FINAL CONTRACT REPORT

INTEGRATION OF MULTIBAND IMAGERY AS A MEANS OF MONITORING WETLAND RESOURCES FOR THE VIRGINIA DEPARTMENT OF TRANSPORTATION

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ABSTRACT

Digital multispectral imagery is a data collection technique that provides digital frame coverage in four spectral bands for color infrared imaging, allowing for the detection of soils, vegetation, water bodies, chemically contaminated areas, and various other resources. It is anticipated that using multispectral digital imagery technology for wetlands data collection will aid the Virginia Department of Transportation's (VDOT) Environmental Division in meeting the increasingly stringent monitoring requirements placed on it by state and federal regulatory agencies. Previous research conducted by the Virginia Transportation Research Council and Virginia Commonwealth University concluded that multispectral imagery was technically feasible and significantly less expensive than traditional field methods.

The primary objective of this research was to aid VDOT in implementing digital multispectral imagery to acquire some of the vegetation data required for the monitoring of its wetland mitigation program by determining the accuracy of the data collected with this technology and comparing it with data collected manually in the field. This was done in the hopes of convincing VDOT and the regulatory agencies that data collected by this means could replace some of the vegetation information currently collected manually.

Multispectral imagery collected at a resolution of 1 m was found to be capable of identifying major plant communities in wetland mitigation sites with an accuracy of approximately 80%. Thus, it can provide more complete information on the major plant communities than can random field sampling alone. In addition, the decreased labor needs and costs associated with using multispectral imagery to collect data as compared to traditional field methods make the technology an effective tool in determining the vegetation composition of wetland mitigation sites.

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INTRODUCTION

Digital multispectral imagery is a data collection technique that provides digital frame coverage in four spectral bands for color infrared imaging, allowing for the detection of soils, vegetation, water bodies, chemically contaminated areas, and various other resources (Anderson and Fitch, 1999). This type of remote sensing differs from traditional methods in that sensor bandpass or wavelengths are typically ≤25 nm wide. Most aerial photography and satellite sensor data are broad banded (±100 nm). These more commonly used lower spectral resolutions (broader bandwidths) do not permit a great degree of selectivity with particular spectrally subtle phenomena (Fitch and Anderson, 2000). It is anticipated that using multiband digital imagery technology to collect mitigation wetlands data will aid the Virginia Department of Transportation's (VDOT) Environmental Division in meeting the increasingly stringent monitoring requirements placed on it by state and federal regulatory agencies. Any mitigation site created after May 1, 1988, is subject to some level of monitoring. The frequency and duration of monitoring are dependent on a number of factors and can vary greatly. However, monitoring typically includes hydrologic and vegetative components. Vegetative monitoring density has increased over the past 10 or so years to the point that VDOT is normally required to monitor approximately 12 woody and 50 herbaceous plots per hectare. VDOT is currently responsible for monitoring in excess of 110 ha of mitigation wetland areas.

In October 2000, researchers at the Virginia Transportation Research Council (VTRC) and Virginia Commonwealth University (VCU) concluded a research project designed to test the technical feasibility of using real-time, digital multispectral imagery for acquiring data related to VDOT's environmental resources (Fitch and Anderson, 2000). The specific data collected included wetland mitigation sites and areas affected by the presence of acid soils. The study concluded that multispectral imagery was a *technically* feasible means of collecting information on the vegetation component of wetland sites currently monitored by VDOT. Based on limited cost information, it was concluded that using multispectral digital imagery for wetland vegetation monitoring could be significantly less expensive than the more traditional field methods. The study also concluded that with the proper production mechanisms in place, this technology could be integrated into VDOT's Environmental Division as a value-added component for resource monitoring.

Even with these positive findings, the researchers were concerned that it would be difficult for VDOT to implement multispectral imagery technology for a number of reasons. Since most VDOT personnel are not familiar with remote sensing and/or digital imagery, it would be risky to expect them to use this new tool without further evidence pertaining to the type of information the system can provide and the benefits of this new form of data. Further, the researchers deemed it presumptuous to assume that the regulatory agencies that oversee the wetland mitigation program would accept any data collected by a new technology without having additional information describing the accuracy of the data derived from such a data collection system. Therefore, this study was undertaken to address some of these barriers to implementation.

PURPOSE AND SCOPE

The primary purpose of this research was to aid VDOT in implementing digital multiband imagery to acquire some of the vegetation data required for the monitoring of its wetland mitigation program. In order to assist VDOT in the incorporation and application of this technology, the researchers concentrated on four primary objectives:

1. *Quantify the strengths and weaknesses of the vegetation identification information to be derived from the digital multiband imagery system.* This was done by conducting an error analysis on a subset of the data collected with the system.

2. *Provide VDOT with digital multiband imagery data for a number of mitigation sites*. This was done to provide personnel with data they could immediately begin analyzing and using without having to go through the collection and correction process that will ultimately be required. Ideally, this would prevent a large time lapse between the time a decision is made to implement the multispectral technology and the time hands-on experience could be gained by staff. These data would also serve as the foundation of a data archive that would allow for the temporal comparison and analysis of the wetland mitigation sites in the future.

3. *Provide a means by which the regulatory agencies (U.S. Army Corps of Engineers [Corps] and the Virginia Department of Environmental Quality [DEQ]) could become more familiar and confident with digital multispectral imagery technology*

and the type of data that it can yield. It was postulated that the regulatory agencies would gain an additional understanding of the type of information that could be derived from the technology by participating in the design of the research study, reviewing the results of the accuracy assessment, and analyzing some of the data sets.

4. *Develop a working or production level model that VDOT could follow for procuring and using digital multiband imagery*. This model would serve as a roadmap for VDOT to follow if and when a decision is made to implement the technology by outlining the major steps that would need to be undertaken and the entities within VDOT that should carry them out.

