ABSTRACT

SMITH, MARK PRESTON: Predicting Fuel Models and Subsequent Fire Behavior from Vegetation Classification Maps. (Under the Direction of Dr. Hugh A. Devine)

The recent trends in wildland fires have created a level of motivation that requires natural resource managers to predict fires through the use of computer based simulation programs. Using vegetation maps delineated from large-scale aerial photography and fuel loading values collected from fieldwork, I simulated how fire would react to changes in fuel model assignments for Booker T. Washington National Monument (BOWA) and George Washington Birthplace National Monument using FARSITE, a fire simulation program. The environments for these fires were based on weather and fuel conditions found during the summer and fall months for each area.

Sample points, stratified by vegetation formation, were selected. Then, field measurements using Brown's transect lines and Burgan and Rothermel ocular procedures were used to calculate the amount of fuel loading in tons/acre for each sample point. These values were then used to assign a fuel load to each vegetation formation class. Then each vegetation polygon on the map was assigned one of the thirteen National Fire Fuel Laboratory fuel models based on fuel load, vegetation type, and overall structure of the surrounding area. The sampling results showed a one to one correspondence of fuel model to vegetation formation.

The sensitivity of FARSITE was tested by changing fuel model layers within FARSITE while holding all other variables constant (e.g., weather, moisture, etc.). Rate of spread and fire line intensity were used to compare the differences between the simulations using different fuel models.

The results from the simulations showed that there was little sensitivity to changes in the assignment of fuel models for forested vegetation for these sites. The rate of spread and fire line intensity for grass fuel models showed sensitivity to changes in fuel model assignment.

PREDICTING FUEL MODELS AND SUBSEQUENT FIRE BEHAVIOR FROM VEGETATION CLASSIFICATION MAPS

by
MARK PRESTON SMITH

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree
of Master of Science

NATURAL RESOURCES,
SPATIAL INFORMATION SYSTEMS TECHNICAL OPTION

Raleigh

2003

APPROVED BY:

_____
Dr. Hugh A. Devine, Chair of Advisory Committee

_____
Dr. Stacy A. C. Nelson
Member of Advisory Committee

_____
Dr. E. Carlyle Franklin
Member of Advisory Committee

DEDICATION

This work is dedicated to my wife, Margaret, a true ray of sunshine in an otherwise cloudy day.

BIOGRAPHY

The author grew up in Fairfax, Virginia and has spent the past eight years living in various places on the coast and in the piedmont of North Carolina. In 1995, he graduated from Virginia Polytechnic Institute and State University with a bachelor's degree in Forestry and Wildlife Resources with a concentration in Outdoor Recreation. Immediately following graduation, he started his career as a seasonal state park ranger on the coast of North Carolina and later moved to Raleigh where he became a state park ranger for six years. His interest in pursuing his knowledge of natural resources persuaded him to enroll at North Carolina State University as a Master of Science student in Natural Resources, concentrating in spatial information systems. He was awarded a research assistantship in the Center for Earth Observation where he worked on vegetation mapping and moasicing of aerial photography for several national parks.

His research interests are applying GIS and GPS to conserve and protect natural resources in wildland and urban settings.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the members of my thesis committee- Dr. Hugh Devine, Dr. Stacy Nelson, and Dr. E. Carlyle Franklin. Likewise, I would like to thank the graduate students and staff of the Center for Earth Observation: Brian Rosenfeld, Mikey Neighbor, Andrew Bailey, Bill Slocumb, and Bill Millinor. I would especially like to thank Frank Koch who was a constant savior when others were unsure of the answer.

Doug Raeburn and Dan Hurlbert from Shenandoah National Park were instrumental in providing guidance and support with fire information and all around knowledge that never seemed to present itself in books nor the internet. Karen Patterson from the Virginia Natural Heritage program provided additional information with mapping the vegetation for George Washington Birthplace National Monument and Booker T. Washington National Monument.

I would also like to thank my family who never seemed to stop believing in me- my parents Jeff and Claudia Smith, Pat Henderson and Joe Phillips, and Frank and Barbara Davide; my brothers Alex, Jason, Tim, Frank and their wives, and to all of my extended family. Finally, to the Captain who provided me with comic relief when I needed it.

TABLE OF CONTENTS

List of Tables ..... **viii**

List of Figures ..... **ix**

1. Introduction **1**

2. Literature Review **3**

2.1 Problems and risks of fires 3

2.1.1 Forest health 3

2.1.2 Development near forests 4

2.2 Fire management techniques 4

2.2.1 Fire prevention 5

2.2.2 Wildland Urban Interface 6

2.3 Review of fire modeling programs 8

2.3.1 FARSITE 8

2.3.2 BehavePlus 9

2.3.3 NEXUS 10

2.3.4 FOFEM 11

2.4 Review of fuel model and fuel loading guides 12

2.4.1 Aids to determining fuel models for estimating fire behavior 12

2.4.2 National Fire Danger Rating System 13

2.4.3 Photo guide for appraising surface fuels in east Texas 14

2.4.4 Inventorying downed woody material for Brown's calculations 15

2.4.5 US Forest Service quick method 16

2.5 Similar fuel modeling and FARSITE research 17

3. Study Areas **21**

3.1 Booker T. Washington National Monument 21

3.2 George Washington Birthplace National Monument 21

4. Objectives **23**

5. Methodology **24**

5.1 Data preparation 24

5.2 Orthorectification 26
5.3 Creating the mosaic images 27
5.4 Delineation of vegetation 28
5.5 Accuracy assessment 30
5.6 Fuel data collection 32
5.7 Fuel data calculation 34
5.8 Creation of FARSITE layers and simulating wildland fire conditions 34
6. Results 40
6.1 Positional accuracy of the mosaiced images 40
6.2 Thematic accuracy for the vegetation layers 42
6.3 Fuel loading calculation and results 49
6.4 Standard sample size for estimating fuel load 56
6.5 Fuel model maps 58
6.6 FARSITE simulations 59
7. Discussion 76
7.1 Creation of orthoimage mosaics 76
7.2 Vegetation map accuracy 76
7.3 Fuel loading calculations 77
7.4 FARSITE simulation 78
8. Conclusion and Recommendations 80
References 83
Appendices 88
Appendix A. Fall mosaic of Booker T. Washington National Monument 88
Appendix B. Spring mosaic of Booker T. Washington National Monument 89
Appendix C. Fall mosaic of George Washington Birthplace National Monument 90
Appendix D. Spring mosaic of George Washington Birthplace National Monument 91
Appendix E. Potential formation classes for both study areas 92

Appendix F. Fuel model maps for Booker T. Washington Monument 94
Appendix G. Fuel model maps for George Washington Birthplace National Monument 100
Appendix H. Error matrix of the vegetation map thematic accuracy assessment of Booker T. Washington National Monument 106
Appendix I. Error Matrix of the vegetation map thematic accuracy assessment of George Washington Birthplace National Monument 107
Appendix J. Brown's transect datasheet 118
Appendix K. Burgan and Rothermel datasheets 109
Appendix L. Fuel loading values for sample plots at Booker T. Washington National Monument 111
Appendix M. Minimum sample size calculations for Booker T. Washington National Monument 114
Appendix N. Fuel loading values for sample plots at George Washington Birthplace National Monument.....116
Appendix O. Minimum sample size calculations for George Washington Birthplace National Monument.....126
Appendix P. Combined minimum sample size calculations 131
Appendix Q. ArcView extension created by Frank Koch 135

LIST OF TABLES

Table 1. Physiognomic-floristic hierarchy of the NVCS 30

Table 2. Polygon counts, acres, and hectares for the formation map of BOWA 42

Table 3. Polygon counts, acres, and hectares for the formation map of GEWA 46

Table 4. Standard sample sizes for BOWA 57

Table 5. Standard sample sizes for GEWA 57

Table 6. Standard sample sizes for combined vegetation 58

Table 7. BOWA simulation results using assigned fuel models 60

Table 8. BOWA simulation results using adjusted fuel models 60

Table 9. BOWA simulation results holding grass formation fuel models constant 61

Table 10. GEWA simulation results using assigned vegetation 62

Table 11. GEWA simulation results using adjusted vegetation 62

Table 12. GEWA simulation results holding grass formation fuel models constant 63

LIST OF FIGURES

Figure 1. Map of Booker T. Washington National Monument.....22

Figure 2. Map of George Washington Birthplace National Monument 22

Figure 3. Vegetation and sampling points for Booker T. Washington National Monument 43

Figure 4. Vegetation and sampling points for Booker T. Washington National Monument 47

Figure 5. 0-0.25 inch fuel loading for BOWA.....51

Figure 6. 0.25-1.00 inch fuel loading for BOWA.....51

Figure 7. 1.00-3.00 inch fuel loading for BOWA.....52

Figure 8. Fuel bed depth for BOWA 52

Figure 9. 0-0.25 inch fuel loading for GEWA.....54

Figure 10. 0.25-1.00 inch fuel loading for GEWA.....54

Figure 11. 1.00-3.00 inch fuel loading for GEWA.....55

Figure 12. Fuel bed depth for GEWA.....55

Figure 13. Summer assigned fuel models rate of spread for BOWA 64

Figure 14. Summer assigned fuel models fire line intensity for BOWA.....64

Figure 15. Fall assigned fuel models rate of spread for BOWA.....65

Figure 16. Fall assigned fuels model fire line intensity for BOWA 65

Figure 17. Summer adjusted fuel models rate of spread for BOWA.....66

Figure 18. Summer adjusted fuel models fire line intensity for BOWA 66

Figure 19. Fall adjusted fuel models rate of spread for BOWA 67

Figure 20. Fall adjusted fuel models fire line intensity for BOWA.....67

Figure 21. Summer assigned grass fuel models rate of spread for BOWA 68

Figure 22. Summer assigned grass fuel models fire line for BOWA 68

Figure 23. Fall assigned grass fuel models rate of spread for BOWA 69

Figure 24. Fall assigned grass fuel models fire line for BOWA.....69

Figure 25. Summer assigned fuel models rate of spread for GEWA.....70

Figure 26. Summer assigned fuel models fire line intensity for GEWA 70

Figure 27. Fall assigned fuel models rate of spread for GEWA 71

Figure 28. Fall assigned fuels model fire line intensity GEWA 71

Figure 29. Summer adjusted fuel models rate of spread for GEWA 72

Figure 30. Summer adjusted fuel models fire line intensity for GEWA 72

Figure 31. Fall adjusted fuel models rate of spread for GEWA 73

Figure 32. Fall adjusted fuel models fire line intensity for GEWA.....73

Figure 33. Summer assigned grass fuel models rate of spread for GEWA 74

Figure 34. Summer assigned grass fuel models fire line for GEWA.....74

Figure 35. Fall assigned grass fuel models rate of spread for GEWA.....75

Figure 36. Fall assigned grass fuel models fire line for GEWA.....75

1. INTRODUCTION

According to the National Interagency Fire Center website (http://www.nifc.gov/index.html), approximately seven million acres of forests burned across the country during the 2002 fire season. The high numbers of acres lost to fire has promoted the development of computer simulations to predict and consequently manage forest fires. The creation of fuel models is integral to these simulations. Fuel models are a set of numerical values that describe the amount of fuel present within a natural setting. Fuel is defined as any substance that can burn such as sticks, grass, and leaf litter. Through the use of fuel models, the U.S. Forest Service created several approaches to estimate how fires will react under certain conditions. The National Forest Fire Laboratory (NFFL) fuel models are comprised of thirteen fuel models that estimate fuel loading from four separate fuel types (grasses, brush, timber, and slash). These types are further broken down into measures of fuel loading for fine and course downed woody debris, fuel bed depth, and moisture of extinction. These measures for the fuel models are collected in the field using transect lines developed by James K. Brown (1974).

The NFFL fuel models are dependent upon vegetation found within designated areas. By correlating the amount of fuel found within each vegetation class, fuel models can be assigned to these classes. Currently, the amount of sampling required to estimate fuel loading using standard sampling procedures is prohibitive (e.g. 2800 sample sites at George Washington Birthplace National Monument). Predicting fuel models from an existing national vegetation mapping program would dramatically reduce the cost of fuel load sampling. The goal of my research was to develop a method to predict fuel models from

formation level vegetation maps for Booker T. Washington National Monument (BOWA) and George Washington Birthplace National Monument (GEWA) for summer and fall conditions. A secondary goal was to evaluate the sensitivity of FARSITE (Finney 1998) simulation results relative to the variations in fuel model predications for the above two parks. To accomplish this goal, I varied the fuel model inputs to FARSITE and observed the differences between rate of spread and fire line intensity.

2. LITERATURE REVIEW

This literature review describes the problems associated with fire and management techniques currently being used in the natural resources field. Several fire simulators and fuel model guides will be compared and evaluated to show why FARSITE and Brown's transect lines were utilized in this research project. Finally, projects with similar fuel loading and FARSITE research will be compared.

2.1 Problems and risks of fire

The Forest Service has stated that nearly 73 million acres of national forests (61 million in the West and 12 million in the East) are at high to moderate risk of catastrophic fire (Alvarez 2003). This risk is due to a lack of fire management techniques that reduce the amount of fuel loading. According to the National Interagency Fire Center, 1.6 billion dollars was spent in 2002 to suppress and protect forests as well as areas adjacent to these lands. The damage from fire is detrimental to forests and negatively impacts the development of urbanized areas that are encroaching on natural areas.

2.1.1 Forest Health

The lack of fire within national forests and public lands has increased the chance for fire to occur. The suppression of fire in these areas by natural resources managers has contributed to fuel buildup, prevented tree stocking, and increased the population of endemic and exotic pests. These factors have resulted in increased frequency and intensity of fires in

natural areas. Large, intense wildfires have proven difficult to control and have resulted in catastrophic damage to property and resources, and the tragic loss of lives (SAF 2002). While these fires can damage ecological conditions, areas will eventually regenerate to their natural characteristics.

2.1.2 Development near forests

A surge in development near forested and natural areas has increased the risk of damage to these areas by fire. The area where structures and other human developments meet or blend together with undeveloped wildland or vegetative fuels is known as the "wildland urban face" (Federal Register 2001). According the FIREWISE, a program developed to educate the public about the hazards of living in the wildland urban interface, 88,458 fires occurred during the 2002 fire season (FIREWISE 2003). Despite a cost to federal agencies of $1.6 billion dollars to suppress, a total of 815 structures were burned. These totals highlight the fact that as development continues to intermix with wildland settings, fire will destroy more houses and developed areas.

2.2 Fire management techniques

The management of fire involves numerous methods to reduce fuel loading and prevent fire. An important feature of these techniques is the use of a geographic information system (GIS). GIS programs allow managers to administer fire on a spatial scale in a computer environment. In addition, GIS maps are essential in both describing the potential

of wildland fire and the actual plan to its suppression. GIS also allows the interactive display of historical fire information and the rapid infusion of new fuel data to these map documents.

2.2.1 Fire prevention

The suppression of fire in many landscapes has increased the amount of available fuel to be burned in wildland fires. The Mineral King Valley, located in Sequoia National Park, has suppressed fires for several seasons and as a result, fuel loads have increased (Menning *et a*l. 1998). This has affected the regeneration of trees and increased the risk to insect attacks and disease. Several researchers from the University of California at Berkeley are using prescribed burning to reduce the amount of fuel loading and allow regeneration of many suppressed tree species (Menning *et al*. 1998). Researchers are also measuring the effectiveness of prescribed burning by establishing field plots randomly located throughout the valley. Within each plot, field crews record tree characteristics, fuel loading conditions, brush and plant conditions, slope and aspect, and light penetration. Aerial photographs also provide an additional source of information for the field crews to assess forest health and results of the prescribed burn. The results from this study are ongoing and are currently being published.

Keifer *et al*. (2000) looked at twenty-seven plots located in the Sequoia and Kings Canyon National Parks in southern California. The plots were located within areas burned between 1982 and 1997. Monitoring data, fuel load, and tree density were recorded for pre-burn, immediately post-burn, and 1, 2, 5, and 10 year post burn conditions for each plot. The results from the information collected at the monitoring plots indicated that prescribed

burning was successful in reducing fuel loading and restoring giant sequoia-mixed conifer forest.

van Wagtendonk *et al*. (2002) created a fire management regime that included prescribed burning for Yosemite National Park. The plan incorporated the use of a geographical information system (GIS) along with previous experience from Keifer *et al*. (2000) to monitor prescribed burning in the park. It was found that an effective fire management plan requires spatial and non-spatial data. This information has allowed the managers to restore the natural fire regime in many areas of the park.

2.2.2 Wildland Urban Interface

People are building homes and communities closer to wooded areas every day. These communities are also developing near federally owned lands such as national parks and forests. The close proximity of development near housed has increased the chance of loss due to fire from surrounding areas. A program called FIREWISE COMMUNITIES was developed by the National Wildland/Urban Interface Fire Program to aid communities in effectively protecting them from damage caused by wildland fires (National Wildland Urban Interface Fire Program 2001). The program reviews the problems communities may face by being close to the wildland urban interface and assigns a hazard severity rating based upon history of the development, vegetation types, fuel loading, access routes, land use information, and fire protection capabilities. A GIS plays an integral part in mapping these communities and its surrounding areas to provide residents with an idea of where high-risk communities are located. Utilizing information from the hazard rating potential allows

communities to prevent damage from wildland fires. It also allows natural resource managers to identify high-risk communities and target them first to prevent further fires from spreading and damaging more homes as well as forests.

Mattsson and Thoren (2002) developed a wildland/urban interface model using GIS for the town of Pocatello, Idaho based on vegetation characteristics and fire suppression access. The input layers into the model were slope, aspect, and fuel loading. The slope and aspect layers were created from a USGS digital elevation model (DEM) and the loading assessment was performed using a supervised classification from a Landsat 7 Enhanced Thematic Mapper image. The input layer results were assigned a weighted value in order to reach an overall hazard rating value. The program provides communities as well as natural resource managers with information on areas having a high risk of damage from wildland fires.

Radke (1995) developed a spatial decision support system (SDSS) so planners and decision makers could better manage and formulate policy to help reduce the risk of future fires in the East Bay Hills of California. The system combines two models: one to assess the wildland fire hazard and the second to assess the urban/residential fire hazard within a GIS to map risk areas for the region and neighborhood. The wildland fire hazard was rated based on weather, topography, and fuel type and the urban/residential fire hazard rating was based on structural and vegetation fuels. The wildland vegetation layer was delineated using aerial photographs and assigned a fuel model correlating with the Anderson (1982) fuel model guide. The fuel models were then simulated in BEHAVE (Andrews 1986) to obtain flame length, rate of spread, heat released, and crowning potential. The urban/residential fire hazard was rated on the fuel characteristics of structural and vegetative fuels. These results

were then combined to produce an overall rating for the East Bay Hills area to provide decision makers with the information necessary to prevent future wildland fires.

2.3 Review of Fire Modeling Programs

The following section will provide a brief description about existing programs that simulate fire as well as allow the user to create custom fuel models. There are several different types of programs under development to predict fire and its characteristics. This section clarifies the differences between the various programs and justifies the use of FARSITE in this project.

2.3.1 FARSITE

Dr. Mark Finney from the U.S. Forest Service Rocky Mountain Research station created Fire Area Simulator (FARSITE) to simulate growth and fire behavior as it spreads through different fuel types and terrain patterns. The program is based on Huygens' principle that states the spread direction and rate of the fire are based on an elliptical transformation (Finney 1998). The transformation calculates ellipse shape and direction based on wind and slope characteristics for an area. It also calculates ellipse size based on fire spread rate and length of time step for the simulation.

FARSITE requires spatial and non-spatial layers created by the user. A Geographic Information System (GIS) is used to create the spatial layers for each simulation. Three required spatial layers are derived from elevation grids. These are elevation, slope, and aspect. The other spatial layers are typically derived independently. The canopy cover layer

represents the percent of an area covered by vegetation canopy while the fuel model layer is derived from the National Fire Fuel Laboratory fuel models (Anderson 1982). The remaining FARSITE inputs are non-spatial and are created from existing weather conditions for the area where the fire will be simulated.

The outputs from FARSITE can be created either as a GRASS ASCII or GRID ASCII format. The user has the option of choosing from the following output grids: time of arrival, fireline intensity, flame length, rate of spread, heat / area, reaction intensity, crown fire activity, spread direction. All of these grids can then be analyzed in a GIS to predict and manage for current wildfire or plan for future fires.

2.3.2 BehavePlus

BehavePlus was created by Patricia L. Andrews, currently working with the USDA Forest Service, Rocky Mountain Research Station, and Collin Bevins, Systems for Environmental Management. This program runs fire simulation models for BehavePlus inputs of surface fire spread, intensity, flame length, area and perimeter of a point source fire, spotting distance, probability of ignition, scorch height, and tree mortality (Andrews and Bevins 1998). The user enters information on "worksheets" that are provided within the program. These "worksheets" are then manipulated in the program to produce several outputs such as rate of spread, heat per unit area, fireline intensity, flame length, etc. These outputs can be displayed in either graphical format (non-map) or tabular format.

There are several differences between FARSITE and BehavePlus. BehavePlus makes predictions of wildland fire behavior for a point in time and space given user defined fuel

load, weather, and topography. This is unlike FARSITE which predicts fire growth across a given landscape for variable fuel loads, weather, and topography. BehavePlus inputs can be determined easily in the field while FARSITE inputs require extensive GIS support and theme development (Carlton 2001). FARSITE allows the user to define the point of ignition in the landscape while the user has to change the worksheet settings in BehavePlus to simulate a wildfire at a different position. Finally, BehavePlus also allows the user to create custom fuel models based on measurements collected in the field while FARSITE only allows the user to input custom fuel models into the simulation.

2.3.3 NEXUS

Joe Scott, Systems for Environmental Management, and Elizabeth Reinhardt, Missoula Fire Sciences Laboratory, developed NEXUS in 1999 as a spreadsheet program to couple Rothermel's (1972) surface fire and (1991) crown fire models to simulate the full range of behavior possible in a forest stand (Scott 1999). Among its capabilities, NEXUS is able to predict surface fires, passive crown fires, and active crown fires. Prediction of crown fires is particularly important since they greatly affect the intensity and rate of spread of a fire.

The user enters information for surface and crown fire on a spreadsheet provided with the program. The information of surface fires consists of fuel models (standard or custom), live and dead surface fuel moistures, slope, 20-foot wind speed, wind reduction factor, and wind direction. For crown fires, the user enters crown base height and crown bulk density.

The output from NEXUS is similar to BehavePlus but it includes the type of fire created during the simulation. This information is presented to the user in tabular format

within the Excel spreadsheet. NEXUS also can create charts and graphs of selected fire characteristics such as spread rate and flame length, crown fire hazard assessment, and fire characteristics (Scott 1999).

Major differences between NEXUS and FARSITE include; NEXUS is only able to compute fire behavior information for up to six spatial areas while FARSITE is unlimited in its spatial extent. Additionally, NEXUS information is only in tabular or graphical form while FARSITE creates grids that can be displayed in a GIS. FARSITE is more applicable than NEXUS for this project since both study areas have significantly more vegetation areas as well the map output will an provide more detailed information about the fire.

2.3.4 FOFEM

Bob Keane, Elizabeth Reinhardt, Jim Brown, and Larry Gangi with the Intermountain Fire Sciences Laboratory developed First Order Fire Effects Model (FOFEM) to meet the needs of resource managers, planners, and analysts in predicting and planning for fire effects (Reinhardt, Keane, and Brown 1998). FOFEM version 5.0, created in 2002, provides users with fire effects information about tree mortality, fuel consumption, smoke, and soil heating. FOFEM provides forest cover types for four geographical regions within the United States: the Pacific West, Interior West, Northeast, and Southeast.

The program uses a Microsoft Windows Operating System based graphical user interface (GUI) to allow for easy data entry into the program. Inputs are based on the Anderson fuel models (Anderson 1982): litter surface fuels, vegetation cover type, litter, duff, herb, and shrub fuels, dead woody fuel loading, crown foliage load, crown branches

load, stand height, crown base height, dead and live fuel moisture, and soil moisture (FOFEM 2003). The program provides defaults for the above values and the user is able to change these values.

The outputs from FOFEM are fuel consumption, smoke production, emissions, fire intensity, tree mortality, and soil heating. This information can be presented in table and graphical format to the user.

There are several differences between FOFEM and FARSITE. The major differences are similar to BehavePlus and NEXUS in that fire simulation is limited to a few stands and the output results can only be displayed as graphs or tables.

2.4 Review of Fuel Model and Fuel Loading Guides

The following section provides a brief description of existing fuel models and fuel loading guides that provide natural resource managers the means to predict fire behavior. This section clarifies the differences between various guides and justifies the use of the Anderson (1982) fuel model guide and fuel loading calculations developed by Brown.

2.4.1 Aids to Determining Fuel Models for Estimating Fire Behavior

Hal E. Anderson created a guide to assist natural resource managers in predicting fire behavior through the use of photographic illustrations. This guide was developed from thirteen fuel models calculated by Rothermel (1972) and Albini (1976) to estimate fire behavior predictions. The fuel models are broken down into four different fuel groups: grasses, brush, timber, and slash. The differences in fire behavior among these groups are

essentially related to the fuel load and its distribution among the fuel particle size classes (Anderson 1982). For each of the fuel groups, a series of photographs are provided that describe a "potential" scene of what this model may look like in a natural setting. A brief description is also provided to define "potential" field characteristics present in a particular fuel model. Fuel loading values, fuel bed depth, rate of spread, flame length, and moisture of extinction for dead fuels are also provided for each fuel model. Finally, a correlation value chart to the National Fire Danger Rating System is provided for each fuel model within the guide. This guide is widely accepted by fire managers since it provides pictures of what a typical area would look like given the specific fuel model. It is also prevalent in a majority of fire simulators found within the natural resources/fire management field.

2.4.2 National Fire Danger Rating System

The National Fire Danger Rating System (NFDRS) was originally developed in 1972 to produce an analytical system based on the physics of moisture exchange, heat transfer, and other aspects associated with fire. The system produces three indexes of occurrence, burning, and fire load based upon four fire components consisting of risk, ignition, spread, and energy release (Deeming 1972). The indexes provide a day-to-day guide for fire managers to assess the potential for fire in a wildland setting. The 1972 NFDRS produced nine fuel models based on the amount of fuel loading for each wildland area. This system was revised in 1978 to address several shortfalls in the original system. The 1978 version of NFDRS included 11 new fuel models (which increased the total to 20 models overall) to better represent vegetation found nationwide, improve the response to drought conditions,

and identify a better way to assess live fuel conditions (Deeming *et al*. 1977). The 1978 NFDRS was updated again in 1988 to improve the capability to respond to drought in humid environments, adjust fuel models to better predict fire danger in humid climates, correct for the overrating of fire danger in the autumn and after rainfall, and reflect the greening and curing of live fuels (Burgan 1988).

The twenty fuel models within the 1988 NFDRS are grouped into six general classes defined by their predominant surface fuel: lichens and mosses; marsh grasses and reeds; grasses and forbs; brush, shrubs and tree reproduction; trees; and slash (Schlobohm and Brain 2001). These surface fuel sources are further broken down into sub-classes that comprise the twenty fuel models. There is a section within the NFDRS that correlates to the thirteen fuel models that are presented in the guide produced by Anderson (1982).

The NFDRS is different from the Anderson fuel model guide in that it presents a fire hazard rating system that natural resource managers can follow. The Anderson fuel model guide is more applicable since this project only deals with simulating fire instead of estimating fire danger rating.

2.4.3 Photo Guide for Appraising Surface Fuels in East Texas

Dr. Hershel C. Reeves created a photo guide in 1988 to depict different levels of fuels ranging from open grassy conditions to dense pine plantations (Reeves 1988). A total of nine different photo series taken in east Texas were used to assist natural resource managers in selecting fuel models including, grass, clear cut, seed tree, loblolly/shortleaf pine, slash pine, longleaf pine, and hardwood. Plot photos for each fuel model are shown in the guide along

with a data sheet describing the down and dead woody fuel loadings, litter and herbaceous loading, fire potential rating, and other fuel data. Dr. Reeves included a NFDRS fuel model and a stylized fuel model for each plot within the guide. The stylized fuel model directly correlates with Anderson fuel model guide (Anderson 1982).

This guide is similar to the one produced by Anderson (1982) but it provides different plot pictures and fuel loading values. It also breaks down potential fuel sources into nine different photo series. This photo series along with the one created by Anderson (1982) provides natural resource managers with greater capability to assign fuel models to vegetation found in the field.

2.4.4 Inventorying Downed Woody Material for Brown's Calculations

A handbook was developed by James K. Brown that defined how to inventory downed woody debris material using a vertical sampling plane and entering this information into a provided formulas to estimate the amount of fuel loading in tons per acre (Brown 1974). The handbook provides users with guidelines to locate sampling plots, tally rules, necessary field equipment, and other information to be used in calculating the amount of fuel loading. The data collected at each sampling plot is then entered into either one of two formulas known as Brown's calculations. The first formula calculates the amount of fuel loading for downed woody debris that is 0 – 3 inches in diameter. Components of the formula include number of intersects along the sampling plane, squared average diameter, specific gravity, horizontal angle correction factor, and a slope correction value. The second formula calculates the amount of fuel loading for downed woody debris that is 3 inches or greater. The components

of the formula are the same except that the diameters of the downed woody debris are squared and the debris is classified as rotten or sound. The result of both formulas provides an amount of fuel loading for each size class in tons per acre.

Brown's handbook is used to estimate the amount of fuel loading in wildland settings. The National Park Service uses this method and has created their own handbook for field staff to use (USDI NPS 2001). This handbook includes field collection protocol procedures along with protocols to monitor vegetation, pre and post-burn fire plots, and data analysis. The data that was collected for my research will be used by the National Park Service so all the defined protocols in this book were used in the field.

2.4.5 US Forest Service Quick Method

The quick method was developed by Cary Rouse and Donna Paananen from the US Forest Service North Central Forest Experiment Station to allow fire managers to make rapid and accurate estimates of fuel loading in the field (Rouse and Paananen 1988). A condensed formula from Brown's calculation and measurements from a planar intersect line (Brown 1974) are used to calculate the amount of fuel loading for a specific area. Planar intersect size classes of downed woody debris are 0 - ¼ inches, ¼ - 1 inch, and 1 -3 inches. The user then applies one of several provided composite factors for each of the three size classes to the formula. The final result is an estimate for the amount of fuel loading in tons per acre for each size class.

A problem with the condensed formula is that it uses more Northeastern fuel types so users need to extrapolate to use other fuel types (Raeburn 2003). This method of calculating

the amount of fuel loading was not well documented and very few agencies have used this method to estimate fuel loading.

2.5 Similar fuel modeling and FARSITE research

Several methods have been used to estimate fuel models based on remotely sensed images. Scott *et al*. (2002) used aerial photographs to estimate fuel loading for the Sanger de Cristo (Santa Fe watershed) and Jemez mountains (Los Alamos National Laboratory) of New Mexico. The purpose of their research was to create fuel load prediction equations based on pine composition, pine basal area, and crown closure information acquired from aerial photos. Large-scale aerial photographs (1:15840) were used to delineate different vegetation types within the two areas. A total of 60 sample sites were used for the Santa Fe Watershed (SFWS) and 56 sample sites were used for the Los Alamos National Laboratory (LANL). Field data collected at the two study areas included fuel loading values based on Brown's (1974) transect lines, tree species, canopy density and height. A fuel model was assigned to each of the plots based on the field data collected and also on the photo guide developed by Reeves (1988). Scoot *et al*. created an equation that produced similar fuel loading values from aerial photographs compared to field sampling values for the SFWS. Unfortunately, they were not able to predict these values for the LANL. Similar research conducted by Oswald *et al*. (1999) found that fuel models could be successfully estimated from aerial photography. That study did assign fuel models to vegetation found within the two study areas but it did not use any fire spread models to estimate how the study areas would react to a wildland fire.

Keane *et al*. (2000) created fuels and vegetation spatial layers for FARSITE for the Gila National Forest located in New Mexico. This included: elevation, slope, aspect, fire behavior fuel models (FBFM), canopy cover, average stand height, average crown base, and crown bulk density. The GIS layers were created from field data, satellite imagery (using Landsat TM), and local knowledge. Areas with unique vegetation types were delineated using textural classification methods. A supervised classification was then used to assign vegetation categories. A total of 1,000 sampling plots, each 405 m^2 in size, were used to collect fuel loadings, tree size distributions, plant species compositions, ecological attributes, and stand characteristics. The fuel loading was measured using Brown's (1974) method at 890 of points located in the National Forest. Sixty-foot transect lines facing east were used to estimate the amount of fuel loading while my research utilized 50 foot lines. Also, fuel bed depth was measured at the 35 and 60-foot marks instead of every five feet and at least 3 transect lines were used to measure intersects instead of two. The fuel loading along with field measurements was used to assign one of the thirteen fuel models (Anderson 1982). The remaining input layers were created from field measurements and were incorporated into the remaining layers. This study did not create a simulation for the Gila National Forest but it did create similar layers that were used for FARSITE.

Troy *et al*. (1998) created a FARSITE simulation for Strawberry Canyon in the East Bay Hills area of California north of Berkeley and Oakland. The objective of their study was to create a defensible fuel profile zone (DFPZ) along the ridge between Claremont and Strawberry Canyon to protect structures along a panoramic drive. A cost/benefit analysis was also performed to minimize cost and reduce negative aesthetic results from the fire. The

input layers for this project were created using a digital elevation model (DEM), black and white aerial photography with a 2-foot resolution, and local information. The vegetation and canopy layer were created using a supervised classification to define different vegetation found within the study area. The fuel models were assigned using the classification and local knowledge of the vegetation. Several manipulations were tested to determine the most beneficial management plan for the study area including reducing the fuel model by 2, starting the fire at several ignition points, and varying the area of the fire to be burned. This study provided some insight into how different simulations from FARSITE affect the cost of the proposed management plan.

Etlinger *et al*. (1999) also created a FARSITE simulation for Claremont Canyon, in the same region as Troy *et al*. The purpose of their simulation was to prepare a management strategy using FARSITE to reduce fire potential and increase feasible habitat for the federally threatened Alameda snake. The input layers into FARSITE were created from an existing vegetation layer and fieldwork. The vegetation coverage was provided by the East Bay Vegetation Consortium but was clipped down to the study area. The fuel layer was created from the vegetation layer by assigning a fuel model to each vegetation type. The crown base height and crown height layers were collected from fieldwork. The crown bulk density was enabled in FARSITE by linking crown density and canopy cover. The canopy cover layer was created by classifying 1:24000 black and white aerial photographs into four canopy classes instead of recording this measurement from fieldwork. A total of four different treatments were simulated in FARSITE: no action (treatment 0), reduction of fuel load of sage-scrub from fuel model 4 to 5 (treatment 1), reduction of eucalyptus from fuel model 10

to 1 (treatment 2), and reduction of oak-bay woodland from fuel model 4 to 8 (treatment 3). The results from the simulation found that treatment 1 and 3 burned fewer acres than treatment 0 and treatment 2 increased the total acreage burned.

The previous studies did not test the correlation of fuel load and subsequent fuel model with field data. In addition, they did not examine the sensitivity of FARSITE results to changes in fuel model. My work addresses both of these issues.

3. STUDY AREAS

3.1 Booker T. Washington National Monument

Booker T. Washington National Monument (BOWA), located 22 miles southeast of Roanoke in Hardy, Virginia, is the birthplace of Booker T. Washington (Figure 1). The 224 acres surrounding the Burroughs farm where Booker T. Washington was born was dedicated as a national monument in 1957 (NPS, 1995). The vegetation map of Booker T. Washington created for my thesis research included areas that bordered the park. From this map, approximately 214 acres were forested, 202 acres were grass fields, and 11 acres were agricultural fields.

3.2 George Washington Birthplace National Monument

George Washington Birthplace National Monument (GEWA) in Virginia is the ancestral home of George Washington (Figure 2). The 394-acre plantation including several historical structures was dedicated as a National Monument in 1932 (NPS, 2001). The vegetation map of George Washington created for my thesis research included areas that bordered the park. From this map, 436 acres were forested, 9 acres were woodland, 61 acres were shrubland, and 712 acres were grassland.

