DISCUSSION

The project described in this thesis had a single, brief, encompassing primary objective. This objective was expanded into a wide range of methodological problems or secondary objectives. This discussion section is organized by these objectives. The primary objective was to produce a current land cover map of Virginia using Landsat Thematic Mapper imagery. The secondary objectives addressed some of the specific issues of the primary objective.

The first secondary objective was: To demonstrate the feasibility of producing a fine-scale map covering a relatively large area, in a reasonable amount of time using a personnel computer. This objective sought to demonstrate future potentials.

The next secondary objective was: To provide working solutions to the common problems of haze/clouds, shadow, and to obtaining ground points in reflectance-based remote sensing. These problems have been a part of remote sensing from the beginning. There are no ideal answers.

The last secondary objective was to present data on the areas and proportions of Virginia currently in major land cover types. The information presented herein may be used as a baseline to assess changes and trends within the landscape of Virginia.

Primary Objective

To produce a current land cover map of Virginia using Landsat Thematic Mapper imagery seems to be a relatively simple objective. The fulfillment of this object should include questions of timeliness, proper use of Landsat TM, overall map quality, and benefit to wildlife and natural resource management. However, upon closer inspection several questions required answers. What is considered *current*? Even the question of what is *Virginia* can be asked. What categories are considered *land cover*? How is this valuable to wildlife and natural resource management? And finally, how *good* is the map?

Timeliness

The question of timeliness or currentness of maps was discussed by Williamson (1981). He termed this issue the Obsolescence Problem. Most maps are obsolete by the time they are printed (Giles pers. comm.). The every-changing nature of land cover makes this problem important. This does not mean that classifying land cover is not worthwhile, but rather, should be done in a timely manner. Users of these products should definitely be aware of the dates of original imagery and dates of classification.

The majority (9) of the TM scenes were from 1992, with one from 1991 and 4 from 1993 (Table 3). These were the most recent scenes available. As stated in the Methods section, the Landsat TM data were bought as part of the Virginia Gap Analysis Project through the MRLC consortium. If more recent images, of any quality, were available, they would have cost significantly more. A January 1998 terrain corrected Landsat TM image of scene 1635 costs $5950 (Space Imaging EOSAT 1998). If this estimate was extrapolated to the entire Commonwealth, the cost would be $83,300. Therefore, the MRLC consortium saved this project a significant amount of money. The scenes used in this thesis were the most recently dated feasible images.

The other issue of timeliness lies with the temporal difference between training data, Landsat TM scene, and accuracy assessment reference data. This subject will be addressed in the discussion of accuracy.

Area

Aside from time, the more obvious dimension of space is also a question. With questionable base maps, border disputes, and changing shorelines, it is difficult to determine the exact area and extent of Virginia. This thesis used the Virginia border provided by the U.S. Census Bureau via TIGER files. This 1:100,000 scale digital map was created around the time of the 1990 census.

To avoid some of the problems described above, a 1 kilometer buffer was drawn around the border. The assumption was made that *too much area mapped is better than too little area mapped* (i.e., errors of commission are less bad than errors of omission). It is also necessary for natural resource planners and managers to have information about neighboring land as well as their area of interest. The 1 km buffer provides some of this information. If more information is needed, data on surrounding lands or data on a broader scale may be required.

Classification System

Within Virginia, basic land cover was delineated. In this classification, basic land cover includes deciduous forest, coniferous forest, mixed forest, shrub/scrub, herbaceous, open water, disturbed land, and coastal wetlands. This classification system is useful for assessing wildlife habitat on a very broad scale. Other categories were later requested by interested parties using the preliminary results. These requested categories include: row crop and pasture (separated from herbaceous), rock outcrops and urban areas (separated from disturbed lands). While these classes would undoubtedly be useful for assessing habitat for some wildlife species, most of the categories are more land use than land cover and would require extensive training data, imagery analysis, and reference data in order to obtain a reasonable accuracy level. These additional categories are beyond the scope of the project reported in this thesis.

Natural Resource Applications

The potential uses of the produced land cover map (Figure 27) are many. Mapping potential species distribution based on basic habitat associations; determining how much area of each basic habitat type is present; assessing the degree of fragmentation, interspersion, and diversity of habitat types; all can be done relatively easily with this digital land cover map and a GIS.