METHODS

Six tasks were completed to achieve the study objectives:

1. An oversight committee was formed to help guide the research.

2. Imagery data were collected for analysis and archival purposes.

3. An accuracy assessment was conducted on a subset of the imagery collected.

4. Presentations were made to the oversight committee and other VDOT personnel.

5. Multispectral imagery data and data collected by traditional field methods were compared.

6. A step-by-step production flow model was outlined for implementing multispectral imagery.

Development of Oversight Committee

A committee composed of representatives from the state and federal regulatory agencies responsible for reviewing the monitoring data for VDOT's mitigation program was formed soon after initiation of the project to help develop the research plan. It was initially envisioned that this group would assist the researchers in guiding the project and help eliminate concerns about the use of the digital multiband imagery technology to supplement the more traditional field methods currently used to monitor mitigation wetlands. The Corps, the DEQ, the Environmental Protection Agency, the Department of Game and Inland Fisheries, the Natural Resource Conservation Service, and the National Resources Section of VDOT's Environmental Division were invited to participate in this group.

Collection of Data

Imagery Acquisition

Committee members provided help in selecting locations to be used for the study. Initially, 14 sites were considered. Final site selection was based on the availability of previous data, location of the sites within the state, and proximity of the sites. Images were eventually acquired for a total of 10 sites beginning in the spring of 2001. Images for some of the sites were obtained again in the late summer of 2001, and images for most of the sites were collected again at least once during the spring of 2002. Images for two of the sites, the Ft. Lee and Charles City mitigation sites, were collected multiple times during the summer of 2002.

For the most part, imagery collection followed a pattern similar to that outlined in the first phase of the study (Fitch and Anderson, 2000). Coordinates for each site were determined by a mapping grade global positioning system (GPS) receiver and sent to the vendor responsible for the aerial collection of the data (TerraNautical Data, Inc., and Flightlan, Inc.) for input into an onboard navigational system. With the exception of one mission, the planes used for all sites were flown at an altitude of 1650 m, resulting in a ground sample distance (GSD) of 1.0 m. The GSD represents the area on the ground covered for each pixel in the image. Due to cloud cover, one of the Ft. Lee missions was flown at an altitude of approximately 800 m, resulting in a GSD of 0.5 m.

Interference filters were placed in front of each camera forelens to allow capture of a single spectral wavelength. The wavelength band centers at 10-nm bandwidths were blue (450 nm), green (550 nm), red (680), and near IR (770 nm). Imagery collected in the first phase of the study had bandwidths of 25 nm. Such narrow bandwidths allow for optimal spectral resolution, resulting in greater discrimination of the vegetation and soil features (Fitch and Anderson, 2000).

Imagery Correction

Raw data were electronically downloaded from the vendor via the Internet as *.tif* files, and geometric corrections were performed using ENVI image processing software at VCU's Geographic Information Systems (GIS) lab. Images were then sent to VTRC for geometric rectification and returned to VCU. The geometric corrections were designed to reduce the errors of skew, rotation, and perspective for the four images (one each from the four spectral bands) of the raw data. The geometric rectification provided real-world coordinate system values so that each image represented real space on the earth's surface. Upon retrieval of the rectified image, supervised raster classifications were performed using ERDAS Imagine 8.5 software. Using statistical transformed divergence, different land covers were assigned training signatures obtained by in-field verifications such that the signature separation scores were at least 1,900 (of a possible score of 2,000). This allowed only the highly separable features to be assigned to a specific vegetation class, resulting in a classification map for the wetland (Fitch and Anderson, 2000). Depending on how a particular classification map was to be analyzed and stored, some of the maps were converted to ArcView shapefiles.

Assessment of Accuracy

The separate data accuracy assessments were conducted to determine and quantify the errors associated with the remote digital imagery classification method. This was accomplished by comparing the computer-based assignment of species classes with the true species classification at randomly selected points throughout a wetland mitigation site. Because there is still significant debate among remote sensing specialists regarding the best approach to be used when analyzing the accuracy of remotely sensed data (Congalton and Green, 1999), each assessment was conducted differently based on the method of field data collection used and/or the sampling design.

Sampling Design

Accuracy Assessment 1

The first analysis was conducted on data collected at the Ft. Lee mitigation site. This mitigation site was created by excavating a steep-sided basin of the hillside between I-295 south of Richmond, Virginia, and Cabin Creek, Virginia, to form a lowland adjacent to the floodplain and natural forested wetlands (Whittecar and Daniels, 1997). Based on previous work by Congalton and Green (1999) and the classification scheme used for developing the species class maps, it was assumed the multispectral data collected had a multinomial distribution. Following this assumption, the number of samples needed to assess the classification was calculated using the following formula:

$$n = \beta \Pi_i (1 - \Pi_i) / b_i^2$$

where:

n = sample size

β = Chi square constant (α, $df = 1$)

Π_i = percentage of map area that is species i

b_i = precision

Two measures of accuracy are taken into account in this formula: confidence level and precision. Confidence level is accounted for in the Chi-square value. Typically, 85% confidence is used for accuracy assessments. Precision is the range of the confidence level. Therefore, a confidence level of 85% and a precision of 5% will give the user 85±5% confidence that the accuracy assessment values are correct.

For Accuracy Assessment 1, a confidence level of 85% and a precision of 10% were used. The results of the equation indicated that 126 samples needed to be collected. An additional 24 samples were collected for surety, bringing the total samples collected to 150. The sampling unit for this analysis was 1 pixel, or 1 square meter.

