To the Graduate Council:

I am submitting herewith a thesis written by Pamela J. Nabors entitled "The Current Status and Potential Spread of an Invasive Exotic Species: Chinese Yam (*Dioscorea batatas*) in the Great Smoky Mountains National Park." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Kenneth H. Orvis, Major Professor

We have read this thesis
and recommend its acceptance:

Sally P. Horn

Carol P. Harden

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

THE CURRENT STATUS
AND
POTENTIAL SPREAD
OF AN
INVASIVE EXOTIC SPECIES:

CHINESE YAM (*Dioscorea batatas*)
IN THE
GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Pamela J. Nabors
May, 1996

ACKNOWLEDGMENTS

I am truly indebted to Dr. Richard Clements, Dr. Ed Clebsch, and Dr. Eugene Wofford for taking time to answer questions concerning the Chinese yam and the original Smoky Mountains Exotic Plant Survey. I am especially indebted to Dr. Richard Clements, whose previous time-consuming field work made this thesis possible.

I would like to thank the Great Smoky Mountains Conservation Association for granting me a Carlos C. Campbell Fellowship. Their financial support allowed me to complete the field work portion of this thesis. Thank you also to the GRSM Twin Creeks staff for their wonderful cooperation and help – especially Denise Williams, Keith Langdon, Chuck Parker, Tom Remaley, Melodie Kertis, and Kristine Johnson.

I express my gratitude to all my professors, secretaries, friends, family, and co-workers. Thank you to Dr. Ken Orvis, Dr. Sally Horn, and Dr. Carol Harden for guiding me through my graduate school years. I would not have made it without them. Thank you to other Geography department members, particularly Lisa Kennedy for letting me borrow reference material. Thank you also to members of the Pellissippi GIS Group, Tracy Jo Engel, and Douglas Hamilton Cain for providing me with emotional support and advice. And, of course, thank you to my family for encouraging me through to the end.

ABSTRACT

Field work is integrated with Geographic Information System (GIS) techniques to report the status, spread, and potential to spread of an invasive non-native plant species, the Chinese yam (*Dioscorea batatas*), in the Great Smoky Mountains National Park (GRSM). Field work results show that *D. batatas* primarily occurs in the lower elevations in areas of disturbance such as old homesites and the sides of roads, trails, and streams. Comparisons with earlier research conducted by Clements, Clebsch, and Wofford in 1987-1988 show that *D. batatas* has spread and continues to affect the herbaceous understory by shading or crowding. To determine potential spread, I developed a predictive computer model using IDRISI GIS software. This is the first known use of GIS to model the potential spread of an invasive plant species within the park. Results from the potential-spread model show that *D. batatas* sites in the northeastern region of GRSM have the highest potential for spread. Results are used to generate target site lists which aid in determining management strategies for *D. batatas* within the Great Smoky Mountains National Park. This approach of combining GIS analysis with field work investigation is recommended for future natural resource planning.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF TERMS

ARC/INFO - a Geographic Information System software package marketed by the Environmental Systems Research Institute (ESRI)

C - a computer programming language

ERDAS - a Geographic Information System software package produced by Erdas Inc.

ESRI - Environmental Systems Research Institute

GIS - Geographic Information System(s)

GRSM - Great Smoky Mountains National Park (official National Park Service abbreviation)

IDRISI - a Geographic Information System software package produced by Clark University (see Eastman, 1995)

NPS - National Park Service

SMEPS - Smoky Mountains Exotic Plant Survey conducted by Clements, Clebsch, and Wofford in 1987-1988

Chapter 1
INTRODUCTION

Exotic pests and diseases are affecting native ecosystems worldwide. Familiar examples in the United States include the gypsy moth, zebra mussel, kudzu, and chestnut blight. The cumulative effects of introduced species, air pollution, acid rain, and habitat fragmentation are rapidly changing our environment. Scientific research and public awareness are necessary to understand and mitigate such human induced stresses. The present study extends earlier research conducted on an invasive non-native plant species: the Chinese yam or cinnamon vine, *Dioscorea batatas* Dcne. Field work and GIS-based modeling techniques are used to report its status, spread, and potential for future spread within the Great Smoky Mountains National Park (GRSM).

Whether introduced intentionally or accidentally, invasive exotic species can disrupt the balance of native ecosystems, create human health hazards, or cause economic hardships. Innate aggressive behavior, the absence of pre-adapted natural predators, and lack of competition enable invasive exotic species to expand rapidly and outcompete native species. Such uncontrolled expansion can cause the decline or disappearance of native species as their space for living, eating, and reproducing dwindles. For example, approximately 80 European starlings (*Sturnus vulgaris*) were introduced into Central Park, New York in the late 1800's (Elton, 1977). The species multiplied so rapidly that within 60 years the alien had spread throughout the United States (Elton, 1977). As a consequence, the bluebird (*Sialia sialis*) and the yellow-shafted flicker (*Colaptes auratus*) have been largely displaced in the eastern United States (Cox and Moore, 1993).

At times, invasive species possess traits that are harmful to humans. Giant hogweed (*Heracleum mantegazzianum*), an introduced ornamental plant species, is rapidly expanding in Europe and Canada. The alien is not only displacing native plant species, but its phototoxic sap is causing serious cases of skin damage in humans (de Waal et al., 1994). Invasive exotic species can also take local human diseases to epidemic proportions. The African mosquito *Anopheles gambiae* caused major malaria outbreaks in Brazil in the 1930's. Approximately 20,000 lives were lost and over $2 million was spent before the outbreak could be controlled (Elton, 1977).

It only takes a single introduction by one person to cause severe damage. In 1884, a Floridian woman brought home a beautiful flowering plant from an exposition (Vietmeyer, 1975; Knight, 1993). The plant multiplied rapidly in her water garden and choked out her other plants, so she removed the invading plants and tossed them into the local canal (Knight, 1993). The species, known as the water hyacinth (*Eichhornia crassipes*), eventually clogged so many important transportation waterways that the state of Florida had to request disaster relief from Congress in 1897 (Vietmeyer, 1975). The water hyacinth continues to be a problem in Florida today.

Such introductions are made not only by individuals, but also by government and private organizations. The Animal and Plant Health Inspection Service (APHIS) is in charge of inspecting plants and animals before they are introduced into the United States. Since they only test for damage that may be caused to agriculture, many species are allowed to be introduced in the United States without ever being tested for their potential to damage native ecosystems (Williams, 1994). Kudzu (*Pueraria lobata*) was originally introduced by the U.S. government as a ground cover to prevent soil erosion. It is now commonly seen smothering trees and entangling power lines in the southeastern United States. Woodlot owners and farmers spend an estimated $100 million each year in attempts to control kudzu (Williams, 1994). Despite the damages they cause, many other invasive plant species such as purple loosestrife (*Lythrum salicaria*) and Japanese honeysuckle (*Lonicera japonica*) are allowed to be propagated and sold for profit by plant nurseries within much of the United States.

As one branch of our federal government is allowing the introduction of invasive species, another is trying to eradicate them. The National Park Service (NPS) was established in 1916 "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations" (Campbell, 1969). The spread of invasive exotic species is a direct threat to these goals. Our national parks are already pressured by many other problems such as air, water, and noise pollution; poaching; urban encroachment; increased usage; and underfunding. To assist in the endeavor to preserve our natural heritage, I have chosen the Great Smoky Mountains National Park (GRSM) as my research area.

SITE DESCRIPTION

THE REGION

The Great Smoky Mountains are a part of the eastern United States' Appalachian mountain system which stretches from Alabama northeast to Maine. Studies of the Appalachian region's three rock types — sedimentary, metamorphic, and intrusive igneous — indicate that these mountains were formed by folding and faulting and have since been eroded into the landforms we see today (Hunt, 1967; Redington, 1978; Raitz and Ulack, 1984; Espenshade, 1992). Precipitation generally averages 100 to 125 centimeters per year, and can reach over 250 centimeters per year near the border of North Carolina and Georgia (Redington, 1978; Raitz and Ulack, 1984; Espenshade, 1992). This contributes to the high density of rivers and small permanent streams in the landscape.

The abundance of water also fosters a great variety of plant life in the Appalachians. Redington (1978) has grouped the natural vegetation into three general categories:

1) Spruce-Fir Forest — found in the areas of cooler, more severe climate. Red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) dominate in the Northern and Central Appalachians, whereas red spruce (*Picea rubens*) and Fraser fir (*Abies fraseri*) dominate in the Southern Appalachians in the higher elevations and are considered to be climatic relics.
2) Northern Hardwood Forest — found in areas with less severe climate. Sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and beech (*Fagus grandifolia*) are dominants in association with eastern hemlock (*Tsuga canadensis*). Red maple (*Acer*

rubrum), eastern white pine (*Pinus strobus*), and black cherry (*Prunus serotina*) are also common.

3) Appalachian Oak Forest – considered a part of the Central Hardwood Forest. Various oaks (*Quercus* spp.) and hickories (*Carya* spp.) co-dominate with white ash (*Fraxinus americana*). Tulip tree (*Liriodendron tulipifera*), various pines (*Pinus* spp.), maples (*Acer rubrum, Acer saccharum*), hemlock (*Tsuga canadensis*), American basswood (*Tilia americana*), and black gum (*Nyssa sylvatica*) are also common.

In the Southern Appalachians, the Blue Ridge Province contains the highest peaks of the Appalachian mountain system. Mount Mitchell, North Carolina stands at 2,038 meters (6,684 ft.) and is the *highest* mountain in the eastern United States (King and Stupka, 1950; Redington, 1978; Raitz, 1984). Mount LeConte, Tennessee stands at 2,010 meters (6,593 ft.) and is the *tallest* mountain [largest difference between base and summit] in the eastern U. S. (Campbell, 1969; Kemp, 1995). Most of the highest mountain peaks east of the Mississippi River are located in the Great Smoky Mountains.