The land cover map presented in this thesis can become a powerful tool, especially when combined with other digital spatial layers. Hassouna (1997) combined this land cover map and digital elevation models (DEMs) to estimate soil erosion over an area. Roth et al. (1996) and Wang et al. (1997) combined land cover with hydrography, and aquatic health indicators to determine the effect of land cover on aquatic habitat. Gap Analysis uses land cover to predict species distribution (Klopfer 1997, McCombs 1997) and eventually species richness then compares richness to biodiversity management of an area (Scott et al. 1993). Countless other natural resources research, planning, and management activities rely on knowledge of land cover.

Accuracy

For a map of this type to be useful in natural resource applications, it must be relatively accurate (Congalton 1996). Great effort was put forth prior to classification to insure high spatial fidelity. However, the spatial accuracy was never directly quantitatively assessed. Qualitative checks were performed at various stages before and after classification. Checks included matching the raw and classified TM imagery with known spatial data such as roads, streams, and SPOT 10 m panchromatic imagery.

Greater quantitative attention was placed on thematic accuracy than on spatial accuracy. This project was fortunate to have a large number (1773) of independently labeled reference points. These points were fairly evenly dispersed across the Commonwealth (Figure 11). Unfortunately, the reference points were spatially unreliable. The pitch, roll, and yaw of the videography aircraft caused this spatial error. Reports of reference points being greater than 70 m from their intended position was common (Slaymaker et al. 1996). Spatial errors of 240 m were infrequently found in the mountainous videography transects.

To continue using these reference points, the land cover map was “filtered”. This filtering process identified areas with homogeneous land cover. The 5x5 homogeneous filter identified areas that were truly assessable. This was accomplished by analyzing pixels at the center of a 5 cell by 5 cell matrix and retaining only pixels with all 25 cells having the same land cover type. A 3x3 homogeneous filter (all 9 cells must have the same value) was also performed. The 3x3 filter does not account for all of the spatial inaccuracies within the reference data. This step was completed to get a better idea of the affects of homogeneous filtering on both assessable map area and map accuracy values.

The 3x3 homogeneous filter reduced the assessable area of Virginia to 6,094,746 ha or 53.3% of the full area (Table 136). As described herein, “assessable area” refers to the area for which the reference data are valid (i.e., homogeneous pixels which reduce the spatial inaccuracies of the reference information). The 5x5 homogeneous filter reduced the final assessable area to 3,675,617 ha or 32.2% of the full area (Table 137).

Throughout both filtering processes, mixed forest and shrub/scrub were the categories most affected (Figure 27). After the 5x5 filter, approximately 5% of each class remained from the every-pixel level. Both of these categories, the mixed forest and shrub/scrub areas have extensive edges and highly interspersed patterns. Mixed forest may occur at edges between deciduous and coniferous forests, but in the piedmont and coastal plain there are large areas where mixed forest is not an edge phenomenon. Shrub/scrub typically occurs where forest and herbaceous land intertwines. Some old fields, less-dense eastern red cedar patches, and christmas tree plantations (or other young tree regeneration areas) might result in large homogeneous shrub/scrub areas.

Open water was, by far, the category least affected by the filters. Open water retained almost 85% of its original area following the 5x5 homogeneous filter. The vast majority of open water is found in the Chesapeake Bay and in large reservoirs. These bodies of water are definitely homogeneous objects.

Deciduous forest and herbaceous were the second and third least affected cover types, respectively. Deciduous forest retained 36% of its original area while herbaceous retained 31%. Large blocks of continuous forest, especially along mountainous ridges, and large blocks of pasture and row crop were the primary reasons for the results of these land cover classes.

Coniferous forest, disturbed land, and coastal wetland all retained between 15% and 19% of their original, every-pixel level, area. These categories did not have the continuity of open water, deciduous forest, or herbaceous types, but had larger homogeneous blocks than those of mixed forest and shrub/scrub.