Accuracy Assessment 2

The second accuracy assessment was conducted for imagery data collected in the summer of 2001 for the Charles City wetland mitigation site. This site is characterized as a restored, emergent wetland approximately 20 ha in size. The sampling units for this second error analysis were clusters of pixels at least 3x3 (9 square meters). Again, because there are still differing opinions among remote sensing specialists as to the proper sampling unit size, a decision was made to use these larger clusters or polygons made up of several pixels (as opposed to the single pixels sampling units used in Accuracy Assessments 1 and 3) to help ensure that the size of the units sampled did not drastically affect the accuracy assessment results. Since the sampling units for this analysis were much larger than those of the other two, no attempt was made to adhere to the sample number formula outlined under Accuracy Assessment 1.

Accuracy Assessment 3

The third accuracy assessment used imagery data collected for Ft. Lee in the summer of 2002. As in Accuracy Assessment 1, the sampling unit for this analysis was 1 square meter. However, the sampling points were not selected randomly. Instead, researchers used field data previously collected by VDOT environmental staff. These data had been collected by following a field sampling procedure prescribed by the Corps for monitoring wetland mitigation sites. As a result, 10-m-radius buffers were measured around each groundwater monitoring well installed at the site, which lay along 10 transects that run east-west across the site. Within each buffer, four 1-m samples were randomly selected from the north, south, east, and west quadrants of the buffered circle. Due to the lower number of sampling points (76) collected, the resulting analysis had a confidence level of 70% and a precision of 10%.

Ground Truth Data

Accuracy Assessment 1

Ground truth, or reference, data were collected by first obtaining the latitude/longitude coordinates for each of the 150 randomly generated sample locations. These coordinates were then downloaded to a Trimble GeoExplorer 3 GPS receiver. Once in the field, the receiver was connected to the supplementary Beacon on a Belt system that provided corrected coordinates in real time. Using this system, the researcher navigated to each of the previously determined sample locations. Once at the specified location, the dominant species present for 1 square meter (estimated from the percentage cover of visible canopy) was recorded and checked against that generated by the classification software in the office.

Accuracy Assessment 2

In the second accuracy assessment, most of the dominant species were identified in the field with the help of personnel from VDOT's Environmental Division. The coordinates and dominant species of approximately 40 randomly selected locations were recorded. The researchers attempted to collect the dominant plant communities visible from the ground while including as much of the site geographically as possible.

Accuracy Assessment 3

As was previously described, VTRC used very detailed vegetation information collected by VDOT environmental personnel for this error analysis. This information was collected by VDOT as part of the normal monitoring data required by the Corps. Specifically, percent cover was calculated and recorded for woody and herbaceous species in the 10-m-radius buffers. Stem counts were also made for the woody species in the buffered areas. Four plots, 1 meter square, were "semi-randomly" located in each of the 10-m-radius buffers around each of the groundwater monitoring wells, and percent cover for each species found in these square-meter areas was recorded. The coordinates for these sites were recorded using a Leica GS50 GPS receiver, producing location information with sub-meter accuracy.

Error Matrix

Three error matrices were developed to analyze the data collected for each accuracy assessment. A simple comparison could have been made to determine if the species assigned to a particular sample unit was the same as (correct) or different from (incorrect) the reference data collected in the field, but this would have yielded simply a percentage of correct versus incorrect species assignments. Alternatively, an error matrix, defined as "a square array of numbers set out in rows and columns that express the number of sample units assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification" (Congalton and Green, 1999), is a preferable method because it compares two classifications on a species-by-species level rather than just an overall level (Lillesand and Kiefer, 2000). The columns of the matrix represent the reference, or ground truth, data collected. The rows represent the classification data generated by the multispectral imagery (the data being analyzed). An example of a simplified error matrix is shown in Table 1.

Table 1. Error Matrix Example

Reference Data

Classified Data		A	B	C	D	Total
	A	5	0	1	0	6
	B	0	4	1	1	6
	C	0	1	2	0	3
	D	0	0	1	4	5
	Total	5	5	5	5	20

The method of using an error matrix for analyzing error in remotely sensed data is much more effective because not only are the individual accuracies of each classification derived but the types of errors that occur also become obvious. Classification errors will be attributed to either errors of commission (including something in a category to which it does not belong) or errors of omission (excluding something in a category to which it does belong). This type of error distinction allows for a more complete examination of why errors are occurring.

Presentation and Evaluation of Multiband Imagery

To help VDOT environmental personnel and the other members of the oversight group become more familiar with the data that could be captured using digital multiband imagery, two meetings were held where the fundamentals of the technology were further described. The technology was also presented at the spring 2001 and 2002 meetings of the Environmental Research Advisory Committee, a group of VDOT and environmental regulatory agency representatives that help prioritize environmental research undertaken by VTRC. Previously collected data sets were shown, as were some preliminary error analysis numbers. Representatives from TerraNautical Data, Inc., the vendor who collected the majority of the data for this project, made a presentation to the oversight committee outlining the data collection procedures followed by the flight contractor. They provided details on the new multispectral system that they had recently assembled and were currently using for data collection.

Throughout the study, personnel from VDOT's Natural Resources Section provided a great deal of input as to how they would like to see the accuracy assessment conducted. They provided input on the site selection and sampling regime undertaken and provided the majority of the ground truth, or reference, data used in the accuracy assessments.

Comparison of Multispectral Imagery Data and Traditional Field Data

The data sets collected by way of multispectral imagery were compared to field data that are currently required by the Corps for monitoring. Data used in the accuracy assessments were used, as were the GIS coverages developed from the raw multispectral imagery. The pros and cons for each data collection method were outlined.

Development of Production Model

A step-by-step production model was developed to provide specific actions for collecting, correcting, and analyzing mitigation wetland vegetation information. This was done by following many of the steps previously summarized in Fitch and Anderson (2000) and adding specific changes that were required because of recent changes in the hardware used to collect the data and the software used to correct and analyze the imagery. Additional input was also sought from VDOT's Information Technology Applications Division's GIS Program to determine what role they could play in processing, manipulating, and archiving the data that VDOT's Environmental Division could potentially acquire.