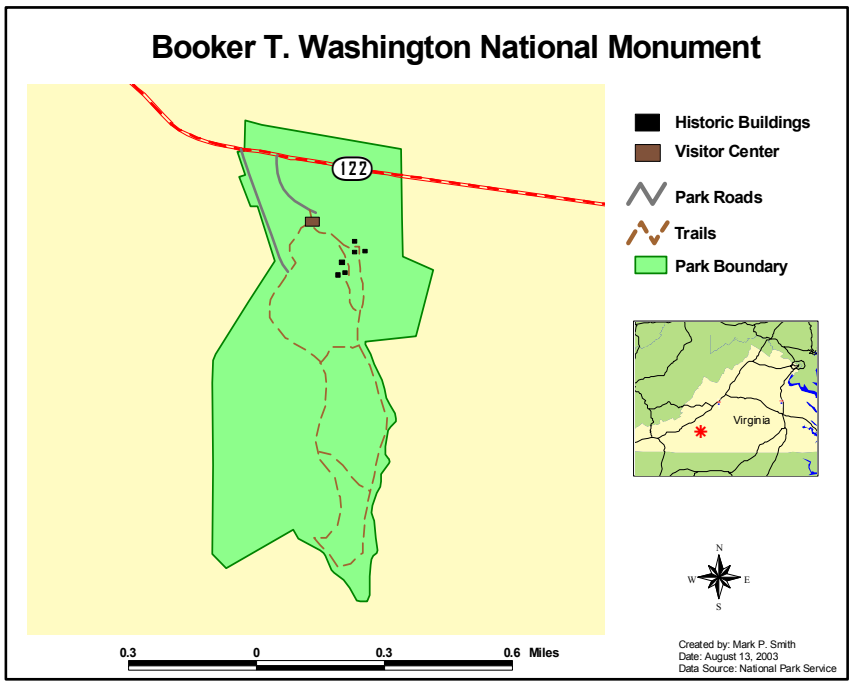


Figure 1. Map of Booker T. Washington National Monument

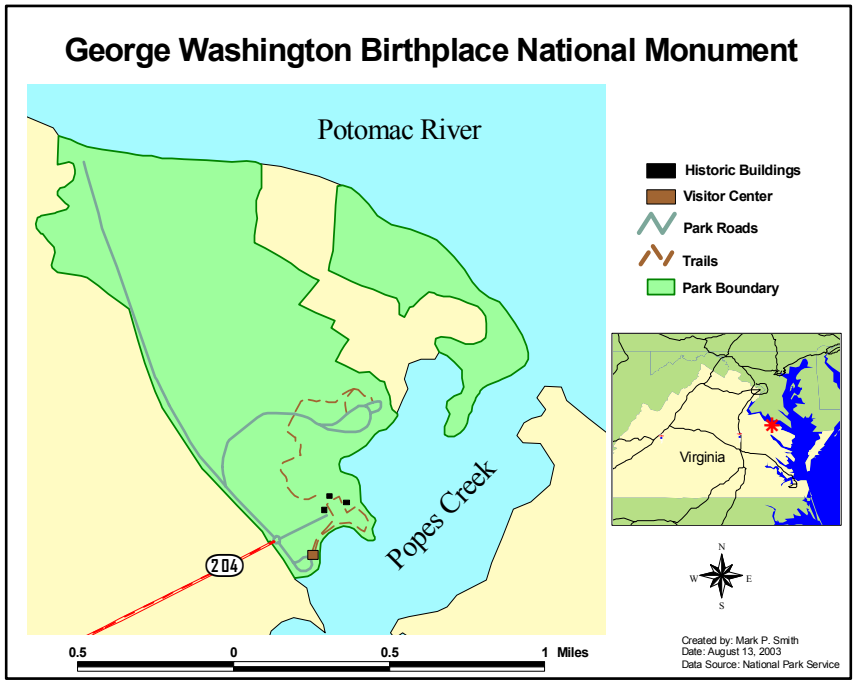


Figure 2. Map of George Washington Birthplace National Monument

4. PROJECT OBJECTIVES

The following are my research objectives for this project:

- Develop an automated method to predict both summer and fall condition fuel models from formation level vegetation maps for Booker T. Washington National Monument and George Washington Birthplace National Monument.
- Evaluate the sensitivity of FARSITE simulation results relative to the variations in fuel model predications for the above two parks.

5. METHODOLOGY

The process for developing an automated method to predict both summer and fall condition fuel models began with preparing photo mosaic images of both study areas. From these images, vegetation maps were created by delineating vegetation based upon the National Vegetation Classification system (Weakely *et al.* 1988) to the formation level. The vegetation maps were then used to locate sample points stratified by formation. Brown's transect lines and Burgan and Rothermel ocular measurements were used to estimate the amount of downed woody debris found at the sample sites. The amount of downed woody debris provided an estimate for the amount of fuel loading found for each formation sampled. Based upon the amount of fuel loading measured in the field, fuel models were assigned to the formation classes for each study area.

In addition, the sensitivity of FARSITE to the variations in the fuel model assignment was tested. The following section describes how each of the steps was completed to achieve the objectives for this project.

5.1 Data Preparation

The creation of an aerial photo mosaic for each study area started with acquiring the aerial photos. Kucera International, Inc. acquired the color-infrared (CIR) aerial photographs for both study areas at a target scale of 1:6000 in leaf-on and leaf-off conditions. For GEWA, twenty-four aerial photographs with leaf-on conditions were captured on October 20, 2001 and twenty-three aerial photographs with leaf-off conditions were captured on February 18, 2002. Thirteen aerial photographs with leaf-on conditions were taken on

October 22, 2001 and ten aerial photographs with leaf-off conditions were captured on February 19, 2002 for BOWA. Kucera International, Inc. also provided airborne GPS measurements and inertial measurement units (IMU) for each of the four photo missions mentioned above in a *.dat (ASCII text) file format.

The CIR aerial photographs for both study areas were scanned using an Epson Expression 836 XL or an Epson Expression 1640 XL desktop scanner. Each image was scanned with 24-bit color, no filters, and at a 600 dot-per-inch (dpi) scanning resolution and then imported into Adobe Photoshop 6.0. Each scanned image was cropped to reduce the amount of black edges while still preserving the fiducials. The images were then saved as a Tagged-Image File Format (TIFF). The aerial photographs for each study area were darker in comparison to images used in similar projects. To correct for this, the TIFF images were adjusted in Adobe Photoshop 6.0 using Auto Levels command. This command moves the levels in the image to automatically set highlights and shadows. It defines the lightest and darkest pixels on the image and then redistributes intermediate pixel values proportionately (Adobe 2001). The TIFF images were then converted to *.img files in ERDAS Imagine 8.5 (ERDAS Imagine's native file format).

Four USGS 7.5-minute digital elevation models (DEMs), corresponding to the Hardy, Goodview, and Moneta, Virginia quadrangles were obtained for BOWA. Three DEMs, corresponding to the Colonial Beach South, Stratford Hall, and Rollins Fork, Virginia quadrangles were obtained for GEWA. The DEMs were acquired from the Radford University GIS website, USGS seamless data website, and from the parks. These DEMs were mosaiced in ERDAS Imagine 8.5 into a single file for each park. The DEMs for

GEWA were brought into ESRI ArcInfo where a focal mean was run to remove the seam between the three DEMs. Richard Easterbrook, GIS Specialist for Petersburg National Battlefield, provided the park boundary coverage for BOWA. Rijk Morawe, Natural and Cultural Resources Management Chief for GEWA, provided the GEWA boundary using existing survey maps for the area. The DEMS were resampled in ESRI ArcInfo GRID using a cubic convolution algorithm (i.e. from 30-meters resolution to 10-meters) to match the ground resolution of the scanned aerial photographs. The DEMS along with the airborne GPS and IMU have projection settings of UTM NAD 83 18 North meters for GEWA and UTM NAD 83 17 North meters for BOWA.

5.2 Orthorectification

The process of orthorectification was completed in ERDAS Imagine's OrthoBase. This program uses "block files" to store platform characteristics and interior and exterior orientation. In the block files, the projection was set according to the *.dat file. A camera calibration report containing focal length and fiducial information provided by Kucera International, Inc. was used in the block file. The *.dat file was brought into the block file for ground control. The next step was to attach all the scanned aerial photographs in *.img format to the block file. The interior orientation for each block file was established using the Frame Editor in OrthoBase. The correct fiducial orientation for each image was selected from the four possible choices based upon flight direction of the platform. Fiducials were then marked on each image using the Frame Editor until the root mean squared error (RMSE) was less than 0.33 pixels (Koch 2001). Opening the Frame Editor and changing all the

exterior settings from "initial" to "fixed" established the exterior orientation for each block file. Once all of the parameters were set for each block, each image was resampled using bilinear interpolation to create orthophotos using a batch process in OrthoBase.

5.3 Creating the Mosaic Images

The orthorectified images from the four flight missions were mosaiced into one image for each of the study areas. The spring aerial photography from BOWA and the spring and fall aerial photography for GEWA were mosaiced in ERDAS Imagine 8.5 using the Mosaic Images tool. An area of interest (AOI) layer was selected on each image using the AOI Tool. The center area was chosen on each image since distortion was at a minimum and there was no sidelap or endlap from adjoining photographs (Avery and Berlin 1992). Each orthophoto and its AOI were brought into the mosaic tool. The "no cutline" and "feather" options were chosen under the mosaic options. The no cutline option was chosen since the AOI for each image acted as the cutline. The feather option was chosen because it has been shown to be an effective option when moasicing aerial photographs (Millinor 2000). Finally, the nearest neighbor interpolation method was used to create the mosaic. The resulting output file size for each mosaic was large and was subsequently compressed using the MrSID Geospatial Encoder 1.4 (Multi-resolution Seamless Image Database) compression program from LizardTech, Inc. The ratio of compression for each image was 20:1.

The fall mosaic for BOWA was created with ER Mapper 6.2, a program developed by Earth Resource Mapping Ltd. This software mosaics images in a similar fashion to ERDAS Imagine 8.5 but it is quicker and more effective at color balancing images. The orthophotos

for BOWA were converted to LAN files in ERDAS Imagine 8.5 and then brought into ER Mapper. They were then converted to *.ers files, the native file format for the program, using an ESG_Import_LAN_Batch.erb batch script provided by ER Mapper. The *.ers files where then mosaiced to create one seamless image using the mosaic tool within ER Mapper 6.2. It was then color balanced using no black and white edges. An algorithm with these settings was saved for each of the images so they could be opened again without having to reload all the images and reset the preferences. The final mosaic was saved as a *.bil file in ER Mapper and converted in ERDAS Imagine to an *.img file using a generic binary format. The final mosaic was compressed using the MrSID compression tool at a rate of 20:1.

5.4 Delineation of Vegetation

The unique vegetation types found within each study area was delineated in ERDAS Imagine Stereo Analyst using the same procedure followed by Millinor (2000) and Koch (2001). They found that delineating different vegetation using a virtual three-dimensional model allowed for high accuracy in assigning vegetation classes. While vegetation for BOWA was delineated by another student, I followed the same procedure when delineating the vegetation for GEWA.

The first step in the vegetation delineation was to define areas of different vegetation on screen without assigning a formation type to the area. Each formation type was chosen based on characteristics separating one type from another such as texture, tone, pattern, shape, and color (Avery, 1992). The block file for each study area was opened in Stereo Analyst and a specific Feature Project was created. This file type is used to store the feature

class created on screen. Arcs were the feature class used to delineate the different vegetation types. The minimum mapping unit (MMU) of 0.2 hectares (approx. 0.5 acres) was used for each study area. Due to the high resolution of the aerial photography, areas smaller than the MMU were used for roads, buildings, and historic monuments. Delineating the vegetation in stereo provided the advantage of finding streams and low-lying areas that would not have otherwise been detected in a two-dimensional setting. Once all the arcs were created, the Feature Project was exported as a shapefile. In ArcCatalog, the arc shapefile was cleaned and built and polygon topology was added. By using arcs instead of polygons in Stereo Analyst, slivers were not created.

The next step was to assign a formation to each of the polygons. The shapefiles created in Stereo Analyst were brought into ArcMap where the previously created mosaics were used as backdrops. The vegetation for each study area was assigned using The Nature Conservancy's National Vegetation Classification System (NVSC) at the formation level. The NVCS is a hierarchical system that allows the interpreter to choose the level of classification (Table 1). The NVCS defines the physiognomic levels as Class through

Table 1. Physiognomic-floristic hierarchy of the NVCS (Weakley *et al*., 1998)

Level	Primary Basis for Classification	Example
Class	Growth form and structure of vegetation	Woodland
Subclass	Growth form characteristics, e.g., vegetation	Deciduous Woodland
Group	Leaf types, corresponding to climate	Cold-deciduous Woodland
Subgroup	Relative human impact (natural/semi-natural or cultural)	Natural/Semi-natural
Formation	Additional physiognomic and environmental factors, including hydrology	Temporarily Flooded Cold-deciduous Woodland
Alliance	Dominant/diagnostic species of uppermost or dominant stratum	*Populus deltoides* Temporarily Flooded Woodland Alliance
Association	Additional dominant/diagnostic species from any strata	*Populus deltoides – (Salix amygdaloides)/ Salix exigua* Woodland

Formation while the floristic levels are defined as Alliance and Association. A list of possible formations was provided by Richard Easterbrook, GIS specialist from Petersburg National Battlefield, and Bill Millinor, research associate for North Carolina State University's Center for Earth Observation (Appendix E).

5.5 Accuracy Assessment

The first accuracy assessment checked was the positional accuracy for the mosaic images that were created in ERDAS Imagine. Points were located on each mosaic image that could easily be identified on-screen as well as in the field. A total of 21 points for BOWA spring and fall mosaic images and 27 points for GEWA spring and 20 points for GEWA fall were used to access the positional accuracy. The USGS-NPS Vegetation Mapping Program requires that an adequate number of survey points be spread evenly across the images (Bailey *et al*., 1994). A point theme was created in ArcView where each chosen point was given X

and Y coordinates. A gps_writewaypointtextfile Avenue script developed by David Kimball was used in ArcView to convert the point theme to a text file that was loaded into a Trimble Pro XR GPS unit. This script is free and available online at http://arcscripts.esri.com/. These positions were then located in the field and a three-minute occupancy time positional fix was taken. Real time correction was used whenever possible for each field position. The field X and Y positions acquired with the GPS were compared to the X and Y positions that created from the mosaics in ArcView. The same field X and Y positions were used in the spring and fall mosaic image for each study area and adjusted accordingly to ensure the position was at the same point in each mosaic. The Euclidean difference between the X and Y positions was then calculated to determine the accuracy for the spring and fall mosaic images for each study area.

Thematic accuracy of the formation level vegetation maps was the next accuracy verified. Frank Koch, a doctoral candidate at North Carolina State University, developed an extension to run in ArcView that creates and randomly samples points within a vegetation map for accuracy assessment (Appendix N). This extension follows USGS-NPS National Vegetation Mapping Program protocol. The script also creates a shapefile for the points as well as adds an X and Y coordinate to each point. A total of 68 accuracy assessment points were created for the BOWA vegetation map and 74 for the GEWA map. An additional 22 points were provided by Virginia Natural Heritage to increase the total accuracy points for GEWA to 96 points. The point layer created from the script and the vegetation polygons from each area were both opened in ArcView. The gps_writewaypointtextfile script was used to convert the accuracy point shapefile to a waypoint file and then loaded into a Trimble Pro XR GPS unit.

The vegetation was assessed for accuracy following the USGS-NPS National Vegetation Mapping Program protocol. Although the protocol suggests using a 50-meter radius study area based on a 0.5-hectare mmu, a 20-meter radius was used since the project used a 0.2 mmu. Data collected in the field followed protocol defined by Millinor (2000). An error matrix was created to show the vegetation map accuracy for BOWA (Appendix E) and GEWA (Appendix F).

5.6 Fuel Data Collection

The major objective of my research work was to predict fuel models from vegetation maps for both areas. In order to predict the fuel models, fieldwork was conducted to measure the amount of fuel loading for each formation class found within the vegetation maps. Brown's transect lines and Burgan and Rothermel ocular measurements were used in the field to estimate the amount of fuel loading.

The first step was to estimate the amount of fuel loading in each vegetation type. Sample points were subjectively located within different vegetation polygons on the two vegetation maps. Field measurements of downed woody debris were collected using Brown's transect lines and Burgan and Rothermel ocular measurements while canopy cover was collected during the formation accuracy assessment. A total of 9 points were chosen for BOWA and 28 points were chosen for GEWA. The number and location of points were based on the number of formation classes and total area per vegetation class. The points were created as a separate layer in ArcView, assigned an X and Y position, and then converted into a waypoint text file using the gps_writewaypointtextfile script.

The points were located in the field using a Trimble Pro XR GPS unit with real time correction. At each point, National Park Service protocol developed by Shenandoah National Park was followed to collect the amount of downed woody debris (Carmichael and Cass, 2001). The protocol requires collecting the slope measurement along each transect line, amount of fine and coarse woody debris intersects along each transect, duff and litter depth, and an ocular estimation for the amount of fuel loading using Burgan and Rothermel's estimation. The measurements for all the points to estimate the amount of fuel loading at each plot was recorded on a data sheet developed by Shenandoah National Park (Appendix G and Appendix H). The first step was to lay 50 foot transect lines in the north and east directions from the point origin. A survey pin was placed at the point to mark the position as well as to hold the two 50 foot transect tapes in place. A measure of the slope, in degrees, along each transect was taken using a clinometer. The next step was to count the number of fine and course woody debris intersects along each transect line. Fine woody debris is broken down to one-hour fuel, 0 to ¼ inch in diameter, ten-hour fuel, ¼ to 1 inch, one hundred-hour fuel, 1 to 3 inches, while coarse woody debris is anything greater than 3 inches. The next step was to measure the duff depths and litter depths in tenths of an inch at prescribed intervals (1 foot, then 5 foot, and continuing every five feet to 45). The final step was to take a picture of the north and east transect lines and the area between the transect lines. The pictures provided a reference source if future questions arose as well as provide a pictorial key for the fuel loading in each formation.

The ocular measurement of the fuel loading was collected in the area between the two transect lines using Burgan and Rothermel's estimation method (Andrews 1986). An

imaginary box created by extending a line parallel to the east transect line and a line parallel to the north transect line delineated the area where these measurements were taken. For each plot I collected type, amount, and bulk density of the grasses and shrubs found within the box. The measurement procedures use 70% of the tallest dominant grass and shrub species found within the plot as the average height. The procedure also requires the user to define the primary litter source, compactness, litter depth, and estimate the litter load found within the box.

5.7 Fuel Data Calculation

The amount of downed woody debris measured in the field was calculated using the equation provided in Brown's handbook (Brown 1974). This formula was used to calculate the fuel loading in a tons/acre value for fine and coarse debris. This calculation is based upon the number of intersects for each transect line, a slope correction factor, average squared debris diameters, specific gravity, and transect line lengths (Brown, 1974). The fuel loading values along with fuel bed depth for each study area was measured, calculated and graphed using Microsoft Excel spreadsheets. The findings from each calculation are discussed in section 6 of this paper.

5.8 Creation of FARSITE layers and Simulating Wildland Fire Conditions

The final procedure was to simulate fire for the two study areas using the information fuel loading values collected in the field. The National Park Service requires each park to provide a fire management plan describing how fire would react and identify potential fire

related threats to resources within the park. Fire simulation tools such as FARSITE provide natural resource managers with an effective tool to model fire. In order to run FARSITE, raster input layers of slope, elevation, aspect, canopy cover, and fuel models must be provided as well as local weather and wind conditions.

The slope, elevation, and aspect layers were created in ArcView Spatial Analyst. The DEM from each study area was used to create these layers in a grid format with a cell size of 30 meters. The Surface Analysis option under Spatial Analyst was used to create a separate layer for the slope and aspect of each study area while the DEM was used as the elevation input. An important requirement for each simulation was to set each spatial layer to the same cell size and spatial extent. The simulation will not run or will provide incorrect results if the spatial extent or cell size of each layer is different.

Summer and fall canopy cover layers were created using the vegetation maps, mosaic images and fieldwork. The percent canopy cover for summer conditions was recorded when the formation maps were checked for thematic accuracy. This value was assigned to the entire polygon. For polygons that were not visited in the field, an average percent canopy from the visited polygons was used. The percent canopy cover for fall conditions was estimated from the spring mosaic image. Each polygon was assigned a value based on the amount of evergreen canopy present since the deciduous trees had lost their leaves. This percent canopy was based on the amount of cover for the entire polygon. FARSITE allows the user to define the percent canopy cover in percent form or assign a value of 1-4. Each canopy cover layer was created by adding a field to the formation attribute table, assigning

the percent canopy cover from the field, and creating a grid using the newly created field values as the raster cell value.

Separate fuel model layers were created for each park to represent summer and corresponding fall conditions. Summer fuel models were based on field measurements and their correlation to vegetation formation. Fall fuel models were estimated from the summer conditions based on local knowledge of the study areas by National Park Service Personnel (Doug Raeburn, personal communication 2003). Three summer and fall fuel model layers were assigned from fieldwork and the vegetation formation maps. A second set of fuel model layers were created by adjusting these initial assigned fuel models. Each formation fuel model was changed to its most likely confused model. For example, a deciduous forest was adjusted from an assigned fuel model value of 8 to a fuel model 9. A third set of fuel model layers were created by leaving the grass formations in their initial assigned fuel models and changing only the forested formations. The grass formations were given their assigned value from the first layer and the forested formations were given their adjusted fuel model value from the second layer. Each fuel model layer was created by adding a field to the formation attribute table, assigning the appropriate fuel model number to each formation, and creating a grid using the newly created field as the raster cell value. The value for each cell in the grid was based on the fuel model number for each polygon.

The next step was to convert all the raster input layers from grids to ASCII text files using a batch process in ArcToolbox. FARSITE requires all input files to be in ASCII text format to run the simulation. The tutorial guide for FARSITE recommends placing all the

input files for the simulation into one folder, labeled Input, and all output files from the simulation into folder, labeled Output, to organize files associated with the program.

The fire simulation is dependent upon local weather conditions such as moisture and wind direction. To simulate fire behavior, a weather file (*.wtr) is created that represents the humidity, temperature, and precipitation amount for the area over the burn period. A wind file (*.wnd) is also created in FARSITE that describes the forecast for the wind direction and speed during the fire simulation. The weather and wind file for BOWA were created from the weather station in Buena Vista, Virginia which is approximately 35 miles north of BOWA. Gregory Sanders, fire management officer with the George Washington and Jefferson National Forests, provided the archived data from the weather observation station for November and July of 2001. The weather and wind file were created from this information using the time period of July 6 – July 10 for the summer simulation and November 6 – November 10 for the fall simulation. The weather and wind file for GEWA was created from the Blackwater remote automated weather station (RAWS) in Maryland. Archived information from this station is available online at http://www.met.utah.edu/roman/states/MD_state_frame.html. This station is approximately 30 miles northeast of GEWA. The GEWA weather and wind file used the time period of June 6 – June 10, 2003 and November 14- November 18, 2002.

Another layer created in FARSITE is an adjustment factor file (*.adj). This file can be used to fine tune the spread rate of the fire using a factor that will decrease, increase, or not change the rate of spread for the fire. This file was left to the default values provided by FARSITE.

The final local condition is the initial moisture of the fuel before the simulation is run. A layer in FARSITE called Initial Fuel Moisture is created based upon the moisture for each fuel type along with the moisture for live woody and herbaceous species in the specified area. This moisture allows the simulation to estimate how fast the fuel type will catch on fire and well as spread. Greg Kneipp, Natural Resource Management Specialist for Fredericksburg and Spotsylvania Military Battlefield, suggested that the typical live woody and herbaceous initial fuel moistures for the summer conditions average around 250% during normal weather conditions and 40% during fall conditions. The weather observation for Buena Vista collected the fuel moisture for 1, 10, and 100-hour fuels. These values were used for BOWA and GEWA in the initial fuel moisture file.

The raster input files that were converted to ASCII text files are placed into a Landscape File (*.lcp) in FARSITE. This file is a collection of all the inputs as well as the latitude value for the study area and a general comments section that can be saved and merged with other *.lcp files. Next, the *.lcp, weather, wind, adjustment, and initial fuel moisture files area were loaded into a project inputs file. This file can easily be changed to reflect new weather and wind files without having to change the *.lcp file. A new parameter created in this file is a burn period file (*.bpd) which defines when the burn period will be for the simulation. The burn period was set for 5 days since all the inputs were based on 5 days worth of information from the summer and fall seasons. Once all the inputs have been loaded in the into the project input file, the entire project is saved as a *.fpj file which saves the project input file. All the files that are created from this project, such as the *.bpd, *.wtr, and the *.lcp were saved into the Input folder to keep all the files organized.

In order to run the simulation, an ignition point must be chosen within the landscape. A random point was created for BOWA and GEWA using Random Point Generator 1.1 ArcView extension. This extension was developed by Jeff Jenness, a wildlife biologist, from the US Forest Service Rocky Mountain Research Station and is available online at http://arcscripts.esri.com/. Each point was saved as a shapefile in ArcView and then opened in FARSITE. The ignition point used in the summer simulation for each study was also used in the fall simulation.

6.0 RESULTS

6.1 Positional accuracy of the mosaiced images

According to the USGS-NPS Vegetation Mapping Program protocol, positional accuracy assessment refers only to the horizontal map accuracy. Positional accuracy is estimated using the root-mean-square error (RMSE). RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points (FGDC 1998). For each coordinate value, the RMSE is calculated separately for each coordinate direction using the following formula:

$$\mathbf{RMSE_x} = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(\delta \mathrm{X}_i - \delta \mathrm{X}_c)^2} \qquad \text{(Merchant, 1985)}$$

where N is the total number of field coordinate values, $\delta \mathrm{X}_i$ is the x-coordinate location measured from the mosaiced image, and $\delta \mathrm{X}_c$ is the x-coordinate measured by an independent source of higher accuracy. The source used for this higher accuracy was a differentially correcting GPS unit. This process is repeated for the y-coordinate direction by substituting $\delta \mathrm{X}_i$ and $\delta \mathrm{X}_c$ with $\delta \mathrm{Y}_i$ and $\delta \mathrm{Y}_c$.

The positional accuracy was assessed for the leaf-on and leaf-off mosaic images for both study areas. The RMSE for the fall mosaic of GEWA was calculated using 20 field survey points spread throughout the image and 27 points were used for the spring mosaic. The overall RMSE for the fall mosaic was 1.07 meters in the x direction and 1.28 meters in the y direction while the spring mosaic was 0.83 meters in the x direction and 0.91 meters in

the y direction. According to the National Map Accuracy Standards for large-scale maps, an image at a scale of 1:6000 requires a RMSE of 1.5 meters or less to receive a Class 1 planimetric accuracy value. The fall and spring image mosaics RMSE values are considered to be Class 1 accurate in the x and y-coordinate direction.

The RMSE for the fall and spring mosaic of BOWA were calculated using 21 field survey points. The overall RMSE for the fall mosaic was 1.58 meters in the x direction and 0.54 meters in the y direction while the spring mosaic was 1.31 meters in the x direction and 0.65 meters in the y direction. The National Map Accuracy Standards for large-scale maps state that an image with an RMSE greater than 1.5 and less than 3 receive a Class value of 2. The fall mosaic is considered Class 2 in the x-coordinate direction and Class 1 in the y-coordinate direction.

Positional accuracy can also be measured using the mean Euclidean difference for the coordinate locations:

$$\text{Mean Euclidean difference} = \frac{\sqrt{\sum_{i=1}^{n} (\delta X)^2 + (\delta Y)^2}}{N}$$

where N is the total number of coordinate locations, δX is the difference between the map and the surveyed x-coordinate for a point, and δY is the difference between the map and the surveyed y-coordinates for the location (Koch 2001). The mean Euclidean distance for the GEWA fall mosaic was 1.54 meters and 1.08 meters for the spring mosaic. The BOWA fall mosaic was 1.38 meters and 1.16 for the spring mosaic.

6.2 Thematic accuracy for the vegetation layers

A total of 68 polygons were delineated for BOWA with 10 formation classifications (Figure 3). A summary of the vegetation classes along with the total number of polygons, acres, and hectares per class are presented in Table 2. The most abundant vegetation class was medium-tall sod temperate or subpolar grassland (V.A.5.C.n) while the least abundant was developed open land (1.2 Developed Open Land). Lowland or submontane cold-deciduous forest (I.B.2.N.a) has the most abundant amount of polygons while agriculture (Ag and Cultivated 2), temporarily flooded cold-deciduous forest (I.B.2.N.d), and cold-deciduous woodland (II.B.2.N.a) had the fewest amounts of polygons.

Table 2. Polygon counts, acres, and hectares for the formation map of BOWA

Vegetation Class	Count	Acres	Hectares
1.2 Developed Open Land	3	5.21	2.11
Ag and Cultivated 2	1	10.84	4.39
I.A.8.N.b	10	35.73	14.46
I.B.2.N.a	29	135.26	54.75
I.B.2.N.d	1	12.41	5.02
I.C.3.N.a	5	30.53	12.36
II.B.2.N.a	1	1.71	0.69
Road	4	8.00	3.24
V.A.5.C.x	4	38.69	15.66
V.A.5.N.c	10	163.44	66.14
Sum	68	441.82	178.80

An error matrix was created for the vegetation delineated from the photo mosaics to illustrate which formations contributed the most errors in the vegetation mapping process (Appendix E). The diagonal cells in the table represent the number of polygons that were

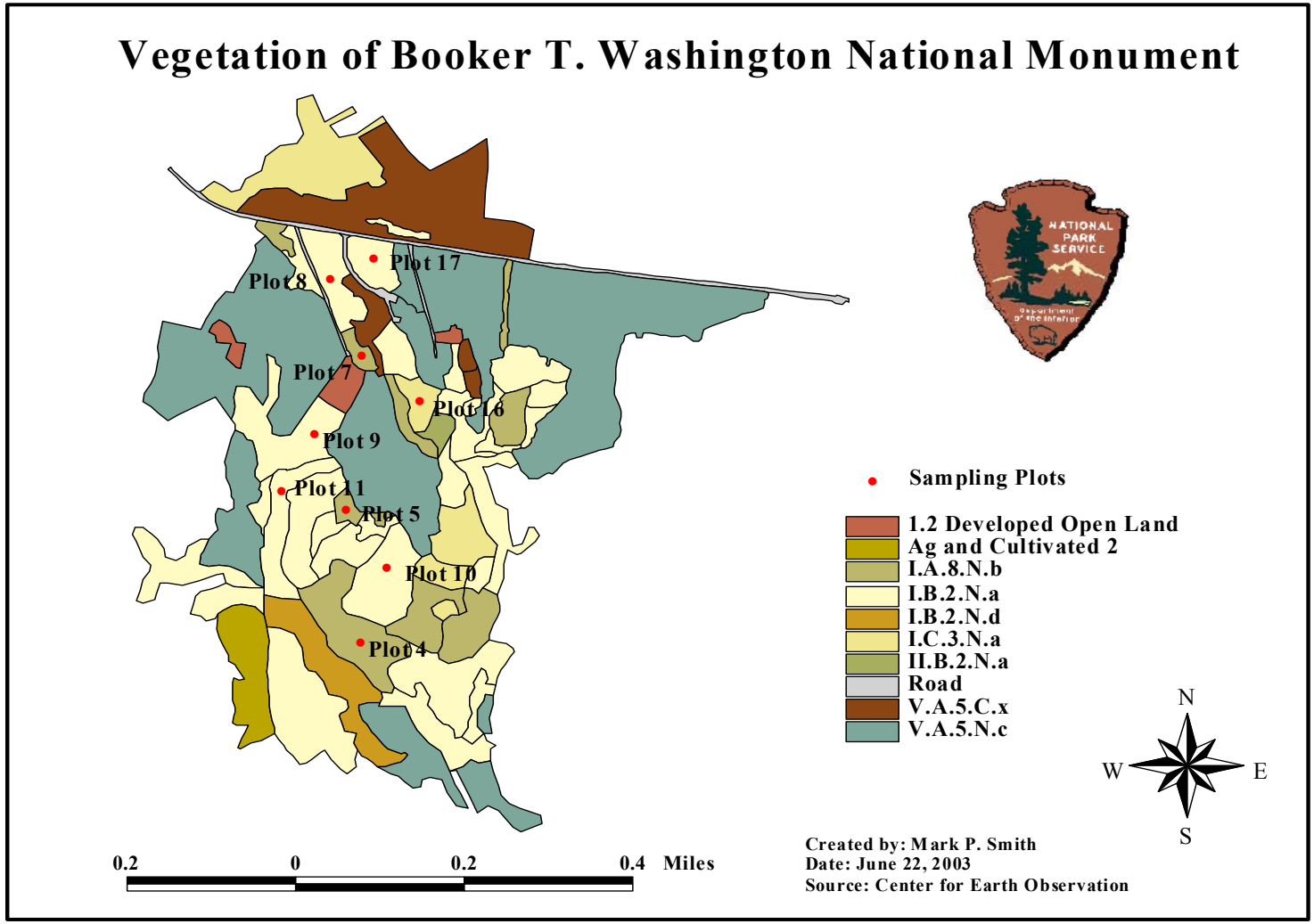


Figure 3. Vegetation and Sampling Points for Booker T. Washington National Monument

correctly classified on the mosaic image while values that are not in the diagonal are incorrectly classified. These values are summed for the row and columns to provide the errors of omission and commission. Omission errors are errors that indicate the number of sites not identified as being in a particular class. Commission errors are errors that indicate the number of sites identified as being in a particular class when they belong to a different class. A total of 12 vegetation classes are presented in the error matrix. The accuracy for the initial vegetation map using the information collected in the field was 60.94%. Misclassification of two formation types resulted in the lower vegetation accuracy. The first formation was lowland or submontane cold-deciduous forest (I.B.2.N.a). For this formation, six polygons were mislabeled as temporarily flooded cold-deciduous forest (I.B.2.N.d) and three polygons were labeled as mixed needle-leaved evergreen – cold deciduous forest (I.C.3.N.a). A potential reason for this misclassification was the hydrological regime of the forest. The misclassification with the evergreen forest is due in part to the presence of deciduous trees mixed under the canopy of evergreen trees.

The second often missed formation was medium-tall sod temperate or subpolar grassland (V.A.5.N.c). Three polygons were mislabeled as seasonally flooded temperate or subpolar grassland (V.A.5.N.k) and four were mislabeled as a mowed field (V.A.5.C.x). The first misclassification was due to a hydrological regime problem. These polygons were thought to be wet areas when they were actually dry. The second misclassification is due in part to how members from the Virginia Natural Heritage wanted these polygons labeled. Initially, areas that were mowed were classified as V.A.5.C.x and areas that were hayfields were to be labeled as V.A.5.N.c. This created confusion for identification purposes since some areas may be mowed one year and then converted to hayfields the next. This problem

was repeated in the vegetation map for GEWA. Future classifications of mowed fields and agricultural fields will be classified as V.A.5.N.c. A total of 64 out of 68 polygons were visited in the field which allowed the vegetation polygons to be adjusted to achieve an overall map accuracy of 94.1%.

A total of 262 polygons were delineated for GEWA with 25 formation classifications (Figure 4). A summary of the vegetation classes along with the total number of polygons, acres, and hectares per class are presented in Table 3. The most abundant vegetation class was medium-tall sod temperate or subpolar grassland (V.A.5.C.n) while the least abundant was temporarily flooded temperate perennial forb vegetation (V.B.2.N.d). Medium-tall sod temperate or subpolar grassland has the most abundant amount of polygons while developed mixed forest (1.1.3 Developed Mixed), seasonally flooded cold-deciduous forest (I.B.2.N.e), and semi-permanently flooded cold-deciduous scrubland (III.B.2.N.f) have the fewest amounts of polygons.