Much attention has been placed on forest fragmentation, patch size, and edge area in recent years through the emerging field of landscape ecology (Trani 1996). These filters were not intended to show any biological implications of the landscape, but rather to develop a procedure for using the reference data in assessing the error. A 5x5 matrix containing deciduous forest and mixed forest may be considered not fragmented (or homogeneous) by most landscape ecologist, but was considered heterogeneous through the 5x5 filter. For biological applications, this type of analysis becomes dependent on scale (both thematic and spatial). As a secondary consequence of filtering to improve validity of the reference points, the percentage of a type (e.g., 31% of herbaceous retained after the 5x5 homogeneous filter) may be an expression useful in landscape pattern change over time (cf. Trani 1996).

The homogeneity filters had profound impacts on map accuracy (Figures 28 and 29). Generally, the overall accuracy within each scene increased following the filters (Table 133). The only decrease was observed between the 3x3 filter and the 5x5 filter of scene 1635. This anomaly could be a result of the low number of usable reference points (14 out of 117) available for the 5x5 analysis.

This pattern continued with the statewide mosaic both for overall accuracy and Kappa values (Figure 29) and for each individual land cover class (Figure 28). In the measure of user's accuracy, mixed forest was the only category to decline. Mixed forest along with shrub/scrub were the only categories to decline in producer's accuracy following the filters. These results are probably due to the low number of useable reference data and the difficulty of classifying and assessing these transitional cover types.

Each land cover category possesses characteristics or tendencies that may cause classification confusion with other categories. Some of this confusion, evident in the error matrices, can be explained.

Deciduous forest accuracies, both user's and producer's, increased following use of both homogeneity filters (Figure 28). The largest source of omission (producer's accuracy) error, in all 3 assessment levels, was with coniferous forest. Pixels labeled coniferous when they should have been label deciduous, could have been caused by coniferous (or at least persistent leafed) understory vegetation with deciduous overstory vegetation. Rhododendron (*Rhododendron* spp.) and mountain laurel (*Kalmia latifolia*) are common understory shrubs. An understory dominated by coniferous trees or shrubs can appear similar to a coniferous overstory on the medium scale 1:40,000, leaf-off, color-infrared NAPP photographs used as training data. Deep shadows caused by long steep slopes also make deciduous areas appear coniferous.

In terms of commission error, deciduous forest pixels were most often confused with shrub/scrub, herbaceous, and mixed forest areas in that order (Table 142). The shrub/scrub confusion could be due to different interpretations of shrubby areas by the image processing and the videography analysts. Forested areas could also have been thinned between 1991-92 (TM imagery dates) and 1995-96 (videography dates). Several timber harvest areas were noticed on the aerial video data. Areas cut between 1992 and 1995 would definitely appear as herbaceous. This is the most likely explanation for commission error between deciduous forest and herbaceous ground cover. The confusion with mixed forest is probably another difference in interpretation between image processing and videography analysts. It is sometimes difficult to distinguish between mixed forest and deciduous or coniferous forests at this broad scale.

Coniferous forest producer’s and user’s accuracies increased after each of the homogeneity filters (Figure 28). The highest source of omission error was from deciduous forest. Deciduous forest is by far the category with the most reference points. Therefore, if there is any omission error it is most likely to be from deciduous forest. This could reflect some spatial error in the reference points, which were greater than 70 m (i.e., they were unaccounted for by the 5x5 homogeneity filter). Coniferous forests were typically proximal to deciduous forests.

Coniferous forest was also confused with deciduous forest and mixed forest resulting in a 50.7% user′s accuracy. The deciduous forest misclassification, probably was caused by evergreen understory vegetation and topographic shadows. The mixed forest confusion was, as discussed above, a result of difference of opinion or scale between image processor and videography interpreter.

Mixed forest was the land cover type most difficult to classify. This was mainly due to a subjective interpretation of a continuous distribution (e.g., is an area deciduous or mixed or coniferous) and difficulties identifying adequate classification training areas.

Mixed forest had the lowest accuracies. Both (user's and producer's) were reduced to 0% after the 3x3 and 5x5 homogeneity filters (Figure 28). This was the result of insufficient reference data. Of the 22 homogeneous (at the 5x5 level) reference points (Table 142), 11 fell on coniferous forest pixels, 10 fell on deciduous forest pixels, and 1 fell on a shrub/scrub pixel. This indicates that lack of classified mixed forest may be due to the video interpreter labeling points that the image processor viewed as either deciduous or coniferous.