RESULTS AND DISCUSSION

Imagery Data

During the 2-year study, more than 20 imagery data sets were collected. In some cases, data for multiple sites were collected during a single flight, and in other instances (due primarily to weather related problems), several flights had to be made to collect acceptable data for a single site. Table 2 lists all the sites for which data were collected during the current study and the flights that were made during the first phase of the study completed in 2000. Data for Ft. Lee and Charles City were collected multiple times during 2001 and 2002. Though the images collected represent a significant amount of data, the researchers originally intended to collect imagery for five or six additional sites. Unfortunately, the original vendor that was under contract experienced problems with its digital imagery system and, as a consequence, some time was lost and some data sets went uncollected while the imagery acquisition equipment was being repaired and upgraded. In addition, data were not collected for several weeks following the September 11 terrorist attacks due to flight restrictions on general aviation aircraft. This restriction came during the optimal time period for fall vegetation data collection. The research team contracted with a second vendor, but valuable time was lost.

All imagery data collected were sorted, labeled, and archived on CD-ROMs. It is anticipated that these data will serve an important role in VDOT's future wetland monitoring efforts for years to come by allowing for temporal comparisons of vegetation communities.

Table 2. Location, Acquisition Date, and Coverage

Site	1998	1999	2000	2001	2002
Charles City	X		X	X	X
Chisman Lakes	X	X		X	X
Goose Creek	X	X			X
Ft. Lee	X	X	X	X	X
Warrenton Bypass		X		X	X
Emporia Bypass		X			X
Otterdam	X	X			X
Franklin Bypass		X		X	X
Courtland Bypass		X		X	X
Rt. 13	X				
Swash Bay			X		
Manassas Airport					X

Species Identification Maps

An example of the vegetation species identification maps resulting from the classification of the multispectral imagery data collected is shown in Figure 1. This type of classification coverage was used in the accuracy assessments discussed elsewhere in this report and is typical of the type of output that can be generated from the raw imagery provided by a multispectral

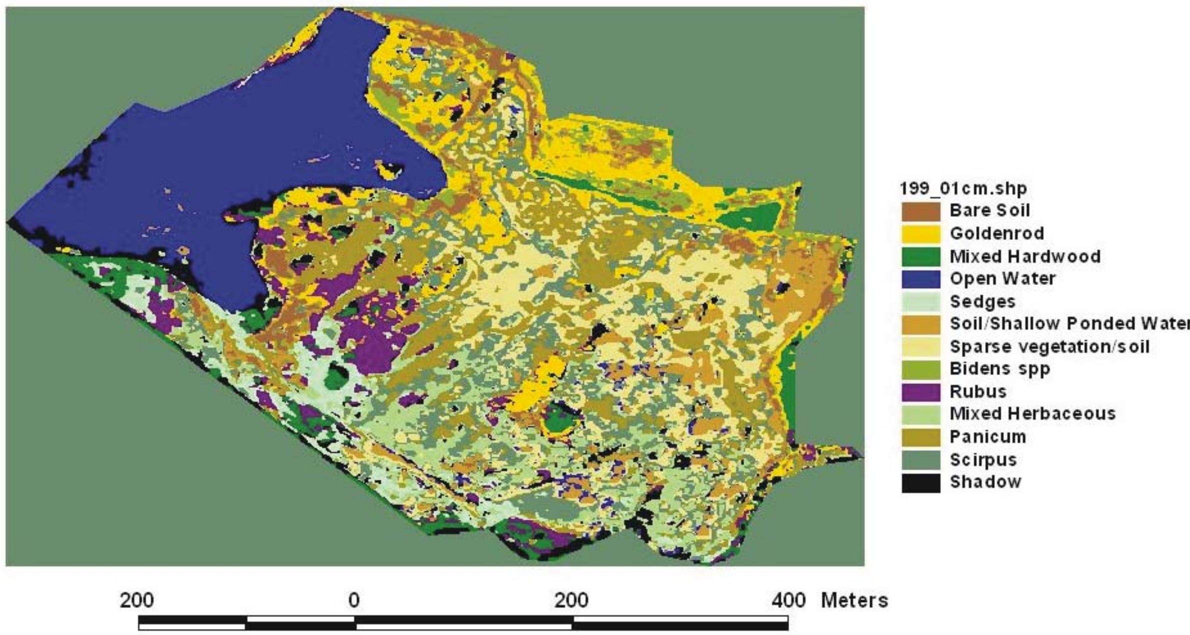

Figure 1. Charles City mitigation wetland site vegetation classification map.

imagery vendor. The data generated are a comprehensive vegetative community classification of the entire wetland system.

Accuracy Assessments

Accuracy Assessment 1

The error matrix constructed for the first accuracy assessment is shown in Table 3. The values on the diagonal (shown in *bold italics*) of the matrix represent the sample units classified correctly (i.e., the computer classification matched the ground truth classification). The overall accuracy of the classification was determined to be 84% (124 of 148), and although this is very good, *overall* accuracy is not always the most telling accuracy value that can be obtained from the matrix. Comparing species-specific accuracy percentages is another means of evaluating the accuracy of the classification. The error matrix reveals the errors related to omission and commission for each species classified. An error of omission is the result of not including a particular sample in the class to which it truly belongs. This is often referred to as producer's error. Conversely, commission errors are due to the inclusion of samples into classifications to which they do not belong. These are referred to as user's errors. All errors revealed using the error matrix are omissions from the proper categories and commissions to the wrong categories (Congalton and Green, 1999). Errors of omission and commission calculated for each of the species classification groupings are shown in Table 4.