THE GREAT SMOKY MOUNTAINS NATIONAL PARK

The Great Smoky Mountains National Park (GRSM) is located on the border of Tennessee and North Carolina (Figure 1.1). The Great Smoky Mountains form the backbone of this unique national park (Figure 1.2). GRSM encompasses over 205,000 hectares in which elevations range from about 260 to 2,025 meters and 50% slopes are common (USDI, 1982; Campbell et al., 1992). The exaggerated relief causes temperatures to vary greatly. There is often a difference of 6°C to 8°C degrees (10°F to 15°F) between the lower and higher

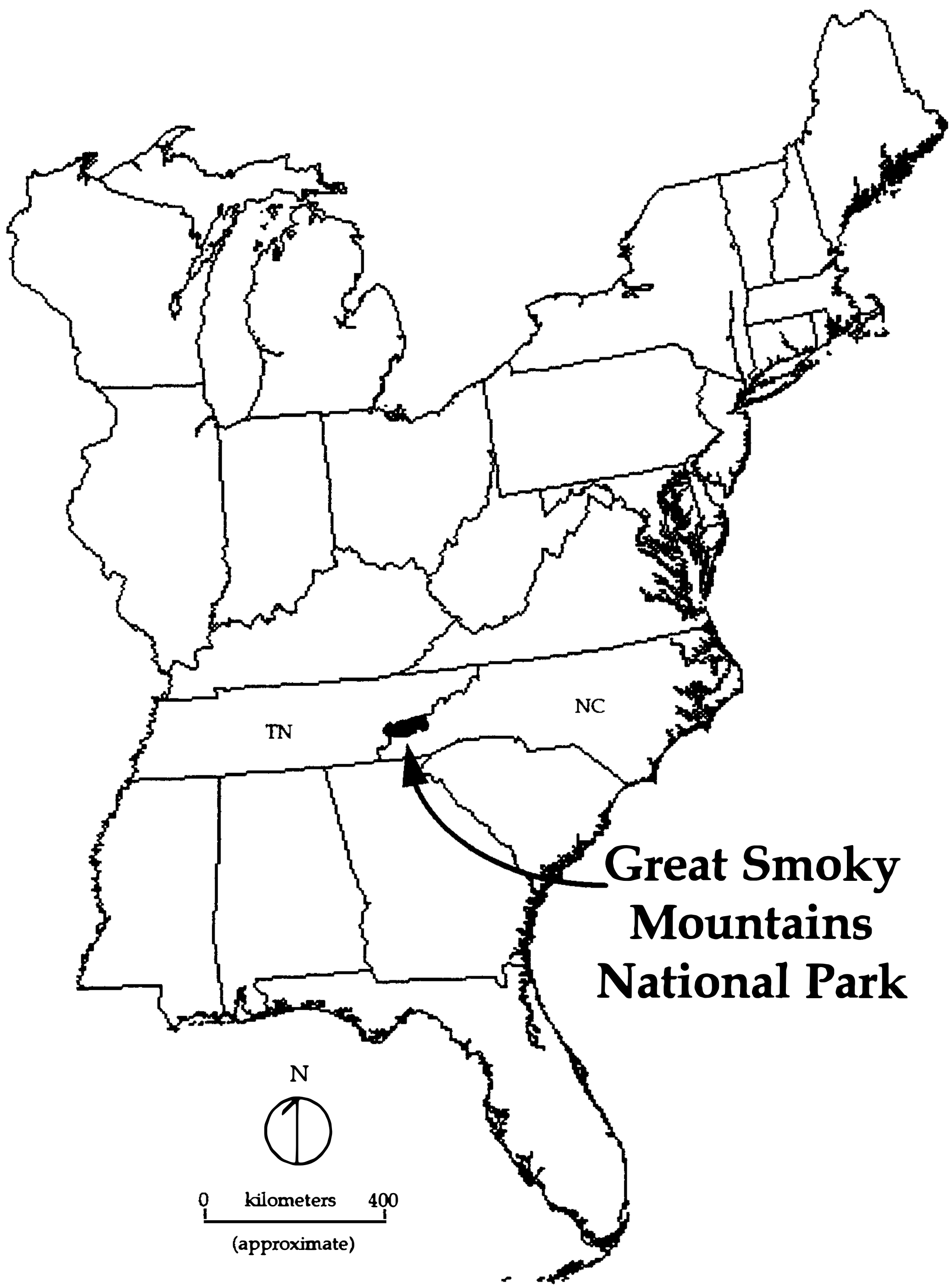


Figure 1.1: Location of the Great Smoky Mountains National Park
(Source: Data from GRSM and 1990 TIGER/Linefile™ Census Files)

GRSM Topography

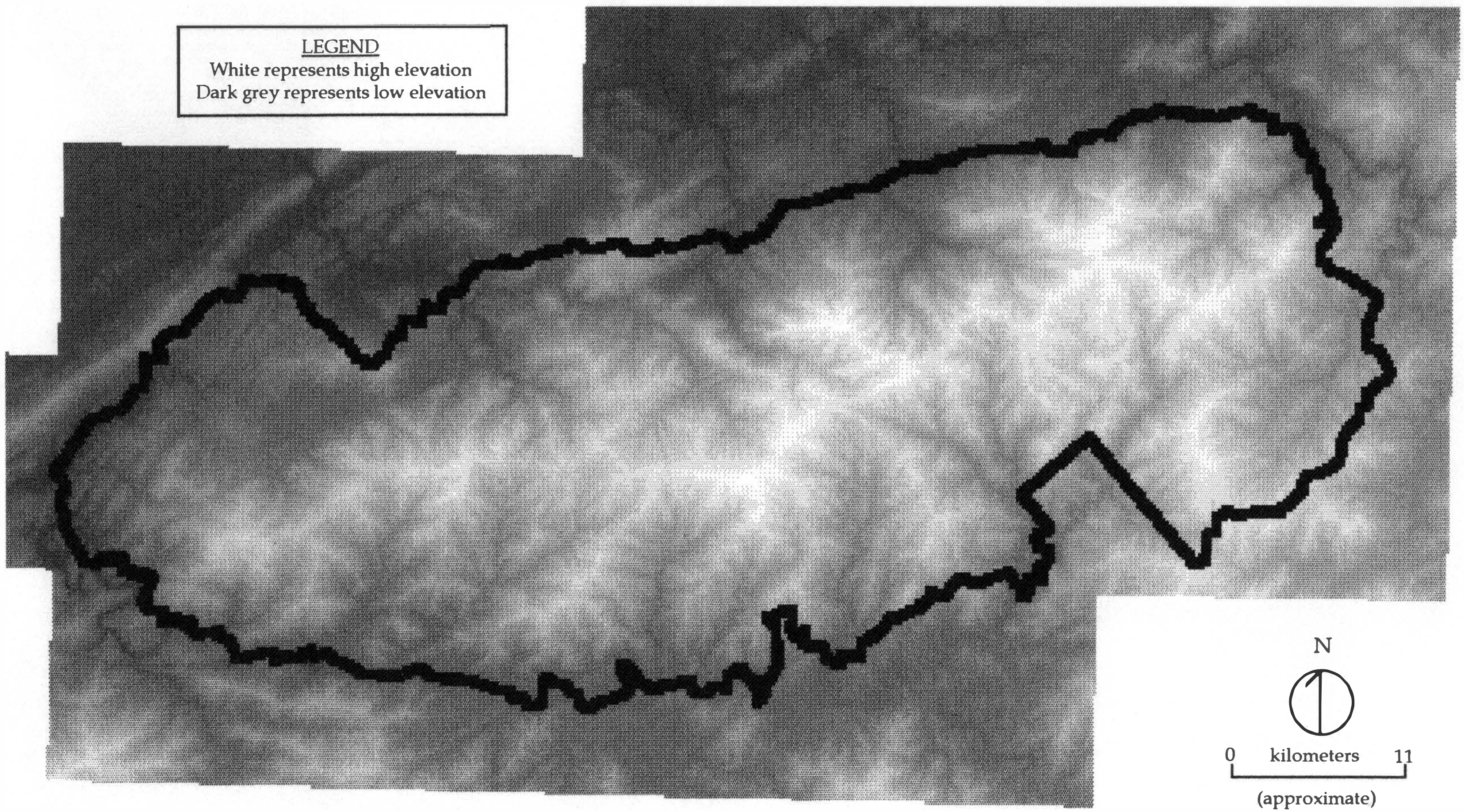


Figure 1.2: Topography of the Great Smoky Mountains National Park
(Source: Data from GRSM)

elevations, especially during the growing season (USDI, 1982). Gatlinburg, Tennessee, which is near the lower elevations of the park, has an annual mean temperature of 13.7°C (56.7°F), with an average maximum of 21.4°C (70.5°F), and a average minimum of 6.3°C (43.3°F) (USDI, 1982).

The topography also influences the amount of precipitation the park receives. One hundred twenty-seven centimeters (50 in.) a year are common in the foothills, but the summits sometimes receive more than 254 centimeters (100 in.) in a year (Campbell et al., 1992). Precipitation throughout GRSM averages 163 centimeters (64 in.) annually which translates into 1.89×10^{12} liters (890 billion gallons) per year (USDI, 1982). Approximately 3.37×10^{12} liters (500 billion gallons) are discharged as runoff in the complex drainage system (Figure 1.3) (USDI, 1982).

The geology of GRSM is also complex (Figure 1.4). Intrusive igneous rock can be found, but the majority of the park consists of metamorphic and sedimentary rocks. Shales, quartzites, and sandstones of the Ocoee Series have formed most of the soils within the park (USDI, 1982).

The variety of soils, temperature, topography, and abundance of water within the Great Smoky Mountains National Park (GRSM) has helped foster a wide variety of plant life (Figure 1.5). In fact, most vegetation types in the entire Appalachian mountain system are represented within the park (King and Stupka, 1950; Larson, 1990). GRSM possesses approximately 1,500 flowering species (Campbell et al., 1992; Kemp, 1995), and over 100 native tree species — which is more than all of Europe (King and Stupka, 1950; Matthews,

GRSM Streams

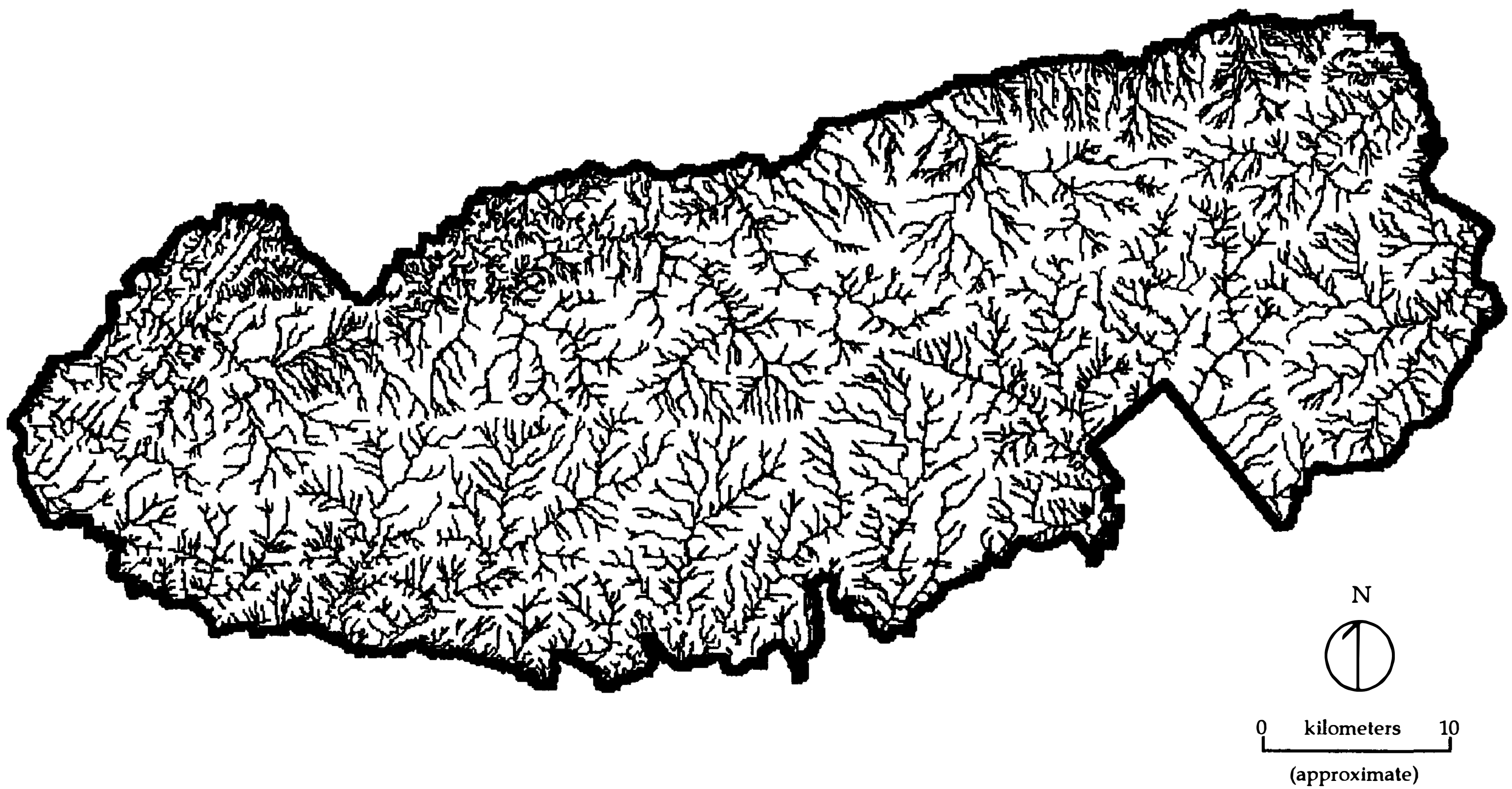


Figure 1.3: Streams of the Great Smoky Mountains National Park
(Source: Data from GRSM)