Only 8 reference points fell on pixels classified as mixed forest. All of these were deciduous forest reference points. This error of commission is another indication of difference in opinion between image analyst and video analyst. Confusion with deciduous forest and coniferous forest is "less bad" than confusion with other categories, since both deciduous and coniferous forest must make up at least 40% of mixed forest areas.

Accuracies were also low for the shrub/scrub category (Table 143). Only 3 of 29 reference points fell on shrub/scrub pixels. The vast majority (24) fell on deciduous forest land. Sparse forest may appear as shrubby areas to the videographer. This scale difference between the image analyst and the video analyst, the general close proximity of shrub to deciduous forest, and the general over abundance of pixels classified as deciduous forest probably account for this disparity.

Shrub/scrub had a higher user's accuracy than producer's. Confusion occurred between shrub/scrub and coniferous forest, mixed forest, herbaceous, and disturbed with coniferous forest having the most confusion (2 points). Eastern red cedar, which can be viewed as either a shrub or a tree, could be the main reason for committing land pixels to the coniferous forest category. Herbaceous areas would be easily confused with shrub land in an old field setting. Overall, shrub/scrub is notably varied, often an edge cover type, and therefore is difficult to classify and assess accurately.

The herbaceous category had accuracies above 85% in both user's and producer's measures. The highest source of confusion, for omission errors, was from deciduous forest. The majority of this error was caused by deciduous areas in 1991 being harvested by 1996, when the video was flown. Harvested areas were interpreted as herbaceous fields (or as shrub/scrub depending on harvesting method and time since harvest).

The largest contributor to commission error, within herbaceous land cover, was disturbed land. Developed or urban areas containing large lawns or open grassy areas could prompt this inaccuracy (i.e., videography labeled the area as developed, but the Landsat imagery could delineate areas of open grass).

Open water had extremely high user′s and producer's accuracies (Table 143). Water is the one cover type most different from the others and should be readily distinguishable. The only confusion (1 out of 60 reference points) occurred as a disturbed pixel was labeled water (Table 142). Sandy beaches were typically labeled disturbed. The proximity of beaches to open water probably caused this commission error.

Disturbed lands had a large disparity between user's (100%) and producer's (40%) accuracies. There was no measurable error of commission. The large degree of omission error indicates that more disturbed areas were observed through videography than through image interpretation (Figure 26). The largest omission confusion occurred between disturbed and herbaceous. This error and the small confusion with open water were discussed in the paragraphs above. Disturbed land had the second lowest number (15) of reference points available for assessment after the 5x5 homogeneity filter.

Coastal wetlands had the lowest number (6) of assessable reference points available after the 5x5 homogeneity filter. User's accuracy for coastal wetlands resulted in 100% accuracy (Table 143). Two of the 6 reference points fell on forested pixels (1 deciduous and 1 coniferous) resulting in a 67% producer's accuracy. The confusion with the forested areas probably occurred due to close proximity of forests to wetlands. It also could be a result of the video interpreter labeling forested wetlands as coastal wetlands (i.e., a difference in definition of the land cover type).

In general, the accuracies were high for each land cover type. The types most affected by the filter, mixed forest and shrub/scrub, were also the types with the lowest accuracies. There were too few homogeneous areas remaining after the filtering to adequately assess these categories. However, mixed forest and shrub/scrub were also the types most difficult to delineated from the TM data. Disturbed lands and coastal wetlands had fewer usable reference points (15 and 6 respectively) than either mixed forest (22) or shrub/scrub (29), yet both had higher accuracies. All four of these land cover types should have had more reference points (perhaps at least 50).

Overall, I believe the results of the 5x5 homogeneous filtered accuracy assessment proved an adequate evaluation of this map. The overall accuracy was 81.8% following the 5x5 assessment (Table 143). The Kappa statistic was very similar, as it was throughout the assessments (Figure 29). The majority of the confusion between categories was with similar cover types. For example, mixed forest errors were divided between confusion with deciduous and coniferous forest. Shrub/scrub was most confused with deciduous forest. Deciduous forest was most confused with coniferous forest. Other sources of error can attempt to be explained by the plausible hypotheses discussed above. Suggestions for ways to improve the classification will be addressed in a later section.