Table 3. Polygon counts, acres, and hectares for the formation map of GEWA

Vegetation Class	Count	Acres	Hectares
1.1.1 Developed Deciduous	4	1.73	0.70
1.1.2 Developed Coniferous	3	4.23	1.71
1.1.3 Developed Mixed	1	0.89	0.36
1.2 Developed Open Land	14	16.48	6.67
Beach	5	7.29	2.95
Building	19	1.56	0.63
I.A.8.C.x	6	43.67	17.67
I.A.8.N.b	22	191.42	77.47
I.B.2.N.a	16	26.55	10.75
I.B.2.N.e	1	2.73	1.10
I.C.3.N.a	23	142.51	57.67
I.C.3.N.b	2	26.74	10.82
I.C.3.N.d	2	0.80	0.33
II.B.2.N.a	3	8.76	3.55
III.A.2.N.f	2	1.14	0.46
III.B.2.N.a	14	29.88	12.09
III.B.2.N.f	1	9.46	3.83
III.B.2.N.h	17	19.72	7.98
Road	5	9.71	3.93
V.A.5.N.c	61	535.60	216.75
V.A.5.N.n	10	27.73	11.22
V.B.2.N.d	1	0.20	0.08
V.B.2.N.g	17	81.76	33.09
V.C.2.N.a	5	68.20	27.60
Water	8	317.45	128.47
Sum	262	1576.20	637.87

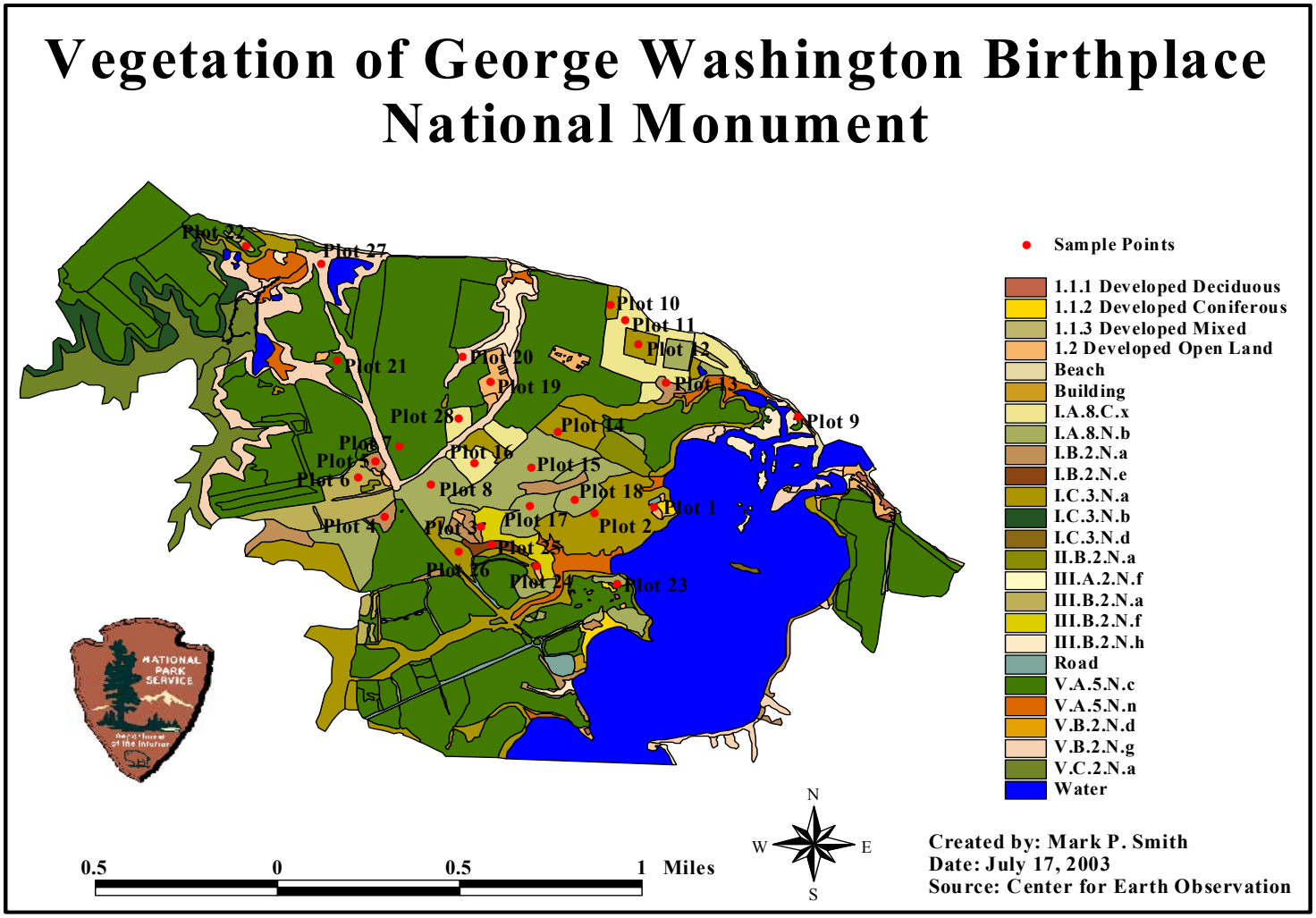


Figure 4. Vegetation and Sample Points for George Washington Birthplace National Monument

An error matrix was also created for the GEWA vegetation delineation using the same method described for BOWA (Appendix F). A total of 28 vegetation classes are presented in the error matrix. The accuracy for the initial vegetation map using the information collected in the field was 73.0%. The formation that contributed the most to the misclassification was the mixed evergreen deciduous forest (I.C.3.N.a). Six of these areas were misclassified as other formations. Two polygons were marked as Developed Coniferous 1.1.2 or Developed Mixed 1.1.3. These two formations are very similar in their description and very difficult to differentiate in the field. Developed Coniferous 1.1.2 is defined as an area with signs of human habitation and more than 80% basal area in *Pinus* spp. and Developed Mixed 1.1.3 is defined as an area with signs of human habitation and 21% to 79% basal area in *Pinus* spp. While these formations are helpful in delineation, they have a tendency to blend with other formations which ultimately creates accuracy errors. Future plans for these formation classes are to stop using them and instead classify areas as developed or some other forested formation. The remaining four misclassified points either were classified as deciduous forest, woodland, shrubland, or evergreen forest. The problem is that these are relatively subjective calls eventually based on the density of the trees. Often the field point will be located in a less than typical dense spot thereby causing some confusion. This was a relatively minor problem. The initial vegetation map was adjusted to reflect field observations which changed the final map overall accuracy to 83.0%.

6.3 Fuel Loading Calculation and Results

The fuel loading values for both study areas were calculated by entering the downed woody debris information collected in the field into the following formula developed by Brown (1974). The point locations for BOWA are displayed in Figure 3 and in Figure 4 for GEWA.

0 to 3 - inch downed woody material: $$\frac{11.64 \times n \times d^2 \times s \times a \times c}{Nl}$$

3+ - inch downed woody material: $$\frac{11.64 \times \sum d^2 \times s \times a \times c}{Nl}$$

n is number of downed woody intersects along the transect line, d^2 is the squared average diameter for each size class, s is the specific gravity, a is the non-horizontal angle correction factor, c is the slope correcting factor, and Nl is the total length of the sampling plane. To assist in estimating the values for the above factors, Brown (1974) provides estimated values for the different size classes and forest species. The information collected in the field for the fuel loading calculations is displayed in Appendix I for BOWA and Appendix J for GEWA. The results are also shown below in graphical form to demonstrate the amount of fuel loading for size classes 0 – 0.25, 0.25 – 1.00, 1.00 – 3.00 and fuel bed depth for both study areas. The numbers beside the figures in the graphs represent the plot number and the direction represents the direction of the transect line.

The fuel loading values for the 0 – 0.25 size class for BOWA showed very little variation in fuel loading among vegetation types (Figure 5). The smallest fuel loading value recorded was 0 tons/acre and the largest was .16 tons/acre. The downed woody debris samples that were measured in deciduous forests showed the largest variance in fuel loading.

The fuel loading values for the 0.25 – 1.00 size class varied the greatest for downed woody debris samples measured in deciduous forests (Figure 6). The fuel loading values varied from 0 to 1.83 tons/acre for this vegetation type. The fuel loading values for native evergreen forest and mixed evergreen forest showed similar variation while there was little variation in fuel loading for temporary flooded deciduous forest.

The fuel loading values for the 1.00 – 3.00 size class had the largest variation in fuel loading for all three size classes (Figure 7). Mixed evergreen forest had the largest variation in fuel loading with a range of 0 to 3.68 tons/acre. The remaining vegetation types also showed a large variation in fuel loading with an average range of 0 to 2.4 tons/acre.

The variation for the average fuel bed depth for each vegetation type was similar except for temporary flooded deciduous forest which had the least number of samples (Figure 8).

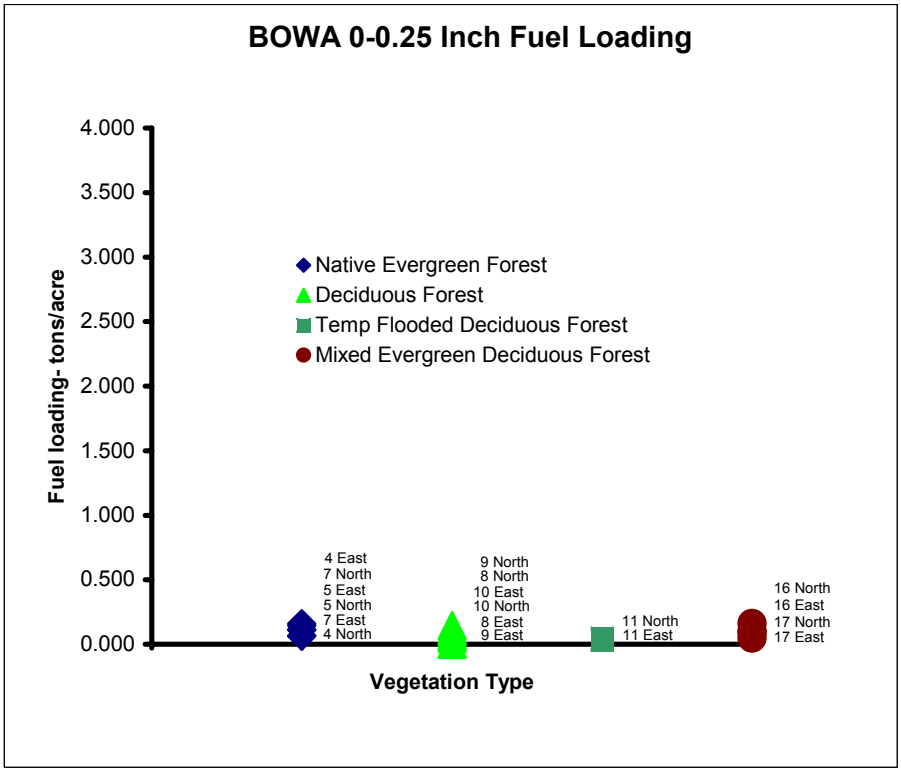


Figure 5. 0-0.25 inch fuel loading for BOWA

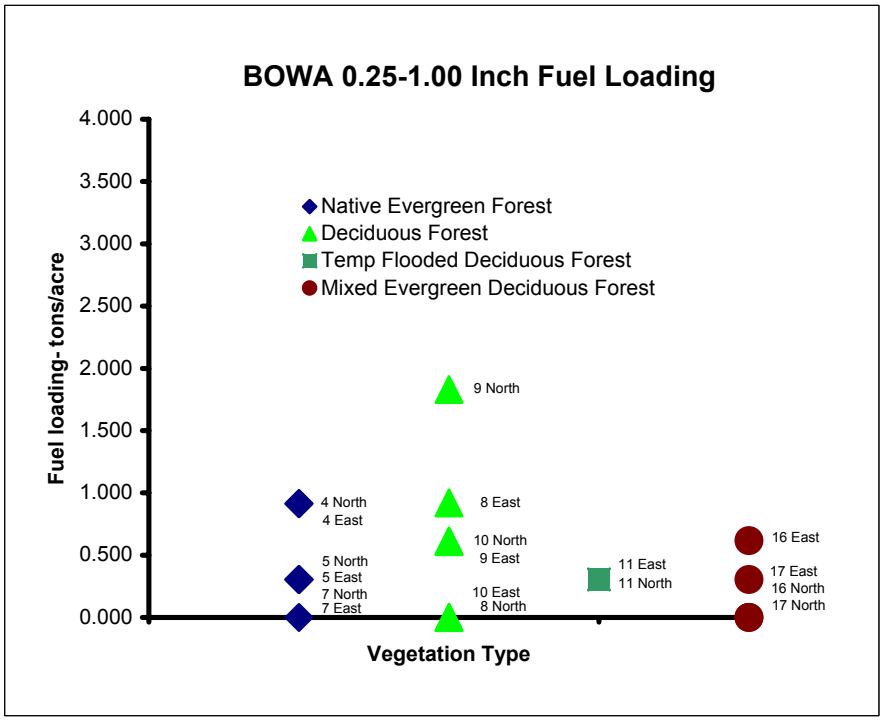


Figure 6. 0.25-1.00 inch fuel loading for BOWA

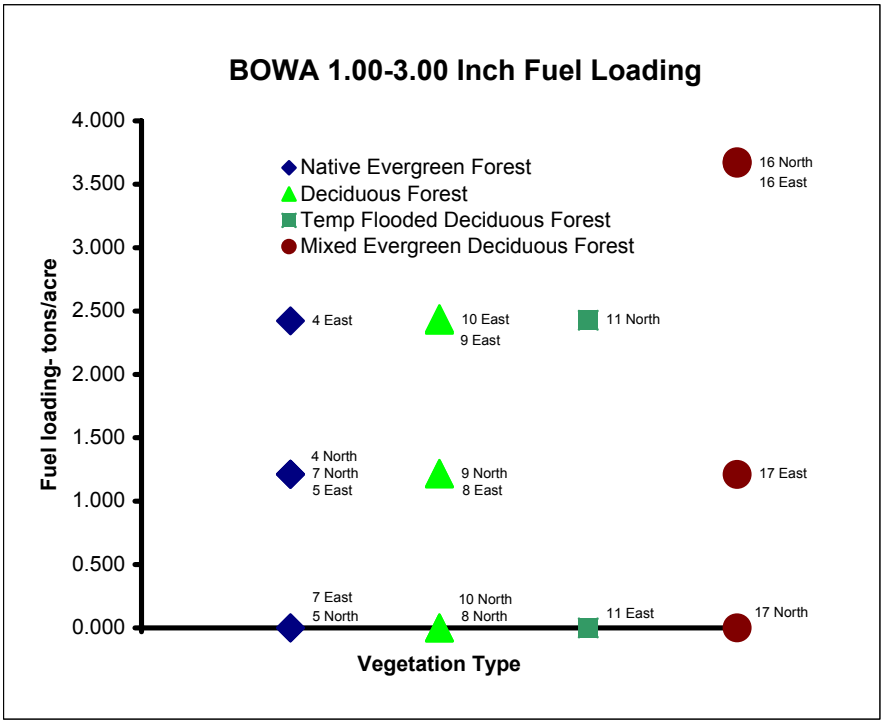


Figure 7. 1.00-3.00 inch fuel loading for BOWA

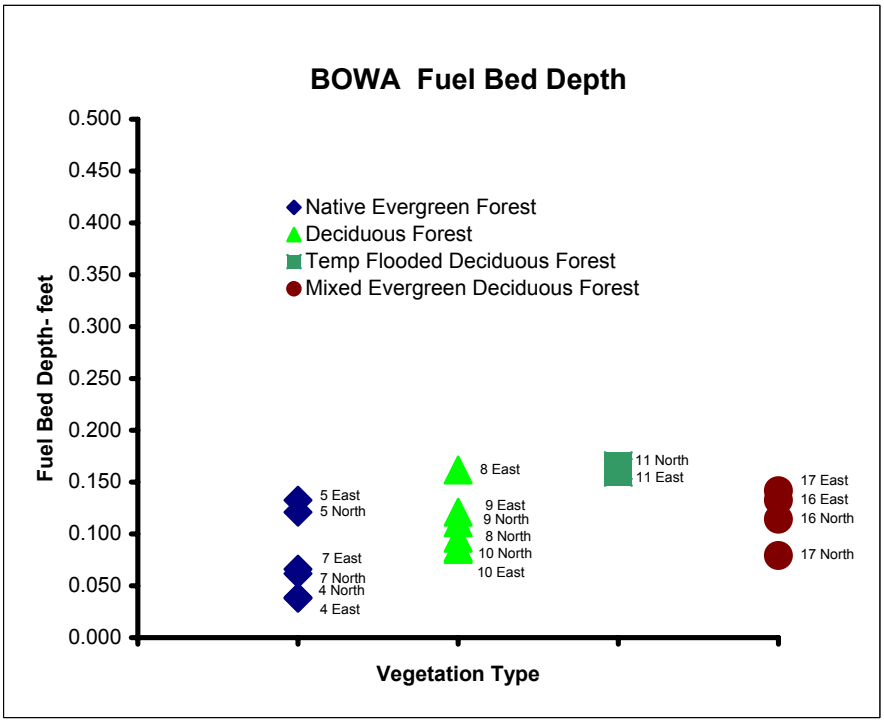


Figure 8. Fuel bed depth for BOWA

The fuel loading values for the 0 – 0.25 size class for GEWA showed similar lack of variation by vegetation type (Figure 9). The smallest fuel loading value recorded was 0 tons/acre and the largest fuel loading value was .20 tons/acre. The mixed evergreen deciduous forest showed the largest variance in fuel loading with a low fuel loading value of 0 tons/acre and a high fuel loading value of 0.21 tons/acre.

The fuel loading values for the 0.25 – 1.00 size class varied the greatest for downed woody debris samples measured in deciduous forests (Figure 10). The fuel loading values varied from 0 to 2.43 tons/acre for this vegetation type. Planted evergreen forests, mixed evergreen deciduous forests, and temporary flooded mixed forests showed some differences but the variation overall was lower than deciduous forests. The remaining vegetation types showed little or no variation in the amount of fuel loading.

The fuel loading values for the 1.00 – 3.00 size class had the largest variation in fuel loading for all three size classes (Figure 11). Planted evergreen forest, temporary flooded deciduous forests, and temporary flooded mixed forests had a similar fuel loading range of 0 tons/acre to 3.63 tons/acre. Native evergreen forests and seasonal flooded deciduous forest showed a similar but lower variation than previously mentioned forest types with a fuel loading range of 0 tons/acre to 2.42 tons/acre. The remaining vegetation types showed little or no variation in fuel loading.

The variation for the average fuel bed depth for seasonally flooded deciduous forest, mowed fields, and grasslands was less than 0.02 tons/acre (Figure 12). The remaining vegetation types had a variation of 0 to 0.16 tons/acre.

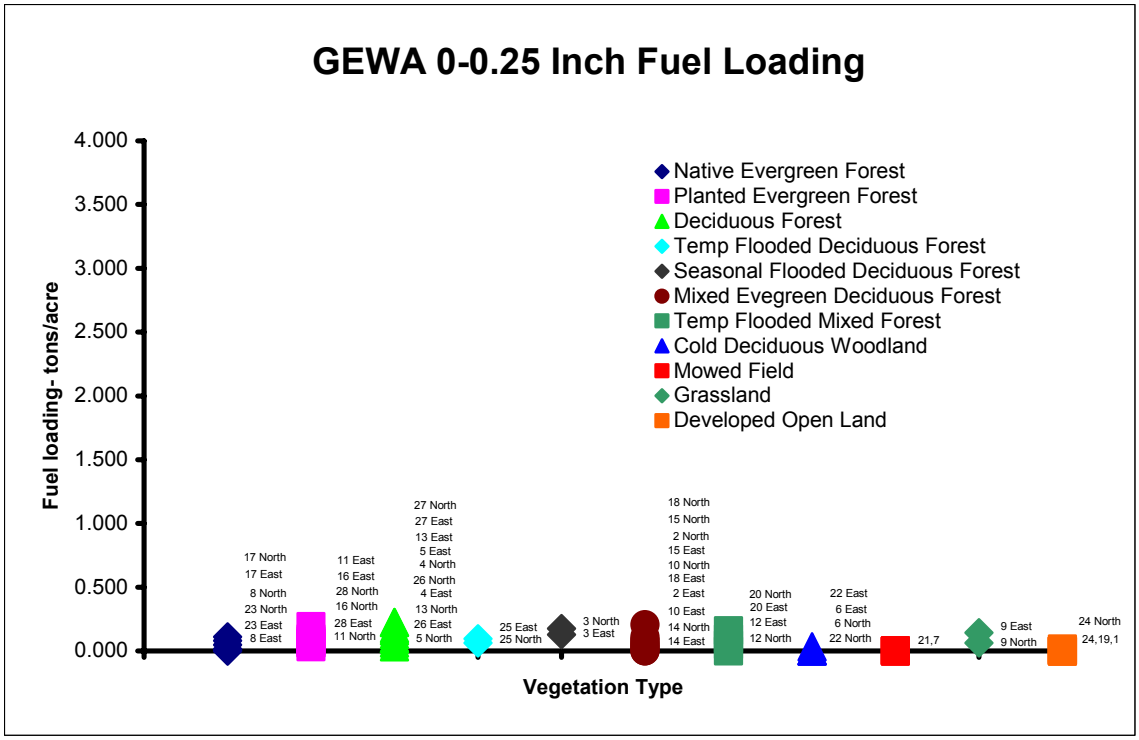


Figure 9. 0-0.25 inch fuel loading for GEWA

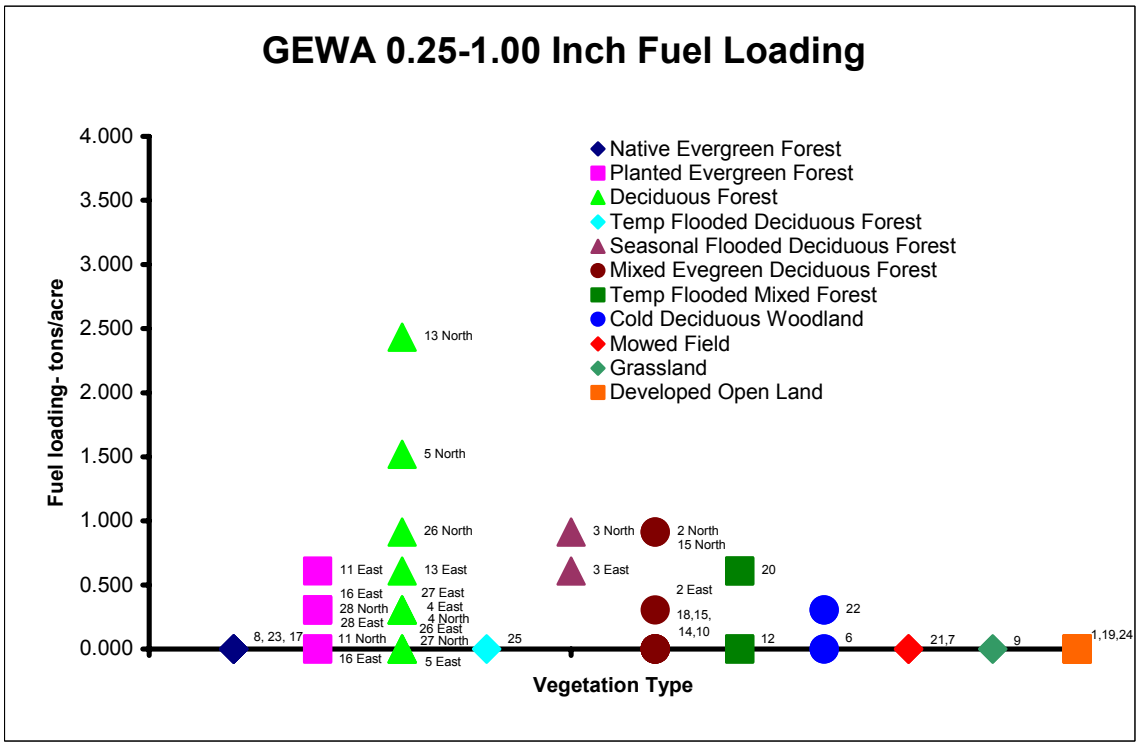


Figure 10. 0.25-1.00 inch fuel loading for GEWA

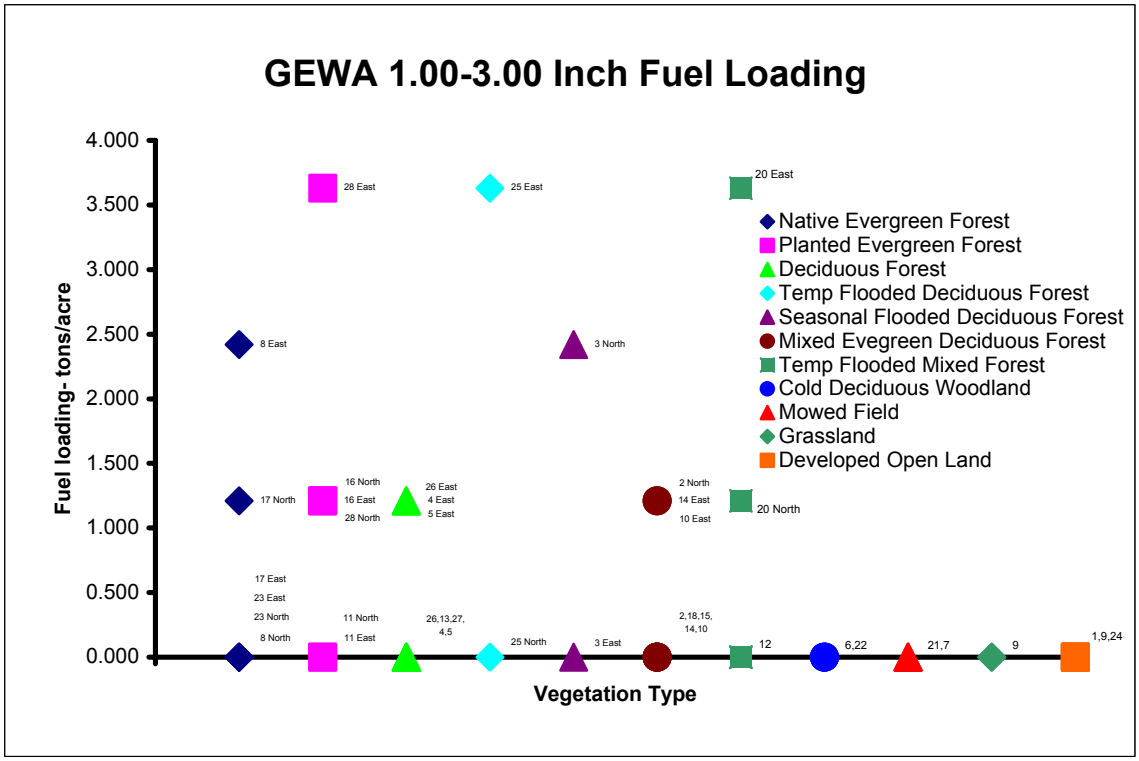


Figure 11. 1.00-3.00 inch fuel loading for GEWA

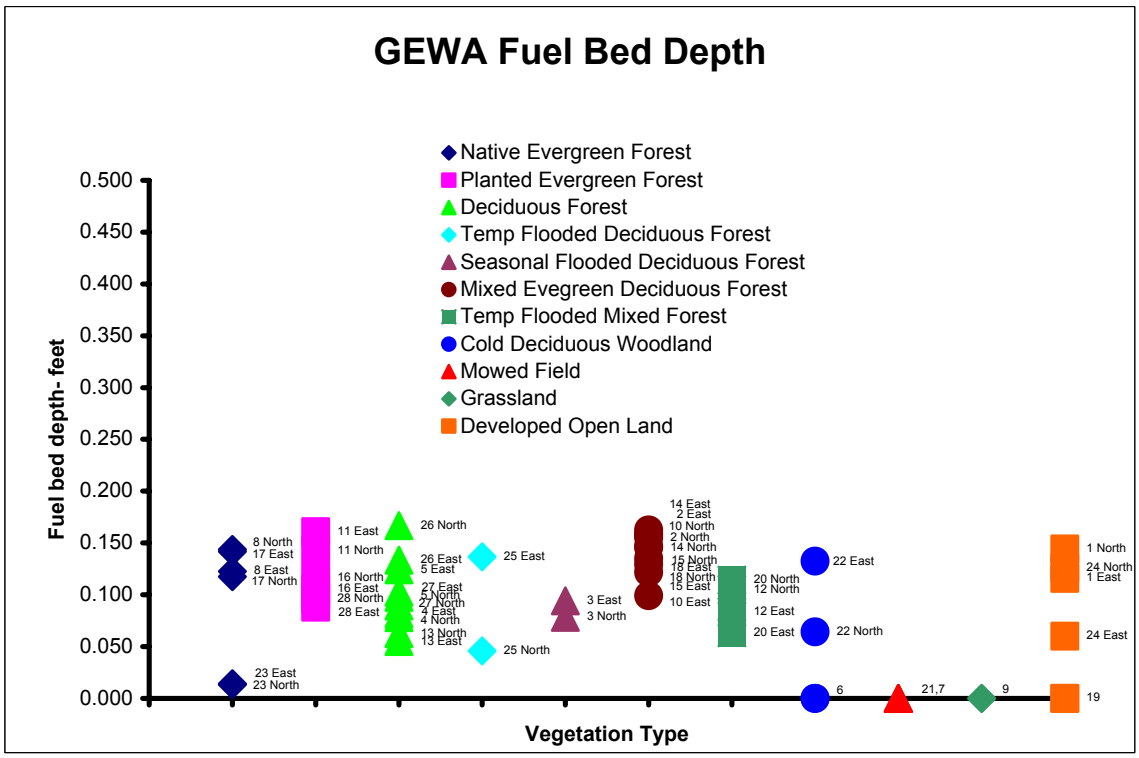


Figure 12. Fuel bed depth for GEWA

6.4 Standard Sample Size for Estimating Fuel Load

The traditional method for estimating the minimum number sample sites needed to calculate fuel load is described in the National Park Service Fire Monitoring Handbook (USDI National Park Service 2001). A sampling site is defined as using one transect line to record the amount of intersects of fine and coarse downed woody debris. Doug Raeburn, a fire ecologist from Shenandoah National Park, suggested using a confidence level of 80% with a desired precision level of 25% for estimating the number of sample sites (Doug Raeburn, personal communication 2003). The minimum sample size was calculated using the following formulas:

Standard Deviation: $$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n-1}}$$

where s is the standard deviation, n is the number of observations within the sample, x_i is the ith sample observation, and $\bar{x}$ is the sample mean.

Confidence Interval Width: $$d = \frac{\bar{x} \times R}{100}$$

where d is the desired precision level (confidence interval width expressed as a percentage of the mean), $\bar{x}$ is the sample mean, and R is the desired precision level as a percentage of the mean. Raeburn suggested that the value for R equal 25% for this calculation.

Minimum Sample Size: $$n = \frac{t^2 \times s^2}{d^2}$$

where n is the minimum number of plots needed, t is the critical value of the test statistic Student's t based on an 80% two-tailed confidence interval, s is the standard deviation of the sample, and d is the desired precision level.

The calculation details for sample size for BOWA can be found in Appendix L and in Appendix M for GEWA. The fuel loading values from similar vegetation formations in each study area were combined to increase the number of sample points per formation class. The calculation details for the combined fuel loading values can be found in Appendix O.

The minimum number of samples for each vegetation type in BOWA is listed in Table 4 and Table 5 for GEWA. The minimum number of samples for similar vegetation types in BOWA and GEWA is listed in Table 6.

Table 4. Standard sample sizes for BOWA

Formation	Minimum Sample Size
I.A.8.N.b - native evergreen forest	33
I.B.2.N.a - deciduous forest	24
I.B.2.N.d - temporary flooded deciduous forest	385
I.C.3.N.a - mixed evergreen deciduous forest	112

Table 5. Standard sample sizes for GEWA

Formation	Minimum Sample Size
I.A.8.N.b - native evergreen forest	86
I.A.8.C.x - planted evergreen forest	46
I.B.2.N.a - deciduous forest	5
I.B.2.N.d - temporary flooded deciduous forest	1899
I.B.2.N.e - seasonally flooded deciduous forest	497
I.C.3.N.a - mixed evergreen deciduous forest	23
I.C.3.N.b - temporarily flooded mixed forest	298
III.B.2.N.a - cold deciduous woodland	2

Table 6. Standard sample sizes for combined vegetation

Formation	Minimum Sample Size
I.A.8.N.b - native evergreen forest	47
I.B.2.N.a - deciduous forest	14
I.C.3.N.a - mixed evergreen deciduous forest	90
I.B.2.N.d - temporary flooded deciduous forest	154

The preceding results show that an overwhelming number of samples would be required to estimate the amount of fuel loading for each formation class found for both study areas. The fuel loading values from the sites that were sampled enabled the assignment of fuel models to the formation classes. A lack of variation between fuel model values for the formation classes prevented the need to sample more sites. .

6.5 Fuel model maps

Six fuel model maps were created for the FARSITE simulation for BOWA (Appendix E) and six fuel model maps were created for GEWA (Appendix F). The fuel models were assigned based on the amount of fuel loading measurements collected in the field, similarity of sample plots to pictures in the Anderson (1982) fuel model guide, and local knowledge of the area.

The fuel model maps were based on the mosaiced aerial photographs and the vegetation maps. No accuracy assessment was performed for the fuel models maps. They may need to be periodically reviewed and updated to ensure proper assignment of fuel models to the formation classes.

6.6 FARSITE simulation

The fuel models created from the fieldwork were used to evaluate the sensitivity of FARSITE to variations in these models. The first step was to use assigned fuel models to assess the results of the summer and fall simulations for FARSITE. The adjusted fuel models where then used to demonstrate if FARSITE would produce different results when the models were changed. Finally, the grass formation fuel models were held constant and the forested fuel models were changed to the adjusted fuel model value. The results from this simulation would show if changing the forested fuel models would produce different results in the simulation. A total of twelve simulations were run for the two study areas using FARSITE. The inputs layers for the two study areas were held constant in all the simulations except the fuel model layers. Two simulations were run using assigned fuel models, adjusted fuel models, and assigned grass fuel model values and adjusted forested fuel models.

The summer and fall simulations for BOWA using assigned models estimated a fire that would burn with an average rate of speed of 8.8 feet/minute for summer weather conditions and 11.7 feet/minute for fall conditions (Table 7). Areas towards the northern part of the park experienced greater rates of spread than other areas. The highest rate of spread in these areas was 60 feet/minute for summer conditions (Figure 13) and 68 feet/minute for fall conditions (Figure 15). The average fire line intensity was 15.8 BTU/feet/second for summer conditions and 125.4 BTU/feet/second for fall conditions. The highest fire line intensity was 97 BTU/feet/second for summer conditions (Figure 14) and 750 BTU/feet/second for fall conditions (Figure 16). The final measurement for the simulation estimated a total of 442.2 acres burned under summer conditions and 447.1 burned under fall conditions.

Table 7. BOWA simulation results using assigned fuel models

Season	Average Rate of Spread (feet/minute)	Average Fire Line Intensity (BTU/feet/minute)	Acres Burned
Summer	8.8	15.8	442.2
Fall	11.7	125.4	447.1

The second set of simulations for BOWA using adjusted fuel models estimated an average rate of spread of 14.4 feet/minute for summer conditions and 7.8 for fall conditions (Table 8). Areas towards the northern and western parts of the park experienced higher rates of spread than other areas. The maximum rate of spread was higher than the assigned fuel model simulation for summer conditions with a rate of spread of 95 feet/minute (Figure 17) but lower during fall conditions with a rate of spread of 46 feet/minute (Figure 19). The average fire line intensity for the study area was also higher in summer conditions with a value of 182.6 BTU/feet/second but lower in lower during fall conditions with a maximum rate of spread of 15.7. The highest fire line intensity was 1280 BTU/feet/second for summer conditions (Figure 18) and 191 BTU/feet/second for fall conditions (Figure 20). The simulation estimated a smaller area would be burned during the summer and fall conditions compared to the previous simulation results.

Table 8. BOWA simulation results using adjusted fuel models

Season	Average Rate of Spread (feet/minute)	Average Fire Line Intensity (BTU/feet/minute)	Acres Burned
Summer	14.4	182.6	433.0
Fall	7.8	15.7	412.2

The final set of simulations for BOWA using values for assigned fuel model for grass formations and adjusted fuel models for forested areas estimated similar average rate of

spread and fire line intensity for fall and summer conditions compared to simulations using assigned fuel models (Table 9). The highest rate of spread (Figure 21 and Figure 23) and fire line intensity (Figure 22 and Figure 24) were also similar to the simulations using assigned fuel models. The simulation estimated an overall smaller area burned for summer and fall conditions compared to the expected fuel model simulations.

Table 9. BOWA simulation results holding grass formation fuel models constant

Season	Average Rate of Spread (feet/minute)	Average Fire Line Intensity (BTU/feet/minute)	Acres Burned
Summer	8.6	14.4	404.4
Fall	10.8	115.4	429.6

The summer and fall simulations for GEWA using assigned models estimated a fire that would burn with an average rate of speed of 7.8 feet/minute for summer weather conditions and 9.6 feet/minute for fall conditions (Table 10). Areas towards the northern and western parts of the park experienced greater rates of spread than other areas. The highest rate of spread in these areas was 50 feet/minute for summer conditions (Figure 25) and 68 feet/minute for fall conditions (Figure 27). The average fire line intensity was 176.8 BTU/feet/second for summer conditions and 114.8 BTU/feet/second for fall conditions. The highest fire line intensity was 317 BTU/feet/second for summer conditions (Figure 26) and 777 BTU/feet/second for fall conditions (Figure 28). The final measurement for the simulation estimated a total of 1072.8 acres to be burned under summer conditions and 1165.3 acres to be burned under fall conditions.

Table 10 GEWA simulation results using assigned fuel models

Season	Average Rate of Spread (feet/minute)	Average Fire Line Intensity (BTU/feet/minute)	Acres Burned
Summer	7.8	12.3	1072.8
Fall	9.6	47.6	1165.3

The second set of simulations for GEWA using adjusted fuel models estimated an average rate of spread of 14.7 feet/minute for summer conditions and 10.11 feet/minute for fall conditions (Table 11). Areas towards the northern and central parts of the park experienced higher rates of spread than other areas. The maximum rate of spread was higher than the assigned fuel model simulation for summer conditions with a rate of spread of 123 feet/minute (Figure 29) and fall conditions with a rate of spread of 73 feet/minute (Figure 31). The average fire line intensity for the study area was also higher in summer condition with a value of 176.8 BTU/feet/second and fall conditions with an average rate of spread of 114.8 BTU/feet/second. The highest fire line intensity was 1612 BTU/feet/second for summer conditions (Figure 30) and 936 BTU/feet/second for fall conditions (Figure 32). The simulation estimated a larger area to be burned during summer conditions and a similar size are would be burned compared to the previous simulations

Table 11. GEWA simulation results using adjusted fuel models

Season	Average Rate of Spread (feet/minute)	Average Fire Line Intensity (BTU/feet/minute)	Acres Burned
Summer	14.7	176.8	1171.2
Fall	10.11	114.8	1162.0

The final set of simulations for GEWA using values for assigned fuel model for grass formations and adjusted fuel models for forested areas estimated similar average rate of

spread and fire line intensity for fall and summer conditions compared to simulations using expected fuel models (Table 12). The highest rate of spread (Figure 33 and Figure 35) and fire line intensity (Figure 34 and Figure 36) were also similar to the simulations that used assigned fuel models. The simulation estimated an overall larger area burned for summer conditions and a smaller area for fall conditions compared to the assigned fuel model simulations.