GRSM Geology

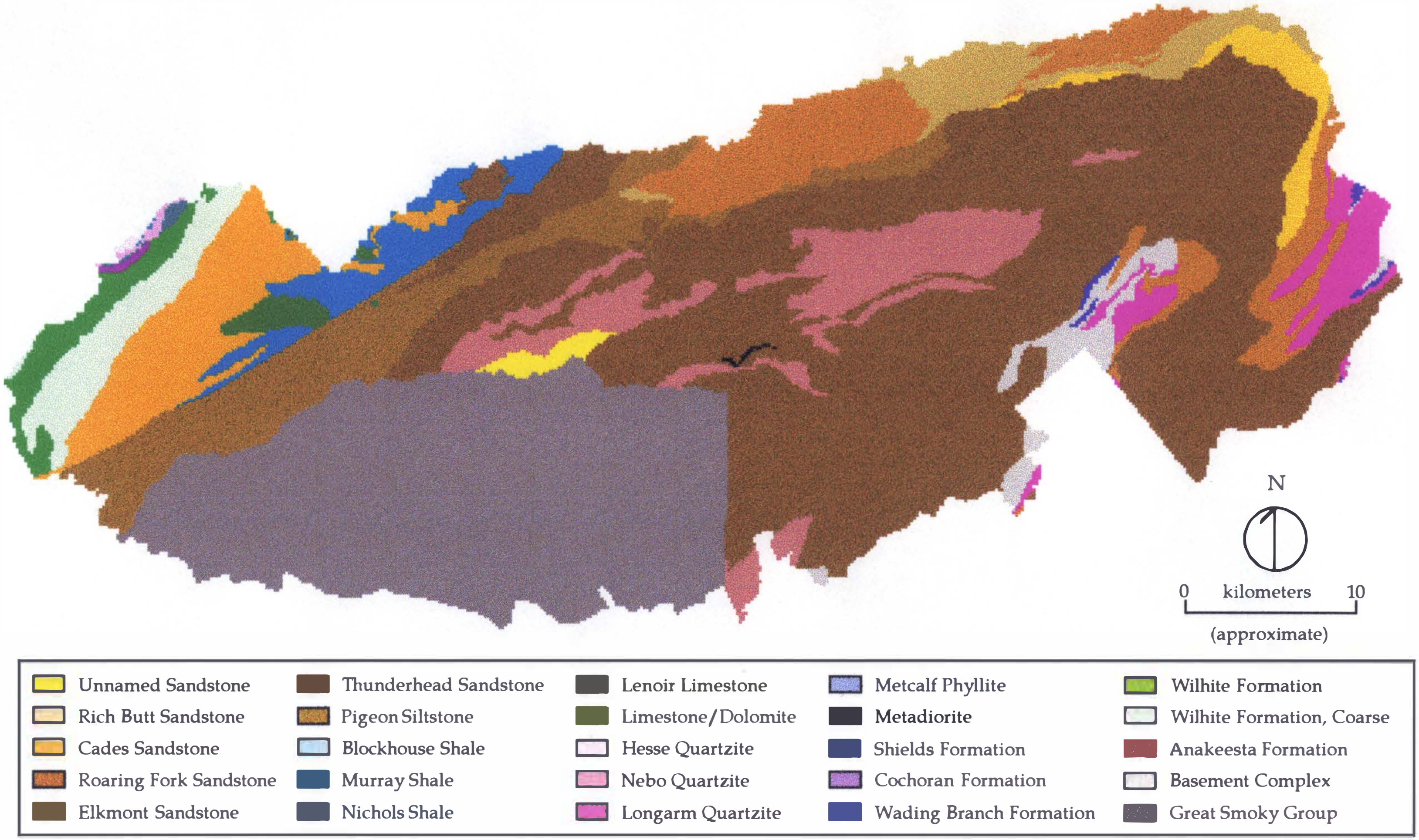


Figure 1.4: Geology of the Great Smoky Mountains National Park
(Source: Data from GRSM)

GRSM Vegetation

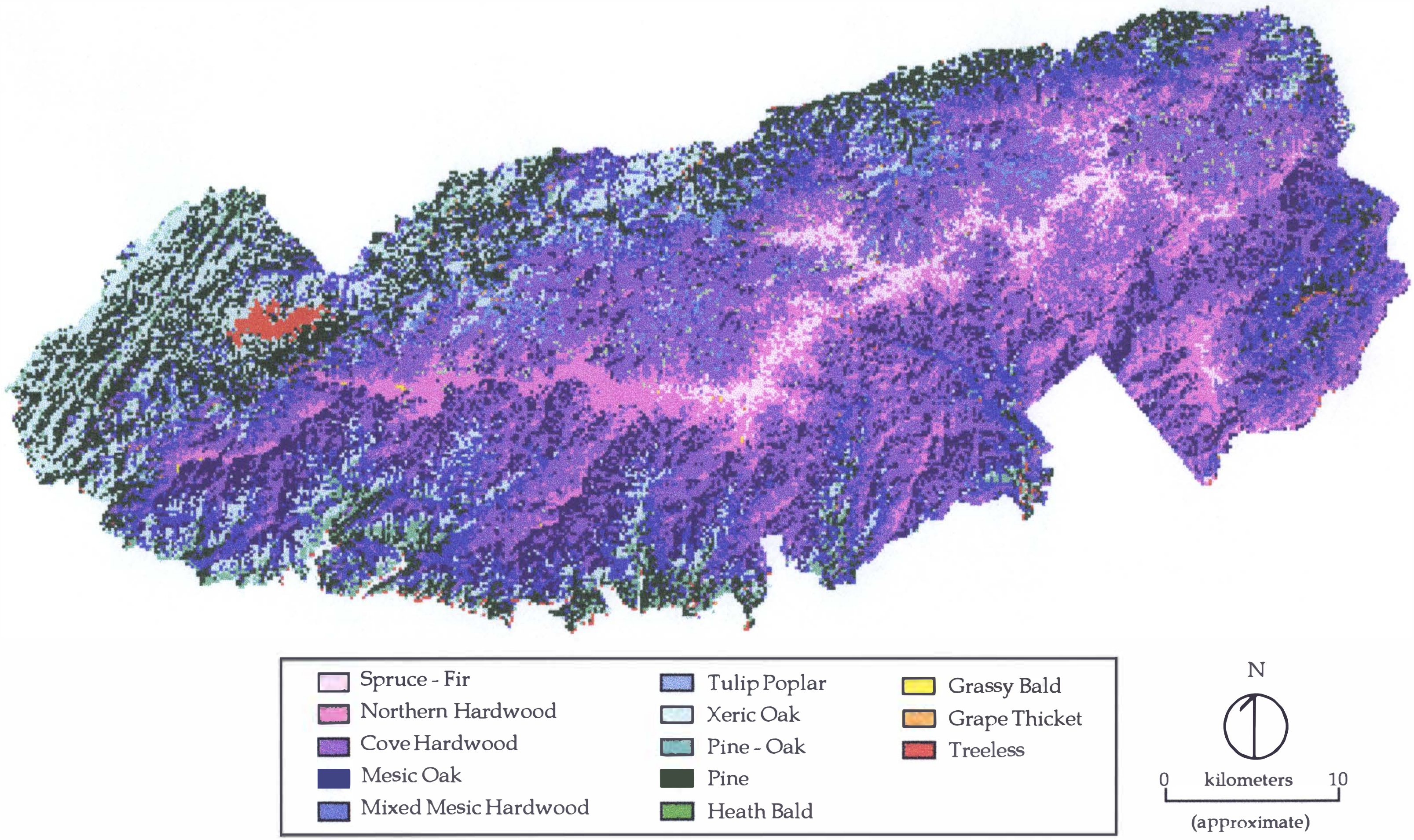


Figure 1.5: Vegetation of the Great Smoky Mountains National Park
(Source: Data from GRSM)

1973). About six percent of the GRSM flora are endemic to the Southern Appalachians, and at least three species are found only within the park (White, 1982). These many factors, along with the abundance of wildlife, have set the Great Smoky Mountains National Park apart as one of the world's finest examples of a temperate deciduous forest ecosystem.

It took considerable effort to preserve these virgin forests and surrounding areas. Previous to the establishment of the national park, all the land was privately owned, the majority by commercial lumber companies. Tracts of land had to be gradually pieced together in order to attain full establishment by Congress – which was not until 1934 (Campbell, 1969).

Although GRSM contains the most old growth forest in the eastern United States (over 41,000 hectares), it is not without a history of human disturbance. Beginning in 1880, many areas of the park were commercially logged (Figure 1.6) and fires were accidentally set during the logging process (Stupka, 1964; USDI, 1982). Other fires were also intentionally set by European settlers and possibly by Native Americans as part of subsistence farming and hunting (Stupka, 1964; Raitz and Ulack, 1984). As a result, many of the forests below 670 meters (2,200 feet) are regenerating after farming, logging, or burning (Baron et al., 1975).

Such disturbance increases the risk of invasion by non-native plant species. These species more readily establish and thrive where native vegetation has been cleared and gaps created in the canopy. In addition, humans facilitate introduction. Many exotic plants, including Chinese yam (*Dioscorea batatas*), were intentionally introduced by European settlers as food crops or ornamental plants before the park was established. The