Table 3. Error Matrix for Accuracy Assessment 1

Reference Data

Classified Data

	Salix nigra	**Mixed grasses**	**Pinus taeda**	**Open Water**	**Lesped-eza**	**Scirpus**	**Row Total**
Salix nigra	*15*	0	0	0	9	0	**24**
Mixed grasses	0	*22*	0	0	0	3	**25**
Pinus taeda	1	0	*21*	0	2	1	**25**
Open water	0	0	0	*20*	0	5	**25**
Lesped-eza	1	0	0	0	*23*	1	**25**
Scirpus	0	1	0	0	0	*23*	**24**
Total	**17**	**23**	**21**	**20**	**34**	**33**	**148**

Table 4. Accuracy Assessment 1 Values Showing Producer's and User's Accuracy for Each Vegetation Class

Species	**Producer's Accuracy**	**% Correct**	**User's Accuracy**	**% Correct**
Salix nigra/Liquidambar	15/17	88	15/24	63
Upland grasses	22/23	96	22/25	88
Pinus taeda	21/21	100	21/25	84
Open water	20/20	100	20/25	80
Lespedeza/Andropogon	23/34	68	23/25	92
Scirpus/Typha latifolia	23/33	70	23/24	96

From this information, it is easy to see the three areas of greatest error: omission of Lespedeza/Andropogon and Scirpus/Typha latifolia classes and commission of Salix nigra/Liquidambar classes. The commission errors (over-inclusion of Salix nigra/Liquidambar) are easier to understand. These two very different species were grouped together for this classification, and even though their spectral signatures were very similar, the signature for the class was broader than it would have been if the two had been given separate classes. This less-specific spectral signature essentially results in a more generic class that allowed additional species to be included inadvertently. The omission errors for the other two classes are more difficult to explain. It is assumed that at least some of the error related to the class including Andropogon is due to the fact that it grows unevenly, creating tufts that are prominent when viewed from an oblique angle, but small when observed from directly overhead (as is the perspective of the multispectral camera). Because of this, plant material immediately adjacent to it will affect the spectral value obtained for that particular pixel. Fifty percent of the error associated with the Scirpus/Typha latifolia class was due to the exclusion of five Typha latifolia samples. These were improperly included in the open water class (these five samples incidentally made up 100% of the commission errors associated with the open water class). Typha was easily spotted when viewed from a ground level perspective. However, when observed from directly overhead, the surface area of this plant appears much thinner, again allowing the area around it to influence the spectral signature. At least five of the misrepresented samples in this case were growing in standing water. Consequently, for the square meter that made up the pixel that was analyzed, the spectral signature of the water was recorded instead of the signature for the Typha.

Accuracy Assessment 2

The error matrix developed for the second error analysis is shown in Table 5. The overall accuracy for this classification map was determined to be 79% (31 of 39). It was originally postulated that because the larger sample units (larger clusters of pixels rather than single pixels) were used for this accuracy assessment, the overall accuracy of the classification would be greater than that calculated in Accuracy Assessment 1. The larger sample units theoretically should have eliminated, or at least reduced, the potential for ground control registration problems or errors associated with an arbitrary square-meter pixel not conforming to the true landscape found in the field (see Figure 2). However, because larger sample clusters were used for this analysis, fewer sample points were collected. As can be seen from the error matrix, several of the classifications were not sampled, and most of those that were sampled had fewer samples collected than would be statistically optimal for such an analysis. The information derived from this analysis is still beneficial to the overall assessment of the multispectral imagery technology, as the overall accuracy achieved was still relatively high. The greatest errors were due to the omission of Panicum and Bidens, but large error trends for particular species do not appear to be evident, as the eight misclassifications were spread over five different classes (see Table 6). It is likely that part of this is due to several species being present in a given sample area, thereby altering the spectral signature for the dominant species, resulting in a misclassification. The classification map does an excellent job of illustrating how the major species are interspersed throughout the site. It is also important to note how well non-vegetated areas are delineated for this particular site, potentially indicating a hydrology or soils problem for certain areas.

Accuracy Assessment 3

The error matrix developed for the third accuracy assessment is shown in Table 7. The overall accuracy for this image classification was 84% (62 of 74). Because VDOT personnel collected the ground truth, or reference, data used for this analysis as a part of the normal monitoring requirements for the mitigation site, the information obtained was very detailed. Instead of only the dominant species, all the species found in a single meter-square plot were recorded. In many instances, three or four species were recorded, with none making up more than half of the plot. Multispectral imagery obtained at 1-m resolution allows for the assignment of only a single species to each square meter, and so the type of sub-meter information collected manually in the field could not be generated. To compensate for this, certain classifications developed from the multispectral imagery were composed of several plant species (i.e., Juncus/Scirpus/Eleocharis class). Staff from VDOT's Environmental Division confirmed that this was acceptable and in some cases even desirable as it would group together species found under the same soil and hydrologic conditions. This provides valuable information about the ability of a site to support wetland vegetation.

Table 5. Error Matrix for Accuracy Assessment 2

Reference Data

	Bidens	Panicum	Rubus	Scirpus	Solidago	Typha	Mixed hardwoods	Mixed herbaceous	Open water	Shadow	Sparse vegetation	Soils	Row Total
Bidens	***3***	0	0	0	0	0	0	0	0	0	0	0	**3**
Panicum	0	***5***	0	0	0	1	0	0	0	0	0	0	**6**
Rubus	0	0	***3***	0	0	0	0	0	0	0	0	0	**3**
Scirpus	0	2	0	***11***	0	0	0	0	0	0	0	0	**13**
Solidago	2	0	0	1	***1***	0	0	0	0	0	0	0	**4**
Typha	0	0	0	0	0	***0***	0	0	0	0	0	0	**0**
Mixed hardwoods	0	0	0	0	0	0	***1***	0	0	0	0	0	**1**
Mixed herbaceous	0	0	0	0	0	0	0	***2***	0	0	0	0	**2**
Open water	0	0	0	0	0	0	0	0	***0***	0	0	0	**0**
Shadow	0	0	0	0	0	0	0	0	0	***0***	0	0	**0**
Sparse vegetation	0	0	0	0	1	0	0	0	0	0	***2***	0	**3**
Soil	0	0	0	1	0	0	0	0	0	0	0	***3***	**4**
Column Total	**5**	**7**	**3**	**13**	**2**	**1**	**1**	**2**	**0**	**0**	**2**	**3**	**39**

