquired.

Remapping Vegetation Classes

Pixels exhibiting little or no spectral deviation from the class mean of their original mapped class will be assumed to be unchanged. Pixels exhibiting change will be remapped using standard methods: unsupervised classification for broad land cover classes (plantations, agriculture, urban, bare) and supervised classification for forest classes. At present, I have used discriminant functions analysis to accurately map vegetation classes in Shenandoah National Park and the Central Appalachians. This method also allows the use of ancillary data (flood maps, topography) to refine the classification. However, if a standard method such as Maximum Likelihood appears to work well, that approach will be used instead.

Accuracy Assessment

Accuracy assessment will proceed as with the original study (Townsend 2000, Townsend & Walsh 2001) in which fuzzy class accuracy is used not only to identify map errors but to classify the direction and magnitude of those errors.

Products

TNC will be delivered a map of forest classes of the Roanoke River floodplain in an ArcMap compatible grid format. Map resolution will depend on the resolution of the imagery used to create the new map. Documentation will be provided that outlines the methods and evaluation, and details vegetation class composition and characteristics. All field data will be provided in spreadsheet format.

Timetable

New image acquisition will be scheduled for summer of 2006 and spring of 2007. Preliminary field data will be collected during the late summer/early fall of 2006. Archived imagery will be processed and prepared for analysis during the summer and fall of 2006. Analyses will proceed during the late fall 2006 through spring of 2007. New field data for map evaluation will be acquired in late spring or early summer of 2007. Map evaluation and revisions will be completed during the summer of 2007. The final map will be delivered to TNC by December 31, 2007.

Budget

See attached spreadsheet.

Budget Justification

The budget includes salary for one year of salary for a master's level graduate student who will conduct much of the remote sensing research. $8000 is requested for tuition remission for the graduate student. The budget includes 0.5 months of Townsend's salary, as well as 2 weeks of salary for a GIS/RS specialist in the Townsend lab to assist the graduate student with data preparation and analysis. Additional funds are requested for satellite image acquisition, software licensing, and travel to the Roanoke for map validation. Indirect costs are request at 10% of total direct costs, as per the letter from Sam Pearsall at The Nature Conservancy

References

Townsend, P. A. 1997. Environmental Gradients and Vegetation Patterns on the Roanoke River Floodplain, North Carolina. Ph.D. Dissertation. University of North Carolina, Chapel Hill.

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