GRSM Disturbance History

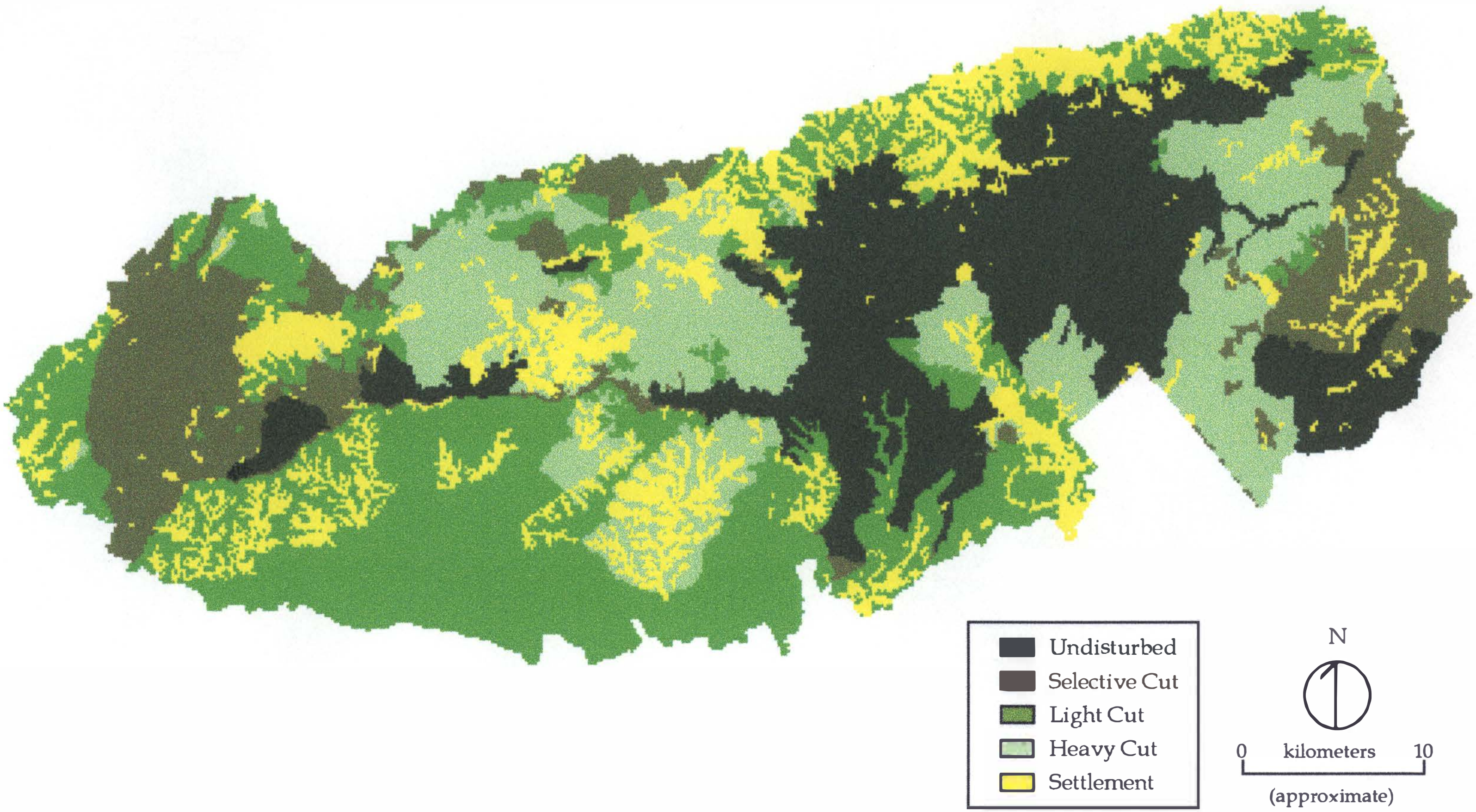


Figure 1.6: Disturbance History of the Great Smoky Mountains National Park
(Source: Data from GRSM, based on maps by Charlotte Pyle (1988))

construction of logging railroads and trails made more areas accessible to humans, thus increasing the risk of accidental introductions. Today, GRSM has approximately 1,370 kilometers (850 miles) of maintained trails (USDI, 1994), and a U. S. highway bisects the park (Figure 1.7). Almost nine million visitors use these roads and trails each year (Kemp, 1995). All these factors have placed the Great Smoky Mountains National Park at great risk from non-native plant species.

GRSM OBJECTIVES

Most of the objectives of the Natural Resources Management section of the Great Smoky Mountains National Park involve eradicating or controlling exotic plant species to keep them from spreading farther, especially into undisturbed areas. These objectives are listed below (USDI, 1981, p. 53):

1) To protect and perpetuate the significant and diverse natural resources and ecosystems found at Great Smoky Mountains National Park, keeping them as free as possible from the adverse influences of human intrusion, consistent with legislative and executive mandates and NPS policies.
2) To protect and, where possible, restore the natural processes as they would proceed if they had never been influenced by non-Indian society.
3) To ensure adequate protection for threatened or endangered species, critical habitat, and unusual or particularly vulnerable natural resources of the park, such as virgin forest, brook trout habitat, beech gaps, and outstanding cove hardwood stands.
4) To minimize, to the extent possible, the adverse impact of exotic plants (e.g., mimosa, kudzu, Japanese honeysuckle, tree-of-Heaven, and princess-tree) and animals (e.g., European wild boar, rainbow and brown trout) on the park's natural resources and processes.

GRSM Roads and Trails

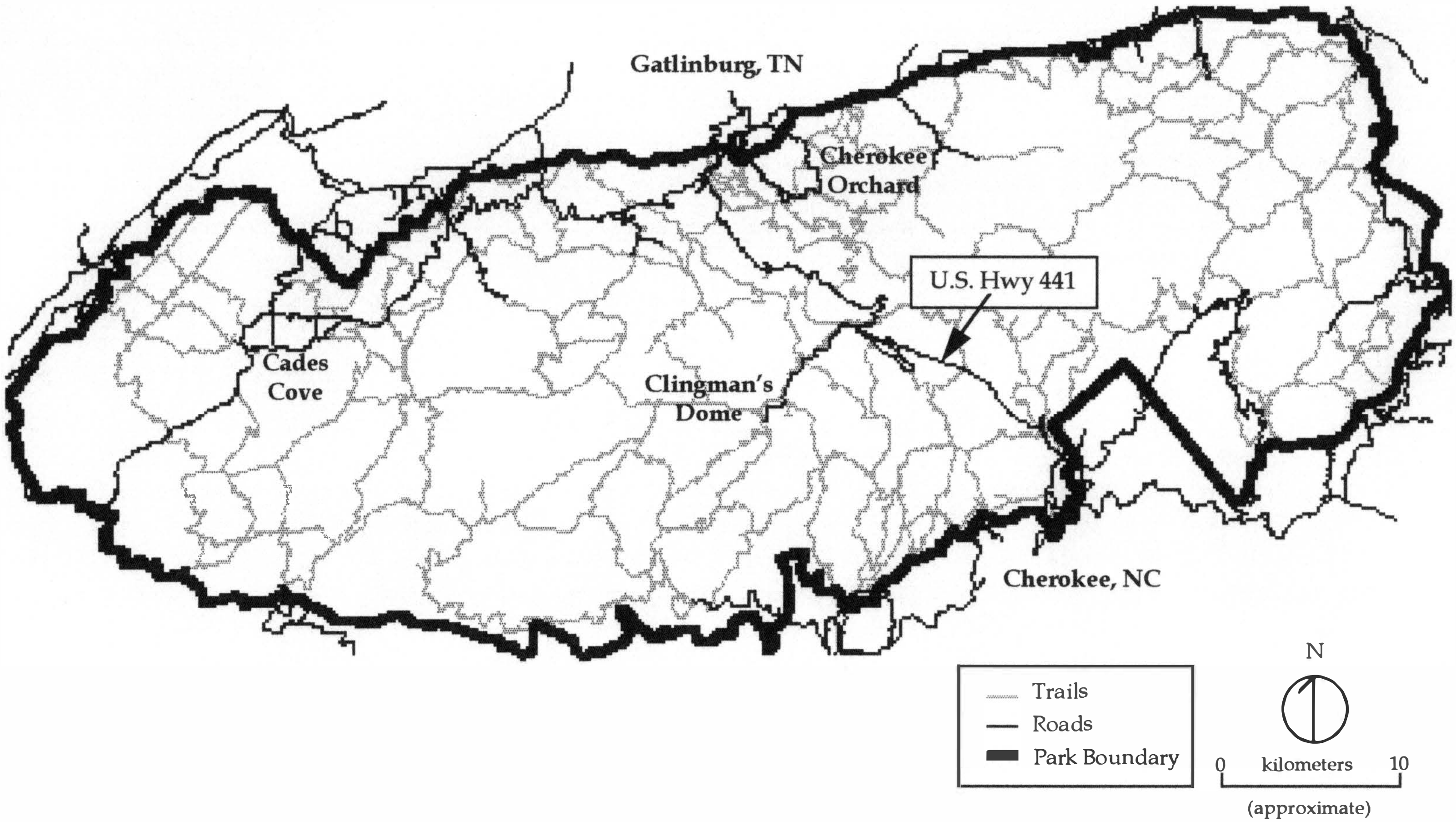


Figure 1.7: Roads and Trails of the Great Smoky Mountains National Park
(Source: Data from GRSM)

GRSM EXOTIC VINES

Four hundred exotic plant species (over 25% of the flora) are known to exist within GRSM (Hiebert and Stubbendieck, 1993). Twenty-nine of the problem exotic plants in the park were recently ranked according to NPS standards (Johnson et al., 1995). Almost one-fourth of these species were vines and are listed below (Johnson et al., 1995):

Chinese yam (*Dioscorea batatas*)
Climbing euonymus (*Euonymus fortunei*)
English ivy (*Hedera helix*)
Japanese honeysuckle (*Lonicera japonica*)
Kudzu (*Pueraria lobata*)
Oriental bittersweet (*Celastrus orbiculatus*)
Wisteria (*Wisteria floribunda*)

Vines are opportunistic species. They rely on other vegetation for structural support and grow rapidly in an attempt to outcompete the surrounding vegetation. For example, Japanese honeysuckle (*Lonicera japonica*) can grow 4.5 meters per year (Baron et al., 1975), and kudzu (*Pueraria lobata*) can grow 30 meters in a season (Haragan, 1991). Few studies have been conducted concerning the role of vines in the ecosystem (Gentry, 1991). Nonetheless, Hegarty et al. (1991) consider the ability of vines to invade forests to be closely related to the type and persistence of disturbances and the size and frequency of canopy gaps. There may be evidence of this relationship in GRSM since most human disturbance has been in the lower elevations (Baron et al., 1975), and most of the vines within GRSM occur only in the lower elevations (Johnson et al., 1995); but it may also reflect climate and edaphic factors.

All of the vines listed above are ranked as difficult to control (Johnson et al., 1995). Underground storage structures make the eradication of some species, such as *D. batatas* and kudzu, very labor-intensive. It takes about six years of repeated root grubbing and herbicide treatments to completely eradicate kudzu from a site (Langdon, 1993; Johnson, 1995). Other species are difficult to eradicate because birds disseminate the seeds throughout the park; examples include Japanese honeysuckle (*Lonicera japonica*) and oriental bittersweet (*Celastrus orbiculatus*).

Most species listed above were ranked as serious threats to GRSM native flora. Many of them kill trees, either by constricting, as with Japanese honeysuckle (*Lonicera japonica*) and oriental bittersweet (*Celastrus orbiculatus*), or by shading, as with kudzu (*Pueraria lobata*) and English ivy (*Hedera helix*) (Johnson et al., 1995). They also profoundly affect the ecology by dominating so that no other species can succeed them. The latter is the case of *D. batatas* in the understory. It often grows in large clumps, crowding out native herbaceous plants.

Botanists have varying opinions on the threat posed by *D. batatas* to other vegetation (Pyne, 1995). According to the National Park Service ranking system, *D. batatas* is one of the lesser threats within GRSM. However, in the Smoky Mountains Exotic Plant Survey, Clements et al. (1989) described *D. batatas* as having a severe impact on the surrounding flora.

THE SMOKY MOUNTAINS EXOTIC PLANT SURVEY

In 1987, GRSM staff contracted Richard Clements, Ed Clebsch, and Eugene Wofford to conduct a large scale survey of the many exotic plant species within the Great Smoky Mountains National Park. The present study extends their work.

The Smoky Mountains Exotic Plant Survey (SMEPS) established baseline information on 86 non-native plant species occurring in highly disturbed backcountry areas of the Great Smoky Mountains National Park (Clements et al., 1989). The backcountry surveys were based on maps provided by NPS employees. Priority was given to areas settled before the national park was established (Pyle, 1988). Exotic plants encountered while traveling to and from sites were also reported.