Table 12. GEWA simulation results holding grass formation fuel models constant

Season	Average Rate of Spread (feet/minute)	Average Fire Line Intensity (BTU/feet/minute)	Acres Burned
Summer	9.3	16.1	1171.8
Fall	9.6	44.8	1138.3

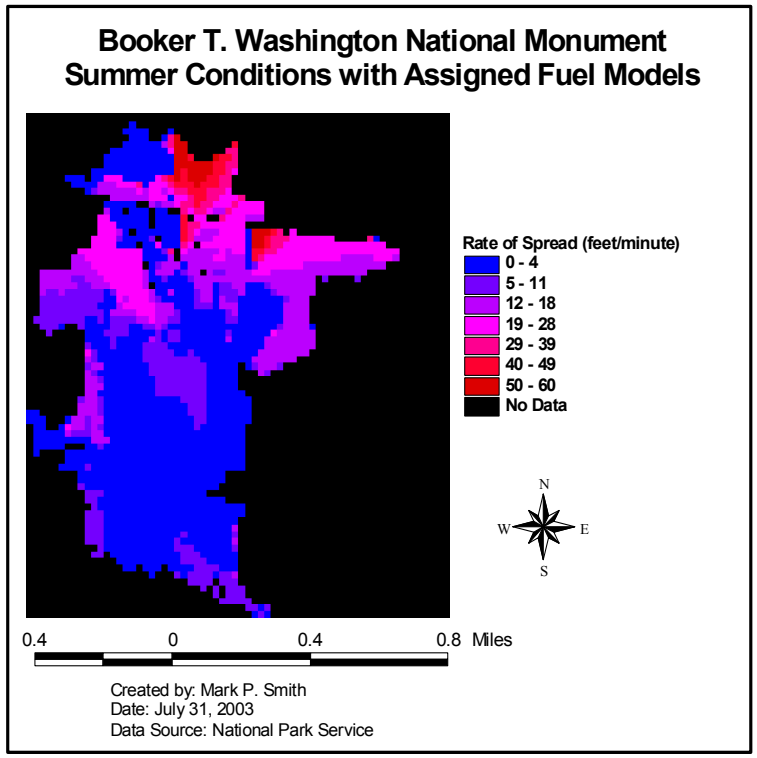


Figure 13. Summer assigned fuel models rate of spread for BOWA

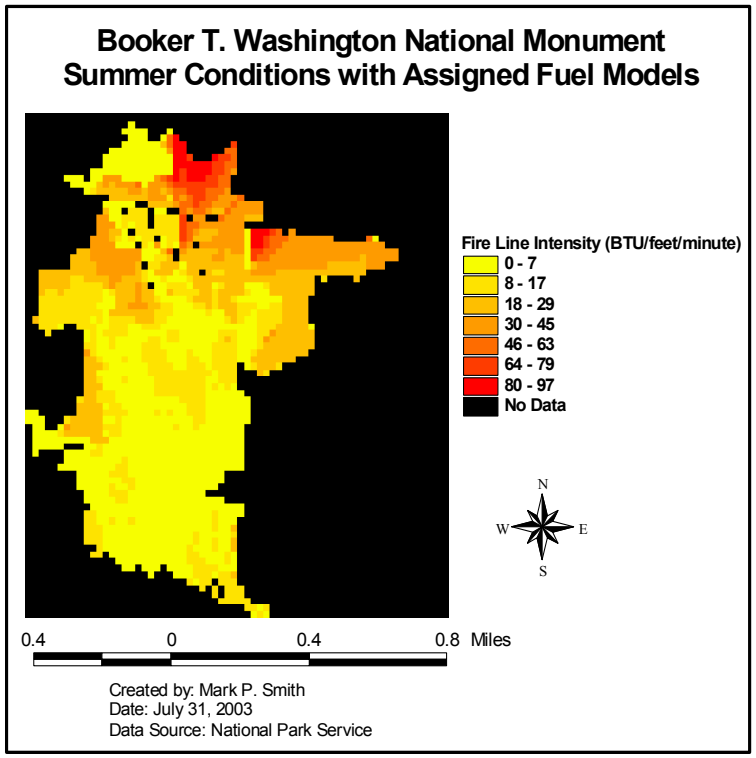


Figure 14. Summer assigned fuel models fire line intensity for BOWA

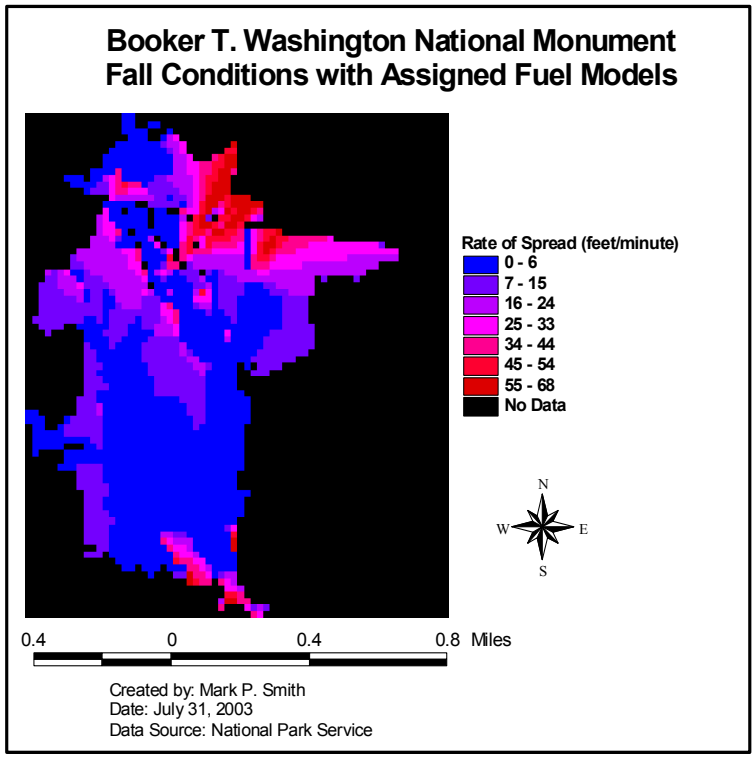


Figure 15. Fall assigned fuel models rate of spread for BOWA

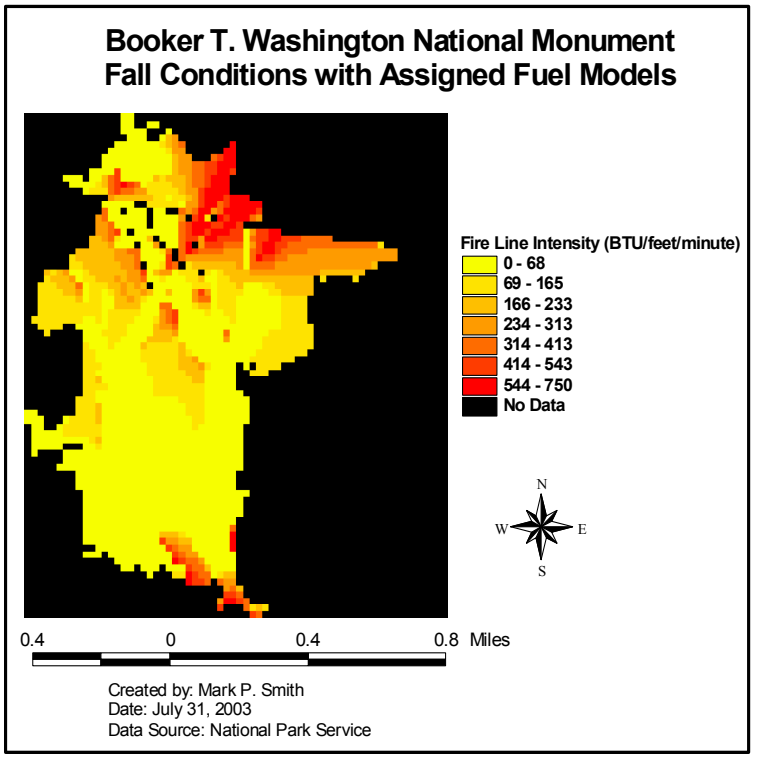


Figure 16 Fall assigned fuels model fire line intensity for BOWA

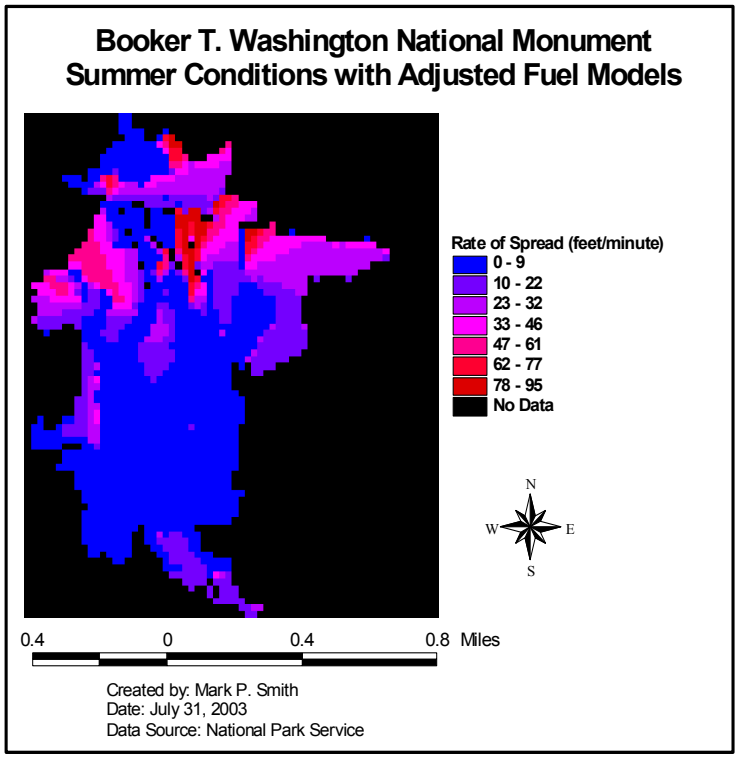


Figure 17. Summer adjusted fuel models rate of spread for BOWA

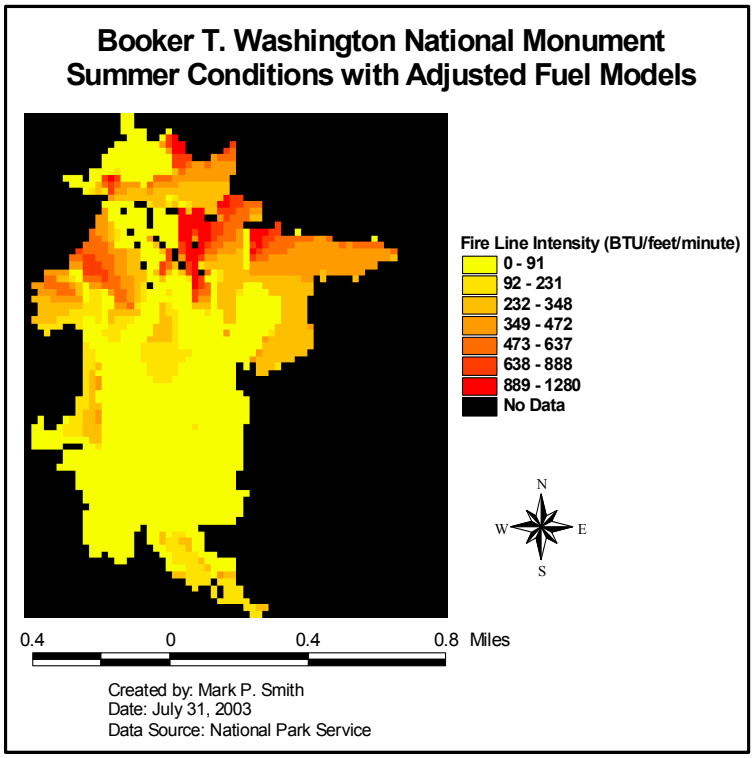


Figure 18. Summer adjusted fuel models fire line intensity for BOWA

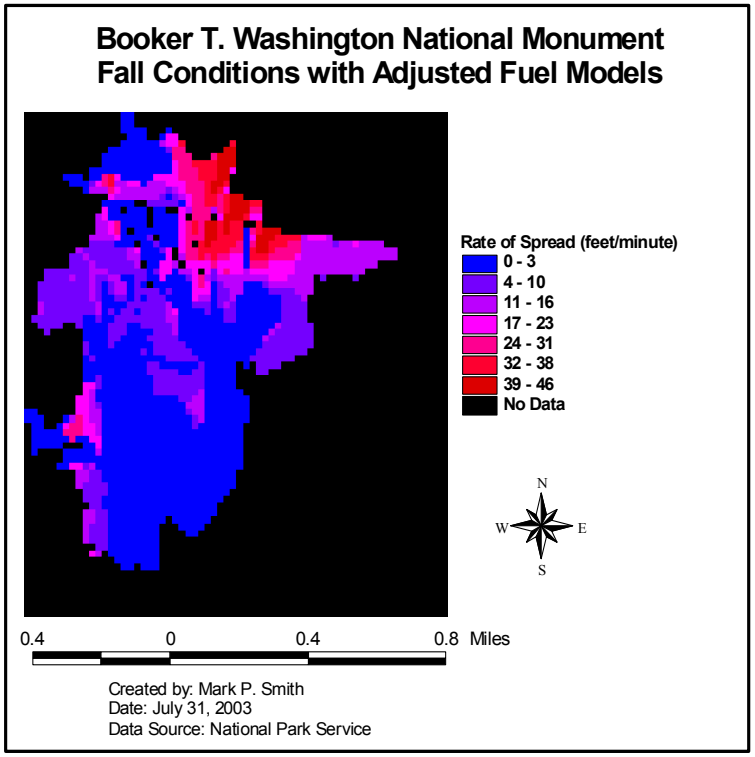


Figure 19. Fall adjusted fuel models rate of spread for BOWA

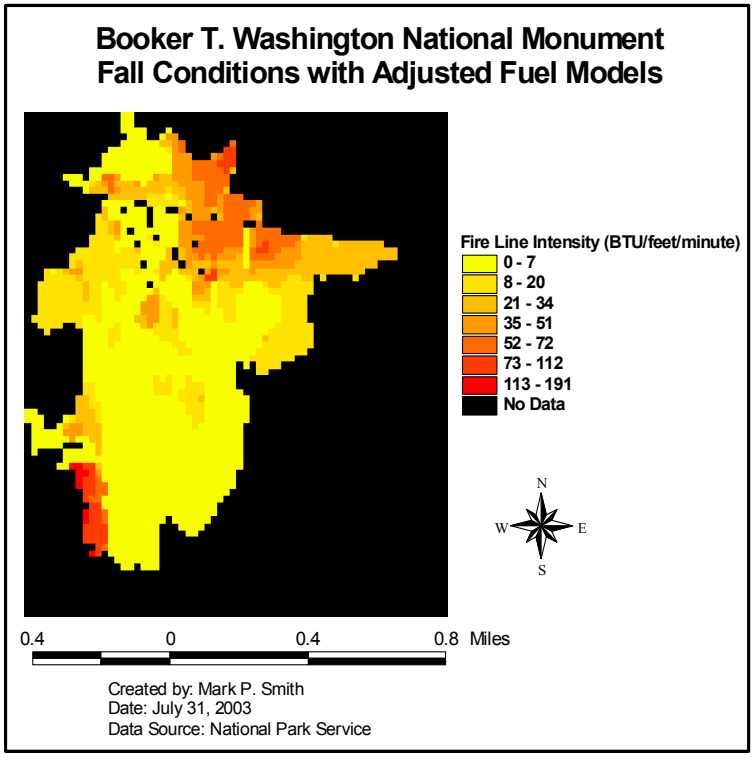


Figure 20. Fall adjusted fuel models fire line intensity for BOWA

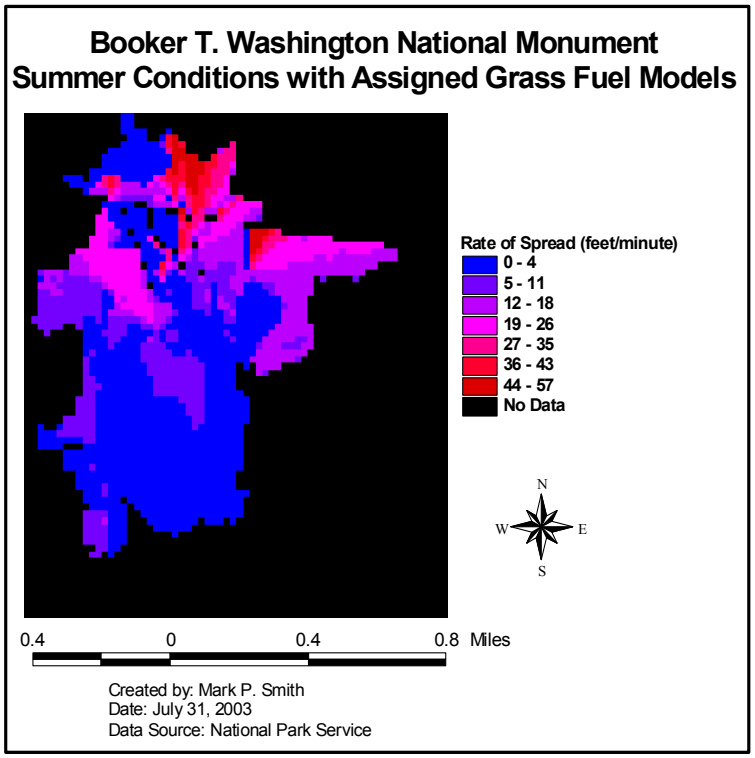


Figure 21. Summer assigned grass fuel models rate of spread for BOWA

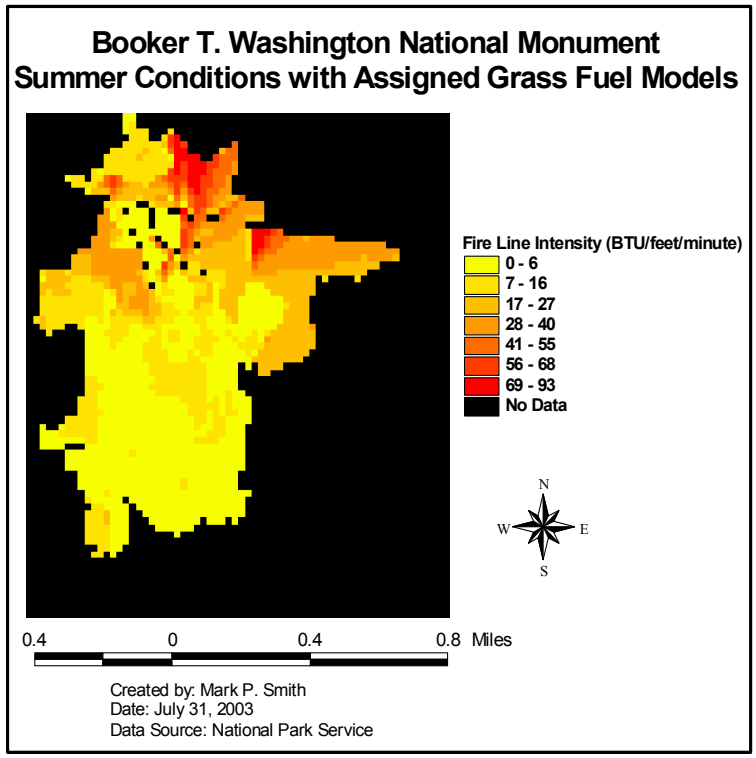


Figure 22 Summer assigned grass fuel models fire line intensity for BOWA

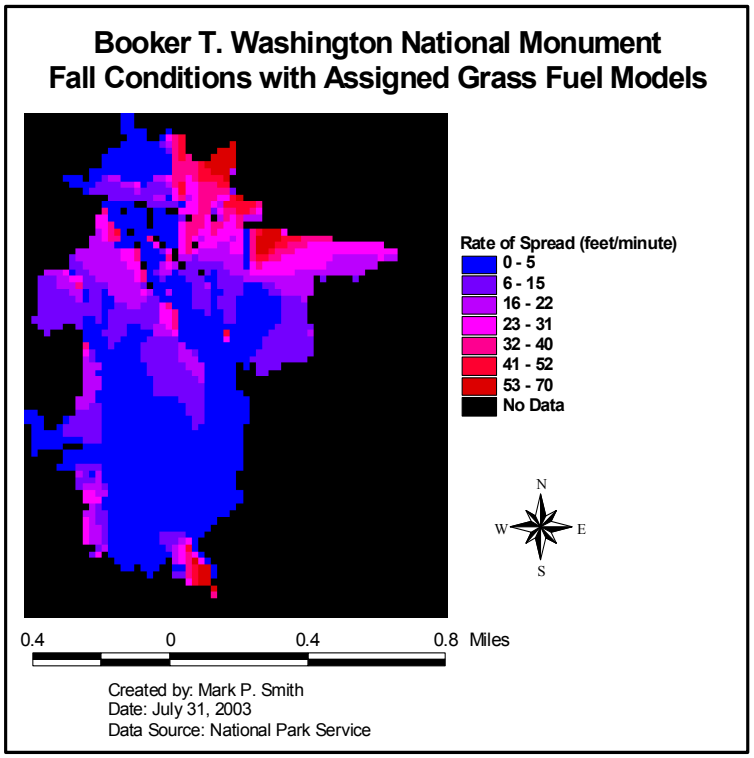


Figure 23. Fall assigned grass fuel models rate of spread for BOWA

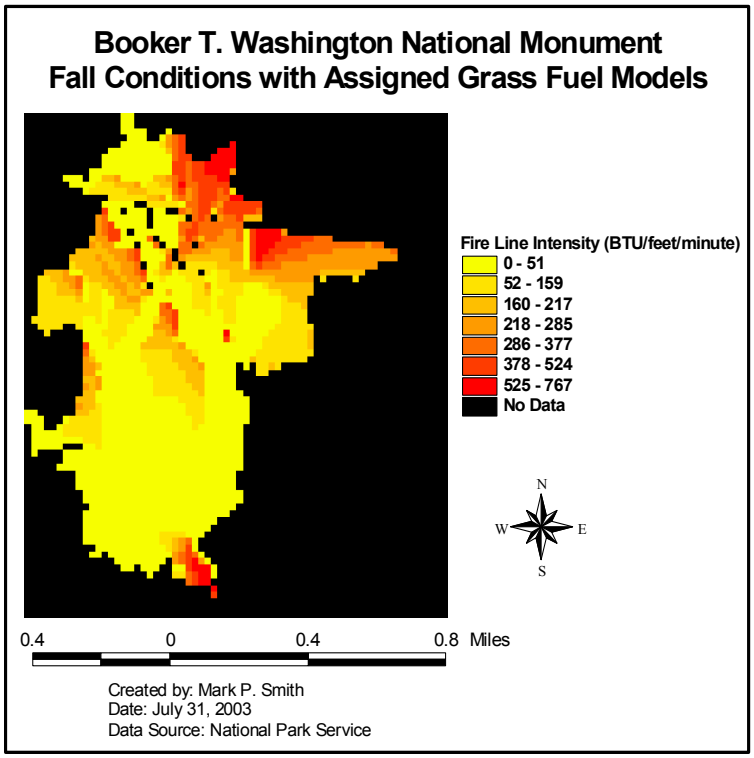


Figure 24 Fall assigned grass fuel models fire line intensity for BOWA

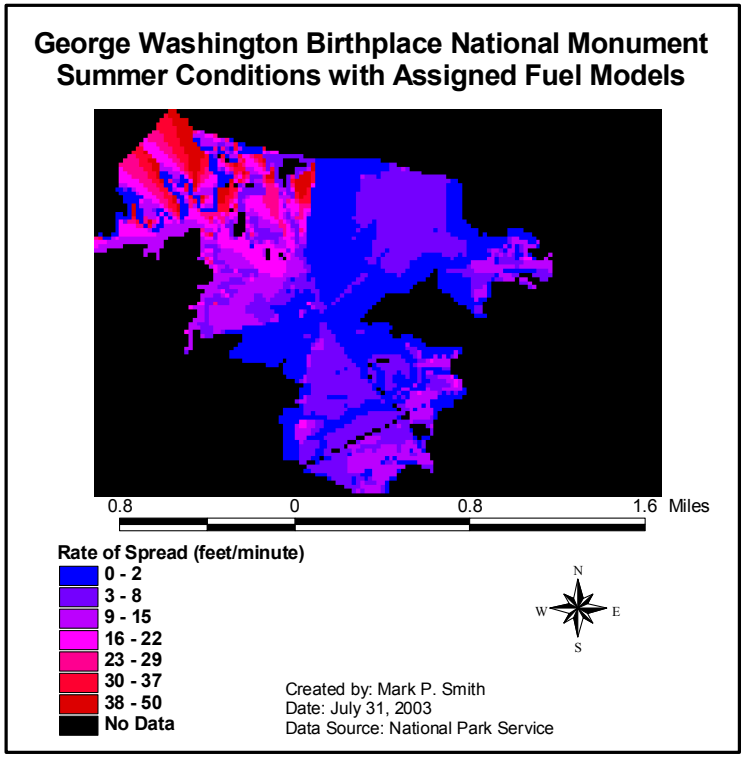


Figure 25. Summer assigned fuel models rate of spread for GEWA

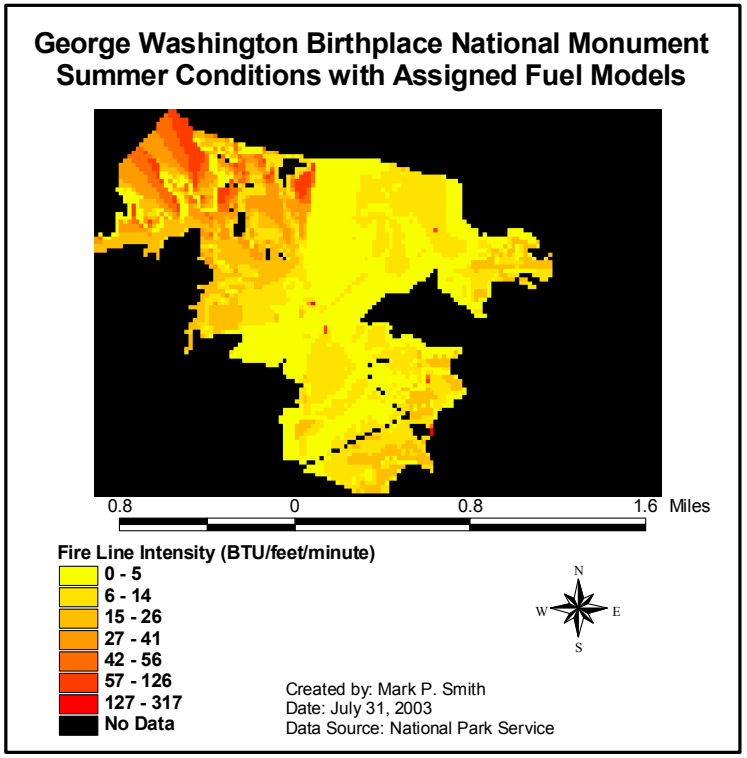


Figure 26. Summer assigned fuel models fire line intensity for GEWA

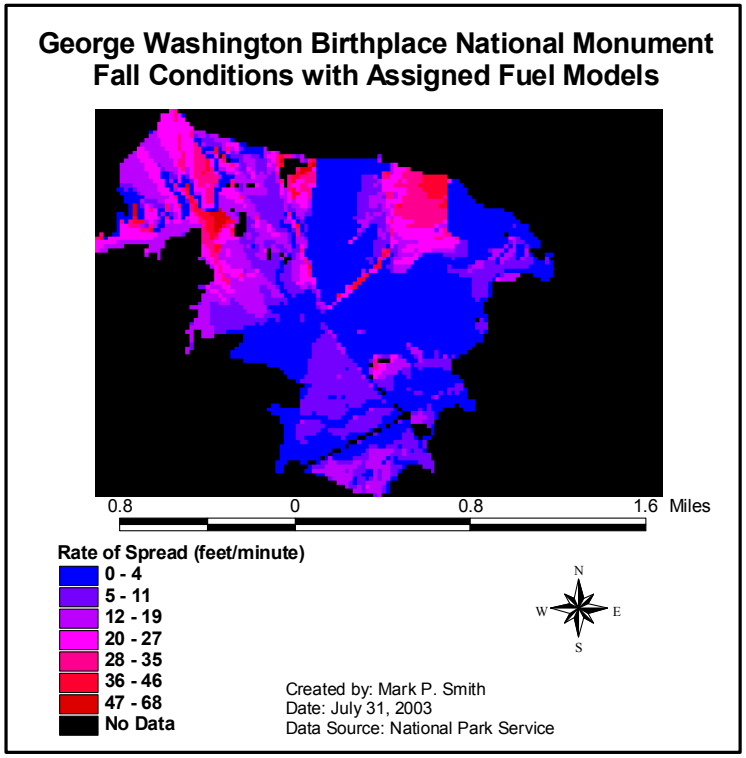


Figure 27. Fall assigned fuel models rate of spread for GEWA

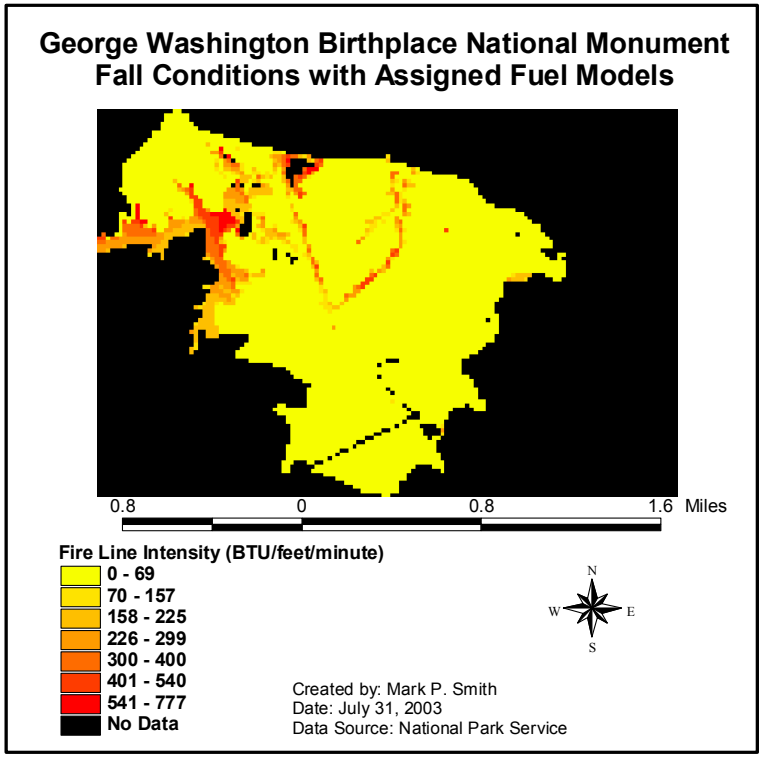


Figure 28. Fall assigned fuels model fire line intensity for GEWA

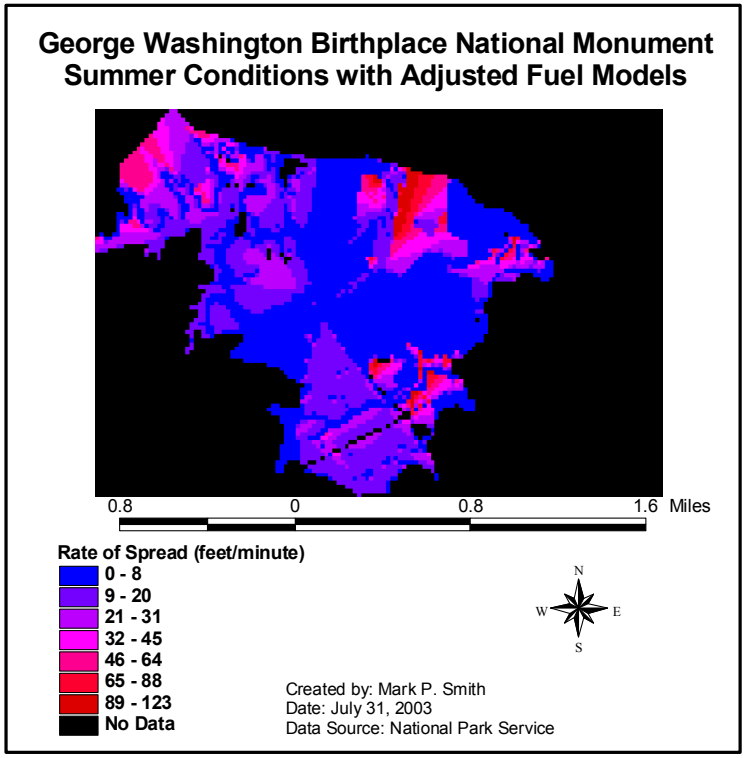


Figure 29. Summer adjusted fuel models rate of spread for GEWA

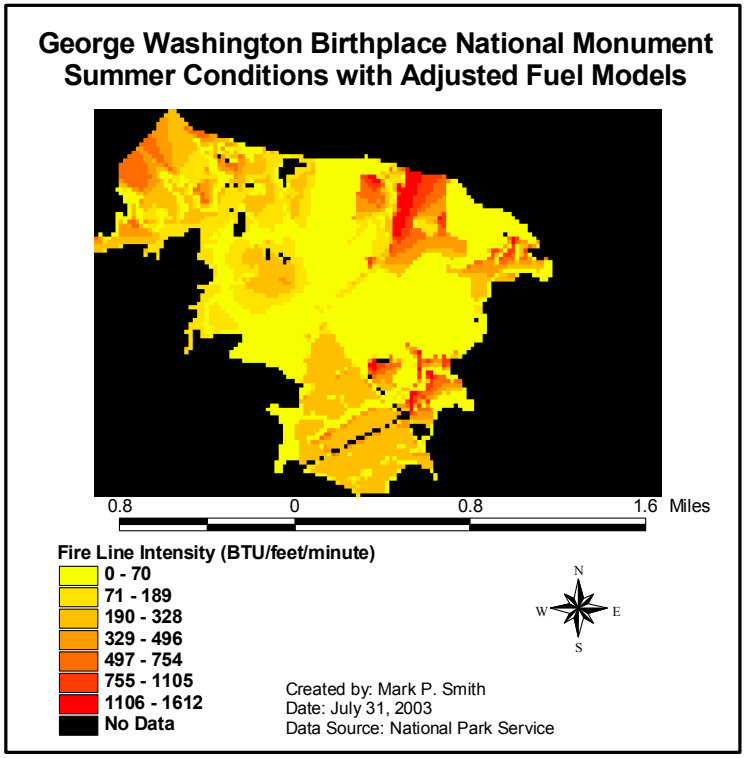


Figure 30. Summer adjusted fuel models fire line intensity for GEWA

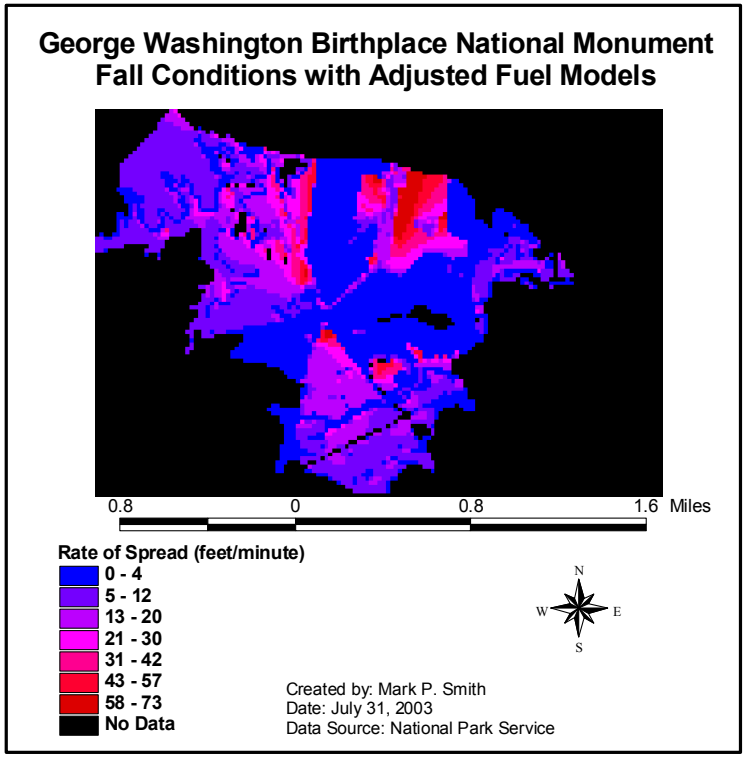


Figure 31. Fall adjusted fuel models rate of spread for GEWA

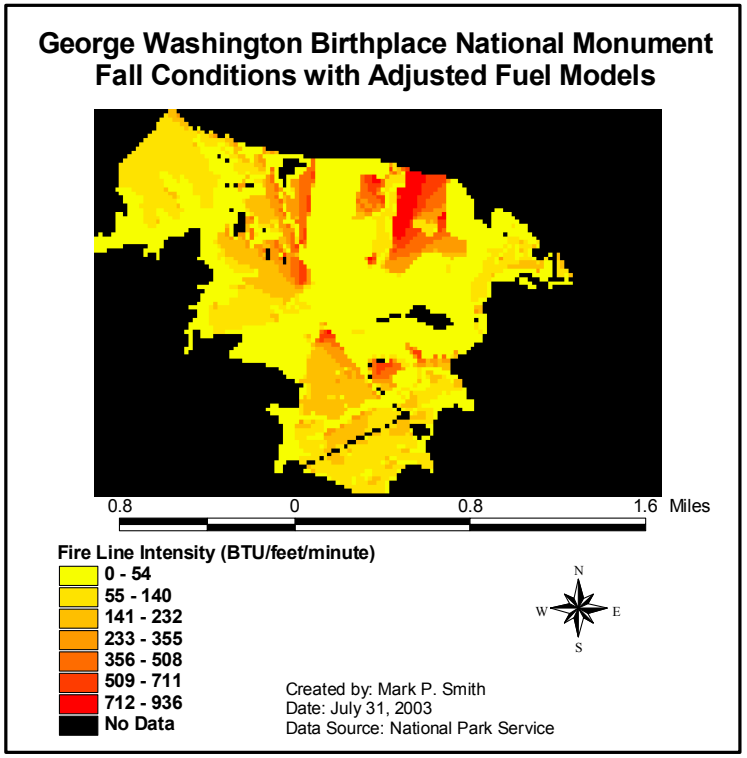


Figure 32. Fall adjusted fuel models fire line intensity for GEWA

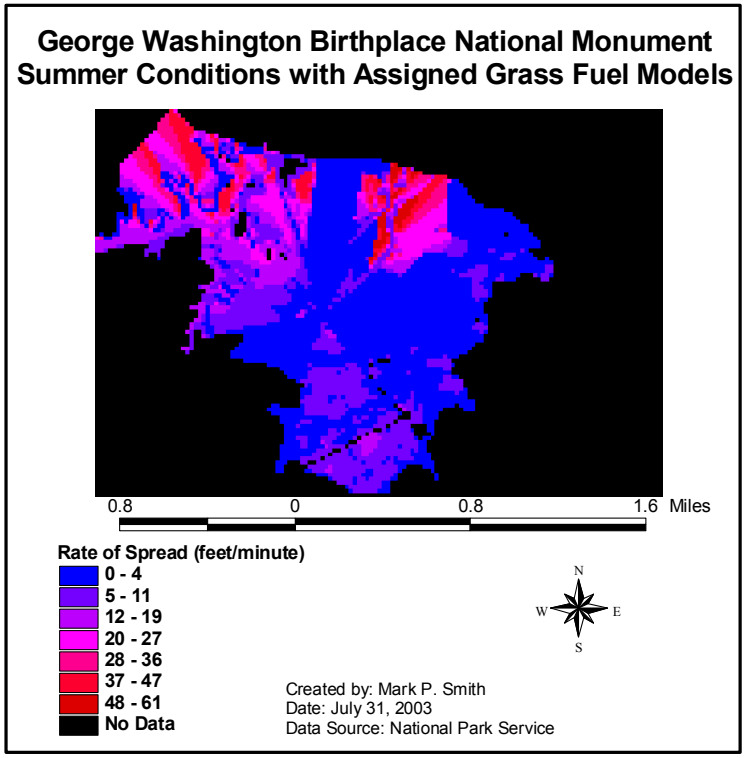


Figure 33. Summer assigned grass fuel models rate of spread for GEWA

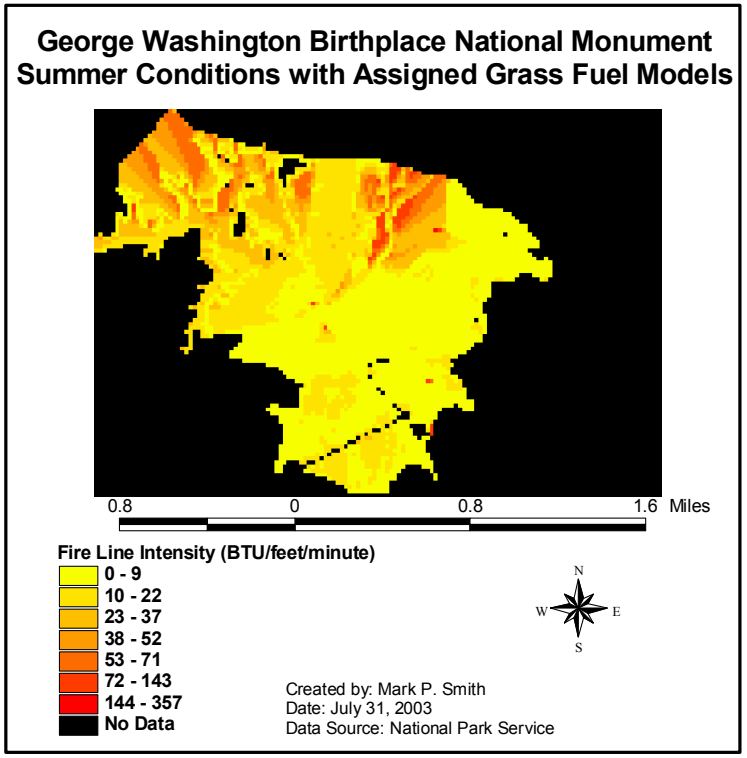


Figure 34. Summer assigned grass fuel models fire line intensity for GEWA

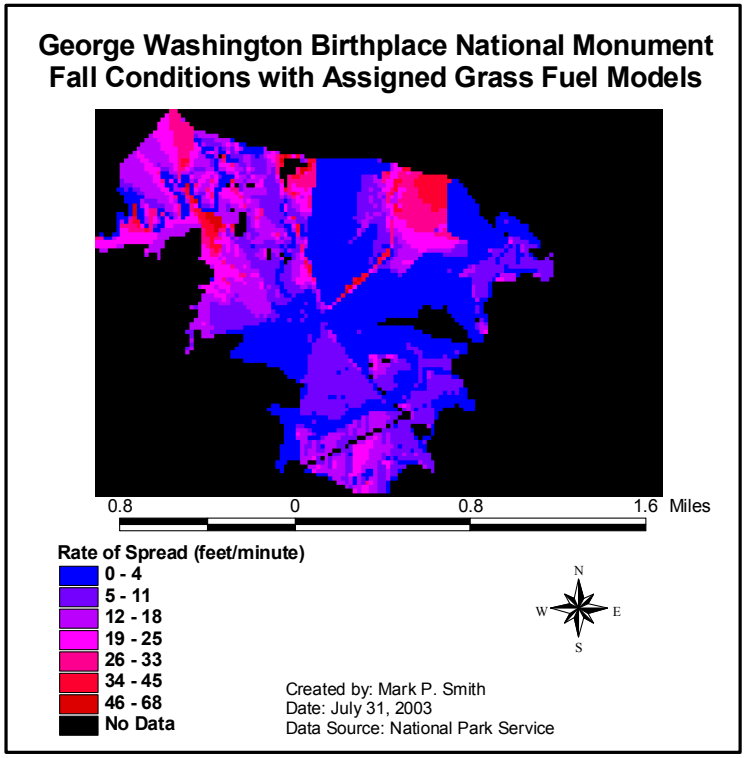


Figure 35. Fall assigned grass fuel models rate of spread for GEWA

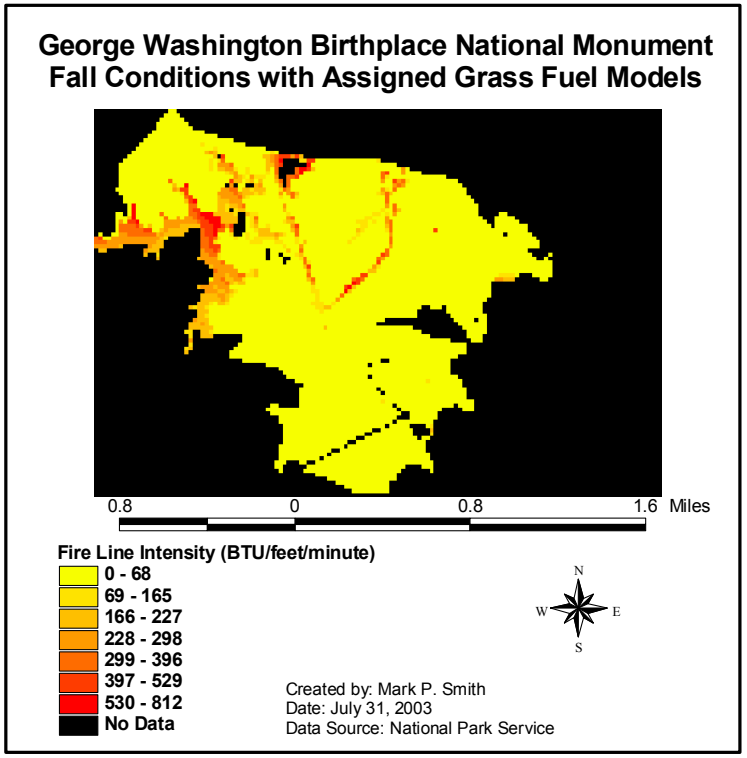


Figure 36. Fall assigned grass fuel models fire line intensity for GEWA

7. DISCUSSION

7.1 Creation of Orthoimage Mosaics

The orthorectified photo mosaic images created for this project allowed for accurate geographic coordinate information due to their high NMAS class level. The x and y direction for the fall mosaic for BOWA and the fall and spring mosaic for GEWA met the NMAS Class 1 map qualifications while the spring mosaic for BOWA meet the Class 1 map accuracy in the y direction and met the Class 2 map accuracy in the x direction.

The method previously used to create mosaics (Millinor 2000, Koch 2001) was different than the one used in this project. The prior method used digital orthorectified quarter quadrangles as a reference source in the orthorectification process. This method was time consuming and was prone to positional accuracy errors. Airborne GPS positions and IMUs were used as the reference source for the orthorectification process in this project. This resulted in lower RMSE in the x and y direction which created a highly accurate geographic coordinate mosaic image. The National Park Service can use the images for several different purposes including backdrops in a GIS format, maps for displays, and documenting cultural resources.

7.2 Vegetation Map Accuracy

The vegetation map created for BOWA had an initial accuracy of 60.94% and a final accuracy of 94.1% which meets the National Park Service accuracy standard of 80%. A total of 64 out of 68 polygons were visited in the field which allowed for higher vegetation accuracy in the final map. Misclassification of two formation types resulted in the lower

vegetation accuracy. The first formation was lowland or submontane cold-deciduous forest (I.B.2.N.a). Six polygons were mislabeled as temporarily flooded cold-deciduous forest (I.B.2.N.d) and three polygons were labeled as mixed needle-leaved evergreen – cold deciduous forest (I.C.3.N.a) when it should have been labeled as I.B.2.N.a.

The vegetation map created for GEWA had an initial accuracy of 73.0% and a final accuracy of 83.0%. The formation that contributed the most to the misclassification was the mixed evergreen deciduous forest (I.C.3.N.a). The remaining misclassification errors were due to differences in interpretation.

7.3 Fuel Loading Calculations

A total of 9 plots were sampled at BOWA and 28 plots were sampled at GEWA to estimate the amount of fuel loading in different vegetation found within each study area. The amount of fuel loading measured in the field was then calculated to provide an estimate for the amount of fuel loading for each plot.

In BOWA, 3 plots were located in rounded-crowned temperate or subpolar needle-leaved evergreen forest (I.A.8.N.b), 3 plots were located in lowland or submontane cold-deciduous forest (I.B.2.N.a), 1 in temporarily flooded cold-deciduous forest (I.B.2.N.d), and 2 in mixed needle-leaved evergreen – cold-deciduous forest (I.C.3.N.a). The average time required to collect the amount of fuel loading and record an ocular measurement using Burgan and Rothermel's sampling method is approximately one hour. A field day was considered successful if 6 or 7 plots were measured. The one-hour occupancy time does not

account for time needed to navigate and successfully locate other sampling plots. These factors limited the number of sampling points collected for each study area.

Using the information collected at the sample plots, I was able to able to achieve a direct correlation between fuel model and vegetation formation. It was unnecessary to calculate the number of sites needed estimate the amount of fuel loading for each formation. Future research could be applied to collecting additional sample points to assign fuel loading values based on formation.

7.4 FARSITE simulation

The simulations for both study areas used either RAWS data or a local weather observation weather station. Both stations recorded several important fire prediction factors such as fuel temperate and moisture along with maximum and minimum temperature. A problem that several national parks and other natural resource managed areas are facing is the lack of weather conditions within the park. There are currently four RAWS weather stations located in the state of Virginia along with some weather observations station. A few national parks like Shenandoah National Park and Fredericksburg/Spotsylvania National Military Park have local weather stations located inside the park. The weather and wind information used in the FARSITE simulation for GEWA was from a RAWS in the Blackwater National Wildlife Refuge near Cambridge, Maryland and the weather and wind information used for BOWA was from a weather observation station in Buena Vista, Virginia. These stations are relatively close to the two study areas but are not directly inside the areas which may result in unrecorded weather changes between the two areas.

The simulations for BOWA and GEWA using the assigned fuel models created a baseline to understand how fire would react in these areas during summer and fall conditions. The results between the summer and fall conditions showed that the maximum and average rate of spread and fire line intensity changed due to seasonal conditions.

The adjusted fuel model simulations showed that FARSITE was sensitive to the change in fuel models. The results for rate of spread and fire line intensity dramatically increased for summer conditions for BOWA and summer and fall conditions for GEWA. The results decreased between the two simulations for fall conditions for BOWA. The outputs maps for BOWA and GEWA showed that certain areas where grass formations were located had greater rates of spread and fire line intensity than the assigned fuel model simulations.

The final simulations showed that even when forested polygons were changed to a different fuel model, the outputs of rate of spread and fire line intensity did not show an obvious change. These results show that assigning the correct fuel model to grass is important for future simulations. Assigning fuel models to forested areas can be off by one fuel model without changing the results of rate of spread or fire line intensity. Problems develop when assigning fuel models to grass areas since each of the two study areas have different management practices in these areas. A common practice for grass areas is to mow selected fields in the park and then convert other fields to hayfields or agricultural fields. In order to properly predict how fire will react in these parks, fuel maps must be updated to reflect management practices for these areas.

8. CONCLUSION AND RECOMMENDATIONS

This project successfully created color infrared orthorectified photo mosaics with a spatial resolution of less than 0.25 meters from aerial photography flown at a scale of 1:6000. Based on the positional accuracy, the spring and fall mosaic for GEWA and the fall mosaic for BOWA meet the NMAS Class 1 map standard in the x and y direction and the spring mosaic for BOWA meets the Class 1 map accuracy in the y direction and Class 2 map accuracy in the x direction. The current method of using airborne GPS and IMU has improved the overall map accuracy from previous methods that used DOQQs as references for orthorectification. These mosaics will be an important component for natural resource management and fuel type mapping in the GIS database for each park.

The vegetation maps for BOWA and GEWA were created in a three-dimensional environment which detects changes in the topography of the both study areas. The overall accuracy for the BOWA vegetation map and the GEWA vegetation map meet the standards set by the National Park Service. Common misclassification errors occurred from a lack of knowledge of both study areas. The hydrological regime also created problems for each area since GEWA is tidally influenced and BOWA has some wet areas during certain parts of the year. The classification of mixed stands also caused problems for both areas due to classification differences between field assessment and computer classification. Future work in vegetation mapping should involve closer work with park personnel or people familiar with the area and the types of vegetation typically found there.

The variations in fuel models for the FARSITE simulations for both study areas demonstrated the importance of correctly identifying and assigning fuel models to grass