Secondary Objectives

Feasibility

To demonstrate the feasibility of producing a fine-scale map covering a relatively large area, in a reasonable amount of time using a personnel computer. More than 470,000,000 pixels were classified over 14 Landsat scenes. Several of the scenes, with only a small portion of their area in Virginia, were subset (or cropped) to reduce the number of pixels and spectral variability. Scenes 1435, 1535, 1635, 1733, 1735, 1834, 1835, and 1935 were all cut to several miles over the Virginia border (Figure 4). If all of the area in each scene had been used, over 765,000,000 pixels would need to be classified. Even with this reduction, something the size of Virginia is a very large area to map.

One commonly used land use/land cover dataset is the Land Use and Land Cover map within the GIRAS (geographic information retrieval and analysis system) mapset. These data were produced by the USGS during the 1970s. Aerial photographs were used to map land use and land cover to 1:250,000 vector polygons. The minimum mapping unit for these products were either 4 ha or 16 ha, depending on the cover type (Mitchell et al. 1977). By comparison, the minimum mapping unit (or cell size) for the map presented in this thesis is 900 square meters (30 m X 30 m) or 0.09 ha. This represents a dramatic increase in detail, as compared to the GIRAS product. It also translated to larger computer storage space and more computer processing time.

Each unprocessed (6 band) Landsat Thematic Mapper scene requires about 350 mb of harddisk space. Such a large file requires considerable computer resources to display, manipulate, and analyze. All computer operations were performed (with the exception of reading the initial data tapes, which required a UNIX machine due to the tape format and compression) on personal computers (PCs), typically Pentium based machines running the Windows operating system. Most of the project was completed with a 90 MHz Pentium with 16 mb of ram running Windows 3.11. The later work was done with a 200 MHz Pentium with 32 mb of ram running Windows95. The lower price of the PCs, compared to UNIX or other larger workstation, allowed an upgrade during the middle of the project for both hardware and software. To store the TM scenes, from unprocessed imagery to various stages of processing, a large amount of space was required. A large local harddisk, a networked fileserver, optical disks, and Iomega ™ Jaz drives and disks were all utilized. CDs and 8 mm tapes were used as long term storage and backup. Storage media changed with the advent of newer technology. This flexibility was very beneficial. The Jaz disks, which hold 1 gb (or 1,000 mb), replaced the lower capacity (per side) and much slower optical disks, which hold 500 mb on each side.

To save processing time in classification, the hyperclustered images were used when possible. In contrast to the 350 mb file unprocessed TM scene, the hyperclusters were only 50 mb in size. This saved time and space. However, the majority of the scenes required full 6-band processing. Once all of the necessary training data were prepared and methods were determined, the actual classification of each scene took approximately 1 week.

Getting data into the correct format, acquiring training and reference data, and determining methods required the vast majority of time. This project was started around January 1995. The final map was complete in October of 1996, 22 months later. (The work was done, except for videography interpretation, entirely by the author, who was also responsible for course work, graduate student commitments, and other projects). The determination of the accuracy assessment procedures, the homogeneous filtering, and actual assessment were completed several months later.

While a land cover map created from 1992 satellite imagery released in 1997 may not be considered "timely", I believe the knowledge gained from this work will improve the "timeliness" of future large-area mapping efforts. It should now be possible to map land cover at this basic level for the area the size of Virginia in a year or less. This schedule assumes that one person can be dedicated to this task and that the data are readily available. Better methods and computers are likely to decrease this time significantly over the next few years.

Working Solutions to Remote Sensing Problems

To provide working solutions to the common problems of haze/clouds, shadow, and to obtaining ground points in reflectance-based remote sensing. This thesis did not attempt to resolve any one of the common issues related to reflectance-based remote sensing, but rather apply what is known and map a large area for the benefit of the natural resource community. Issues of haze and clouds, toposhading, and efficiently obtaining a large sample of ground information still require additional research. Since these items will continue to be problems for remote sensing efforts, especially at the scale of this project, I shall comment on how I addressed these problems.