Materials used for SMEPS were: photocopied maps of designated backcountry areas, overlayed with old roads, railroads, buildings, and cemeteries; trail maps with watershed overlays; hiking trail and flora identification books. Herbarium specimens were occasionally consulted. A vehicle was provided and access was granted to all park service gated areas; therefore, as many sites as possible were visited by vehicle. The survey was conducted for 34 days from May through October in 1987, and for 27 days from May through July in 1988. Final products of SMEPS were as follows:

1. Final report accompanied by daily trip summaries (see Clements et al., 1989).
2. USGS 1:24,000 scale topographic maps showing areas surveyed and some sketches of large exotic populations.
3. Field sheets with location, area of infestation, status, and general distribution for each species encountered.
4. Computer database (dBASE III) created from field sheet data.

5. Computer generated maps for each species (approximate scale: 1 cm = 4 km)
6. GRSM Exotic Plant Manual containing photographs and brief descriptions (see Clements, 1988).
7. Herbarium specimens of most species; one for the GRSM herbarium and one for the University of Tennessee herbarium.

Clements and co-workers (1989) surveyed over 50 square kilometers within the park. The Oconaluftee/Smokemont watershed had the highest number of exotic occurrences (166), Roaring Fork/Cherokee Orchard ranked second with 102 occurrences, and Deep Creek was third with 100 occurrences. A total of 1,105 exotic plant occurrences were reported, which occupied over 1,500,000 square meters. Eight exotic species dominated 98% of the total affected area. These eight major problem species are shown in Table 1.1 (Clements et al., 1989).

Clements et al. (1989) reported *D. batatas* to be "rapidly expanding and severely impacting various habitats". *D. batatas* patch sizes (areal extent of infestation) were visually estimated. They recorded 125 *D. batatas* sites, as shown in Figure 1.8. Most occurrences were in the Cosby Creek, Deep Creek, and Roaring Fork drainages. The drainage basin with the highest total area covered by *D. batatas* was the Middle Prong of the Little Pigeon River. *D. batatas* occurred mostly at lower elevations near old homesites in alluvial areas.

OTHER SURVEYS

Other, less ambitious exotic plant surveys have been conducted in the Great Smoky Mountains National Park (see for example Baron et al., 1975), but SMEPS is the only known

Table 1.1: SMEPS Major Problem Exotics

Rank	Scientific Name	Common Name	Origin	Approx. Area (sq. m.)	Approx. % of Total
1	*Microstegium vimineum*	Japanese grass	Asia	738,480	48%
2	*Lonicera japonica*	Japanese honeysuckle	Asia	363,600	24%
3	*Lespedeza cuneata*	Cuneate bush-clover	Asia	175,640	11%
4	*Festuca elatior*	Tall fescue	Europe	88,420	6%
5	*Rosa multiflora*	Multiflora rose	Asia	71,510	5%
6	*Vinca minor*	Periwinkle	Europe	52,100	3%
7	*Dioscorea batatas*	Chinese yam	Asia	15,300	0.9%
8	*Hedera helix*	English ivy	Europe	11,050	0.7%

SMEPS Chinese Yam Sites (1987-1988)

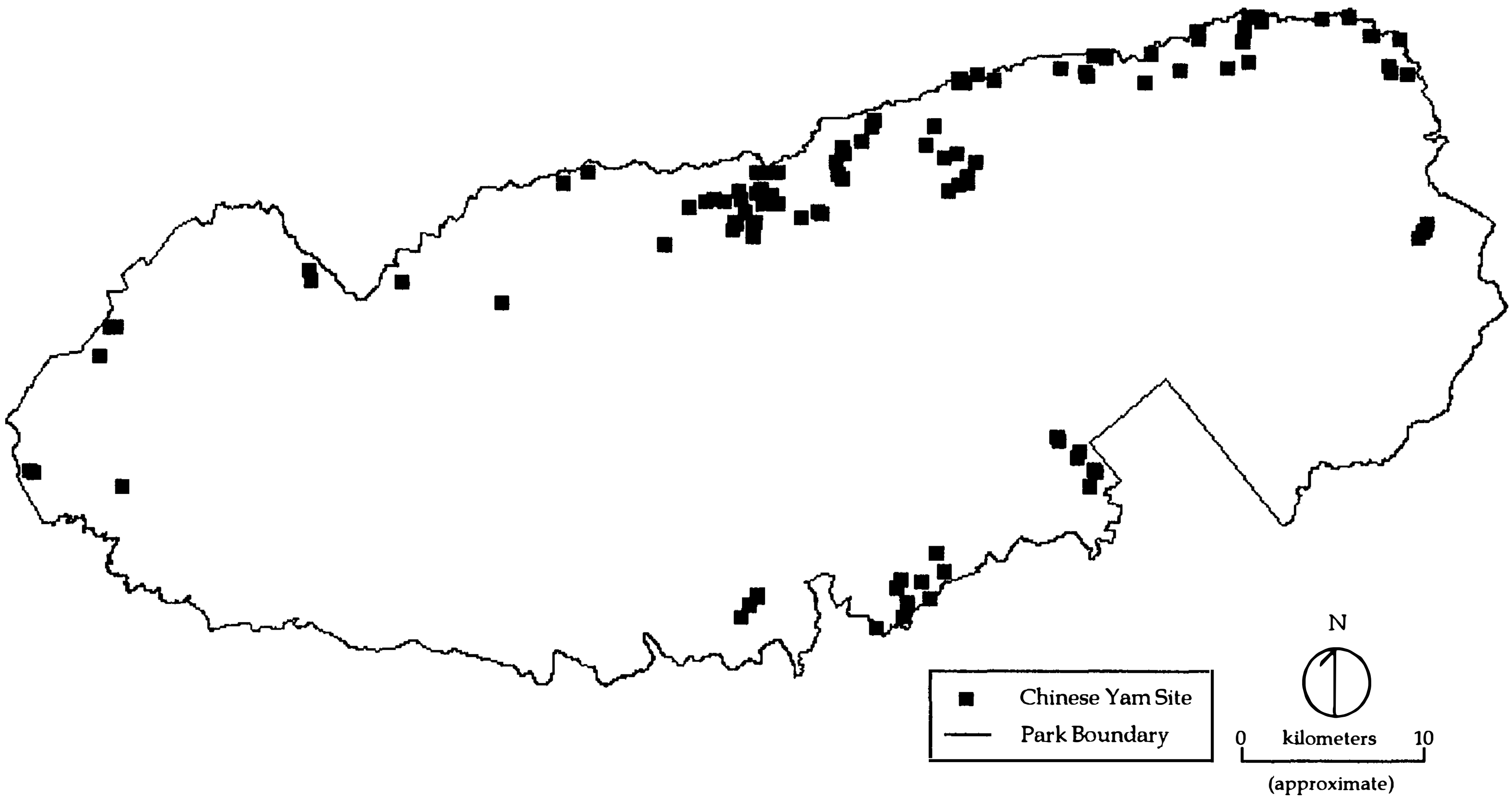


Figure 1.8: Location of Smoky Mountains Exotic Plant Survey Chinese Yam Sites within the Great Smoky Mountains National Park
(Source: Boundary Data from GRSM, Site Data from SMEPS)

large scale survey that has included *D. batatas*. Prior to the current study, the only other known documented *D. batatas* surveys were conducted by Kennedy and Nabors in the Fall of 1993. These were only three-day pilot studies, but they suggested that *D. batatas* populations identified during the Smoky Mountains Exotic Plant Survey had since spread (Nabors, 1993), and that *D. batatas* may be somewhat shade intolerant (Kennedy, 1993).

Although *D. batatas* was determined to be a serious threat by Clements et al. (1989), it has received little attention from park service employees because of lack of funding. However, Great Smoky Mountains National Park staff have recently acquired funding to eliminate or suppress as many of the aggressive exotics as possible in a three year period (Kemp, 1994). *D. batatas* is included as a target species.

STATEMENT OF PURPOSE

The two primary objectives of this study are to determine the current status and the potential spread of *D. batatas* within the Great Smoky Mountains National Park. Current status was determined by onsite reanalysis of as many of the original 125 Smoky Mountain Exotic Plant Survey sites as possible (this work is depicted as Phase One in Figure 1.9). Potential spread was determined through the use of a Geographic Information System as a vehicle for probabilistic modeling (Phase Two in Figure 1.9). Results from this study will aid in determining management strategies for *D. batatas* within the Great Smoky Mountains National Park. This is the first known use of GIS to model the potential spread of *D. batatas* (and possibly any plant species) in the Great Smoky Mountains National Park. The present model can serve as a prototype for future natural resource management computer models.

This thesis is organized into eight chapters. Chapters 1, 2, and 3 cover introductory material, including the natural history of yams and GIS fundamentals. Chapters 4 and 5 discuss data collection methods and results pertaining to the current status of *D. batatas* (Phase One). Chapters 6 and 7 discuss the spatial analysis methods and results pertaining to the potential spread of *D. batatas* in GRSM (Phase Two). Chapter 8 contains discussion and summary of the study as a whole.

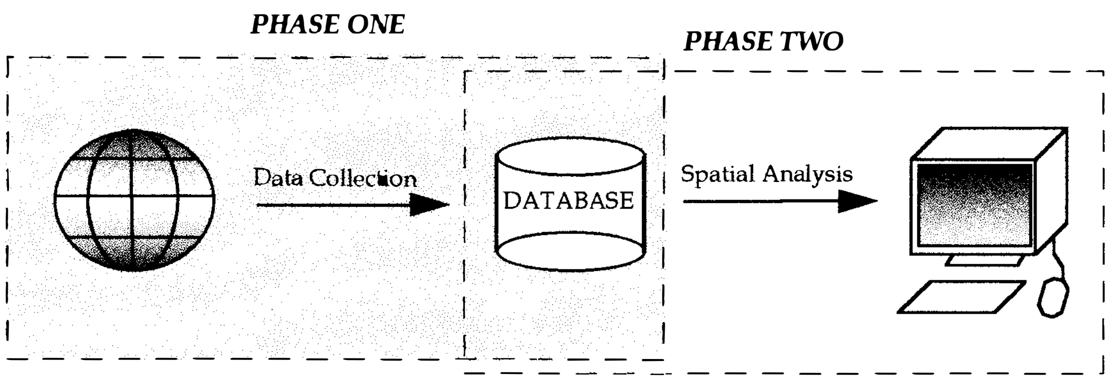


Figure 1.9: The Two Phases of This Study

Chapter 2
UNDERSTANDING YAMS

TAXONOMY

Much controversy surrounds the classification of yams. Scientists disagree on the subclass, order, subfamilies, genus, sections, and species (Al-Shehbaz and Schubert, 1989). It is generally agreed, however, that the species of the present study is classified as follows:

Subclass:	Monocotyledon
Family:	Dioscoreaceae
Genus:	*Dioscorea*
Section:	Enantiophyllum

A typical "yam" bought in an American grocery store is really a sweet potato (*Ipomoea batatas*), which is not a member of the yam family. The name "yam" is often misused in reference to other tropical edible tubers, as well (Coursey, 1967). The scientific term "yam," however, is generally used to describe members of the genus *Dioscorea*, and will be used as such in this study.