fields. Managers will need to maintain an updated database of how fields are managed in both areas. In working at both study areas, it was found that some areas were considered to be mowed fields one year and then converted to hayfields the next. This difference between management practices will effect how fuel models are assigned to these areas.

Future difficulties arise for classifying fuel models when forested areas have grass as an understory. A grass understory can develop as a result of prescribed burning or openings in the forest canopy. While prescribed burning will reduce the amount of fuel loading, grass will be introduced into the understory. These areas still should be burned in order to reduce downed woody debris and grass fuel loads. An increased frequency of prescribed fires would maintain the amount of grasses and thereby reduce the risk of large fires. Managers need to pay close attention to these areas in order to correctly classify what type of grass fuel model is present. Forested areas that have low grass fuel loading should be classified as a forested fuel model. When forested stands have heavy grass fuel loading and ladder fuels, managers should assign grass fuel models to these areas. Ladder fuels are sources that allow forest fires to "climb" to shrubs and trees taller than the initial fuel source for the fire.

Future work for estimating fuel models from vegetation formation should involve looking at areas classified as shrublands. Forests and grass fields dominated both study areas so the sensitivity of FARSITE to changes in shrubland fuel models should be examined. However, the results from my research show that grasses will play in an important role in assigning fuel models to these areas as well.

The results of these simulations are only snapshots in time for each area and conditions can change on a daily basis. Typically, fuel sources will change between the summer and fall

of the year due to curing allowing more fuel sources to become more susceptible to fire. Other conditions such as drought and flooding can affect how fires behave. To successfully simulate a fire, accurate local weather and wind conditions need to be used instead of using data that is similar to an area.

REFERENCES

Adobe, Inc. 2001. Adobe Photoshop 6.0 Reference Guide.

Albini, Frank A. 1976. Estimating wildfire behavior and effects. USDA Forest Service General Technical Report. INT-30. 92 pp. Intermountain Forest and Range Experiment Station, Ogden Utah.

Alvarez, Milagros 2003. Forest Fires in the US. Website accessed on Jul 24, 2003. http://www.safnet.org/policyandpress/forestfires7501.cfm.

Andersen, Hal.E. 1982. Aids to Determining Fuel Models for Estimating Fire Behavior, USDA Forest Service General Technical Report INT-122. 22 pp. Intermountain Forest and Range Experiment Station, Ogden Utah.

Andrews, P.L. 1986. BEHAVE: Fire behavior prediction and fuel modeling system- BURN subsystem, part 1, General Technical Report. INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 130 pp.

Andrews, P. L. and C. D. Bevins. 1998. Update and Expansion of the BEHAVE Fire Behavior Prediction System. Fire Management Notes

Avery, T.E. and G.L. Berlin. 1992. Fundamentals of Remote Sensing and Airphoto Interpretation, Fifth Edition. Macmillan Publishing Company. New York.

Bailey, M., C. Convis, A. Curtis, F. Davis, M. Goodchild, K. Goodin, D. Grossman, X. Li, M. Stadelmann, and R. Vaughan. 1994. USGS-NPS Vegetation Mapping Program: Standardized National Vegetation Classification System. http://biology.usgs.gov/npsveg/classification/index.html.

Brown, James K. 1974. Handbook for inventorying downed woody material. USDA Forest Service General Technical Report INT-16. 24 pp.

Burgan, R. E. 1988. *1988* Revisions to the 1978 National Fire-Danger Rating System. USDA Forest Service, Southeastern Forest Experiment Station, Research Paper SE-273, Asheville, North Carolina. 39 pp.

Carlton, Don. 2001. User's Guide: BehavePlus Fire Modeling System version 1.00.00.

Carmichael, Becky J. and W. Cass. 2001. Vegetation Fuel Mapping Protocol. SHEN-N-021.001. Assessment of Vegetation Communities.

Deeming, J. E., J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M.J. Schroeder. 1972. The National Fire-Danger Rating System. USDA Forest Service, Rocky Mountain Forest and

Range Experiment Station, Research Paper RM-84, Ft. Collins, Colorado. 165 pp. Revised 1974.

Deeming, J. E., R. E. Burgan, and J. D. Cohen. 1977. The National Fire-Danger Rating System –1978. USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-39, Ogden, Utah. 63 pp.

ERDA, Inc. 2001. Imagine Orthobase 8.5 User's Guide. ERDAS, Inc. Atlanta, GA.

Etlinger, Matt, Jim Robins, Terence Philippe, Celine Dutilly. 1999. Claremont Canyon Study: Threatened Alameda Whipsnake and Fire Danger for the University of California, Berkeley Planning Department and The East Bay Regional Parks District. Prepared for: LA221 Quantitative Methods in Environmental Planning. http://www-laep.ced.berkeley.edu/classes/la221/

Federal Register 2001. Urban Wildland Interface Communities Within the Vicinity of Federal Lands That Area at High Risk From Wildfire. Federal Register, Vol. 66, No. 3. Thursday, January 4, 2001.

FGDC. 1998. Geospatial Positioning Accuracy Standards- Part 3: National Standard for Spatial Data Accuracy. Federal Geographic Data Committee. Washington, D.C.

FIREWISE 2003. 2002 Wildland Fire Season Summary. Website access on July 24, 2003. http://www.nifc.gov/information.html

Finney, Mark A. (1998) FARSITE: fire area simulator—model development and valuation. USDA Forest Service Research Paper RMRS-RP-4. Ogden, UT. 47 pp.

Finney, Mark A. Phone conversation. March 28, 2003.

FOFEM website viewed on 5/19/2003: http://www.firelab.org/fep/research/sufm/studyplan/fofemtxt.htm

Keane, Robert E.; Mincemoyer, Scott A.; Schmidt, Kirsten M.; Long, Donald G.; Garner, Janice L. 2000. Mapping vegetation and fuels for fire management on the Gila National Forest Complex, New Mexico, [CD-ROM]. Gen. Tech. Rep. RMRS-GTR-46-CD. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 126 pp.

Keifer, M., N. L. Stephenson, and J. Manley. 2000. Prescribed fire as the minimum tool for wilderness forest and fire regime restoration: a case study from the Sierra Nevada, California. Pages 266-269 *In* D. N. Cole, S. F. McCool, W. T. Borrie, and J. O'Loughlin, compilers. Wilderness Science in a Time of Change Conference -- Volume 5: Wilderness Ecosystems,

Threats, and Management. Proceedings RMRS-P-15-VOL-5. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Kneipp, Greg. Phone Conversation. June 12, 2003.

Koch, Frank Henry, Jr. 2001. A comparison of digital vegetation mapping and image orthorectification methods using aerial photography of Valley Forge National Historical Park. Master's Thesis, North Carolina State University.

Mattson, D., F. Thoren, 2002, Wildland/urban interface and communities at risk, joint fire modeling project, Bureau of Land Management, Upper Snake River District GIS, and Idaho State University GIS Training and Research Center, *ISU GIS Center Research Report* .

Merchant, D.C. 1985. Accuracy specification for large scale maps. Photogrammetric Engineering and Remote Sensing. 51(2): 195-199.

Menning, Kurt, Tracy Benning, John Battles, and Nathan L. Stephenson. 1998. Mineral King Risk Reduction Project- 1998 Annual Report.

Millinor, William A. 2000. Digital vegetation delineation on scanned orthorectified aerial photography of Petersburg National Battlefield. Master's Thesis, North Carolina State University.

National Park Service (NPS). 1995. Booker T. Washington National Monument visitor guide. http://www.nps.gov/bowa/index.htm.

National Park Service (NPS). 2001. George Washington Birthplace National Monument visitor guide. http://www.nps.gov/gewa/index.htm.

Oswald, Brian P., John T. Fancher, David L. Kulhavy, and Hershel C. Reeves. 1999. Classifying fuels with aerial photography in East Texas. International Journal of Wildland Fire 9(2): 109-113.

Radke, John. 1995. A spatial decision support system for urban/wildland interface fire hazards. ESRI conference paper available at http://www.esri.com/library/userconf/proc95/to200/p175.html.

Raeburn, Doug. Phone Conversation. March 19, 2003.

Reinhardt, Elizabeth D., Robert E. Keane, and James K. Brown. 1998. FOFEM: A First Order Fire Effects Model. Fire Management Notes 58 (2) 25-27.

Rothermel, R.C. 1972. A mathematical model for predicting fire spread in wildland fuels. Gen. Tech. Rep. INT–115. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 40 pp.

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the Northern Rocky Mountains. Gen. Tech. Rep. INT–438. Ogden, UT: USDA Forest Service, Intermountain Research Station. 46 pp.

Rouse, Cary and Donna Paananen. 1988. A quick method to determine northeastern woody fuel weights. Fire Management Notes 49(2), 23-24.

Reeves, Hershel C. 1988. Photo Guide for Appraising Surface Fuels in East Texas: grasses, clear-cur, seed tree, loblolly pine, shortleaf pine, loblolly/shortleaf pine, slash pine, longleaf pine, and hardwood. Center for Applied Studies, School of Forestry, Stephen F. Austin State University, Nacogdoches, Texas.

Schlobohm, Paul and Jim Brain. 2001. Gaining an understanding of the National Fire Danger Rating System, National Wildfire Coordinating Group, Fire Danger Working Team, PMS 932, NFES 2665, Boise, Idaho

Scott, Kelly, Brian Oswald, Kenneth Farrish, and Daniel Unger. 2002. Fuel loading prediction models developed from aerial photographs of the Sanger de Cristo and Jemez mountains of New Mexico, USA. International Journal of Wildland Fire, 2002, 11, 85-90.

Scott, Joe H. 1999. NEXUS: A system for assessing crown fire hazard. Fire Management Notes 59 (2):20-24

Stuart-Smith, Kari, Ian T. Adams, and Karl W. Larsen. 2002. Songbird communities in a pyrogenic habitat mosaic. International Journal of Wildland Fire, 2002, 11, 75-84.

Troy, Austin, David Ganz, Mu Lan, Tao Duan. 1998. Group project: Fire risk mitigation in Strawberry Canyon. Prepared for: LA221 Quantitative Methods in Environmental Planning. Access at http://www-laep.ced.berkeley.edu/classes/radke_materials/materials/221-98hi/la221-ay/start.html.

USDI National Park Service. 2001. Fire Monitoring Handbook. Boise (ID): National Interagency Fire Center. 274 pp.

US Fish and Wildlife Service. 1999. South Florida multi-species recovery plan. Atlanta, Georgia. 2172 pp.

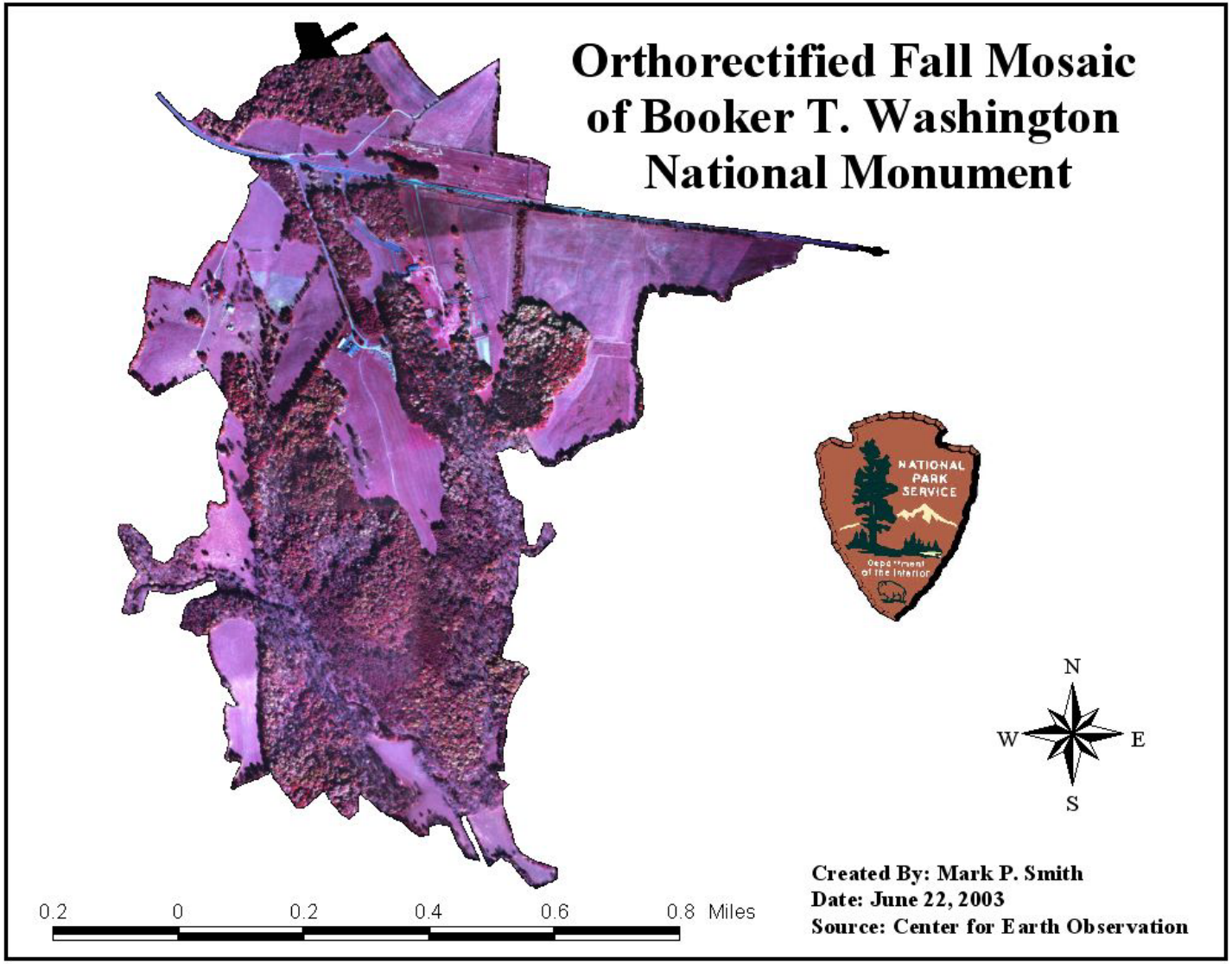
USGS. Unknown. USGS – NPS Vegetation Mapping Program. http://biology.usgs.gov/npsveg (viewed March, 2003).

van Wagtendonk, J.W., K.A. van Wagtendonk, J.B. Meyer, and K. Paintner. 2002. The Use of Geographic Information for Fire Management Planning in Yosemite National Park. The George Wright Forum 19:1, 19-39.

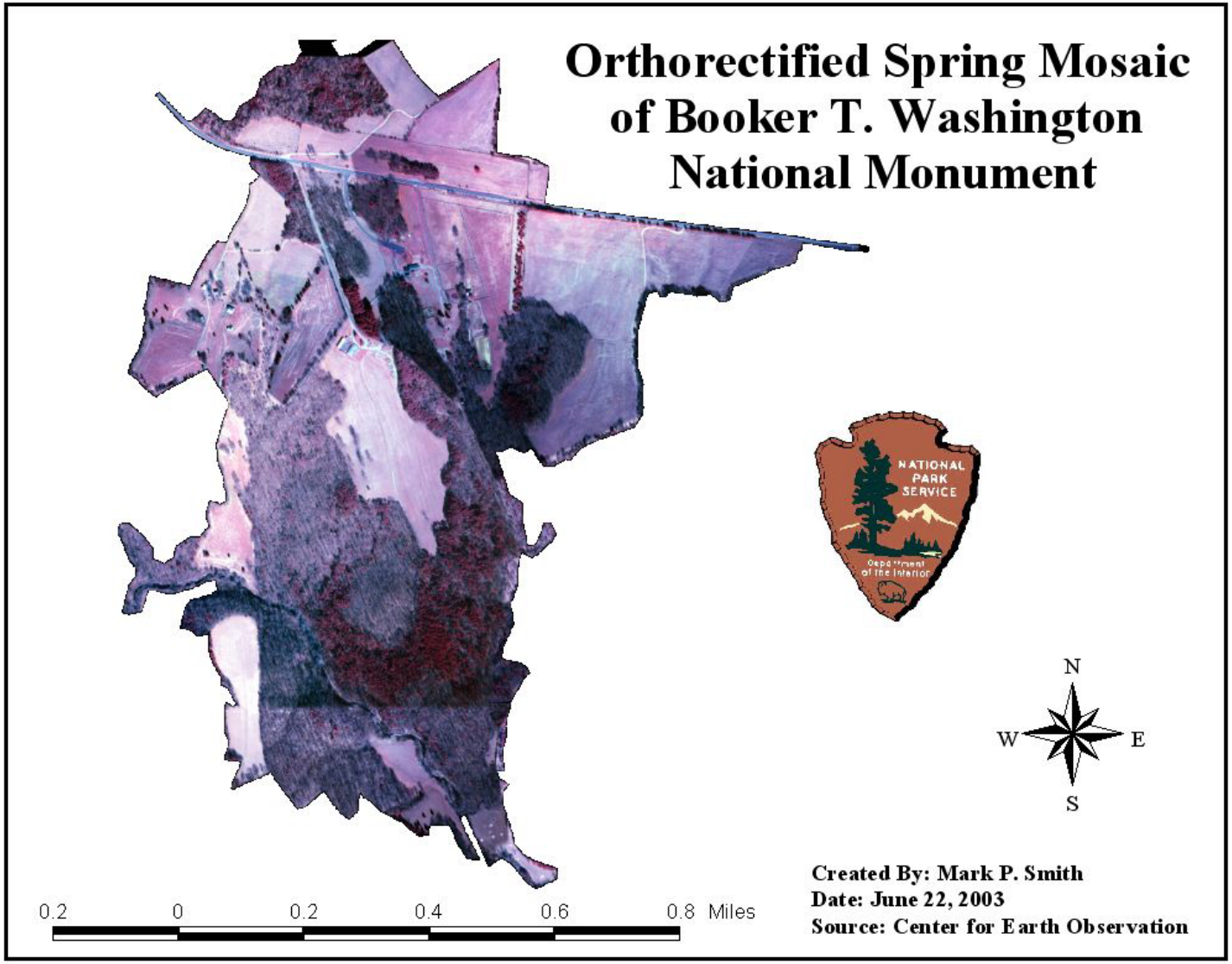
Weakley, A. W., K. D. Patterson, S. Landaal, M. Pyne, and others (compilers). 1998. International classification of ecological communities: Terrestrial Vegetation of the Southeastern United States. Working Draft of September 1998. The Nature Conservancy, Southeastern Conservation Science Department, Community Ecology Group. Chapel Hill, North Carolina.

National Wildland Urban Interface Fire Program. 2001. FIREWISE COMMUNITIES Workbook. Quincy (MA): Firewise Communities. 29 pp.