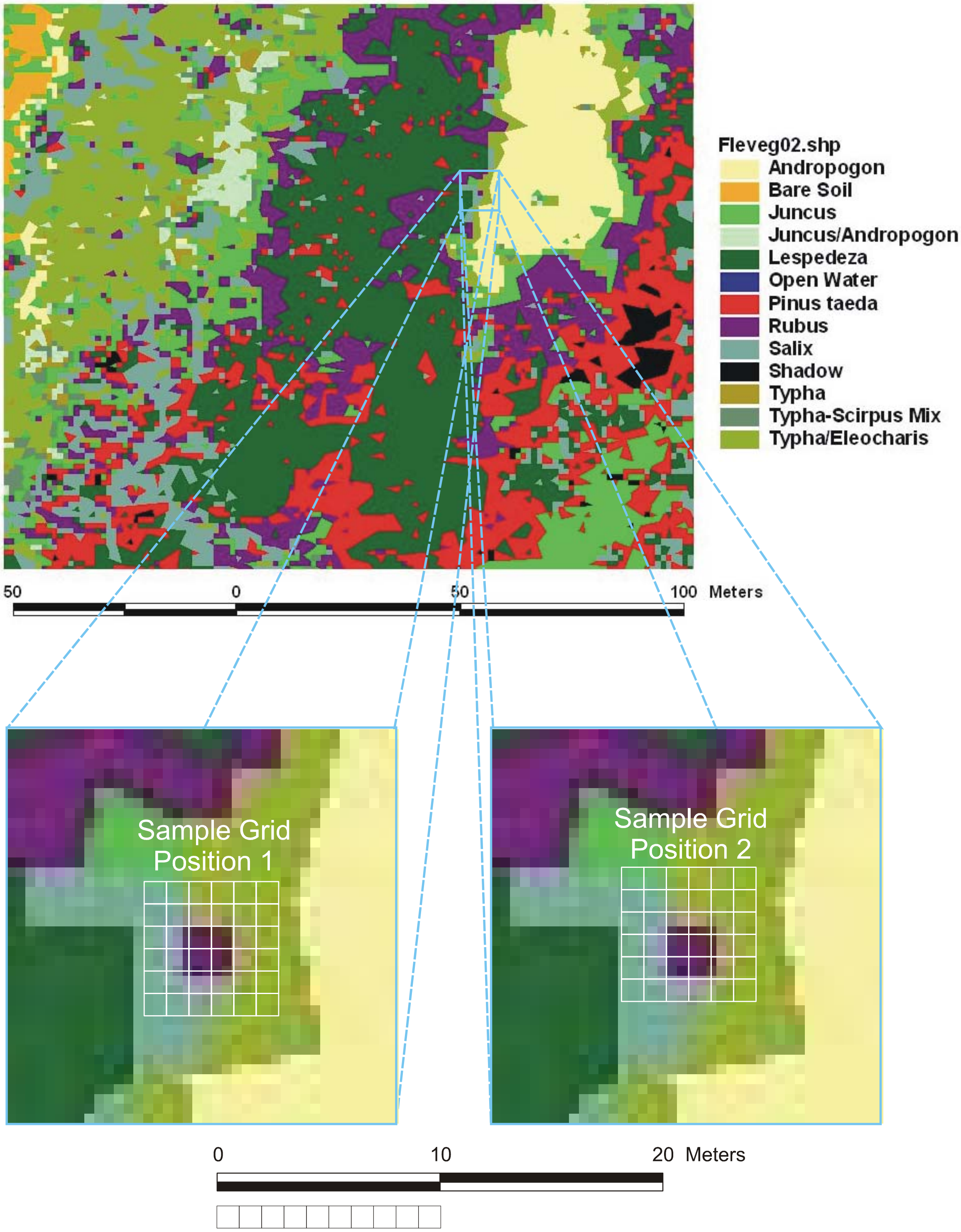

Figure 2. Zoomed-in View of Portion of Ft. Lee Wetland Mitigation Site Showing How Size and Position Can Influence Spectral Signature Obtained for a Given Sample Area

Table 6. Accuracy Assessment 2 Values Showing Producer's and User's Accuracy for Each Vegetation Class

Species	Producer's Accuracy	% Correct	User's Accuracy	% Correct
Bidens	3/5	60	3/3	100
Panicum	5/7	71	5/6	83
Rubus	3/3	100	3/3	100
Scirpus	11/13	85	11/13	85
Solidago	1/2	50	1/4	25
Typha	0/1	0	0/0	NA
Mixed Hardwoods	1/1	100	1/1	100
Mixed Herbaceous	2/2	100	2/2	100
Open Water	0/0	NA	0/0	NA
Shadow	0/0	NA	0/0	NA
Soils	3/3	100	3/4	75

As was the case in the second accuracy assessment, there does not appear to be any specific trend for the errors found in Accuracy Assessment 3. The 12 errors were again spread out over five classes (as shown in Table 8). When collecting field data, VDOT staff recorded several minor species, but these same classes were not identified when the image was trained by assigning species information to specific signature values. This resulted in 3 of the 12 errors found in the image. There is a possibility that misclassification due to insufficient training data could occur with almost any image, as the classification is dependent on the input signatures.