Confusion also surrounds the naming of some of the *Dioscorea* species native to the southeastern United States — *D. hirticaulis*, *D. quaternata*, and *D. villosa* — which may be found in the Great Smoky Mountains National Park (Al-Shehbaz and Schubert, 1989). Scientists often include *D. hirticaulis* with *D. quaternata* or *D. villosa* (Al-Shehbaz and Schubert, 1989; Kartesz, 1990), or simply use *D. villosa* in reference to all three (White, 1982;

Wofford, 1989). In any case, the common name for all three native taxa is wild yam (Gleason, 1968). Therefore, since the current study is only concerned with distinguishing the native species from the exotic species, the native yam species will be referred to as wild yam throughout this study.

There is also disagreement concerning the scientific name for the species of this study. Many researchers believe the name *D. batatas* Dcne. should not be used; the true scientific name should be *D. opposita* Thunb. (Steward, 1958; Coursey, 1967; Purseglove, 1992) or *D. oppositafolia* (Al-Shehbaz and Schubert, 1989; Kartesz, 1990). There is also a very similar species, *D. japonica*, which is much like *D. opposita*, and some taxonomists use the name *D. batatas* to describe the combination of *D. opposita* and *D. japonica* (Osagie, 1992). Kartesz (1990), whose work is recognized by GRSM staff, refers to the species of this study as *D. oppositifolia* and recognizes *D. batatas* as a synonym. GRSM Natural Resources Management personnel refer to the species as *D. batatas*; therefore *D. batatas* will be used here for consistency. The common names for *D. batatas* in the U. S. are Chinese yam and cinnamon vine.

BOTANY

D. batatas is a member of the genus *Dioscorea* which is the largest genus of the Dioscoreaceae family, with 600-850 species (Coursey, 1967; Al-Shehbaz and Schubert, 1989; Purseglove, 1992; Zomlefer, 1994). Most members of the genus are non-woody twining vines. Stems are renewed annually and grow rapidly — up to 15 centimeters per day (Coursey, 1967). Most yam vines need an object with a diameter of one inch or less to successfully twine (Coursey, 1967). Leaves may be alternate, opposite, or whorled, and are usually cordate (Al-Shehbaz and Schubert, 1989).

The majority of the species within the genus are dioecous (plants are unisexual). Although there is controversy about how to determine the sex of *Dioscorea* species, male plants are said to outnumber the female plants (Al-Shehbaz and Schubert, 1989; Purseglove, 1992). Flowers are small, plain colored (beige, green, or brown), nicely scented, and are borne in panicles, racemes, or spikes (Steward, 1958; Coursey, 1967; Al-Shehbaz and Schubert, 1989; Purseglove, 1992). Pollination is most likely accomplished by small night-flying insects (Coursey, 1967; Al-Shehbaz and Schubert, 1989; Purseglove, 1992). Seeds are usually lightweight and flat with three wings, which aid in wind dispersal (Steward, 1958; Coursey, 1967; Al-Shehbaz and Schubert, 1989). Al-Shehbaz and Schubert (1989) noted that the reproductive biology of *Dioscorea* is under-studied.

Al-Shehbaz and Schubert (1989) also stated that little is known about the ecology, cytology, or chemistry of the genus. Furthermore, Onwueme and Haverkort (1991) complained of a lack of data on water and nutrient limitations, solar radiation, measurements of leaf area, and proportion of ground cover. Surprisingly little is known for a genus of such economic importance.

The majority of members of the genus have underground tubers or rhizomes. A few have perennial underground tubers, some of which can grow up to 365 kilograms (Purseglove, 1992). Most of the more important food crop species, of which *D. batatas* is an example, have annually renewed underground tubers (Coursey, 1967). The previous year's tuber shrivels and decays during the active growing season (Coursey, 1967; Purseglove, 1992).

Some of the cultivars rarely flower or set fertile seed (Doku, 1982; Purseglove, 1992). Vegetative propagation is favored instead (Coursey, 1967). Some species form aerial tubers, or bulbils, on the vine which may be dispersed by water, including the ocean (van der Pijl, 1982). Such dispersal is especially promoted in habitats that are subjected to floods or rain washes (Al-Shehbaz and Schubert, 1989).

D. batatas is one of the species of *Dioscorea* which forms miniature aerial potatoes, or bulbils, in the leaf axils (Figure 2.1). Bulbils are produced from August to October and fall to the ground to sprout the following spring. This form of vegetative reproduction seems to be the main dispersal mechanism within the eastern United States. *D. batatas* rarely flowers in the United States and inflorescences seldom, if ever, mature. Seeds are not known from Tennessee (Underwood, 1965). Figure 2.2 shows the annually renewed underground tubers of a *D. batatas* specimen. The new season's tuber on the right has replaced the previous season's tuber on the left.

D. batatas leaves are usually opposite, but may sometimes alternate or occur in three-leaf whorls (Figure 2.3) on the same plant. Stems of *D. batatas* climb by twining from left to right (Figure 2.4).

Three basic characteristics make it easy to differentiate *D. batatas* from the native wild yams. Wild yams twine from right to left (Radford, 1981), the opposite direction of *D. batatas*. Native wild yams produce three-winged capsules as seeds (Figure 2.5), and they never produce aerial tubers on the vine.

Figure 2.1: Bulbils and Opposite Leaves of *D. batatas*

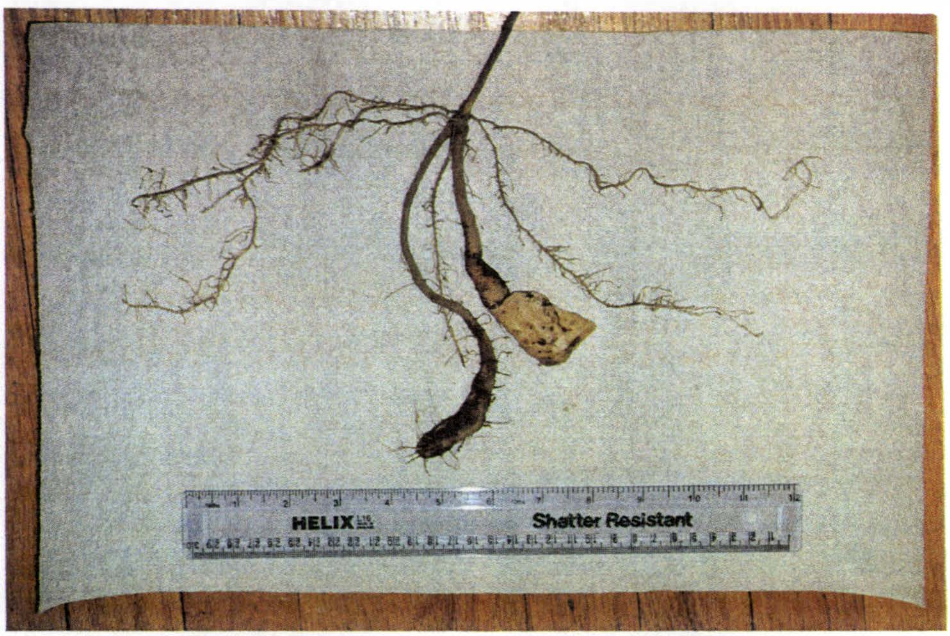


Figure 2.2: Underground Tubers of *D. batatas*

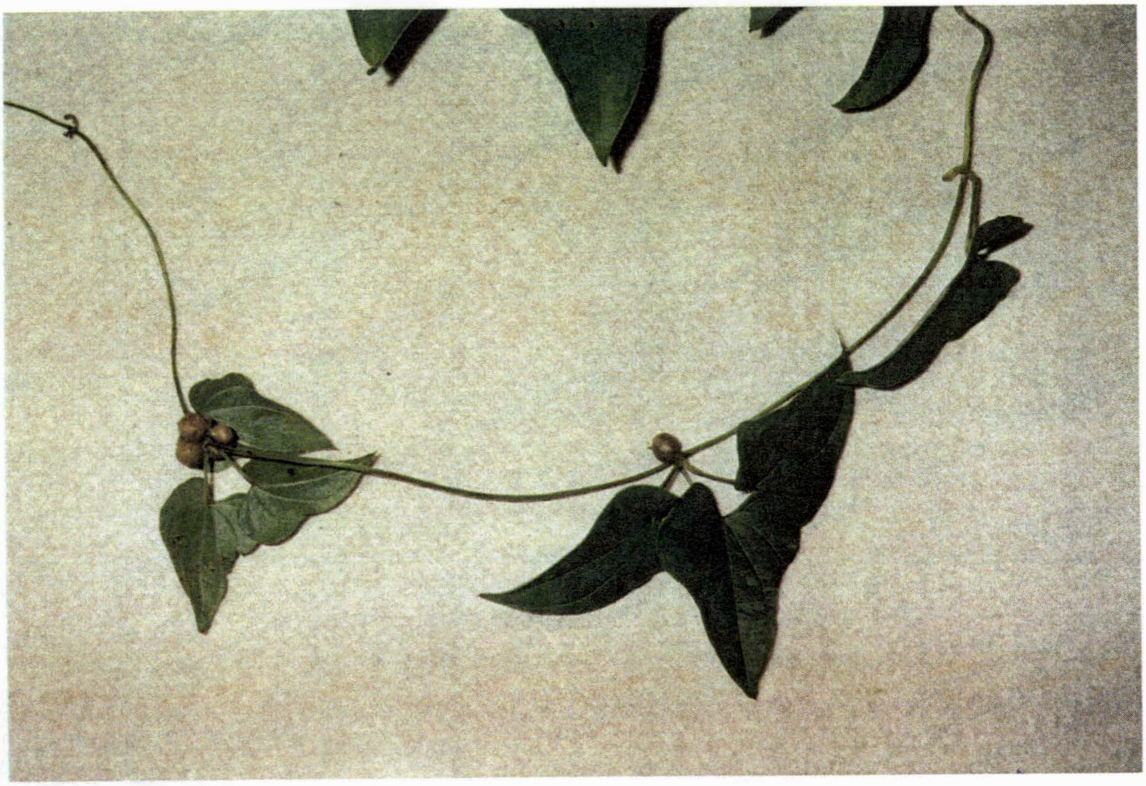


Figure 2.3: Three-Leaf Whorls of *D. batatas*

Figure 2.4: ***D. batatas*** **Twines from Left to Right**

Figure 2.5: Native Wild Yam with Three-Winged Capsules

NATURAL DISTRIBUTION

The genus *Dioscorea* is very diverse. The majority of members are tropical or subtropical; only a few are alpine or temperate (Coursey, 1967). The genus is represented by species on every continent except Antarctica (Al-Shehbaz and Schubert, 1989). This has led Coursey (1967) to believe the ancestors of the genus were widespread before the separation of Africa and America at the end of the Cretaceous period. According to Al-Shehbaz and Schubert (1989), the genus currently has approximately three indigenous species in the United States and Canada, 120 in Central America and Mexico, 130 in Brazil, three in Europe, 160 in Africa, four in Australia, and 250 in Asia. No *Dioscorea* species are native to both the Old and New Worlds (Al-Shehbaz and Schubert, 1989), and *D. bulbifera* is the only edible species that occurs wild in both Asia and Africa (Purseglove, 1992).

Habitats range from rain forest to savanna, and coastal plains to mountains (Coursey, 1967). The only limitations within the tropics seem to be swamps, deserts, and mountains with heavy frost (Coursey, 1967).

CLIMATE

Underground storage mechanisms help yams survive drought. Some species can withstand five months of drought and still complete their life cycle; others can only withstand two months (Purseglove, 1992). Rainfall is most important during the growing season when large amounts of water are necessary for tuber development (Coursey, 1967). Most *Dioscorea* species require over 1,000 mm of rainfall per year, but must have free-draining soil (Purseglove, 1992). Yams prefer deep, fertile, sandy loam soils and temperatures above 20°C (68°F) (Coursey, 1967; Purseglove, 1992). Growth rates increase with temperature, and photoperiodicity has been noted in some species (Coursey, 1967; Purseglove, 1992). Long days seem to favor vine growth and short days seem to favor tuber growth (Coursey, 1967; Purseglove, 1992).