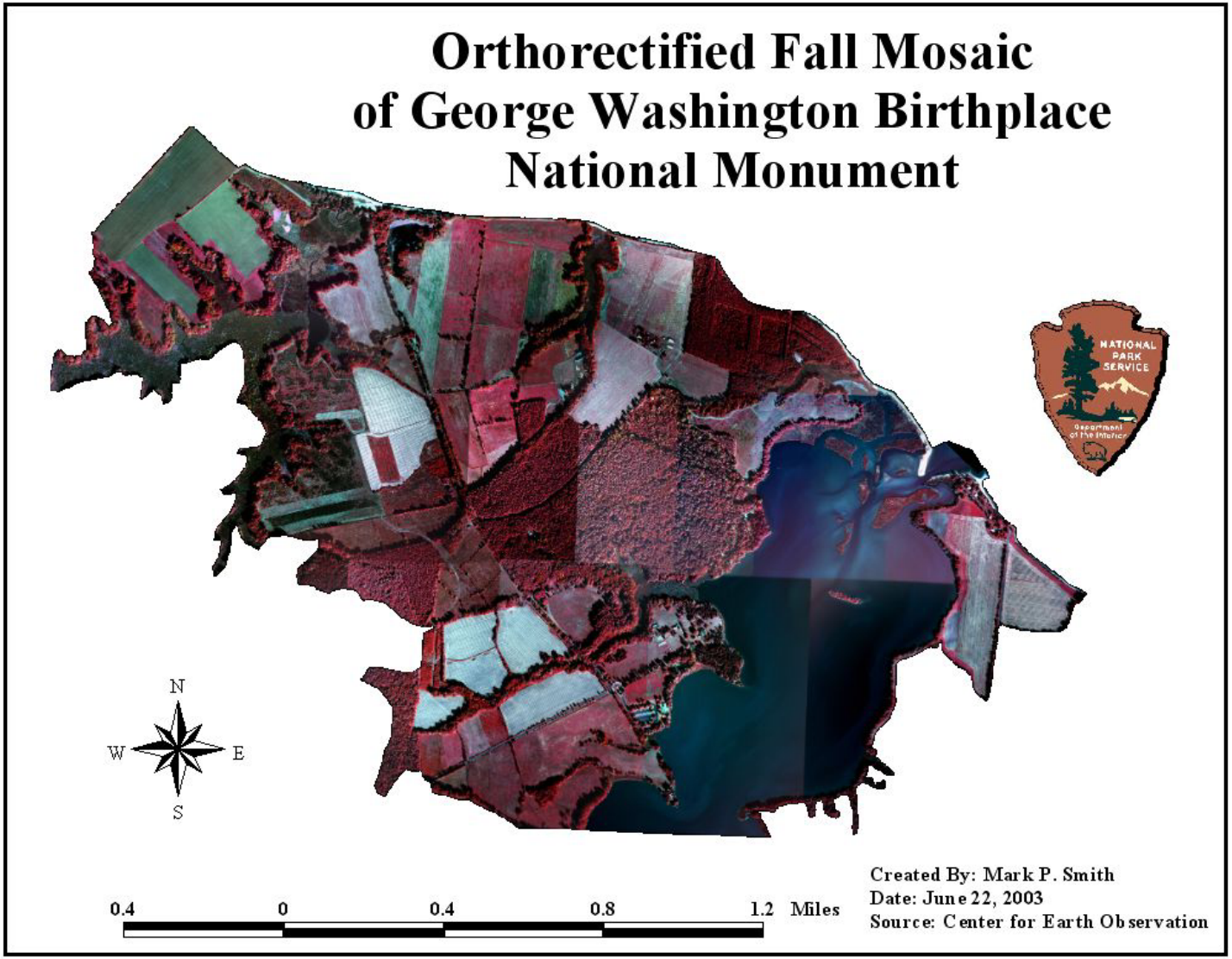
APPENDIX A. FALL MOSAIC OF BOOKER T. WASHINGTON NATIONAL MONUMENT



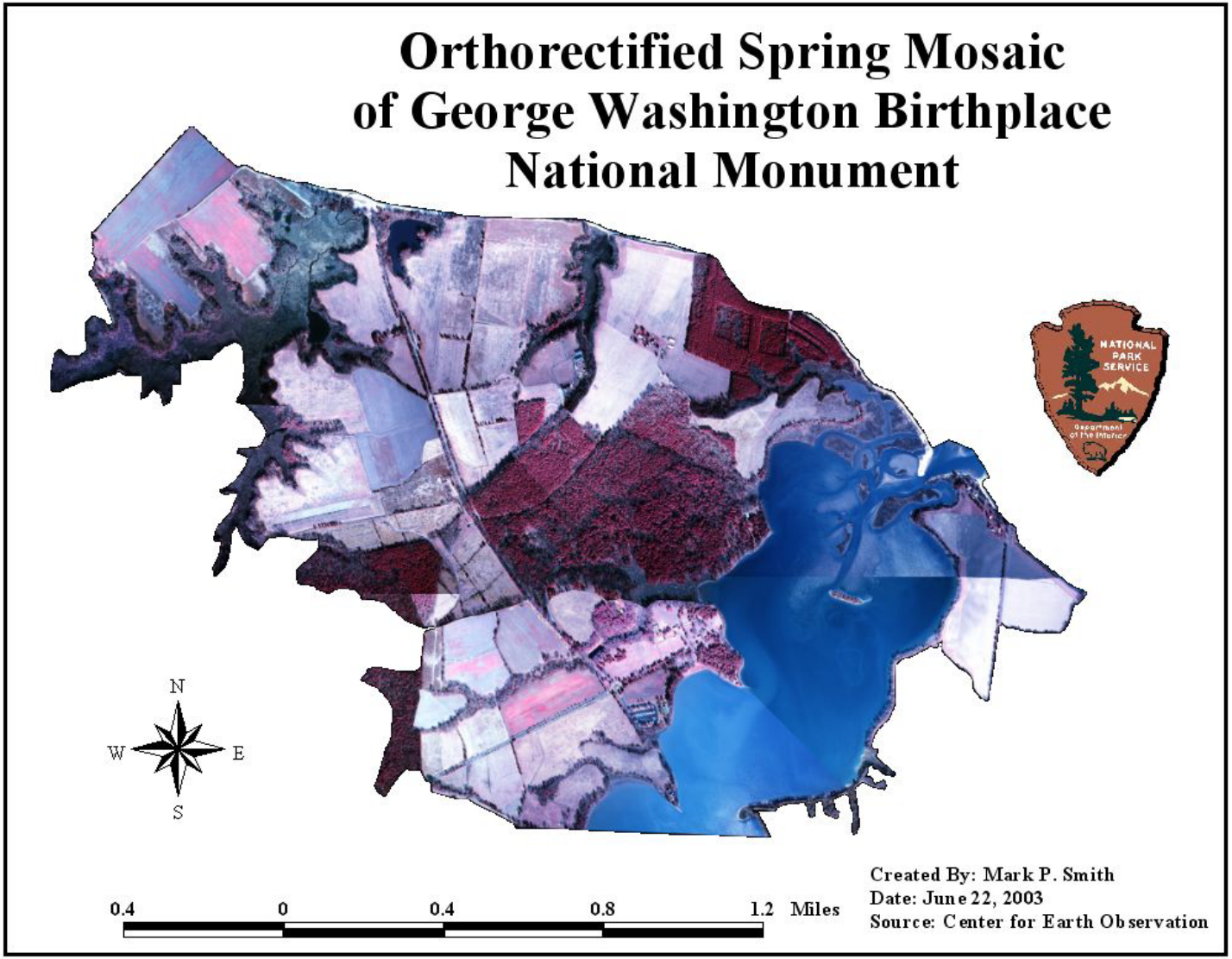
APPENDIX B. SPRING MOSAIC FOR BOOKER T. WASHINGTON NATIONAL MONUMENT



APPENDIX C. FALL MOSAIC OF GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT



APPENDIX D. SPRING MOSAIC FOR GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT

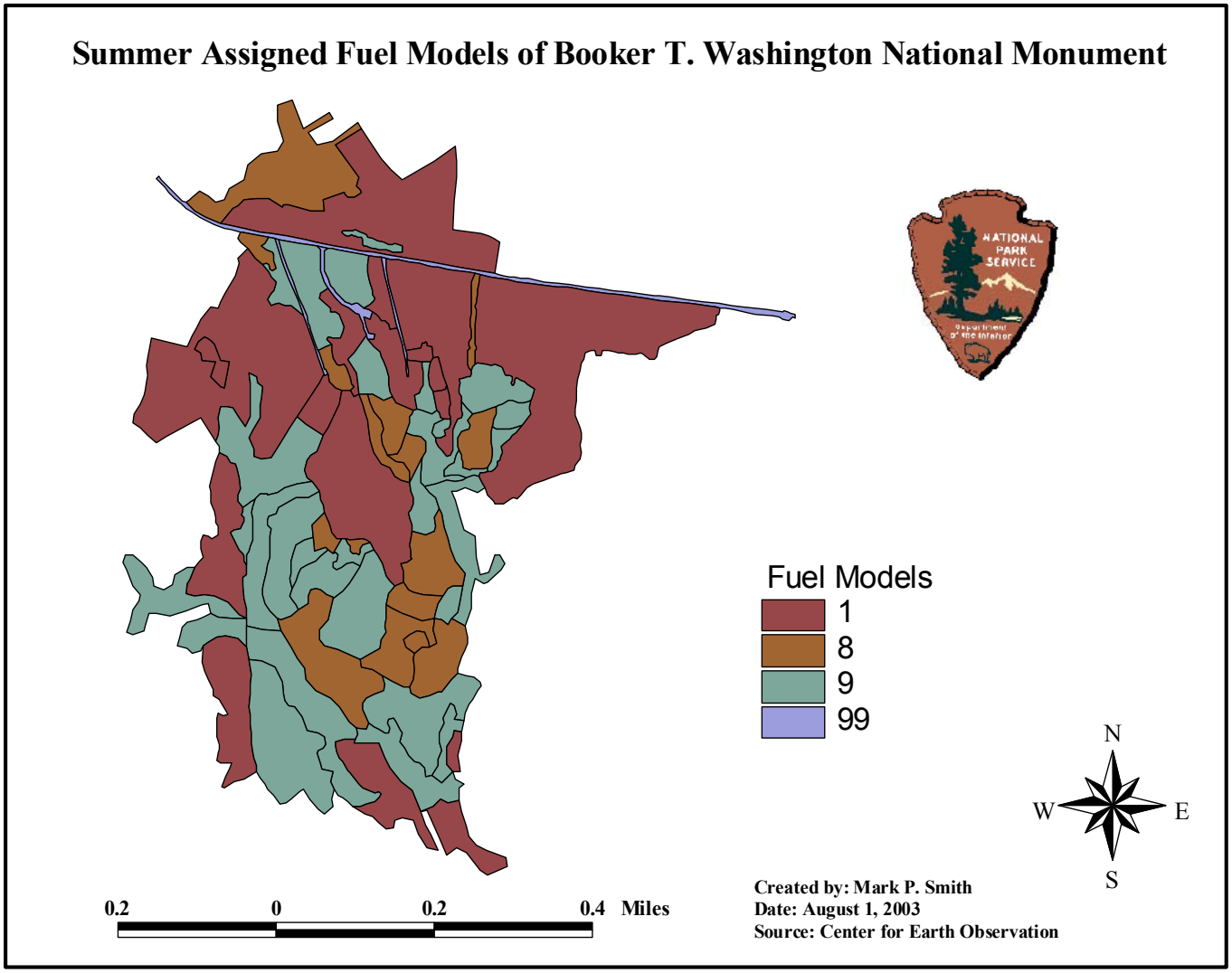


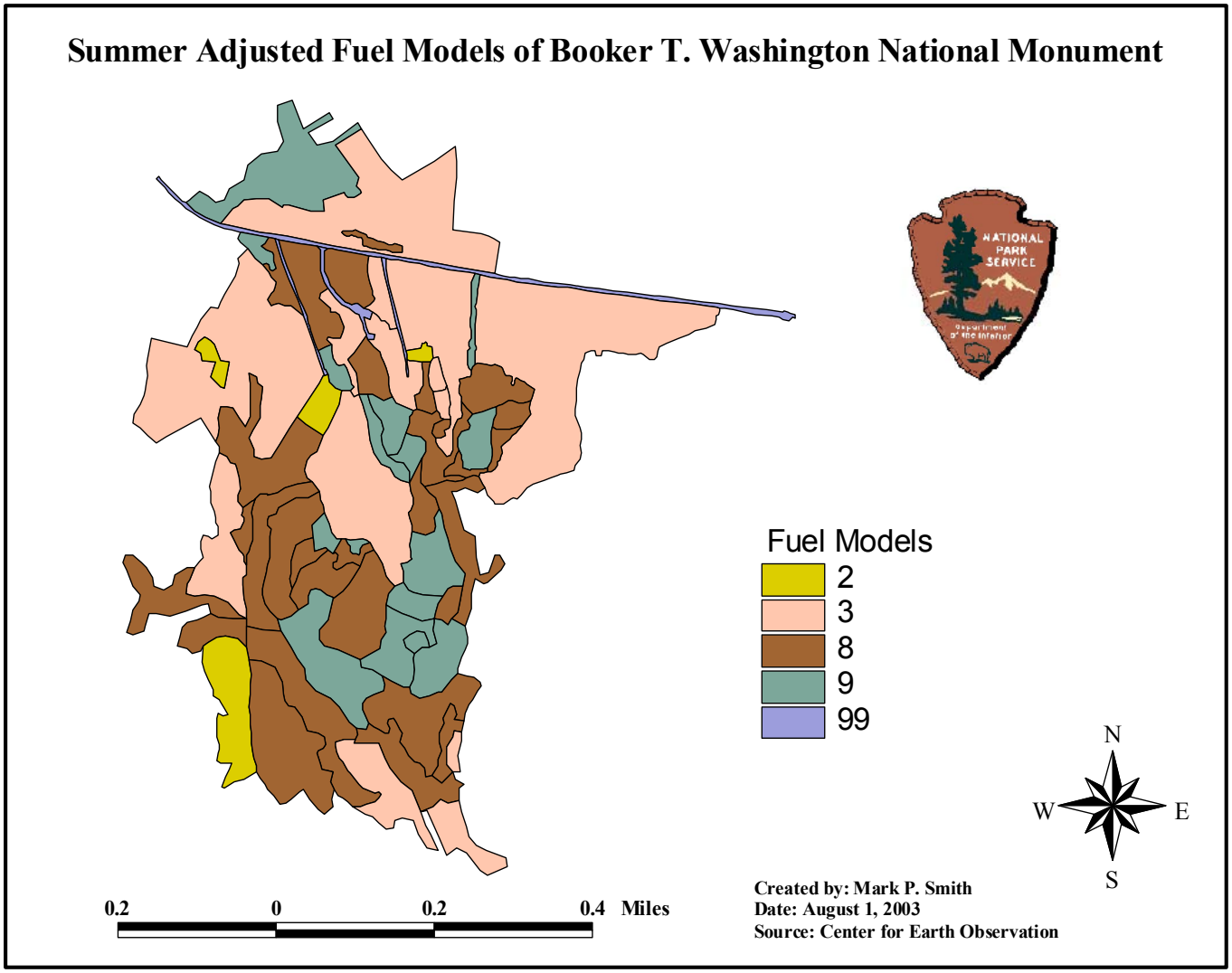
APPENDIX E. POTENTIAL FORMATION CLASSES FOR STUDY AREAS

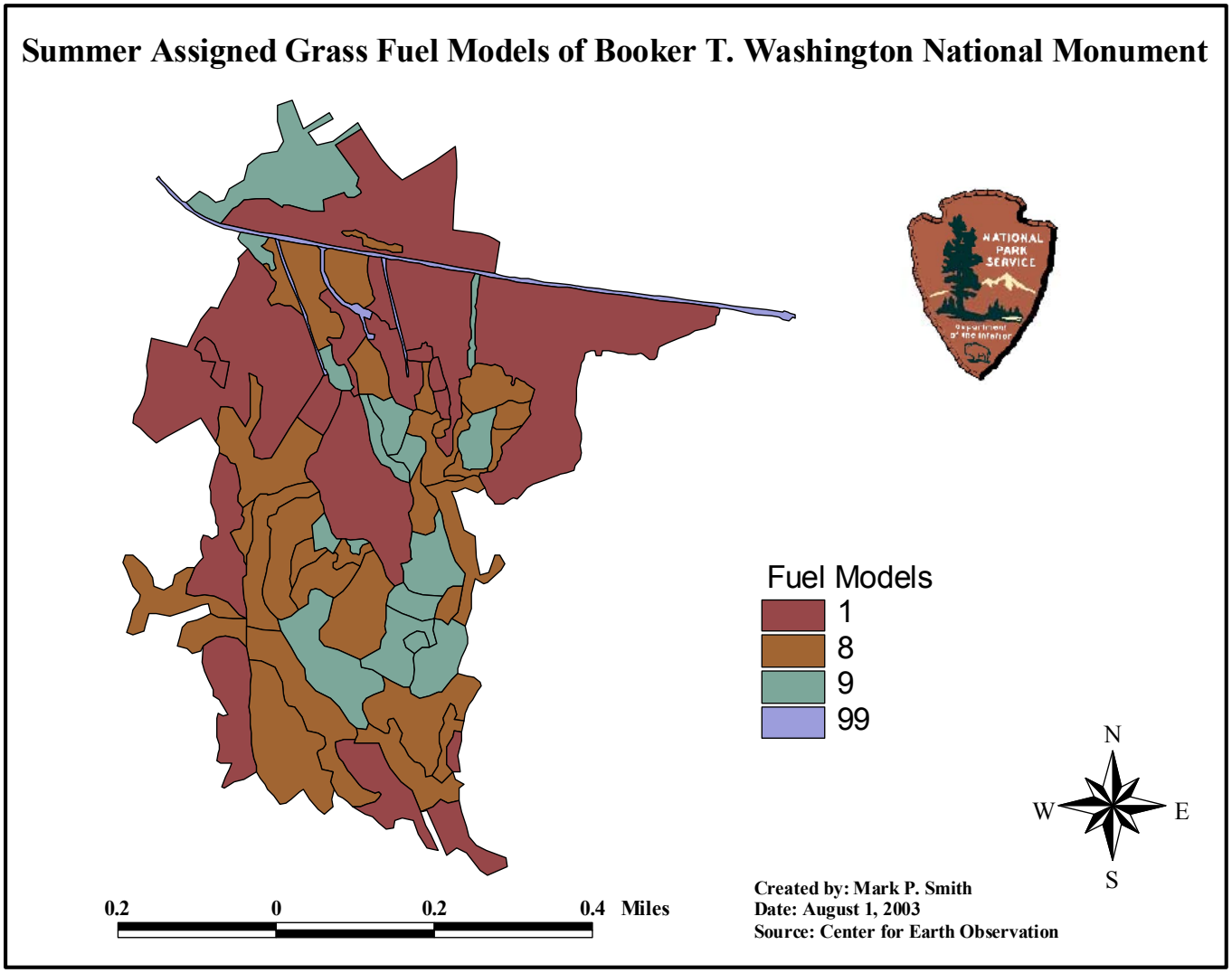
Formation Code	Formation Name
I.A.8.C.x	Planted/cultivated temperate or subpolar needle-leaved evergreen forest
I.A.8.N.b	Round-crowned temperate or subpolar needle-leaved evergreen forest
I.A.8.N.c	Conical- crowned temperate or subpolar needle-leaved evergreen forest
I.B.2.N.a	Lowland or submontane cold-deciduous forest
I.B.2.N.d	Temporarily flooded cold-deciduous forest
I.B.2.N.e	Seasonally flooded cold - deciduous forest
I.B.2.N.g	Saturated cold-deciduous forest
I.C.3.N.a	Mixed needle-leaved evergreen – cold-deciduous forest
I.C.3.N.b	Temporarily flooded mixed needle-leaved evergreen – cold - deciduous forest
I.C.3.N.d	Saturated mixed needle-leaved evergreen – cold - deciduous forest
II.B.2.N.a	Cold-deciduous woodland
III.A.2.N.a	Temperate broad-leaved evergreen shrubland
III.A.2.N.f	Tree layer
III.A.2.N.g	Temporarily flooded temperate broad-leaved evergreen shrubland
III.B.2.N.a	Temperate cold-deciduous shrubland
III.B.2.N.d	Temporarily flooded cold-deciduous shrubland
III.B.2.N.f	Semi-permanently flooded cold-deciduous shrubland
V.A.5.N.c	Medium-tall sod temperate or subpolar grassland
V.A.5.N.k	Seasonally flooded temperate or subpolar grassland
V.A.5.N.l	Semi-permanently flooded temperate or subpolar grassland
V.A.5.N.n	Tidal temperate or subpolar grassland
V.B.2.N.d	Temporarily flooded temperate perennial forb vegetation
V.B.2.N.e	Semi-permanently flooded temperate perennial forb vegetation
V.B.2.N.g	Tidal temperate perennial forb vegetation
V.C.2.N.a	Permanently flooded temperate or subpolar hydromorphic rooted vegetation
V.D.2.N.g	Seasonally flooded temperate annual grassland
Ag and Cultivated 2	Distinguishable agricultural areas
Developed Coniferous 1.1.2	Area with sign of human habitation and more than 80% basal area in *Pinus* spp.
Developed Deciduous 1.1.1	Area with sign of human habitation and less than 20% basal area in *Pinus* spp.
Developed Mixed 1.1.3	Area with sign of human habitation and 21% to 79% basal area in *Pinus* spp.

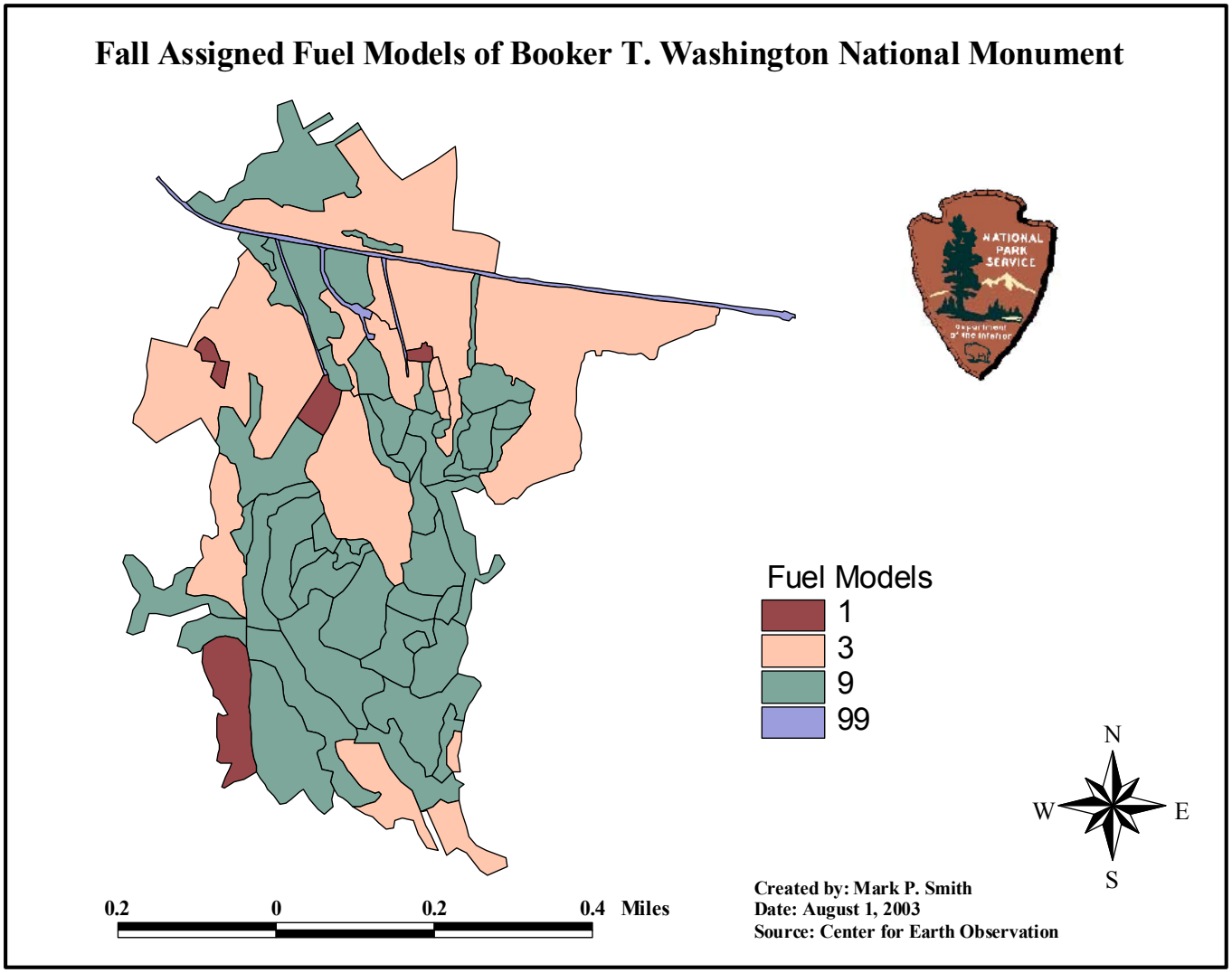
Developed Open Land 1.2	Area with sign of human habitation and less than 10% canopy closure
Recreational Facilities 1.3	Area with sign of human habitation and identifiable recreation areas i.e. playing fields
Transitional Land 5.3	Area undergoing development or construction

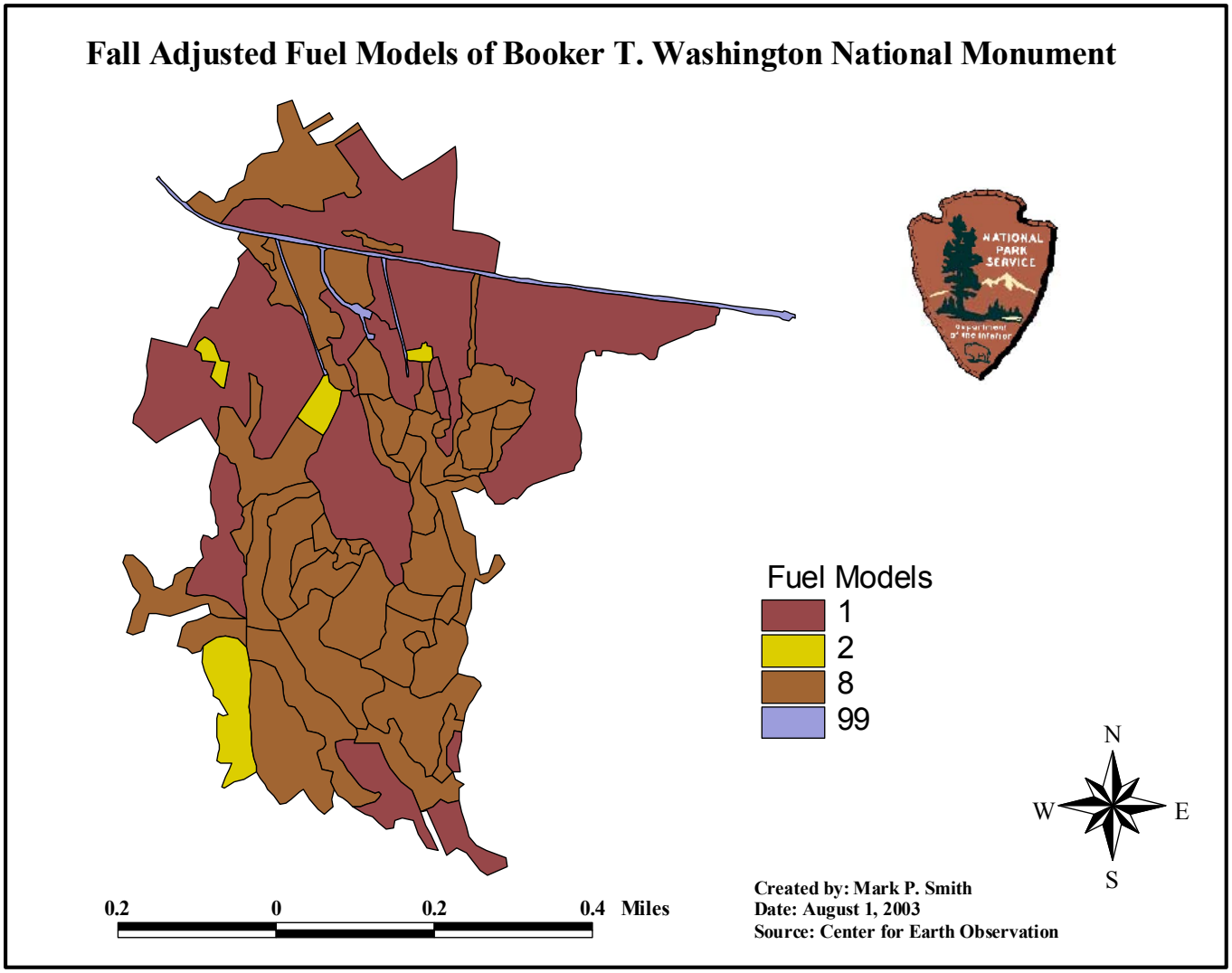
APPENDIX F. FUEL MODEL MAPS FOR BOOKER T. WASHINGTON NATIONAL MONUMENT

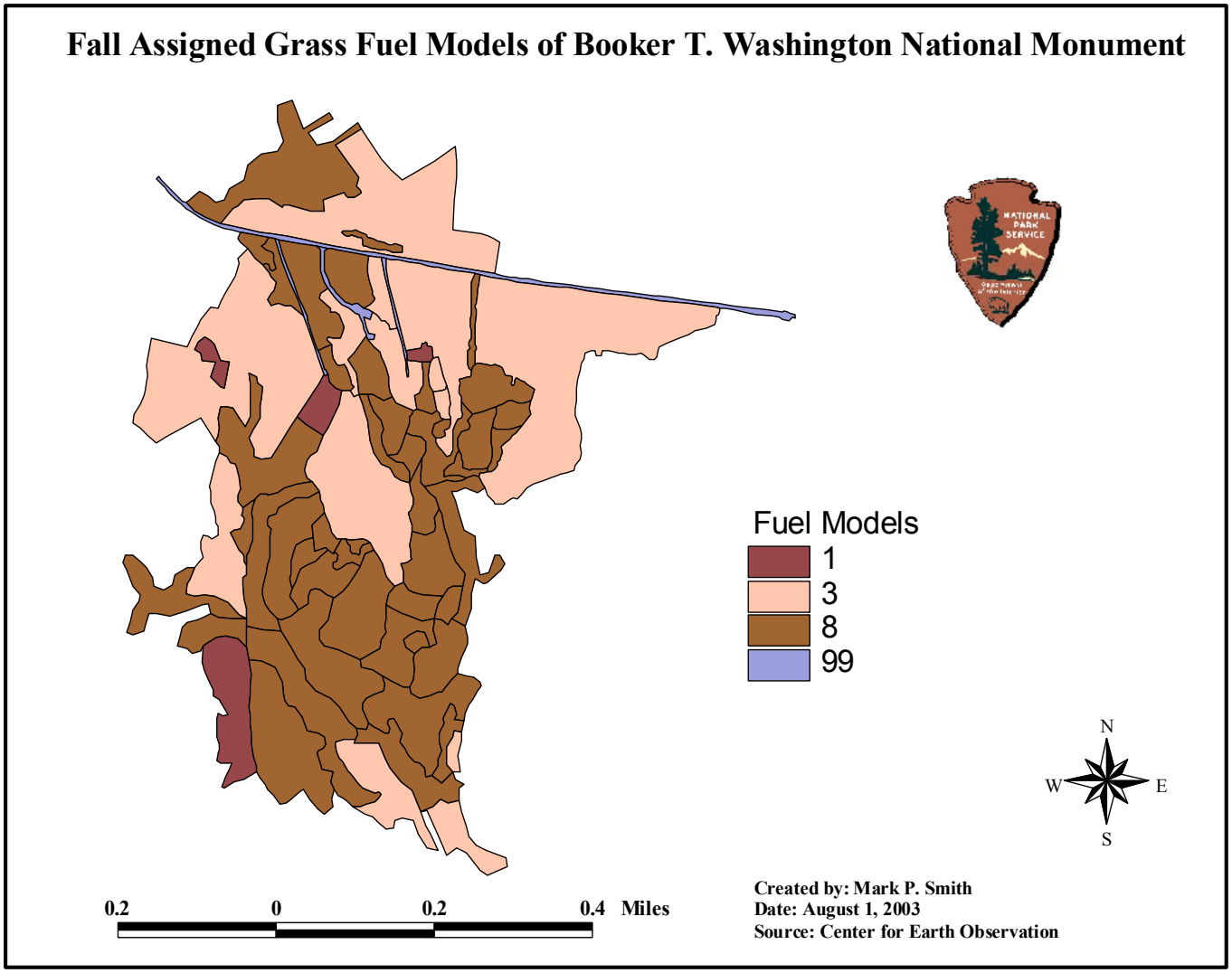



Summer Adjusted Fuel Models of Booker T. Washington National Monument
NATIONAL PARK SERVICE
Fuel Models
2
3
8
9
99
N
W
E
S
0.2
0
0.2
0.4
Miles
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation

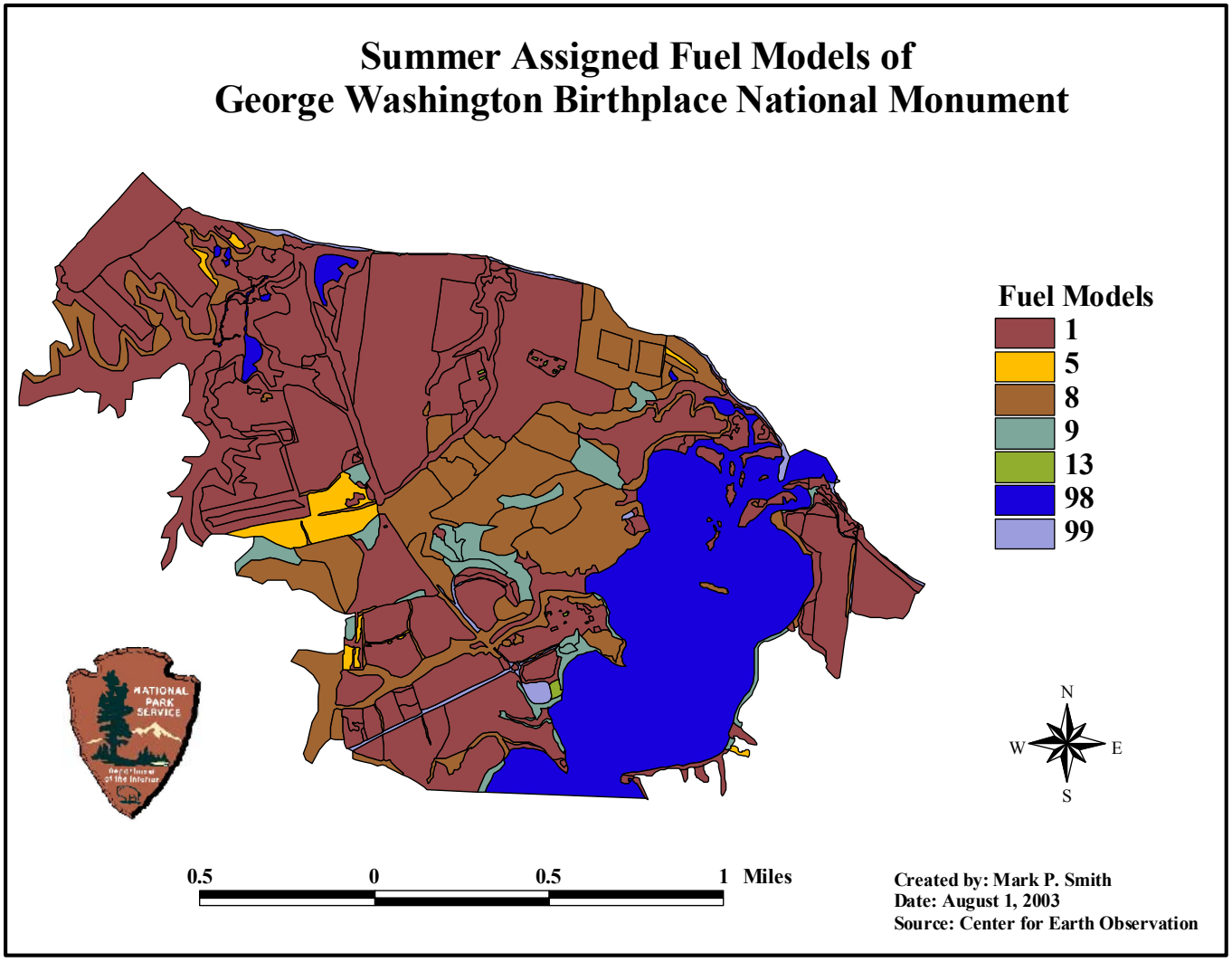

Summer Assigned Grass Fuel Models of Booker T. Washington National Monument
NATIONAL PARK SERVICE
Fuel Models
1
8
9
99
N
W
E
S
0.2
0
0.2
0.4
Miles
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation


Fall Assigned Fuel Models of Booker T. Washington National Monument
NATIONAL PARK SERVICE
Fuel Models
1
3
9
99
N
W
E
S
0.2
0
0.2
0.4
Miles
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation

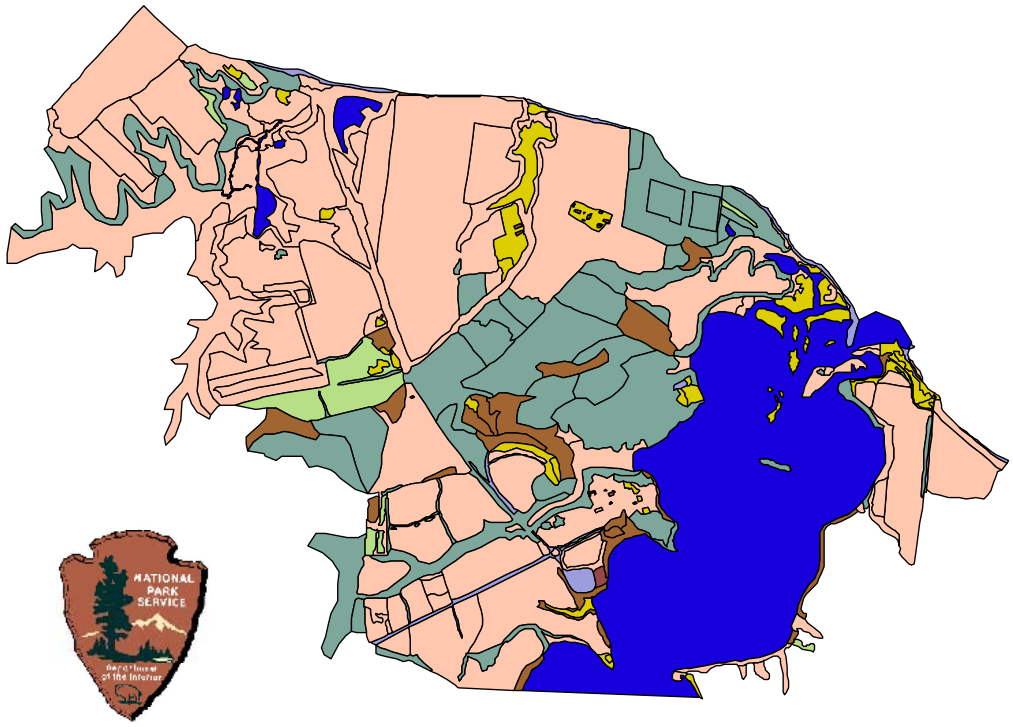

Fall Adjusted Fuel Models of Booker T. Washington National Monument
NATIONAL PARK SERVICE
Fuel Models
1
2
8
99
N
W
E
S
0.2
0
0.2
0.4
Miles
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation


Fall Assigned Grass Fuel Models of Booker T. Washington National Monument
Fuel Models
1
3
8
99
N
W
E
S
0.2
0
0.2
0.4
Miles
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation

APPENDIX G FUEL MODEL MAPS FOR GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT



Summer Adjusted Fuel Models of George Washington Birthplace National Monument



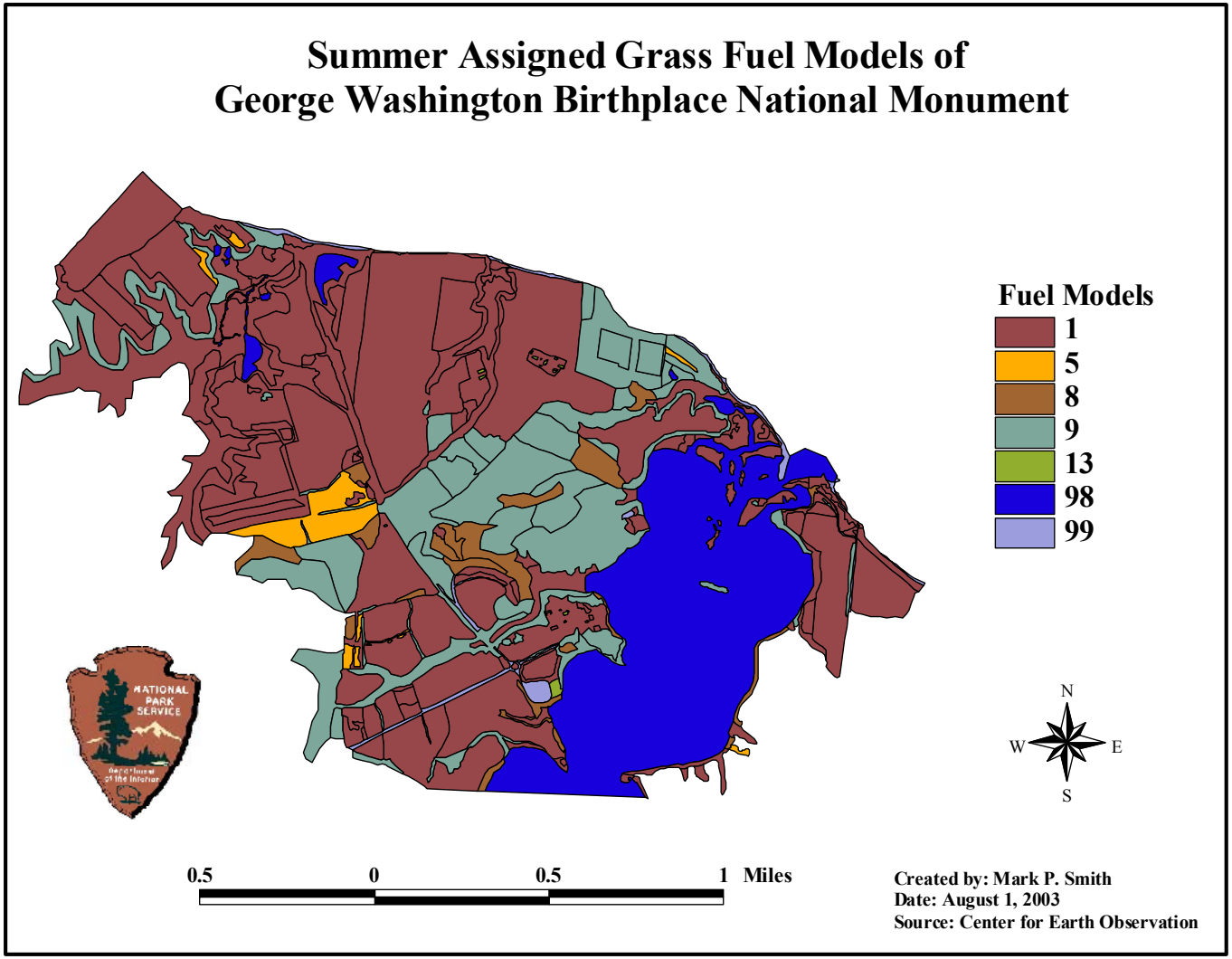
Fuel Models

- 1
- 2
- 3
- 6
- 8
- 9
- 98
- 99

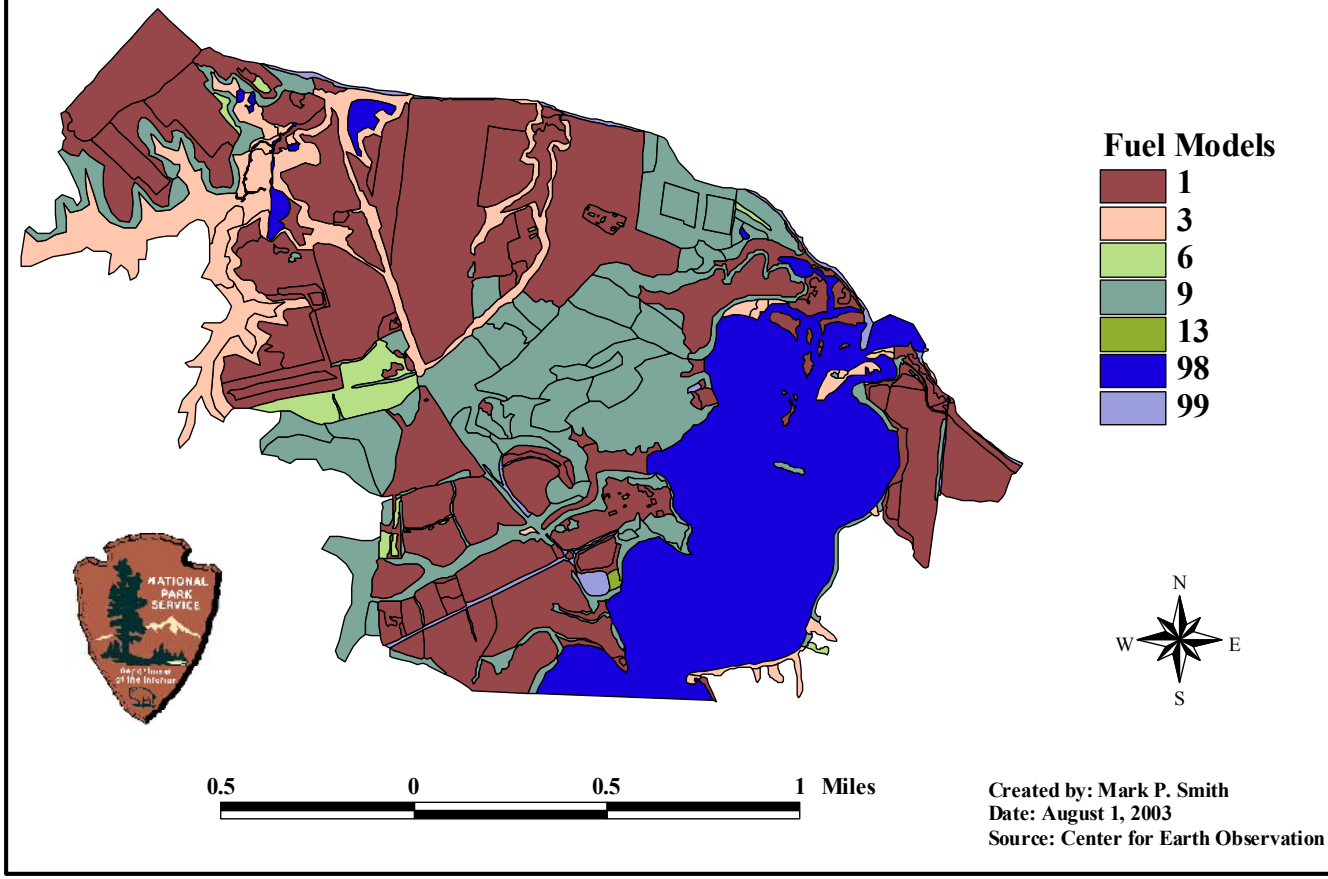
N
W E
S

0.5 0 0.5 1 Miles

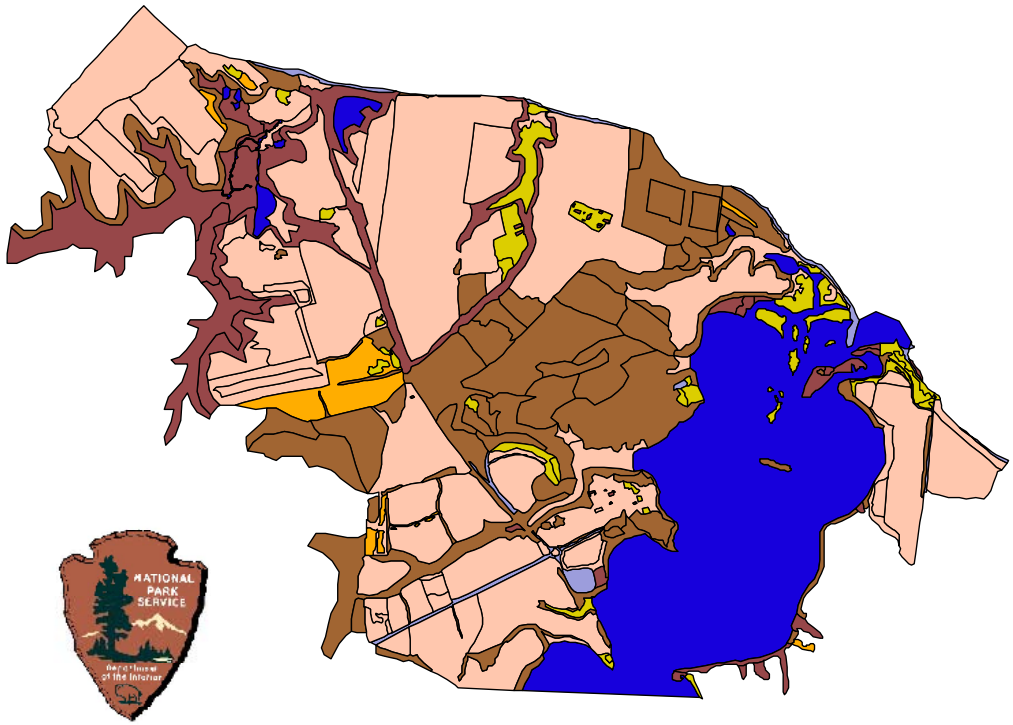
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation


Summer Assigned Grass Fuel Models of
George Washington Birthplace National Monument
Fuel Models
1
5
8
9
13
98
99
N
W
E
S
NATIONAL PARK SERVICE
0.5
0
0.5
1 Miles
Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation

Fall Assigned Fuel Models of George Washington Birthplace National Monument



Fall Adjusted Fuel Models of George Washington Birthplace National Monument



Fuel Models

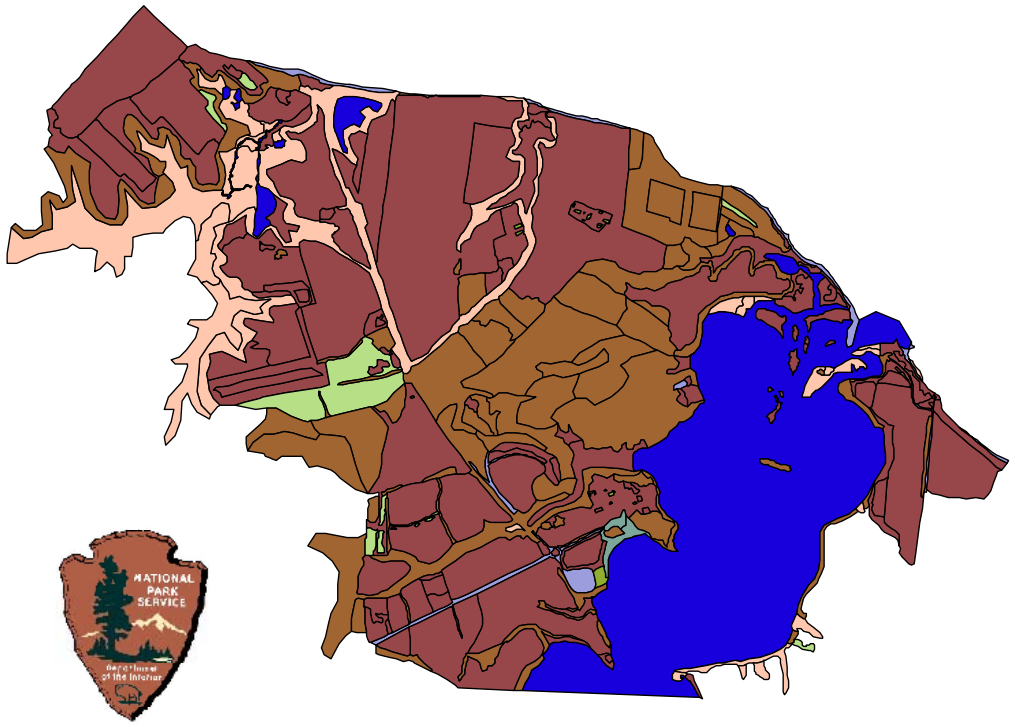
- 1
- 2
- 3
- 5
- 8
- 98
- 99

N
W E
S

0.5 0 0.5 1 Miles

Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation

Fall Assigned Grass Fuel Models of George Washington Birthplace National Monument



Fuel Models

- 1
- 3
- 6
- 8
- 9
- 13
- 98
- 99

N
W E
S

0.5 0 0.5 1 Miles

Created by: Mark P. Smith
Date: August 1, 2003
Source: Center for Earth Observation

APPENDIX H. ERROR MATRIX OF THE VEGETATION MAP THEMATIC ACCURACY ASSESSMENT OF BOOKER T. WASHINGTON NATIONAL MONUMENT

			Reference Totals													
Classification Totals	**Class**	**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total Cl.**	**Total C.E.**
	Agriculture and Cultivated 2	**1**	0								2	2			4	4
	1.1.3 Developed Mixed	**2**		0						1					1	1
	1.2 Developed Open Land	**3**			2							1			3	1
	I.A.8.N.b	**4**				9									9	-
	I.B.2.N.a	**5**					18								18	-
	I.B.2.N.d	**6**					6	0							6	6
	I.C.3.N.a	**7**				1	3		5						9	4
	II.B.2.N.a	**8**								0					-	-
	V.A.5.C.x	**9**			1						1	4			6	5
	V.A.5.N.c	**10**									1	0			1	1
	V.A.5.N.k	**11**										3	0		3	3
	Road	**12**												4	4	-
	Total Ref.		-	-	3	10	27	-	5	1	4	10	-	4	64	
	Total O.E.		-	-	1	1	9	-	-	1	2	10	-	-		

APPENDIX I. ERROR MATRIX FOR THE VEGETATION MAP THEMATIC ACCURACY ASSESSMENT OF GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT

			Reference Totals																							
Classification Totals	Class	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total Cl.	Total C.E.
	Beach	1	1																							1	-
	Developed Coniferous 1.1.2	2		1																						1	-
	Developed Deciduous 1.1.1	3			1																					1	-
	Developed Mixed 1.1.3	4		1		0	1							1												3	3
	Developed Open Land 1.2	5			1		4														1					6	2
	I.A.8.C.x	6						6	1																	7	1
	I.A.8.N.b	7							4																	4	-
	I.B.2.N.a	8							1	4									1							6	2
	I.B.2.N.d	9									0	1														1	1
	I.B.2.N.e	10										0														-	-
	I.B.2.N.g	11								1			0			1										2	2
	I.C.3.N.a	12		1		1			1	1				8		1		1								14	6
	I.C.3.N.b	13												2	0									1		3	3
	II.B.2.N.a	14														0										-	-
	III.A.2.N.a	15								1							0									1	1
	III.B.2.N.a	16																0								-	-
	III.B.2.N.f	17																	0							-	-
	III.B.2.N.h	18																		17						17	-
	V.A.5.N.c	19					1											2			15					18	3
	V.A.5.N.n	20																				8				8	-
	V.B.2.N.d	21																				1	0			1	-
	V.B.2.N.g	22																						0		-	-
	V.C.2.N.a	23																				1			1	2	1
	Total Ref.		1	3	2	1	6	6	7	7	-	1	-	11	-	2	-	3	1	17	16	10	-	1	1	96	
	Total O.E.		-	2	1	1	2	-	3	3	-	1	-	3	-	2	-	3	1	-	1	2	-	1	-		

APPENDIX J. BROWN'S TRANSECT DATASHEET

Figure 7. Brown's Transect Datasheet (front)

VEGETATION MAP FUELS INVENTORY DATA SHEET
SHENANDOAH NATIONAL PARK

Plot ID: _____

District: _____ B/C (Circle One) Date: ___/___/___

Recorder(s): _____ Photo Numbers: _____ Total # taken: ____

Transect Lengths (ft); 0-0.25: _____ 0.25-1: _____ 1-3: _____ 3+r: _____

UTMs: _____ e _____ n _____ +/-m

NORTH Compass

Dir._____

Slope____%

# of Intercepts			Diameter (in)		Litter and Duff Depths (in)							
0-0.25" (1-hr)	0.25-1" (10-hr)	1-3" (100-hr)	3+s (1000-h)	3+r		L	D	Note		L	D	Note
					1				25			
					5				30			
					10				35			
					15				40			
					20				45			

NOTES:

EAST Compass

Dir._____

Slope____%

# of Intercepts			Diameter (in)		Litter and Duff Depths (in)							
0-0.25" (1-hr)	0.25-1" (10-hr)	1-3" (100-hr)	3+s (1000-h)	3+r		L	D	Note		L	D	Note
					1				25			
					5				30			
					10				35			
					15				40			
					20				45			

NOTES

APPENDIX K. BURGAN AND ROTHERMEL DATASHEETS

Figure 9. Burgan and Rothermel Datasheet (front)

Fuel Data Entry Form
Shenandoah National Park

District:_____ Plot:_____

Recorders:_____ Date:_____

UTMs:_____e _____n _____+/-m

Grass

Model Type 1. Dynamic
2. Static

Grass Type 1. Fine -- colonial bent, poverty, oat grass
2. Medium -- fescue, orchard, japanese bromegrass
3. Coarse -- sedges and rushes
4. Very Coarse -- sawgrass, tall oatgrass

Bulk Density Class (1-6) _____

Total Grass Load (0-30 tons/arce) _____ or Grass Depth (0-10 ft) _____

Dynamic Models enter maxium % that can be live (0-100%) _____

Static Models enter current % live (0-100%) _____

Percentage of area covered by grass (0-100%) _____

Shrub

Shrub Type 1. Fine stem, thin leaves -- Huckleberry, Gooseberry
2. Medium stem, thin leaves -- Chiquapin, Alder, Spicebush
3. Medium stem, thick leaves -- Ceanothus, Vaccinium
4. Densley packed fine stems and leaves -- Spirea, Rubus
5. Thick stems and leaves -- Mt. Laurel, Rhododendron

Bulk Density Class (1-6) _____

Total Shrub Load (0-80 tons/acre) _____ or Shrub Depth (0-10 ft) _____

Percentage of total shrub load in each size class. Enter as whole % (must tot. 100%)

1. 1-HR dead (0-1/4 inch) _____
2. 10-HR dead (1/4-1 inch) _____
3. 100-HR dead (1-3 inches) _____
4. Live leaves and twigs (0-1/4 inch) _____

Percentage of area covered by shrubs (0-100%) _____

Oils and Waxes Yes or No

NOTES

Figure 10. Burgan and Rothermel Datasheet (back)

Plot:_____ Date:_____

Litter

Litter Source 1. Conifers _____
2. Hardwoods
3. Both but atleast 30% of lessor type

Needle length if conifers or both (1-2) _____
1. Medium/ Long
2. Short

Litter Compactness 1. Loose (freshly fallen) _____
2. Normal
3. Compact (older compressed)

Total litter load (0-100 tons/acre) _____
or
Litter Depth (0-5ft) (ft=cm/30.48) _____

Percentage of total litter load in each size class. Enter as whole % (must tot. 100%)
1. 1-HR (0-1/4 inch) _____
2. 10-HR (1/4-1 inch) _____
3. 100-HR (1-3 inches) _____

Percentage of area covered by litter (0-100%) _____

NOTES

APPENDIX L. FUEL LODING VALUES FOR SAMPLE PLOTS AT BOOKER T. WASHINGTON NATIONAL MONUMENT

-

Formation Type: I.B.2.N.a
Plot Number 10

Transect Line	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	4	0.0151	0.48	1.13	1.00	6	0.0636357
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1.00	6	0.6089637
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1.00	12	0
	3.00 + S	11.64		0	0.4	1.00	1.00	50	0
	3.00 + R	11.64		53.3	0.3	1.00	1.00	50	3.7271222
								Total	4.3997216

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	6	0.0151	0.48	1.13	1.00	6	0.095639
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1.00	6	0
	1.00 - 3.00	11.64	2	2.76	0.4	1.13	1.00	12	2.4279211
	3.00 + S	11.64		0	0.4	1.00	1.00	50	0
	3.00 + R	11.64		0	0.3	1.00	1.00	50	0
								Total	2.52356

Formation Type: I.B.2.N.a
Plot Number 9

Transect Line	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	9	0.0151	0.48	1.13	1.00	6	0.1434585
	.25 - 1.00	11.64	6	0.289	0.48	1.13	1.00	6	1.8304413
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1.00	12	1.2139605
	3.00 + S	11.64		0	0.4	1.00	1.00	50	0
	3.00 + R	11.64		30.6	0.3	1.00	1.00	50	2.1439318
								Total	5.3317922

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1.01	6	0
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1.01	6	0.6133218
	1.00 - 3.00	11.64	2	2.76	0.4	1.13	1.01	12	2.4405537
	3.00 + S	11.64		0	0.4	1.00	1.01	50	0
	3.00 + R	11.64		41	0.3	1.00	1.01	50	2.8875347
								Total	5.9414102

Formation Type: I.B.2.N.a
Plot Number 8

Transect Line	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	7	0.0151	0.48	1.13	1.00	6	0.1112735
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1.00	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1.00	12	0
	3.00 + S	11.64		0	0.4	1.00	1.00	50	0
	3.00 + R	11.64		0	0.3	1.00	1.00	50	0
								Total	0.1112735

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	3	0.0151	0.48	1.13	1.01	6	0.0480092
	.25 - 1.00	11.64	3	0.289	0.48	1.13	1.01	6	0.9188511
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1.01	12	1.2187759
	3.00 + S	11.64		0	0.4	1.00	1.01	50	0
	3.00 + R	11.64		26.01	0.3	1.00	1.01	50	1.8295707
								Total	4.0152069

Formation Type: I.B.2.N.d
Plot Number 11

Transect Line North

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	3	0.0151	0.48	1.13	1.00	6	0.0478195
.25 - 1.00	11.64	1	0.289	0.48	1.13	1.00	6	0.3050736
1.00 - 3.00	11.64	2	2.76	0.4	1.13	1.00	12	2.4279211
3.00 + S	11.64		55.25	0.4	1.00	1.00	50	5.1613174
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	7.9421315

East

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	2	0.0151	0.48	1.13	1.00	6	0.0317797
.25 - 1.00	11.64	1	0.289	0.48	1.13	1.00	6	0.3041172
1.00 - 3.00	11.64	0	2.76	0.4	1.13	1.00	12	0
3.00 + S	11.64		34.69	0.4	1.00	1.00	50	3.2304943
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	3.5663912

Formation Type: I.C.3.N.a
Plot Number 16

Transect Line North

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	10	0.0151	0.48	1.13	1.01	6	0.1604402
.25 - 1.00	11.64	0	0.289	0.48	1.13	1.01	6	0
1.00 - 3.00	11.64	3	2.76	0.4	1.13	1.01	12	3.6656873
3.00 + S	11.64		0	0.4	1.00	1.01	50	0
3.00 + R	11.64		55.2	0.3	1.00	1.01	50	3.8927653
							Total	7.7188929

East

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	6	0.0151	0.48	1.13	1.01	6	0.096547
.25 - 1.00	11.64	2	0.289	0.48	1.13	1.01	6	0.6159398
1.00 - 3.00	11.64	3	2.76	0.4	1.13	1.01	12	3.6764572
3.00 + S	11.64		0	0.4	1.00	1.01	50	0
3.00 + R	11.64		15.21	0.3	1.00	1.01	50	1.0757775
							Total	5.4647214

Formation Type: I.C.3.N.a
Plot Number 17

Transect Line North

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	6	0.0151	0.48	1.13	1.00	6	0.0953535
.25 - 1.00	11.64	0	0.289	0.48	1.13	1.00	6	0
1.00 - 3.00	11.64	0	2.76	0.4	1.13	1.00	12	0
3.00 + S	11.64		0	0.4	1.00	1.00	50	0
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	0.0953535

East

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	3	0.0151	0.48	1.13	1.00	6	0.0476696
.25 - 1.00	11.64	1	0.289	0.48	1.13	1.00	6	0.3041172
1.00 - 3.00	11.64	1	2.76	0.4	1.13	1.00	12	1.2101549
3.00 + S	11.64		0	0.4	1.00	1.00	50	0
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	1.5619417

Formation Type: I.A.8.N.b
Plot Number 7

Transect Line North

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	9	0.0151	0.48	1.13	1.00	6	0.1431802
.25 - 1.00	11.64	1	0.289	0.48	1.13	1.00	6	0.3044819
1.00 - 3.00	11.64	1	2.76	0.4	1.13	1.00	12	1.2116061
3.00 + S	11.64		0	0.4	1.00	1.00	50	0
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	1.6592682

East

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	7	0.0151	0.48	1.13	1.00	6	0.1117782
.25 - 1.00	11.64	0	0.289	0.48	1.13	1.00	6	0
1.00 - 3.00	11.64	0	2.76	0.4	1.13	1.00	12	0
3.00 + S	11.64		0	0.4	1.00	1.00	50	0
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	0.1117782

Formation Type: I.A.8.N.b
Plot Number 4

Transect Line North

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	4	0.0151	0.48	1.13	1.00	6	0.0636706
.25 - 1.00	11.64	3	0.289	0.48	1.13	1.00	6	0.9139466
1.00 - 3.00	11.64	1	2.76	0.4	1.13	1.00	12	1.2122706
3.00 + S	11.64		0	0.4	1.00	1.00	50	0
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	2.1898878

East

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	10	0.0151	0.48	1.13	1.00	6	0.1590177
.25 - 1.00	11.64	3	0.289	0.48	1.13	1.00	6	0.9130355
1.00 - 3.00	11.64	2	2.76	0.4	1.13	1.00	12	2.4221242
3.00 + S	11.64		0	0.4	1.00	1.00	50	0
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	3.4941774

Formation Type: I.A.8.N.b
Plot Number 5

Transect Line North

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	4	0.0151	0.48	1.13	1.00	6	0.0635563
.25 - 1.00	11.64	1	0.289	0.48	1.13	1.00	6	0.304102
1.00 - 3.00	11.64	0	2.76	0.4	1.13	1.00	12	0
3.00 + S	11.64		38.25	0.4	1.00	1.00	50	3.56184
3.00 + R	11.64		10.89	0.3	1.00	1.00	50	0.7605576
							Total	4.6900558

East

Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
0 - .25	11.64	7	0.0151	0.48	1.13	1.00	6	0.1112735
.25 - 1.00	11.64	1	0.289	0.48	1.13	1.00	6	0.3042388
1.00 - 3.00	11.64	1	2.76	0.4	1.13	1.00	12	1.2106388
3.00 + S	11.64		84.79	0.4	1.00	1.00	50	7.899197
3.00 + R	11.64		0	0.3	1.00	1.00	50	0
							Total	9.5253482

APPENDIX M. MINIMUM SAMPLE SIZE CALCULATIONS FOR BOWA

Plot Number	Formation	1 hour 0-0.25	10 hour .25-1.00	100 Hour 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
7 North	I.A.8.N.b	0.143	0.304	1.212	0.066	1.659
7 East	I.A.8.N.b	0.112	0.000	0.000	0.062	0.112
4 North	I.A.8.N.b	0.064	0.914	1.212	0.038	2.190
4 East	I.A.8.N.b	0.159	0.913	2.422	0.039	3.494
5 North	I.A.8.N.b	0.064	0.304	0.000	0.121	0.368
5 East	I.A.8.N.b	0.111	0.304	1.211	0.133	1.626
	Sum	0.652	2.740	6.057	0.458	9.449
	Mean	0.109	0.457	1.009	0.076	1.575
	Fuel Value squared	0.079	1.947	10.271	0.043	22.549
	Variance	0.002	0.139	0.831	0.002	1.534
	Standard Deviation	0.040	0.373	0.912	0.041	1.238
	Confidence Interval Width					0.394
	Minimum Sample Size					33.067

Plot Number	Formation	1 hour 0-0.25	10 hour .25-1.00	100 Hour 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
10 North	I.B.2.N.a	0.064	0.609	0.000	0.087	0.673
10 East	I.B.2.N.a	0.096	0.000	2.428	0.085	2.524
9 North	I.B.2.N.a	0.143	1.830	1.214	0.111	3.188
9 East	I.B.2.N.a	0.000	0.613	2.441	0.121	3.054
8 North	I.B.2.N.a	0.111	0.000	0.000	0.096	0.111
8 East	I.B.2.N.a	0.048	0.919	1.219	0.162	2.186
	Sum	0.462	3.972	7.301	0.661	11.735
	Mean	0.077	0.662	1.217	0.110	1.956
	Fuel Value squared	0.048	4.942	14.810	0.077	31.099
	Variance	0.003	0.463	1.185	0.001	1.630
	Standard Deviation	0.051	0.680	1.089	0.000	1.277
	Confidence Interval Width					0.489
	Minimum Sample Size					24.198

Plot Number	Formation	1 hour 0-0.25	10 hour .25-1.00	100 Hour 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
11 North	I.B.2.N.d	0.048	0.305	2.428	0.166	2.781
11 East	I.B.2.N.d	0.032	0.304	0.000	0.159	0.495
	Sum	0.080	0.609	2.428	0.325	3.276
	Mean	0.040	0.305	1.214	0.163	1.638
	Fuel Value squared	0.00	0.19	5.89	0.05	7.98
	Variance	0.000	0.000	2.947	0.000	2.612
	Standard Deviation	0.011	0.001	1.717	0.000	1.616
	Confidence Interval Width					0.410
	Minimum Sample Size					385.388

Plot Number	Formation	1 hour 0-0.25	10 hour .25-1.00	100 Hour 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
16 North	I.C.3.N.a	0.160	0.000	3.666	0.114	3.826
16 East	I.C.3.N.a	0.097	0.616	3.676	0.133	4.389
17 North	I.C.3.N.a	0.095	0.000	0.000	0.079	0.095
17 East	I.C.3.N.a	0.048	0.304	1.210	0.142	1.562
	Sum	0.400	0.920	8.552	0.468	9.872
	Mean	0.100	0.230	2.138	0.117	2.468
	Fuel Value squared	0.046	0.472	28.418	0.057	36.351
	Variance	0.002	0.087	3.378	0.001	3.995
	Standard Deviation	0.046	0.295	1.838	0.028	1.999
	Confidence Interval Width					0.617
	Minimum Sample Size					112.474

APPENDIX N. FUEL LODING VALUES FOR SAMPLE PLOTS AT GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT

Formation Type: I.B.2.N.a
Plot Number: 26

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	6	0.0151	0.48	1.13	1	6	0.09533
	.25 - 1.00	11.64	3	0.289	0.48	1.13	1	6	0.91231
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.00764

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	4	0.0151	0.48	1.13	1	6	0.06356
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		80	0.3	1.00	1	50	5.5872
								Total	6.86085

Formation Type: I.B.2.N.a
Plot Number 13

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	6	0.0151	0.48	1.13	1	6	0.09533
	.25 - 1.00	11.64	8	0.289	0.48	1.13	1	6	2.43282
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		169	0.4	1.00	1	50	15.7373
	3.00 + R	11.64		9	0.3	1.00	1	50	0.62856
								Total	18.894

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	11	0.0151	0.48	1.13	1	6	0.17478
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1	6	0.6082
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		16	0.4	1.00	1	50	1.48992
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	2.2729

Formation Type: I.B.2.N.a
Plot Number 27

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	14	0.0151	0.48	1.13	1	6	0.22245
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.22245

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	14	0.0151	0.48	1.13	1	6	0.22245
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		51.86	0.4	1.00	1	50	4.8292
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	5.35575

Formation Type: I.B.2.N.a
Plot Number 4

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	8	0.0151	0.48	1.13	1	6	0.12711
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.43121

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	6	0.0151	0.48	1.13	1	6	0.09533
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		42.25	0.4	1.00	1	50	3.93432
	3.00 + R	11.64		50	0.3	1.00	1	50	3.492
								Total	9.03585

Formation Type: I.B.2.N.a
Plot Number 5

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	2	0.0151	0.48	1.13	1	6	0.03178
	.25 - 1.00	11.64	5	0.289	0.48	1.13	1	6	1.52051
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.55229

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	10	0.0151	0.48	1.13	1	6	0.15889
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.36899

Formation Type: Developed Open Land 1.2
Plot Number 24

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	1	0.0151	0.48	1.13	1	6	0.01589
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.01589

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: Developed Open Land 1.2
Plot Number 19

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: Developed Open Land 1.2
Plot Number 1

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: I.A.8.N.b
Plot Number 8

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	3	0.0151	0.48	1.13	1	6	0.04767
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		30.25	0.3	1.00	1	50	2.11266
								Total	2.16033

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	2	2.76	0.4	1.13	1	12	2.42019
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		56.25	0.3	1.00	1	50	3.9285
								Total	6.34869

Formation Type: I.A.8.N.b
Plot Number 23

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	1	0.0151	0.48	1.13	1	6	0.01589
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.01589

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: I.A.8.N.b
Plot Number 17

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	7	0.0151	0.48	1.13	1	6	0.11122
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		240.25	0.4	1.00	1	50	22.3721
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	23.6934

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	5	0.0151	0.48	1.13	1	6	0.07945
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.07945

Formation Type: I.A.8.C.x
Plot Number 16

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	4	0.0151	0.48	1.13	1	6	0.06356
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.27365

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	6	0.0151	0.48	1.13	1	6	0.09533
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.60953

Formation Type: I.A.8.C.x
Plot Number 28

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	5	0.0151	0.48	1.13	1	6	0.07945
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.59364

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	4	0.0151	0.48	1.13	1	6	0.06356
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	3	2.76	0.4	1.13	1	12	3.63028
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	3.99794

Formation Type: I.A.8.C.x
Plot Number 11

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	2	0.0151	0.48	1.13	1	6	0.03178
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.03178

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	12	0.0151	0.48	1.13	1	6	0.19067
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1	6	0.6082
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.79887

Formation Type: V.A.5.N.n
Plot Number 9

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	4	0.0151	0.48	1.13	1	6	0.06356
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.06356

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	9	0.0151	0.48	1.13	1	6	0.143
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.143

Formation Type: III.B.2.N.a
Plot Number 6

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: III.B.2.N.a
Plot Number 22

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.3041

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	2	0.0151	0.48	1.13	1	6	0.03178
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.33588

Formation Type: I.B.2.N.e
Plot Number 3

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	11	0.0151	0.48	1.13	1	6	0.17478
	.25 - 1.00	11.64	3	0.289	0.48	1.13	1	6	0.91231
	1.00 - 3.00	11.64	2	2.76	0.4	1.13	1	12	2.42019
	3.00 + S	11.64		194	0.4	1.00	1	50	18.0653
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	21.5726

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	8	0.0151	0.48	1.13	1	6	0.12711
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1	6	0.6082
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		42.25	0.4	1.00	1	50	3.93432
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	4.66964

Formation Type: I.B.2.N.d
Plot Number 25

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	4	0.0151	0.48	1.13	1	6	0.06356
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.06356

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	6	0.0151	0.48	1.13	1	6	0.09533
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	3	2.76	0.4	1.13	1	12	3.63028
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		12.25	0.3	1.00	1	50	0.85554
								Total	4.58116

Formation Type: V.A.5.C.x
Plot Number 21

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: V.A.5.C.x
Plot Number 7

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

Formation Type: I.C.3.N.b
Plot Number 12

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	3	0.0151	0.48	1.13	1	6	0.04767
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.04767

Formation Type: I.C.3.N.b
Plot Number 20

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	10	0.0151	0.48	1.13	1	6	0.15889
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1	6	0.6082
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.97719

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	6	0.0151	0.48	1.13	1	6	0.09533
	.25 - 1.00	11.64	2	0.289	0.48	1.13	1	6	0.6082
	1.00 - 3.00	11.64	3	2.76	0.4	1.13	1	12	3.63028
	3.00 + S	11.64		81	0.4	1.00	1	50	7.54272
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	11.8765

Formation Type: I.C.3.N.a
Plot Number 2

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	5	0.0151	0.48	1.13	1	6	0.07945
	.25 - 1.00	11.64	3	0.289	0.48	1.13	1	6	0.91231
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	2.20185

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	2	0.0151	0.48	1.13	1	6	0.03178
	.25 - 1.00	11.64	1	0.289	0.48	1.13	1	6	0.3041
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		120.25	0.3	1.00	1	50	8.39826
								Total	8.73414

Formation Type: I.C.3.N.a
Plot Number 18

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	13	0.0151	0.48	1.13	1	6	0.20656
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.20656