Haze

Before classification began, a literature review was conducted to find ways of dealing with haze. The method had to be applicable to an entire scene, not require *in situ* data (or information on atmospheric conditions collected at the time the satellite image was acquired), and attempt to correct each pixel individually depending on its haze characteristics. The method outlined by Lavreau (1991) was chosen. This method used the 4^{th} tasseled cap (TC4) transformation, which contains atmospheric noise, to create an index of haze within each pixel. Each pixel was then corrected based on this amount of haze displayed in the TC4 band. If haze effects were still apparent in the resulting corrected bands, then band 1 was removed from classification. Band 1 is often highly correlated with the other visible bands (2 and 3) and, because of its shorter wavelength, it is the band most affected by atmospheric conditions.

This method had mixed results. Because the threshold of the TC4 correction required homogeneous land cover to be determined, water was used as the calibrating cover type. As a result, the haze over water was corrected very well. Haze over other land cover types was not handled as adequately as water. This is somewhat apparent in Figure 8.

The Classification Preview function within PCI was critical as feedback for adjusting the Threshold and Bias values during the supervised classification. The ability to make a classification visually similar to the training areas was invaluable for dealing with hazy as well as topographically-influenced areas.

Toposhading

Initially, it was hoped that DEMs could help solve the dramatic reflectance differences within land cover types on different aspects. The steep terrain in western Virginia required some correction. This problem was essentially restricted to forest types since relatively few areas of other land cover types occurred on these slopes. A procedure described by Civico (1989) attempted to use DEMs to create a hillshading model based on the sun angle and elevation (height in the sky) at the time the satellite image. The hillshading model was then used as a correction index similar to the way the TC4 image was used in the haze correction process. This method did not work for several reasons. The resultant image appeared flat, however, it had more areas of intense shadow and intense brightness (Figure 7) than the unprocessed image. It would also have been difficult, if not impossible, to obtain all the information required for an accurate hillshading model for each scene (i.e., sun angle and elevation). Not having all of the necessary information was one of the draw backs of getting the imagery through the MRLC rather than directly from EROS Data Center or EOSAT corporation. This process would also have required the manipulation and management of another large dataset (hillshading derived from DEMs).

A much simpler approach was used. Instead of attempting to correct the problem and then classify the image, it was decided just to take these reflectance differences into account during the actual classification. During the supervised classification, 3 aspect classes were labeled for each forest type (deciduous, coniferous, and mixed). Each of these forest types had a north-facing, flat, and south-facing sub-class. Once classification was complete, these 9 categories were aggregated to the 3 standard forest cover types.

This method worked very well at this scale. One problem was with the amount of training data needed. Instead of training data for 3 categories, data for 9 categories was now required. Deciduous and coniferous forest had plenty of identifiable training areas. Unfortunately, mixed forest was very difficult to delineated on sloping terrain. This may be one reason why, compared to the reference data, mixed forest accounts for a smaller proportion of area. If a more detailed forest classification system was used, this problem would magnify.

Obtaining Ground Points

For any remote sensing effort, information about actual ground cover is needed both in classification (training data) and in the accuracy assessment (reference data). In classifying an area the size of Virginia, this requirement becomes a major concern. This project used existing aerial photography, digital maplets, and expert knowledge for training data. Several weeks were spent gathering and manipulating datasets into a useable format. Expert review was used at several stages for feedback.

The major drawback to this method was the differences in quality, time of creation (or acquisition), classification schemes (or land cover definitions), and format of the various types of training data. Each digital maplet had to be evaluated for its classification scheme, accuracy, and timeliness. A better method, although certainly more costly, would be to use standard aerial photographs (possibly NAPP products) at regular intervals throughout the Commonwealth. The use of study areas worked out very well, however, an ideal distribution of training data throughout each scene was probably not achieved. A regular distribution of a standard training data source (e.g., NAPP photographs) would fulfill this need. Existing digital maplets and expert review could still be used within each study area in order to refine methods.