HUMAN USES

FOOD AND FIBER

Edible yams are cultivated in the Caribbean, Asian and Pacific regions, and Africa (Coursey, 1967; Purseglove, 1992). About 20 million tons of yams are produced per year, mostly in West Africa (Purseglove, 1992). Edible tubers (underground or aerial) contain carbohydrates, protein, and vitamin C, making them an important staple food in West Africa.

Yams are mostly used as a subsistence crop. They are usually associated with slash and burn agriculture. Farmers clear and burn the land, grow crops for about two to four years, then abandon the land to revegetate. A few trees are left as support for the yam vines to climb, or stakes are provided. Purseglove (1992) noted that providing a means of support for the vines yielded larger tubers. Yam crops are propagated by tubers, bulbils, seeds, or pieces of tubers or stems (Al-Shehbaz and Schubert, 1989). According to Coursey (1967), if a tuber is harvested early in the growing season, sometimes another tuber replaces it which can be harvested again before the end of the season. Yams are usually grown in loose soil in mounds or trenches. If grown in a flat area, they must have soft, deep soil such as on a river floodplain. Because cultivating yams is so labor intensive and difficult to mechanize, yams are slowly being replaced by cassava (*Manihot utilissima* Pohl.), taros (*Xanthosoma sagittifolium* (L.) Schott.), sweet potatoes (*Ipomoea batatas* (L.) Poir.), potatoes (*Solanum tubersosum* L. and related spp.), and other less labor intensive crops.

About 50 species of *Dioscorea* are cultivated or collected from the wild for food, but only ten of them are of major importance (Al-Shehbaz and Schubert, 1989). *D. batatas* is one of the important food crops. It takes three years for *D. batatas* to reach a useful size. Harvesting may be very labor-intensive, since the underground tuber can grow up to one meter in length (Coursey, 1967). Currently, *D. batatas* is widely cultivated as a root crop in China, Korea, Taiwan, and Japan (Purseglove, 1992). It is not grown in Africa to any significant extent (Coursey, 1967).

A previous resident of GRSM reported that people may have eaten the underground tuber of *D. batatas* after boiling it (Ogle, 1995). She also implied that the aerial bulbils may be toxic, as are many members of the yam family. However, people have eaten bulbils directly from the vine with no side effects (Clebsch, 1995; Cruze and Cruze, 1995).

CHEMICALS

Many yam tubers or rhizomes contain chemicals that contributed to the naming of the family and genus after Pedanios Dioscorides. Dioscorides was a Greek physician and botanist from the first century who wrote *De Materia Medica*, one of the first books describing the medicinal uses of plants (Steward, 1958; Al-Shehbaz and Schubert, 1989).

Yams are known for their toxicity. Poisonous yam tubers can contain alkaloids, sapogenins, and tannins. They can be used in a variety of ways to benefit humans. The toxic alkaloids can paralyze the central nervous system (Al-Shehbaz and Schubert, 1989;

Purseglove, 1992), and are often used for hunting tigers, monkeys, or fish (Coursey, 1967). The sapogenins can be used for many medicinal purposes, especially oral contraceptives (Al-Shehbaz and Schubert, 1989; Purseglove, 1992). The tannins can be used for dye or tanning leather (Al-Shehbaz and Schubert, 1989). Yams have been used for a variety of products: insecticides, soap, livestock feed, coffee substitute, and childbirth pain killer; and processes: extracting starch, distilling alcohol, brewing beer, tattooing, and coloring ice cream (Coursey, 1967; Al-Shehbaz and Schubert, 1989). Extracts have also been said to "cure colic, dysentery, ulcers, syphilis, sore throat, swellings, pulmonary complaints, diarrhea, hemorrhoids, boils, tumors, corns, diabetes, cuts, superficial lesions, and hysteria" (Al-Shehbaz and Schubert, 1989, citing Hartwell; Karnick; Perry; Sastri; Watt and Breyer-Brandwijk).

Members of the section Enantiophyllum, which includes *D. batatas*, are non-poisonous and lack sapogenin (Al-Shehbaz and Schubert, 1989). Yet *D. batatas* must have useful chemical properties since its Chinese name means "domesticated mountain medicine" (Steward, 1958) and Purseglove (1992) said *D. batatas* was used medicinally in China. *D. batatas* is currently being studied for new chemical compounds.

ORNAMENT

Some yams such as *D. batatas* are grown as ornamental plants. Coursey (1967) noted that *D. batatas* was still being grown as a curiosity in some European gardens in the late 1960's. Gleason (1968) and Al-Shehbaz and Schubert (1989) state that *D. batatas* was used as an ornamental within the United States. Clements (1995) believes that this was its primary use by the previous residents of the Great Smoky Mountains National Park.

DISEASES AND PESTS

Coursey (1967) reported many diseases and pests of the genus *Dioscorea,* especially of cultivated yam crops. The following is a list of some yam fungal diseases (from Coursey 1967, p. 122):

Anthracnose:	*Glomerella cingulata* (Stonem.) Spauld. and Schrenk
Crown gall:	*Agrobacterium tumefaciens* (E. F. Sm. et Towns) Conn.
Leaf blight:	*Corticium solani* (Prill. et Del.) Bourd. et Galz.
Leaf spots:	*Cercospora annulata* Cooke *C. carbonacea* Miles *C. contraria* Syd. *C. cylindrata* Chupp et Linder. *C. dioscoreae* Ell. et Martin *C. pachyderma* Syd. *C. ubi* Raciborski *Colletotrichum capsici* (Syd.) Butl. et Bisby *Gloeosporium pestis* Massee *Mycosphaerella dioscoreicola* Sydow *Pestalotiopsis cruenta* (Syd.) Stey. *Phyllosticta dioscoreae* (Cooke) Cooke *P. dioscoreicola* P. Brun. *P. graffiana* Sacc. *Sclerotium rolfsii* Sacc.
Rust:	*Goplana dioscoreae* Cummins
Root rot:	*Armillaria mellea* (Vahl. ex Fr.) Kummer
Tuber rot:	*Botryodiplodia theobromae* Pat. *Fusarium oxysporium* Schlecht ex Fr. *F. solani* (Mart.) Sacc. *Penicillium sclerotigenum* Yamamoto *Rhizopus nodosus* Namyslowski *Rosellinia bunodes* (B. et Br.) Sacc. *Sphaerostilbe repens* B. et Br.
Witches' broom:	*Phylleutypa dioscoreae* (Wakef.) Petr.

Pests include yam beetles (*Heteroligus meles*, and *Crioseris livida*), yam weevils (*Palaeopus dioscorae*), mole crickets (*Gryllotalpa africana* Palisot de Beauvois), scale insects (*Aspidiella hartii*), and nematodes (*Scutellonema bradys, Meloidogyne* spp., and *Pratylenchus* spp.) (Coursey, 1967; Matsuura et al., 1985). Coursey (1967) also mentioned wild pigs and other root-eating animals as predators.

HUMAN INFLUENCE

Humans have greatly influenced the distribution of many yam species. Coursey (1967) believes that cultivation of yams originated separately in East Asia, Africa, and the western hemisphere. Evidence shows that Christopher Columbus referred to cultivation of *D. trifida* in the Caribbean at about the same time Pacheo Pereira noted cultivation of yams in West Africa. Adoption by seafarers aided in distributing yams around the globe. Yams have long storage times, and the vitamin C helped sailors avoid scurvy. The general trend was to transport Asian species to Africa, and African species to America. Many of the African species were introduced to America during the slave trade. Only one American species, *D. trifida*, was ever adopted for cultivation in the Old World (Ceylon).

According to Al-Shehbaz and Schubert (1989), there are currently six yam species growing in the southeastern United States. Three of these originated in Asia and are now naturalized weeds: *D. bulbifera, D. alata*, and *D. batatas* (Al-Shehbaz and Schubert, 1989). *D. bulbifera* was brought to the New World during the slave trade and is now a widespread weed in Florida, occurring in disturbed woods and thickets (Al-Shehbaz and Schubert, 1989). *D. alata* has been distributed by humans throughout the world as an edible cultivar.

Within the United States, *D. alata* has naturalized only in Florida (Al-Shehbaz and Schubert, 1989).

Al-Shehbaz and Schubert (1989) state that *D. batatas* has naturalized in Tennessee, Georgia, Alabama, North Carolina, South Carolina, and Arkansas. *D. batatas* also occurs in at least five other states (see Table 2.1), and has been reported as being a serious problem in Shawnee National Forest, Illinois (Langdon, 1993). Within the state of Tennessee, herbarium specimens have been collected for almost 30% of the counties (Chester et al., 1993).

D. batatas originated in China, and in the mid-1800's it was used in Europe [France, Germany, England, and Ireland] as an alternative crop to the potato (*Solanum tuberosum* L.) because of the potato blight (*Phytophthora infestans*) (Coursey, 1967). *D. batatas* was most likely introduced into the Smoky Mountains by European settlers (Langdon, 1993).

Table 2.1: National Parks in which *D. batatas* Occurs
(Source: Data from Quinn, 1996)

National Park Service Unit	State
Catoctin Mountain Park	MD
Chattanooga National Military Park	GA
Colonial National Historic Park	VA
Congaree Swamp National Monument	SC
Cumberland Gap National Historic Park	KY
Fort Donelson National Battlefield	TN
Friendship Hill National Historic Site	PA
Great Smoky Mountains National Park	TN-NC
Horseshoe Bend National Military Park	AL
Rock Creek Park	DC
Shiloh National Park	TN

Chapter 3
GIS FUNDAMENTALS

This chapter is intended for readers with little or no knowledge of Geographic Information Systems so that they may better understand Chapters 4 through 7. Although a standard definition of a Geographic Information System (GIS) has not been agreed upon among members of the GIS profession, the two definitions provided below by ESRI (the creators of ARC/INFO) are most appropriate for this study. A Geographic Information System is (ESRI, 1995):

> An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.

or more simply:

> A computer system capable of holding and using data describing places on the earth's surface.

The ability to analyze spatial relationships is what makes Geographic Information Systems unique and powerful tools. For example, a database might have the data fields listed in Table 3.1. We could sum the total area or query the database for non-spatial questions such as "Which plant groups are expanding?". But we could not ask spatial questions unless some locational data were added as in Table 3.2.

Table 3.1: Database Example

Plant Group	Area	Status
1	50	Expanding
2	10	Declining
3	500	Expanding

Table 3.2: Database Example with Locational Information

Plant Group	Area	Status	Latitude	Longitude
1	50	Expanding	35°45′	83°15′
2	10	Declining	35°30′	83°45′
3	500	Expanding	35°30′	83°30′

We could then ask the question "What other plant groups are within 30 kilometers of Plant Group 2?". A traditional mathematical method for solving the problem would be to:

1) Calculate the distance between Plant Group 2 and every other plant group in the list, 2) Convert the distance to kilometers, and 3) Report the plant groups having a distance of 30 kilometers or less.