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	3	0.0151	0.48	1.13	1	6	0.04767
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.04767

Formation Type: I.C.3.N.a
Plot Number 15

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	7	0.0151	0.48	1.13	1	6	0.11122
	.25 - 1.00	11.64	3	0.289	0.48	1.13	1	6	0.91231
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		11.56	0.4	1.00	1	50	1.07647
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	2.1

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	5	0.0151	0.48	1.13	1	6	0.07945
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.07945

Formation Type: I.C.3.N.a
Plot Number 14

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		138.05	0.3	1.00	1	50	9.64141
								Total	9.64141

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	0	0.0151	0.48	1.13	1	6	0
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		16	0.3	1.00	1	50	1.11744
								Total	2.32753

Formation Type: I.C.3.N.a
Plot Number 10

Transect Direction	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
North	0 - .25	11.64	3	0.0151	0.48	1.13	1	6	0.04767
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	0	2.76	0.4	1.13	1	12	0
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	0.04767

	Size Class	Constant	N	D^2	S	A	C	NL	Tons/Acre
East	0 - .25	11.64	1	0.0151	0.48	1.13	1	6	0.01589
	.25 - 1.00	11.64	0	0.289	0.48	1.13	1	6	0
	1.00 - 3.00	11.64	1	2.76	0.4	1.13	1	12	1.21009
	3.00 + S	11.64		0	0.4	1.00	1	50	0
	3.00 + R	11.64		0	0.3	1.00	1	50	0
								Total	1.22598

APPENDIX O. MINIMUM SAMPLE SIZE CALCULATIONS FOR GEWA

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
8 North	I.A.8.N.b	0.048	0.000	0.000	0.144	0.048
8 East	I.A.8.N.b	0.000	0.000	2.420	0.123	2.420
23 North	I.A.8.N.b	0.016	0.000	0.000	0.013	0.016
23 East	I.A.8.N.b	0.000	0.000	0.000	0.014	0.000
17 North	I.A.8.N.b	0.111	0.000	1.210	0.118	1.321
17 East	I.A.8.N.b	0.079	0.000	0.000	0.142	0.079

Sum	0.254	0.000	3.630	0.553	3.885
Mean	0.042	0.000	0.605	0.092	0.647
Fuel Value squared	0.021	0.000	7.322	0.070	7.612
Variance	0.002	0.000	1.025	0.004	1.019
Standard Deviation	0.046	0.000	1.012	0.062	1.010
Confidence Interval Width					0.162
Minimum Sample Size					86.424

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
16 North	I.A.8.C.x	0.064	0.000	1.210	0.116	1.274
16 East	I.A.8.C.x	0.095	0.304	1.210	0.106	1.610
28 North	I.A.8.C.x	0.079	0.304	1.210	0.096	1.594
28 East	I.A.8.C.x	0.064	0.304	3.630	0.088	3.998
11 North	I.A.8.C.x	0.032	0.000	0.000	0.143	0.032
11 East	I.A.8.C.x	0.191	0.608	0.000	0.161	0.799

Sum	0.524	1.521	7.261	0.709	9.305
Mean	0.087	0.253	1.210	0.118	1.551
Fuel Value squared	0.061	0.647	17.572	0.088	23.375
Variance	0.003	0.052	1.757	0.001	1.789
Standard Deviation	0.055	0.229	1.326	0.028	1.337
Confidence Interval Width					0.388
Minimum Sample Size					46.365

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
26 North	I.B.2.N.a	0.095	0.912	0.000	0.167	1.008
26 East	I.B.2.N.a	0.064	0.000	1.210	0.133	1.274
13 North	I.B.2.N.a	0.095	2.433	0.000	0.063	2.528
13 East	I.B.2.N.a	0.175	0.608	0.000	0.055	0.783
27 North	I.B.2.N.a	0.222	0.000	0.000	0.089	0.222
27 East	I.B.2.N.a	0.222	0.304	0.000	0.103	0.527
4 North	I.B.2.N.a	0.127	0.304	0.000	0.078	0.431
4 East	I.B.2.N.a	0.095	0.304	1.210	0.082	1.610
5 North	I.B.2.N.a	0.032	1.521	0.000	0.098	1.552
5 East	I.B.2.N.a	0.159	0.000	1.210	0.124	1.369

Sum	1.287	6.386	3.630	0.990	11.303
Mean	0.129	0.639	0.363	0.099	1.130
Fuel Value squared	0.203	9.710	4.393	0.109	17.029
Variance	0.004	0.626	0.342	0.001	0.472
Standard Deviation	0.065	0.791	0.585	0.034	0.687
Confidence Interval Width					0.283
Minimum Sample Size					5.347

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
25 North	I.B.2.N.d	0.064	0.000	0.000	0.046	0.064
25 East	I.B.2.N.d	0.095	0.000	3.630	0.137	3.726

Sum	0.159	0.000	3.630	0.182	3.789
Mean	0.079	0.000	1.815	0.091	1.895
Fuel Value squared	0.01	0.00	13.18	0.02	13.88
Variance	0.001	0.000	6.589	0.004	6.705
Standard Deviation	0.022	0.000	2.567	0.000	2.589
Confidence Interval Width					0.474
Minimum Sample Size					1898.762

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
3 North	I.B.2.N.e	0.175	0.912	2.420	0.078	3.507
3 East	I.B.2.N.e	0.127	0.608	0.000	0.094	0.735

Sum	0.302	1.521	2.420	0.173	4.243
Mean	0.151	0.760	1.210	0.086	2.121
Fuel Value squared	0.05	1.20	5.86	0.02	12.84
Variance	0.001	0.046	2.929	0.000	3.842
Standard Deviation	0.034	0.215	1.711	0.000	1.960
Confidence Interval Width					0.530
Minimum Sample Size					497.212

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
2 North	I.C.3.N.a	0.079	0.912	1.210	0.155	2.202
2 East	I.C.3.N.a	0.032	0.304	0.000	0.159	0.336
18 North	I.C.3.N.a	0.207	0.000	0.000	0.129	0.207
18 East	I.C.3.N.a	0.048	0.000	0.000	0.135	0.048
15 North	I.C.3.N.a	0.111	0.912	0.000	0.146	1.024
15 East	I.C.3.N.a	0.079	0.000	0.000	0.122	0.079
14 North	I.C.3.N.a	0.000	0.000	0.000	0.147	0.000
14 East	I.C.3.N.a	0.000	0.000	1.210	0.163	1.210
10 North	I.C.3.N.a	0.048	0.000	0.000	0.158	0.048
10 East	I.C.3.N.a	0.016	0.000	1.210	0.099	1.226

Sum	0.620	2.129	3.630	1.412	6.379
Mean	0.062	0.213	0.363	0.141	0.638
Fuel Value squared	0.073	1.757	4.393	0.203	9.029
Variance	0.004	0.145	0.342	0.000	0.551
Standard Deviation	0.062	0.381	0.585	0.020	0.742
Confidence Interval Width					0.159
Minimum Sample Size					22.851

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
12 North	I.C.3.N.b	0.000	0.000	0.000	0.105	0.000
12 East	I.C.3.N.b	0.048	0.000	0.000	0.083	0.048
20 North	I.C.3.N.b	0.159	0.608	1.210	0.114	1.977
20 East	I.C.3.N.b	0.095	0.608	3.630	0.063	4.334

Sum	0.302	1.216	4.840	0.366	6.359
Mean	0.075	0.304	1.210	0.091	1.590
Fuel Value squared	0.037	0.740	14.643	0.035	22.694
Variance	0.005	0.123	2.929	0.001	4.195
Standard Deviation	0.068	0.351	1.711	0.023	2.048
Confidence Interval Width					0.397
Minimum Sample Size					298.967

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
6 North	III.B.2.N.a	0.000	0.000	0.000	0.000	0.000
6 East	III.B.2.N.a	0.000	0.000	0.000	0.000	0.000
22 North	III.B.2.N.a	0.000	0.304	0.000	0.064	0.304
22 East	III.B.2.N.a	0.032	0.304	0.000	0.133	0.336

Sum	0.032	0.608	0.000	0.197	0.640
Mean	0.008	0.152	0.000	0.049	0.160
Fuel Value squared	0.001	0.185	0.000	0.022	0.205
Variance	0.000	0.031	0.000	0.004	0.034
Standard Deviation	0.016	0.176	0.000	0.063	0.185
Confidence Interval Width					0.040
Minimum Sample Size					1.973

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
21 North	V.A.5.C.x	0.000	0.000	0.000	0.000	0.000
21 East	V.A.5.C.x	0.000	0.000	0.000	0.000	0.000
7 North	V.A.5.C.x	0.000	0.000	0.000	0.000	0.000
7 East	V.A.5.C.x	0.000	0.000	0.000	0.000	0.000

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
9 North	V.A.5.N.n	0.064	0.000	0.000	0.000	0.064
9 East	V.A.5.N.n	0.143	0.000	0.000	0.000	0.143

Plot Numbers	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
1 North	Dev Opn 1.2	0.000	0.000	0.000	0.144	0.000
1 East	Dev Opn 1.2	0.000	0.000	0.000	0.116	0.000
19 North	Dev Opn 1.2	0.000	0.000	0.000	0.000	0.000
19 East	Dev Opn 1.2	0.000	0.000	0.000	0.000	0.000
24 North	Dev Opn 1.2	0.016	0.000	0.000	0.126	0.016
24 East	Dev Opn 1.2	0.000	0.000	0.000	0.060	0.000

APPENDIX P. COMBINED MINIMUM SAMPLE SIZE CALCULATIONS

Plot Number	Formation	1 hour 0-0.25	10 hours .25-1.00	100 Hours 1.00-3.00	Fuel bed depth	Sum of Fuel < 3"
7 North	I.A.8.N.b	0.143	0.304	1.212	0.066	1.659
7 East	I.A.8.N.b	0.112	0.000	0.000	0.062	0.112
4 North	I.A.8.N.b	0.064	0.914	1.212	0.038	2.190
4 East	I.A.8.N.b	0.159	0.913	2.422	0.039	3.494
5 North	I.A.8.N.b	0.064	0.304	0.000	0.121	0.368
5 East	I.A.8.N.b	0.111	0.304	1.211	0.133	1.626
8 North	I.A.8.N.b	0.048	0.000	0.000	0.144	0.048
8 East	I.A.8.N.b	0.000	0.000	2.420	0.123	2.420
23 North	I.A.8.N.b	0.016	0.000	0.000	0.013	0.016
23 East	I.A.8.N.b	0.000	0.000	0.000	0.014	0.000
17 North	I.A.8.N.b	0.111	0.000	1.210	0.118	1.321
17 East	I.A.8.N.b	0.079	0.000	0.000	0.142	0.079

BOWA plots
GEWA plots

Sum	0.906	2.740	9.687	1.011	13.333
Mean	0.076	0.228	0.807	0.084	1.111
Fuel Value squared	0.100	1.947	17.592	0.113	30.162
Variance	0.003	0.120	0.888	0.003	1.395
Standard Deviation	0.053	0.347	0.943	0.051	1.181
Confidence Interval Width					0.278
Minimum Sample Size					46.863

10 North	I.B.2.N.a	0.064	0.609	0.000	0.087	0.673
10 East	I.B.2.N.a	0.096	0.000	2.428	0.085	2.524
9 North	I.B.2.N.a	0.143	1.830	1.214	0.111	3.188
9 East	I.B.2.N.a	0.000	0.613	2.441	0.121	3.054
8 North	I.B.2.N.a	0.111	0.000	0.000	0.096	0.111
8 East	I.B.2.N.a	0.048	0.919	1.219	0.162	2.186
26 North	I.B.2.N.a	0.095	0.912	0.000	0.167	1.008
26 East	I.B.2.N.a	0.064	0.000	1.210	0.133	1.274
13 North	I.B.2.N.a	0.095	2.433	0.000	0.063	2.528
13 East	I.B.2.N.a	0.175	0.608	0.000	0.055	0.783
27 North	I.B.2.N.a	0.222	0.000	0.000	0.089	0.222
27 East	I.B.2.N.a	0.222	0.304	0.000	0.103	0.527
4 North	I.B.2.N.a	0.127	0.304	0.000	0.078	0.431
4 East	I.B.2.N.a	0.095	0.304	1.210	0.082	1.610
5 North	I.B.2.N.a	0.032	1.521	0.000	0.098	1.552
5 East	I.B.2.N.a	0.159	0.000	1.210	0.124	1.369

BOWA plots
GEWA plots

Sum	1.749	10.358	10.931	1.651	23.038
Mean	0.109	0.647	0.683	0.103	1.440
Fuel Value squared	0.252	14.652	19.203	0.186	48.128
Variance	0.004	0.530	0.782	0.001	0.997
Standard Deviation	0.064	0.728	0.884	0.032	0.999
Confidence Interval Width					0.360
Minimum Sample Size					13.795

16 North	I.C.3.N.a	0.160	0.000	3.666	0.114	3.826
16 East	I.C.3.N.a	0.097	0.616	3.676	0.133	4.389
17 North	I.C.3.N.a	0.095	0.000	0.000	0.079	0.095
17 East	I.C.3.N.a	0.048	0.304	1.210	0.142	1.562
2 North	I.C.3.N.a	0.079	0.912	1.210	0.155	2.202
2 East	I.C.3.N.a	0.032	0.304	0.000	0.159	0.336
18 North	I.C.3.N.a	0.207	0.000	0.000	0.129	0.207
18 East	I.C.3.N.a	0.048	0.000	0.000	0.135	0.048
15 North	I.C.3.N.a	0.111	0.912	0.000	0.146	1.024
15 East	I.C.3.N.a	0.079	0.000	0.000	0.122	0.079
14 North	I.C.3.N.a	0.000	0.000	0.000	0.147	0.000
14 East	I.C.3.N.a	0.000	0.000	1.210	0.163	1.210
10 North	I.C.3.N.a	0.048	0.000	0.000	0.158	0.048
10 East	I.C.3.N.a	0.016	0.000	1.210	0.099	1.226

BOWA plots
GEWA plots

Sum	1.020	3.049	12.183	1.879	16.251
Mean	0.073	0.218	0.870	0.134	1.161
Fuel Value squared	0.120	2.229	32.811	0.260	45.380
Variance	0.004	0.120	1.708	0.001	2.040
Standard Deviation	0.059	0.347	1.307	0.024	1.428
Confidence Interval Width					0.290
Minimum Sample Size					90.036

11 North	I.B.2.N.d	0.048	0.305	2.428	0.166	2.781
11 East	I.B.2.N.d	0.032	0.304	0.000	0.159	0.336
25 North	I.B.2.N.d	0.064	0.000	0.000	0.046	0.064
25 East	I.B.2.N.d	0.095	0.000	3.630	0.137	3.726

BOWA plots
GEWA plots

Sum	0.238	0.609	6.058	0.508	6.906
Mean	0.060	0.152	1.515	0.127	1.726
Fuel Value squared	0.016	0.186	19.074	0.074	21.730
Variance	0.001	0.031	3.299	0.003	3.269
Standard Deviation	0.027	0.176	1.816	0.056	1.808
Confidence Interval Width					0.432
Minimum Sample Size					153.914

APPENDIX Q. ARCVIEW EXTENSION DEVELOPED BY FRANK KOCH

```
      Name: "USGS-NPS Sampling Tools v4.0"
      FirstRootClassName:     "PMenu"
      Roots:      2
      Roots:      6
      Roots:      8
      Roots:      10
      Roots:      12
      Roots:      13
      Roots:      14
      Version:    32
      About:      "Contains a set of tools for generating sample points
according to the USGS-NPS Vegetation Mapping Program protocol.\nVersion
4.0, 09/30/02"
      InstallScript:    15
      UninstallScript:  16
      ExtVersion: 3
)

(PMenu.2
      InternalName:     "USGS-NPS Tools"
      Help: "\n"
      Child:      3
      Child:      4
      Child:      5
      Label:      "&USGS-NPS"
)

(Choice.3
      Help: "Creates a table listing the number of sample points required
for each vegetation class, according to USGS-NPS Vegetation Mapping
Program protocol."
      Label:      "&Create Summary Table..."
      Click:      "USGS_NPS.SampleSummaryTable"
      Shortcut:   "Keys.None"
)

(Choice.4
      Help: "Creates a stratified random sample of the vegetation polygons
based on a USGS-NPS summary table.  The returned point theme is derived
from the polygon centroids."
      Label:      "&Stratified Random Sample..."
      Click:      "USGS_NPS.StratifRandomSampler"
      Shortcut:   "Keys.None"
)

(Choice.5
      Help: "Adds X and Y coordinates, along with additional data
collection fields, to a theme of sample points."
      Tag:  "XY"
      Label:      "&Add XY Coordinates & Attributes..."
      Click:      "USGS_NPS.SamplePtsAddXY"
```

```
      Shortcut:   "Keys.None"
)

(Butn.6
      InternalName:     "Sample Summary Table"
      Help: "Create Summary Table//Creates a table listing the number of
sample points required for each vegetation class, according to USGS-NPS
Vegetation Mapping Program protocol."
      Icon: 7
      Click:      "USGS_NPS.SampleSummaryTable"
)

(AVIcon.7
      Name: "Summarize2"
      Res:  "Icons.Summarize2"

)

(Butn.8
      InternalName:     "Stratified Random Sampler"
      Help: "Stratified Random Sample//Creates a stratified random sample
of the vegetation polygons based on a USGS-NPS summary table.  The
returned point theme is derived from the polygon centroids."
      Icon: 9
      Click:      "USGS_NPS.StratifRandomSampler"
)

(AVIcon.9
      Name: "BoxLargeDot"
      Res:  "Icons.BoxLargeDot"

)

(Butn.10
      InternalName:     "Add XY Coordinates"
      Help: "Add XY Coordinates & Attributes//Adds X and Y coordinates,
along with additional data collection fields, to a theme of sample
points."
      Icon: 11
      Click:      "USGS_NPS.SamplePtsAddXY"
)

(AVIcon.11
      Name: "XY"
      Res:  "Icons.XY"

)

(Script.12
      Name: "USGS_NPS.SamplePtsAddXY"
      SourceCode: "'This script is part of the USGS_NPS sampling tools
extension\n'It has been modified from simply adding x and y coordinate
fields \n'to creating an entire attribute table for field use\n'Frank Koch
```

```
original 5/04/01, modified 07/23/02\n\n'Make sure map units set to
meters\ntheView =
av.GetActiveDoc\ntheView.SetUnits(#UNITS_LINEAR_METERS)\n\n'Check if point
file was created using the USGS-NPS extension\ntheAnswer =
MsgBox.YesNo(\"Was the sample point file created with the other USGS-NPS
tools?\",\"Point File Origin\",TRUE)
\nIf (theAnswer = False) Then\n  MsgBox.Warning(\"Try the ArcView sample
script for adding X and Y coordinates instead.\",\"Sorry!\")\n  Return
Nil\nEnd\n\n'Check if theme is point\ntheThemeList =
theView.GetThemes\ntheTheme = MsgBox.Choice(theThemeList, \"Please select
the sample point theme:\", \"Select Point Theme\")\nIf (theTheme = Nil)
Then\n  Return Nil\nElseif ((theTheme.GetSrcName.GetSubName =
\"point\").Not) Then\n  MsgBox.Warning(\"Theme must be point.\",\"Point
Theme Only!\")\n  Return Nil\nEnd\n\n'Find fields and edit state
of the theme table\ntheFTab = theTheme.GetFTab\ntheFields =
theFTab.GetFields\nedit_state = theFTab.IsEditable\n\n'Make sure table is
editable and that fields can be added\nif (theFtab.CanEdit) then\n
theFTab.SetEditable(true)\n  if ((theFTab.CanAddFields).Not) then\n
MsgBox.Info(\"Can't add fields to the table.\"+NL+\"Check write
permission.\",\n    \"Can't add X,Y coordinates\")\n    exit\n
end\nelse\n  MsgBox.Info(\"Can't modify the feature table.\"+NL+\n
\"Check write permission.\",\"Can't add X,Y coordinates\")\n  exit\nend\n
\n'check if ID number field exists\nif (theFTab.FindField(\"Unique_id\") =
NIL) then\n  MsgBox.Warning(\"You must have a field labeled 'Unique_id' to
proceed.\",\"Sorry!\")\n  Return Nil\nend\n\n \n'Check if fields named
\"Field_x\" and \"Field_y\" exist\nx_exists =
(theFTab.FindField(\"Field_x\") = NIL).Not\ny_exists =
(theFtab.FindField(\"Field_y\") = NIL).Not\n\n'Overwrite previous
\"Field_x\" and \"Field_y\" \nif (x_exists or y_exists) then \n
MsgBox.Info(\"Existing X and Y coordinate fields will be
updated.\",\"Update Field_x, Field_y\"
)\nend\n\nif (x_exists) then\n
theFTab.RemoveFields({theFTab.FindField(\"Field_x\")})\nend\n\nif
(y_exists) then\n
theFTab.RemoveFields({theFTab.FindField(\"Field_y\")})\nend\n\n'Make new
\"Field_x\" and \"Field_y\" fields\nx = Field.Make
(\"Field_x\",#FIELD_DECIMAL,11,5)\ny = Field.Make
(\"Field_y\",#FIELD_DECIMAL,11,5)\ntheFTab.AddFields({x,y})\n\ntheFTab.Cal
culate(\"[Shape].GetX\", x)\ntheFTab.Calculate(\"[Shape].GetY\",
y)\n\n'Get table field names\ntheList = theFTab.GetFields\n'Check field
count\ntheCount = theList.Count\n'If there are an
y fields beyond shape, Unique_ID, Field_x, and Field_y, they may need to
be replaced\nIf (theCount > 4) Then\ntheAnswer2 = MsgBox.YesNo(\"Attribute
fields (other than the ID, X, and Y fields) may not be set up correctly
for data collection.\"+NL+\n\"Do you want to update the table, erasing
existing attribute information?\",\"Update attributes?\",TRUE)\n  If
(theAnswer2 = False) Then\n    MsgBox.Info(\"The attribute table will not
be changed.\",\"Exiting Table Update\")\n    'Return editing state to pre-
script running state
\n    theFtab.SetEditable(edit_state)\n    Exit\n  End\nEnd\n\n'Check the
existing fields, remove any redundant fields\nif
((theFTab.FindField(\"Elevation\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Elevation\")})\nend\n\nif
```

```
((theFTab.FindField(\"Canopy_closure\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Canopy_closure\")})\nend\n\nif
((theFTab.FindField(\"Aspect\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Aspect\")})\nend\n\nif
((theFTab.FindField(\"Major_species\") = NIL).Not
) then\n
theFTab.RemoveFields({theFTab.FindField(\"Major_species\")})\nend\n\nif
((theFTab.FindField(\"Comments\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Comments\")})\nend\n\nif
((theFTab.FindField(\"Sec_species\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Sec_species\")})\nend\n\nif
((theFTab.FindField(\"Date\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Date\")})\nend\n\nif
((theFTab.FindField(\"Field_form\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Field
_form\")})\nend\n\nif ((theFTab.FindField(\"Topo_des\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Topo_des\")})\nend\n\nif
((theFTab.FindField(\"Fld_form2\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Fld_form2\")})\nend\n\nif
((theFTab.FindField(\"Fld_form3\") = NIL).Not) then\n
theFTab.RemoveFields({theFTab.FindField(\"Fld_form3\")})\nend\n\n'Make new
fields\nelev = Field.Make (\"Elevation\",#FIELD_DECIMAL,9,3)\ncc =
Field.Make (\"Canopy_closure\",#FIELD_DECIMAL,19,3)\nasp = Field.Make
(\"Aspect\",#FIE
LD_CHAR,8,0)\nmsp = Field.Make (\"Major_species\",#FIELD_CHAR,45,0)\ncmts
= Field.Make (\"Comments\",#FIELD_CHAR,254,0)\nssp = Field.Make
(\"Sec_species\",#FIELD_CHAR,45,0)\ndt = Field.Make
(\"Date\",#FIELD_DATE,11,0)\nfldfrm = Field.Make
(\"Field_form\",#FIELD_CHAR,35,0)\ntopo = Field.Make
(\"Topo_des\",#FIELD_CHAR,20,0)\nfldfrm2 = Field.Make
(\"Fld_form2\",#FIELD_CHAR,11,0)\nfldfrm3 = Field.Make
(\"Fld_form3\",#FIELD_CHAR,11,0)\n\ntheFTab.AddFields({elev,cc,asp,msp,cmt
s,ssp,dt,fldfrm,topo,fldfrm2,fldfrm3})\n\n'Return editing state t
o pre-script running state\ntheFTab.SetEditable(edit_state)"
)

(Script.13
      Name: "USGS_NPS.SampleSummaryTable"
      SourceCode: "'This script is part of the USGS_NPS sampling tools
extension\n'Frank Koch 5/04/01\n\n'Make sure data is projected and in
meters\ntheView = av.GetActiveDoc\ntheChoice = MsgBox.YesNo(\"The data are
assumed to be projected and the map units in meters. Is this true?\",
\"Units must be meters!\", TRUE)\nIf (theChoice = False) Then\n
MsgBox.Warning(\"Please project the data as necessary before using this
application.\",\"Project and Retry\")\n  Return Nil\nElse \n
theView.SetUnits(#UNITS_LINEAR_METERS)\nEnd\n\n'User selects the ve
getation theme for summary of classes   \ntheThemeList =
theView.GetThemes\ntheTheme = MsgBox.Choice(theThemeList,\"Please select
the vegetation theme:\", \"Select Theme For Sampling\")\nIf (theTheme =
nil) Then\n  Return Nil\nEnd\n\n'Deactivate all themes except the
vegetation theme\nFor Each thm in theThemeList\n  If (thm.IsActive = true)
Then\n    thm.SetActive(false)\n
End\nEnd\ntheTheme.SetActive(true)\n\n'Check if theme is polygon\ntheFTab
```

```
= theTheme.GetFTab\ntheThemeShape = theFTab.GetShapeClass.GetClassName\nIf
(theThem
eShape = \"Polygon\") Then\n  theSelBitMap = theFTab.GetSelection\n
theSelBitMap.ClearAll\nElse\n  Msgbox.Warning(\"Vegetation must be a
polygon theme.\",\"Polygon Theme Only!\")\n  Return Nil\nEnd\n\n'Make sure
table is editable and that fields can be added\ntheFTabFields =
theFTab.GetFields\nedit_state = theFTab.IsEditable\n\nif (theFtab.CanEdit)
then\n  'Start editing\n  theFTab.SetEditable(True)\n  if
((theFTab.CanAddFields).Not) then\n    MsgBox.Info(\"Can't add fields to
the table.\"+NL+\"Check write permission.\",\n    \"Can't
 add summary data\")\n    Return Nil\n  end\nelse\n  MsgBox.Info(\"Can't
modify the feature table.\"+NL+\n  \"Check write permission.\",\"Can't add
summary data\")\n  Return Nil\nend\n\nMsgBox.Info(\"A field listing the
area of each polygon in hectares will now be added to the table.\",\"New
Area Field\")\n\n'Following code creates or overwrites hectares field,
adds area for each polygon\nhectares_exists =
(theFTab.FindField(\"Hectares\") = Nil).Not\n\nIf (hectares_exists) then
\n  If (MsgBox.YesNo(\"Overwrite existing fields?\",\"Hectar
es field already exists\", false)) Then\n      'Delete existing hectares
field\n      theFTab.RemoveFields({theFTab.FindField(\"Hectares\")})\n
End \nEnd  \n\n'Create new hectares field\nareaField =
Field.Make(\"Hectares\",#FIELD_DECIMAL, 15,
2)\ntheFTab.AddFields({areaField})\ntheFTab.Calculate(\"[Shape].ReturnArea
/10000\",areaField)\n'Stop editing\ntheFTab.SetEditable(False)\n\n'Select
the field that has the vegetation codes or categories\ntheFieldList =
theTheme.GetFTab.GetFields\ntheClassifField = MsgBox.Choice(theFieldList
, \"Please select the classification field:\", \"Select Field For
Sampling\")\nIf (theClassifField = Nil) Then\n  Msgbox.Warning(\"You have
just bailed out of the application!\",\"Application Terminated\")\n
Return Nil\nEnd\n\n'Create a file for saving summary table\ndef =
av.GetProject.MakeFileName(\"Class\", \"dbf\")\ndef = FileDialog.Put(def,
\"*.dbf\", \"Save the sampling summary table:\")\nIf (def = Nil) Then\n
Return Nil\nEnd\n\n'Summarize the vegetation theme\nnewVTab =
theFTab.Summarize(def, dBase, theClassifField, {areaField}
, {#VTAB_SUMMARY_SUM})\n\n'Find criteria fields(# of polygons, polygon
area) for USGS-NPS accuracy assessment protocol\ntheCount =
newVTab.FindField(\"Count\")\ntheArea =
newVTab.FindField(\"Sum_hectar\")\ntheCategory =
newVTab.FindField(theClassifField.AsString)\n\n'Make a new sample points
field\nnewVTab.SetEditable(True)\nSampleField =
Field.Make(\"Sample_pts\",#FIELD_DECIMAL, 15,
0)\nnewVTab.AddFields({SampleField})\n\n'Finds number of sample points
required for each vegetation category\n'Based on USGS-NPS Vegetation Mapp
ing Program criteria\nFor each record in newVTab\n  theC =
newVTab.ReturnValue(theCount, record)\n  theA =
newVTab.ReturnValue(theArea, record)\n  theCat =
newVTab.ReturnValue(theCategory, record) \n  If ((theC >= 30) and (theA >
50)) Then\n    theSampleSize = 30\n  Elseif ((theC >= 20) and (theC < 30)
and (theA > 50)) Then\n    theSampleSize = 20\n  Elseif ((theC > 30) and
(theA < 50)) Then\n    theSampleSize = 20\n  Elseif ((theC > 5) and (theA
< 50)) Then\n    theSampleSize = 5\n  Else \n    theSampleSize = theC\n
End
```

```
\nnewVTab.SetValue(SampleField,record,theSampleSize)\nEnd\nnewVTab.SetEdit
able(False)\n\nTableName = MsgBox.Input(\"The summary table will now be
added to the project. Please select a display name:\",\"Name the
Table\",\"Class Summary\")\n\n'Make the summary table window and add it to
the project\nClassTable =
Table.Make(newVTab)\nClassTable.SetName(TableName)\nav.GetProject.AddDoc(C
lassTable)\nClassTable.GetWin.Open"
)

(Script.14
      Name: "USGS_NPS.StratifRandomSampler"
      SourceCode: "'This script is part of the USGS_NPS sampling tools
extension\n'Frank Koch 5/04/01\n'\n'Updated to accomodate NCSU ArcPad-
based field collection\n'So includes field names specific to that
application\n'07/23/02\n'Further updated to deal with zero sample point
categories\n'07/31/02\n\n'Make sure map units set to meters\ntheView =
av.GetActiveDoc\ntheView.SetUnits(#UNITS_LINEAR_METERS)\n\n'User selects
the vegetation theme \ntheThemeList = theView.GetThemes\ntheTheme =
MsgBox.Choice(theThemeList, \"Please select the vegetati
on theme:\", \"Select Theme For Sampling\")\nIf (theTheme = Nil) Then\n
Return Nil\nEnd\n\n'Check if vegetation theme is polygon\ntheFTab =
theTheme.GetFTab\ntheThemeShape = theFTab.GetShapeClass.GetClassName \nIf
(theThemeShape = \"Polygon\") Then\n  theBitMap = theFTab.GetSelection\n
theBitMap.ClearAll\nElse\n  Msgbox.Warning(\"Vegetation must be a polygon
theme.\",\"Polygon Theme Only!\")\n  Return Nil\nEnd\n\n'User selects the
summary table\nTheDocList = av.GetProject.GetDocs\ntheTable =
MsgBox.Choice(TheDocList, \"Please select
 the summary table:\", \"Select Class Table\")\nIf (theTable = Nil) Then\n
Return Nil\nEnd\n\ntheVTab = theTable.getVTab\ntheFieldList =
theVTab.GetFields\n'Determine the number of records and which fields list
the vegetation category and the number of sample points\ntheCatFld =
theFieldList.Get(0)\nthePtsFld =
theVTab.FindField(\"Sample_pts\")\nNumberOfRows =
theVTab.GetNumRecords\n\n'Pick a file name for the sample point
shapefile\ndef = av.GetProject.MakeFileName(\"Sample\", \"shp\")\ndef =
FileDialog.Put(def, \"*.shp\", \"Desig
nate a shapefile for storing the sample points:\")\nIf (def = Nil) Then\n
Return Nil\nEnd\n'Create FTab for point file\nPointFTab =
FTab.MakeNew(def, Point)\n'Create an ID field\nidFld =
Field.Make(\"Unique_id\", #FIELD_DECIMAL, 5,
0)\nPointFTab.AddFields({idFld})\nShapeField2 =
PointFTab.FindField(\"Shape\")\n\n'Based on each row in the summary table,
select a subset of the vegetation theme's records \nFor Each row in
0..(NumberOfRows-1)\n\ntheC = theVTab.ReturnValue(theCatFld, row)\ntheP =
theVTab.ReturnValue(thePtsFld, row
)\n\nexpr = \"([\" + TheCatFld.AsString + \"] = \"\"\" + theC.AsString +
\"\"\")\"\n'Select the subset\ntheFTab.Query(expr, theBitMap,
#VTAB_SELTYPE_NEW)\ntheFTab.UpdateSelection\n'Export the subset to a
temporary shapefile\ntemp2 = theFTab.Export(\"temp2\".AsFileName, Shape,
true)\ntheNewTheme = FTheme.Make(temp2)\n'Create a bitmap for the new
theme\ntheNewBitMap = temp2.GetSelection\nTotalRecs =
temp2.GetNumRecords\n'Up to the number of required sample points, turn on
bits in the bitmap randomly\nsetbits = 0\nIf (theP > 0) Then\n w
```

```
hile (setbits < theP )\n  newnumber = Number.MakeRandom ( 0,  TotalRecs-
1)\n  theNewBitMap.Set(newnumber)\n  setbits = theNewBitmap.Count\n
end\nend\n\ntheShapeField = temp2.FindField(\"Shape\")\n\n'If the bit for
a particular polygon is turned on, find centroid of that\nFor each rec in
0..(TotalRecs-1)\n  If (theNewBitMap.Get(rec) = TRUE) Then\n    thePolygon
= temp2.ReturnValue(theShapeField, rec)\n    thePoint =
thePolygon.ReturnCenter\n    'Add point to the point shapefile\n
NewRecordNum = PointFtab.AddRecord\n    Poi
ntFTab.SetValue(ShapeField2, NewRecordNum, thePoint)\n  End \nEnd
\n\nEnd\n\nthePointCount = PointFTab.GetNumRecords\n\ntheList =
List.Make\n\nFor Each i in 1..thePointCount\n  theList.Add(i)\nEnd
\n\n'Add ID numbers for each point in the point shapefile\nFor Each record
in 1..thePointCount\n  curcount = theList.Count\n  randnumber =
Number.MakeRandom(0, curcount - 1)\n  IDnumber = theList.Get(randnumber)\n
PointFTab.SetValue(idFld, record-1, IDNumber)\n
theList.Remove(randnumber)\nEnd\n  \ntheBitMap.ClearAll\n'Add point theme
t
o the view and turn it on\nPointFTheme =
Ftheme.Make(PointFTab)\ntheView.AddTheme(PointFTheme)\nPointFTheme.SetVisi
ble(TRUE)\n\nMsgBox.Info(\"Please check the position of the centroid
points before calculating X and Y coordinates.\",\"Check The Points\")"
)

(Script.15
      Name: "Install"
      SourceCode: "'check if there's an active project\nIf (av.GetProject
= Nil) Then\n  Return Nil\nEnd\n\n'the SELF object for this script is the
extension\n'the first object added to the extension is the USGS-NPS
menu\n'the second object added  is the first new button\n'the third object
added is the second new button\n'the fourth object added is the third new
button\n\n'add the menu after all of the view's other menus\ntheMBar =
av.GetProject.FindGUI(\"View\").GetMenuBar\ntheMBar.Add(SELF.Get(0),
999)\n\n'add the button at the end of the v
iew's button bar\ntheButtonBar =
av.GetProject.FindGUI(\"View\").GetButtonBar\ntheButtonBar.Add(SELF.Get(1)
, 997)\n\n'add the button at the end of the view's button
bar\ntheButtonBar.Add(SELF.Get(2), 998)\n\n'add the button at the end of
the view's button bar\ntheButtonBar.Add(SELF.Get(3), 999)\n\n\n\n"
)

(Script.16
      Name: "Uninstall"
      SourceCode: "'check if there's an active project\nIf (av.GetProject
= Nil) Then\n  Return Nil\nEnd\n\n'get the menu bar in the current
project\ntheMenuBar = av.GetProject.FindGUI(\"View\").GetMenuBar\n\n'get
the button bar in the current project\ntheButtonBar =
av.GetProject.FindGUI(\"View\").GetButtonBar\n\n'remove the objects added
by the Install
script\ntheMenuBar.Remove(SELF.Get(0))\ntheButtonBar.Remove(SELF.Get(1))\n
theButtonBar.Remove(SELF.Get(2))\ntheButtonBar.Remove(SELF.Get(3))"
)
```