Comparison of Multispectral Imagery Data and Traditional Field Data

Vegetation coverage information derived from multispectal imagery differs significantly from the vegetation data currently required by the Corps. Plot dominance data that are manually collected provide quantitative values for discrete locations within the mitigation site. In a Branch Guidance document provided to VDOT by the Corps special conditions for compensation site monitoring require that woody plant density counts be collected at five 9.1-m-radius plots randomly selected for each 0.4 ha of wetland. The data are collected for these plots by visually observing and counting the woody species occupying the plot and then making an assumption for the total percentage of the plot that each of these occupies. Herbaceous plant density counts are to be made using 20 1-square-meter plots per 0.4 ha (Federal Interagency Committee for Wetland Delineation, 1989; U.S. Army Corps of Engineers, 1997). The information gathered for the 1-m plots is much more detailed than that garnered from the digital imagery. It is not uncommon for multiple species to occupy 1 square meter in a complex wetland system. Conversely, it is difficult to extrapolate the findings from a relatively small percentage of a wetland area (i.e., 20 1-m plots per 0.4 ha) and assume that the same conditions exist for the entire site. It is similar to trying to determine what picture or object is being represented when looking at only a few pieces of a jigsaw puzzle. The current monitoring protocol as described gives detailed information for 0.5% of the site area and more general data for approximately 33% of the area (see Figure 3). Given the dramatic soil and hydrologic variations that are possible within a given site, it is reasonable to expect similar variations in major plant community establishment.

Table 7. Error Matrix for Accuracy Assessment 3

Reference Data

	Andropo-gon/Festuca	Bare Soil	Juncus/ Scirpus/ Eleocharis	Lespedeza	Pinus/ Liquidambar	Rubus	Salix	Shadow	Typha	Water	Other	Row Total
Andropo-gon/Festuca	***6***	0	0	0	0	0	0	0	0	0	0	**6**
Bare soil	0	***0***	0	0	0	0	0	0	0	0	0	**0**
Juncus/ Scirpus/ Eleocharis	1	0	***31***	1	0	0	0	0	0	0	1	**34**
Lespedeza	0	0	2	***5***	0	0	0	0	0	0	0	**7**
Pinus Liqudambar	0	1	1	0	***15***	0	0	0	0	0	0	**17**
Rubus	0	1	0	0	0	***1***	0	0	0	0	0	**2**
Salix	0	0	1	0	0	0	***1***	0	0	0	2	**4**
Shadow	0	0	0	0	0	0	0	***0***	0	0	0	**0**
Typha	0	0	0	0	0	0	0	0	***3***	0	1	**4**
Water	0	0	0	0	0	0	0	0	0	***0***	0	**0**
Other	0	0	0	0	0	0	0	0	0	0	***0***	**0**
Column Total	**7**	**2**	**35**	**6**	**15**	**1**	**1**	**0**	**3**	**0**	**4**	**74**

Table 8. Accuracy Assessment 3 Values Showing Producer's and User's Accuracy for Each Vegetation Class

Species	Producer's Accuracy	% Correct	User's Accuracy	% Correct
Andropogon/Festuca	6/7	86	6/6	100
Bare soil	0/2	0	0/0	NA
Juncus/Scirpus/Eleocharis	31/35	89	31/34	91
Lespedeza	5/6	83	5/7	71
Pinus/Liquidambar	15/15	100	15/17	88
Rubus	1/1	100	1/2	50
Salix	1/1	100	1/4	25
Shadow	0/0	NA	0/0	NA
Typha	3/3	100	3/4	75
Water	0/0	NA	0/0	NA
Other	0/4	0	0/0	NA

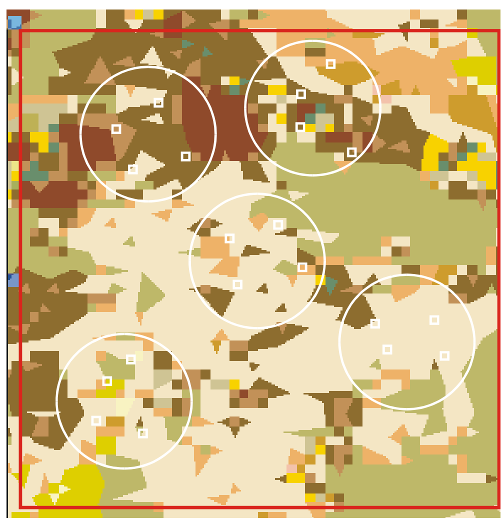

Figure 3. Areas Covered by Monitoring. Square represents 0.4 ha as collected by digital multiband imagery. Circles represent general data collected manually in the field. The small squares inside the circles represent detailed vegetation information collected for square-meter plots.

Multispectral imagery is capable of providing more general but complete data for the entire wetland site. It is very possible, however, that some of the minor species present will go unrecorded as was documented in Accuracy Assessment 3. To eliminate this chance, theoretically more training signatures could be collected in the field, but then the time and cost efficiencies provided by this technology would be reduced and the effort required would be similar to that of the current field methods. The answer to the question of which method provides the most information on how successful a mitigation site is at supporting wetland information can be observed in Figure 4, which shows a classification map generated from multispectral imagery overlaid with areas where field data were manually collected.