Aerial videography had benefits and drawbacks as reference data during the accuracy assessment phase. Videography provided completely independent ground information. The information was, for the most part, obtained and interpreted by different people than those who performed the image analysis. The scale of this information was not from the ground, but from an aerial vantage point. This allowed landscape patterns to be observed and considered. Because of this scale, the videography probably corresponded better to the assessment of satellite imagery than would data collected by a person in the field.

Another advantage of videography was the large number of potential sample points collected statewide in a short period of time. It took only 7 days of flying to obtain the entire videography coverage. These flights attempted to be linear transects, which should cover each cover type in the same proportion to which they occur across Virginia. These transects were not exactly regular north-south sampling lines, but did cover the Commonwealth fairly evenly (Figure 9).

This thesis was not the primary reason that videography was flown across the Commonwealth. Videography data were collected (and continued to be collected) for use in the Virginia Gap Analysis Project. To fulfill the objective of obtaining species-specific community types, it was necessary to fly during peak fall color or peak tree leaf bud-out period (Slaymaker et al. 1996). Attempting to observe the correct phenological time period caused the irregular appearance of the transects. Aerial videography is a relatively new technique. This thesis was intended to identify some of the problems and work towards solutions for this promising data collection method.

The main negative aspect of videography, within the context of reference data for this thesis, was the spatial inaccuracies within these data. These inaccuracies, commonly 70 m or greater, prompted the filtering procedures. The homogeneous filtering took considerable computing time. For a full scene (approximately 7000 rows by 7000 columns) it took a 200 MHz computer 14 hours to determine the 5x5 homogeneous areas. However, the main drawback to the filter was the reduction in assessable area to 32.2% of the original image (Table 137). This area reduction and the corresponding reduction in usable reference points (from 1773 to 637) severely impacted the accuracy assessment.

Considering the impacts of the 5x5 homogeneous filter on the accuracy assessment, the time required to interpret the video and filter the classified images, the thematic detail of this map, and the expense and time to develop and fly the videography system, videography was probably not the most efficient choice for collecting reference ground data. For more detailed land cover classifications at the statewide spatial scale (i.e., for the Virginia Gap Analysis), videography is invaluable. For the single purpose of basic land cover classification presented in this thesis, a field survey or interpretation of independent aerial photographs would have been a more viable solution. It would have been possible to obtain 200 reference points per field day using a “windshield survey” technique (Schairer *pers. comm.*). This consists of observing land cover from an automobile and recording the position from a GPS onto a laptop computer complete with background imagery. Windshield surveys are relatively fast and cheap (Zack 1983). Another option would be to use a standard, evenly distributed, set of independent aerial photography. This would be similar to using the SAA photosets, used as reference data in the far western portion of Virginia, within more precise spatial constraints (i.e., define a better system of obtaining geographic coordinates than the current method of using SPOT imagery), on a statewide level. Either using a windshield survey or standard independent aerial photographs would have provided a more complete accuracy assessment.

Baseline Data for Virginia

T*o present data on the areas and proportions of Virginia currently in major land cover types*. This thesis presented the land cover of Virginia in tabular form, by area (Table 134), and in geographic form (Figure 27). The resultant map shows one "snapshot" in time. Similar methods could be applied to earlier or later dates of satellite imagery. Using several dates of data, trends in land cover change can be determined. Change detection is a very useful tool in landscape level analyses (Dobson et al. 1993, Westmoreland and Stow 1992). It allows the manager or decision-maker to know what is present, what was previously present, and to predict proper use.

One inexpensive opportunity for historic imagery is with the North American Land Characterization (NALC) program. NALC is a cooperative effort between the U.S. Environmental Projection Agency (EPA) and USGS's EROS Data Center. NALC offers Landsat MSS triplicate sets. Each triplicates contain a MSS from the 1970's, 80's, and 90's. As of the printing of this thesis, NALC triplicate cost $15 per set. While the MSS data may not have many of the advantages of Landsat TM imagery, this represents a opportunity to perform change detection work over larger areas at a relatively low cost.

Suggestions for Improvement

Before similar work (i.e., land cover mapping using similar categories, resolution, and area) is commenced, suggestions can be made to improve the process.

Better data could provide better results. Ideally, the dates of the satellite imagery should be close to the dates of the training data and reference data. With TM scenes from 1991-2, training data from 1991-4, and reference data from 1995-6 used in this project, this situation can be improved. Also, TM scenes could have had similar phenology across Virginia. The specific scenes used were from varying seasons (Table 3). I would recommend using leaf-off imagery for the categories mapped.

Both training data and reference could have come from better sources. I would prefer a standardized set of training data within an evenly spaced distribution (e.g., a NAPP photo every 30 km across the entire Commonwealth). Work must also be done to easily separate the understory coniferous vegetation from the overstory coniferous vegetation. Videography, while an interesting method, was probably not the most efficient method of collecting independent reference data. A field survey could have been a more viable alternative.

With a change (for the better) in all 3 categories of data sources, the methods might slightly change accordingly. With improved training data, the classification process could be streamlined. Evaluating each digital maplet, aerial photography, or expert review would become unnecessary. With standard phenology within scene dates, a mosaic of unprocessed TM scenes might be created. This mosaic could then be classified at once. However, this would lack the flexibility which allowed different procedures for handling different topographic and atmospheric conditions in different areas of Virginia. This flexibility was a strength of the presented methodology.

Considering the advances in computers and software, the use of hyperclusters is probably now unnecessary. Hyperclusters were useful for this project, but improvements in technology have continued. The use of preprocessed preclustered (unsupervised classification) TM scenes restricts the control of the analyst. A more consistent map would result from more consistent classification methodology. A supervised method could be used throughout the Commonwealth, otherwise all scenes could be corrected (for topography or haze) and then an unsupervised method could be used. New methods, such as hybrid and contextual classifiers may also prove beneficial.

With better reference data, the homogeneous filtering would not be required. This would save time and would increase confidence. The final product would include a more complete assessment (i.e., significantly more reference points than the current assessment).

Other data could be added to delineate additional land cover categories and possibly to increase accuracy. Several studies have shown the usefulness of adding ancillary datasets to classifying land cover (Zack 1984, Fox et al. 1985, Frank 1988, Bolstad and Lillesand 1992). Previous work in Virginia shows the promise of using DEMs in topographic and climate modeling for predicting forest cover (Hassouna 1996, Klopfer 1997, McCombs 1997). The combinations of remotely sensed land cover and these modeling ideas can yield a very detailed picture of the state of habitat in the Commonwealth.

CONCLUSIONS

This work presented a relatively fine scale image of the land cover of Virginia. Even though the results show a fairly accurate map completed efficiently, there are ways to get even better results.

Land cover is important in many natural resource applications. This thesis showed that land cover can be mapped at 30 m resolution, statewide, using personal computers, in a reasonable amount of time. This technology is no longer the sole domain of university supercomputers. Any natural resource management agency can (and I believe should) have these capabilities. The ability to produce timely land cover maps and maps of other habitat factors, along with analysis of trends through time, can provide a complete picture of natural resource condition for improved decision making.

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Curriculum Vitae

David Dean Morton was born on May 10th, 1972 to David William Morton II and Jacqueline Rose Morton. After graduating from Northville High School (Northville, Michigan) he entered Michigan State University. He received his Bachelor's of Science in Fisheries and Wildlife, with honors, from Michigan Statue University in May of 1994. After an extended Alaskan vacation and several months assisting in waterfowl research in Manitoba, Canada, he started his graduate work at Virginia Tech.

During his Master's work he became interested in geographic information systems (GIS) and remote sensing applications. He co-developed and taught several short-courses in these technologies to natural resource managers. He was also involved in the Virginia GIS State Agency User's Group, The Wildlife Society GIS Working Group, American Society for Photogrammetry and Remote Sensing, and the Virginia Tech Office of GIS and Remote Sensing Research. During the last few years of his graduate studies he acted as the GIS and remote sensing coordinator for the Fish and Wildlife Information Exchange (FWIE). Other activities included serving on the Virginia Tech Graduate Honors Board, acting as wildlife representative the Fisheries and Wildlife Graduate Student Association, and maintaining several e-mail listservers.

On May 23rd 1998 he married A. Melody Kirkendall. He completed his Master's of Science requirements in June 1998. Shortly thereafter, he gained employment with U.S. Geological Survey – Biological Resources Division as a remote sensing biologist.