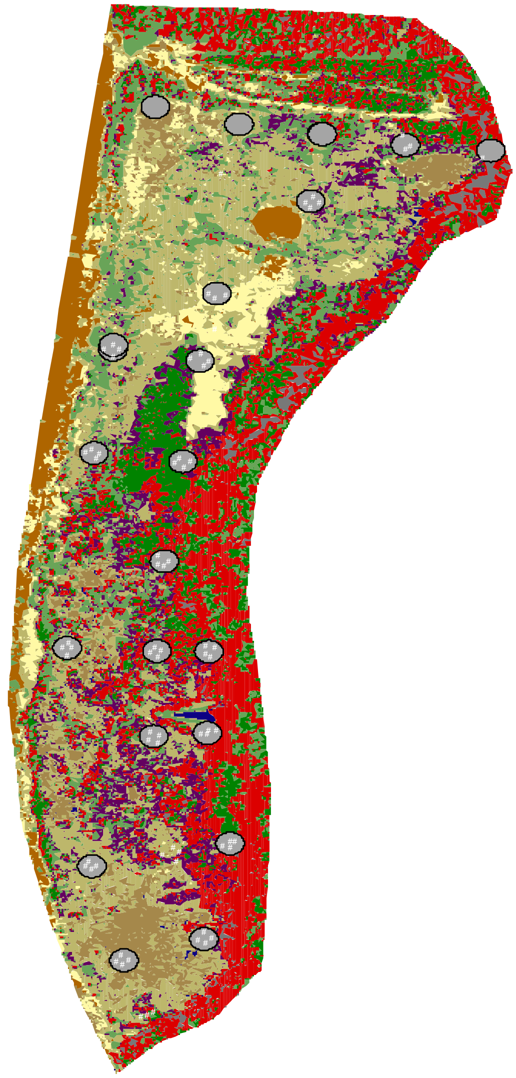

Figure 4. Vegetation classification map. The circles represent 10-m-radius buffers, and the white dots represent locations where normal in-field vegetation information would be collected.

In addition to the differences in total area for which information is generated, the classification map derived from multispectral imagery allows for the digital examination and analysis of the entire site as a single unit, making the identification and quantification of specific areas demonstrating success or failure possible. In the field, manual monitoring provides only a listing of species found in square-meter plots or an estimation of plants found in 10-m buffers along a series of transects. The more detailed data provided by plot examination are indeed useful in determining the success of a particular part of a wetland and its ability to support desirable species but not the best means available by which to judge the success of the entire wetland.

CONCLUSIONS

- *Multispectral imagery collected at a resolution of 1 m can identify major plant communities in wetland mitigation sites with an accuracy of approximately 80%.*

- *The errors (misclassifications) resulting from the use of multispectral imagery appear to be the result of altered spectral signatures.* Alterations in the signatures in this study were from (1) thin vegetation canopies allowing the signature of the ground or water below the plant to be measured, and (2) several species occupying a given pixel, thereby causing the pixel to have a signature value that was different from any of the individual species in it.

- *Species classification information obtained from square-meter multispectral imagery does not provide the level of detail that can be obtained when species composition is examined manually in the field for square-meter plots.*

- *Multispectral imagery provides more complete information on the major plant communities in a given wetland system than does random field sampling by providing vegetation classification information for the entire site.*

- *Because the multispectral data are in a digital format, various types of automated analyses can be performed (i.e., specific area calculations, temporal comparisons).* This is not possible with the current manual field practices employed.

- *Based on the accuracy of data obtained, the increased quantity of data provided for a given site, and the decreased labor needs and costs associated with the collection of the data as compared to traditional field methods (Fitch and Anderson, 2000), it is concluded that multispectral imagery is an effective means of determining the vegetation composition of VDOT's mitigation wetland sites.*

RECOMMENDATIONS

General

So that VDOT can begin collecting better wetland vegetation monitoring data in a more timely and cost-effective fashion than is currently possible with manual field methods, the following recommendations are made:

1. *The Natural Resources Section of VDOT's Environmental Division should begin using multispectral imagery as a means of obtaining some of the vegetation information required for the monitoring of its wetland mitigation sites*. These data should be used by natural resources staff to supplement field data that are currently being collected manually.

2. *The Natural Resources Section of VDOT's Environmental Division should request permission from the Corps, Norfolk District, to allow the use of vegetation classification data derived through multispectral imagery to monitor wetland vegetation*. In consultation with the Corps and the DEQ, natural resources staff should develop an agreement to combine the data acquired with multispectral imagery with a subset of those currently collected manually.

Implementation

To implement the use of multispectral imagery in the most effective and time-efficient manner, the following implementation steps are recommended:

1. *The Natural Resources Section of VDOT's Environmental Division should obtain GPS coordinates for all wetland sites requiring monitoring*. The wetland boundary should be identified in the field and properly registered by way of GPS. This information should be used by these same staff members to generate a wetland boundary coverage that specifies the exact area to be analyzed on the multispectral imagery collected.

2. *VDOT should select a vendor to collect multispectral imagery*. Staff of the Natural Resources Section should select a vendor capable of providing four-band multispectral digital imagery, based on the vendor's price for collecting the data and ability to collect the data in the time period specified. Staff will need to provide the vendor with the flight line coordinates for each site to be flown and the desired date that the collection is to occur. Staff can determine flight line coordinates directly from the previously collected GPS delineation.

3. *Staff of the GIS Program in VDOT's Information Technology Applications Division should rectify imagery provided by the vendor*. This step will reference the imagery to a real-world coordinate system. This can be done with an image processing software package of choice or within a GIS environment, both of which are readily available to GIS program staff.

4. *Staff of the Natural Resources Section should classify the imagery*. A limited amount of vegetation information will need to be collected by staff in the field to help with the initial classification of the imagery. The approximate location of the major plant species will need to be noted, as these data will be used to "train" the image. This vegetation information can be collected at the same time GPS coordinates are collected for the site boundary. After the initial classification is performed on the raster image, it will be necessary to convert the image to a vector GIS coverage. Again, this classification and the final conversion will need to be conducted in an image processing or GIS environment and should be conducted by natural resources staff.

5. *Staff of the Natural Resources Section should perform the desired analysis*. Following the development of the GIS coverage, a variety of spatial analyses can be

performed to calculate areas for specific species, calculate and measure change detection, or conduct a number of other more complex analyses available in a GIS or image processing environment. Natural resources staff should perform all analyses conducted.

6. *Staff of the GIS Program should archive all data*. After the desired analyses have been conducted for a given data set by natural resources staff, the GIS coverage, the classified raster image, and the unclassified reference image should be archived by GIS program staff.

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