With a GIS, however, solutions to spatial questions can be computed in a different manner. It is much easier to understand spatial relationships between objects by looking at a map. A GIS makes data visualization possible by taking the locational data from a database and creating a digital map. It is important to understand that maps are two-dimensional representations of real places. Cartographers and mathematicians have developed many "projections" for converting the earth's three-dimensional surface to a two-dimensional map surface (Figure 3.1). When using a GIS, it is not necessary to know the mathematics behind projecting from one surface to another; these capabilities are built into the GIS. But it is important to choose a projection that will place the data in an appropriate coordinate system. For this thesis I used a Universal Transverse Mercator (UTM) projection to place all data in a UTM coordinate system.

For our example, we would first create a digital map of the plant group locations from Table 3.2. If we project this plant groups map into a UTM coordinate space, all of the locations can then be represented in meters. We can now easily estimate a distance of 30 kilometers by creating a "buffer" of 30 kilometers surrounding Plant Group 2 (Figure 3.2). The computer can then determine whether plant groups fall inside or outside the buffer zone, and add this information to the database (Table 3.3). To answer the question: "What other plant groups are within 30 kilometers of Plant Group 2?", the computer can then simply select the data records other than Plant Group 2 that have the "Inside Buffer" field equal to "Yes". In our example, only Plant Group 3 would be reported.

The previous example was very simple and based on information from only one digital map. Geographic Information Systems provide the ability to solve more complicated problems by adding or "overlaying" other maps. If we overlay a streams map with the plant groups map (Figure 3.3), we can then determine the distance from each plant group to the nearest stream. With the addition of an elevation map layer (Figure 3.4), we can also estimate distance along the natural terrain surface instead of assuming a flat surface.

In a similar manner, buffering and overlaying techniques are used in this study to calculate the distance from each SMEPS site to the nearest stream. Also, data from an

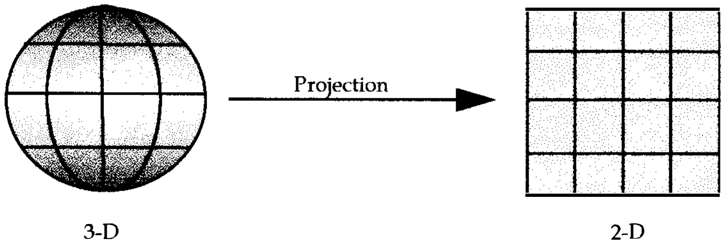


Figure 3.1: A Projection Converts a 3-D Surface to a 2-D Surface

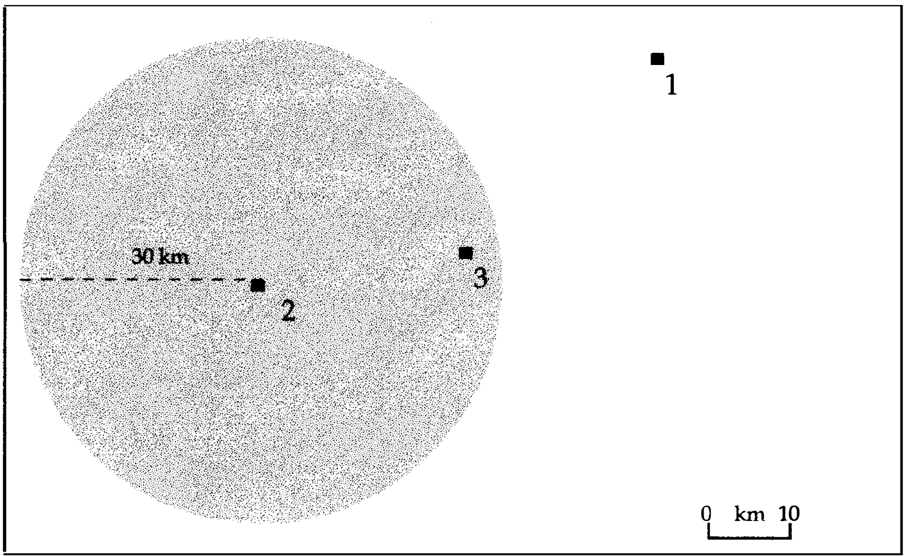


Figure 3.2: Example Map with 30 km Buffer

Table 3.3: Previous Database Example with the Added Buffer Field

Plant Group	Area	Status	Latitude	Longitude	Inside Buffer
1	50	Expanding	35°45′	83°15′	No
2	10	Declining	35°30′	83°45′	Yes
3	500	Expanding	35°30′	83°30′	Yes

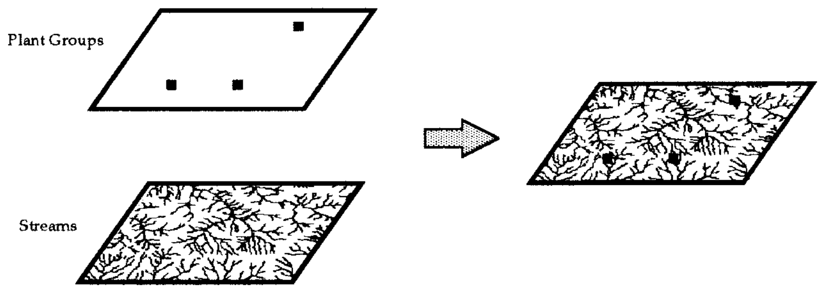


Figure 3.3: Map Overlay Example

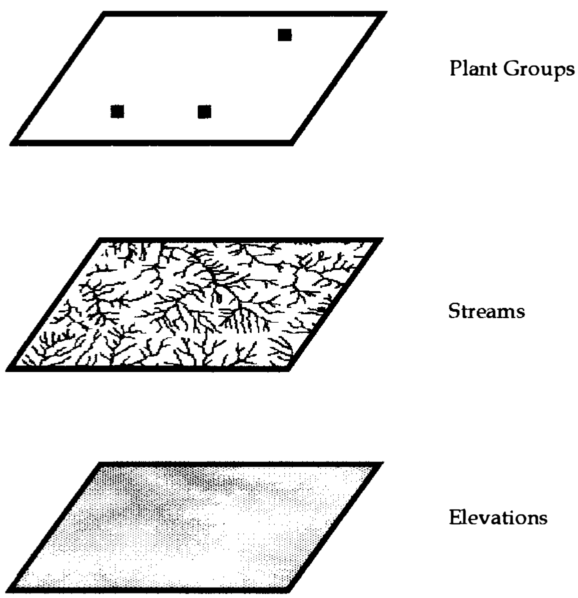


Figure 3.4: Additional Elevation Map Layer

elevation map layer are used to determine the distance and direction propagules would move across the terrain from a plant group starting location.

All Geographic Information Systems have the basic capabilities of buffering and overlaying, but some are specialized for certain types of spatial analyses. When trying to answer more complicated questions, it is important to select an appropriate GIS. To do this, it is essential to understand the two basic ways Geographic Information Systems represent map features.

Notice that in Figure 3.4 there are three different types of map features represented: points (plant groups), lines (streams), and a continuous surface (elevations). A GIS can represent these map features in two ways: "vector" format or "raster" format. With vector format, only the necessary coordinates are stored to form points, lines, or polygons. In Figure 3.5, the point feature would be represented as a single coordinate pair: (5,15); the line as: (10,12), (16,14) and (20,13); and the polygon as: (4,2), (7,6), (12,7.5), (13,5.5), (17,4), (16,2.5), and (4,2). Vector format saves disk storage space and is good for representing linear features such as streams.

Raster format is a grid based format. Each location in the coordinate system is represented as a grid cell with a value. When data is displayed, point values are used to "fill" their respective grid cells. The example in raster format would look like Figure 3.6, if it were sampled at a grid spacing of 1x1. Raster is much better suited for representing continuous data, such as elevation data or image data. Figure 3.7 is an example of how a raster elevation image would be stored, and one possible way to display it.

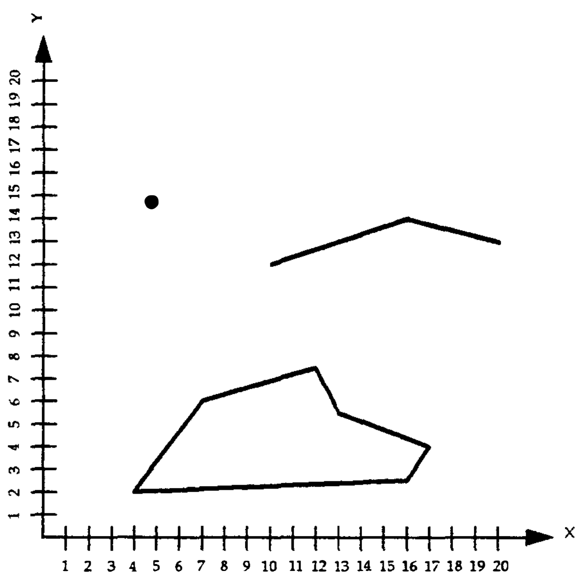


Figure 3.5: Vector Representation of a Point, Line, and Polygon

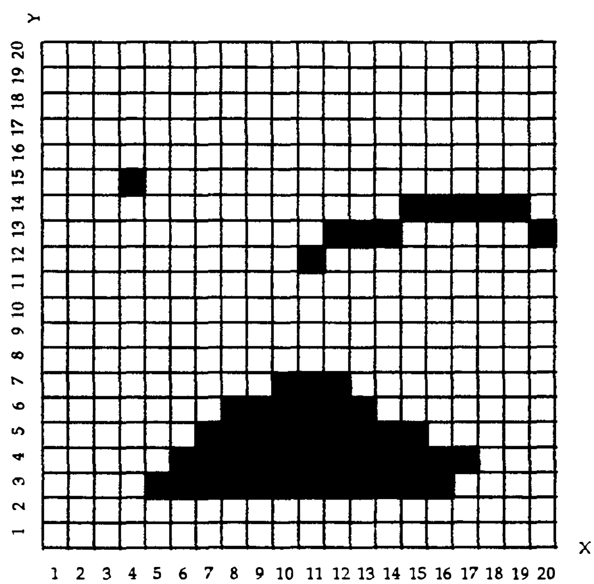
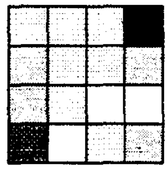


Figure 3.6: Raster Representation of a Point, Line, and Polygon

200	200	200	80
160	200	200	160
160	200	240	240
120	240	200	160

(a) Values



(b) Image

Figure 3.7: Raster Elevation Values and Image Example

Although most Geographic Information Systems provide both vector and raster capabilities, each GIS usually specializes in a particular format. For instance, ARC/INFO is mainly a vector based system, although it provides a separate module (GRID) for raster analysis. ERDAS and IDRISI are mainly raster based systems.

In my literature review I did not find a computer model suited for simulating the dispersal of plant seeds or propagules. Therefore, I designed the potential-spread model for *D. batatas* independently and implemented it using the available GIS tools. After reviewing some of these tools, I chose IDRISI as the most suitable. IDRISI is a simple, inexpensive GIS that possesses all the necessary capabilities for performing the required analyses (see Eastman, 1995). As a raster-based system, it contains many functions for manipulating continuous surface data (e.g., elevations). Of particular importance is the DISPERSE module (Eastman, 1993). DISPERSE allows computation of cost surfaces which are commonly used for modeling the spreading effect of phenomena such as fires or point source pollution. DISPERSE and other IDRISI functions are used in this study to simulate the spreading of *D. batatas* from known site locations.

Chapter 4
DATA COLLECTION METHODS

COLLECTION OF EXISTING DATA

The following data were obtained from the Great Smoky Mountains National Park Natural Resources Management personnel:

1. GIS map layers of streams, trails, and roads in ERDAS vector format (see Figures 1.3 and 1.7). GRSM employees had digitized 1:24,000 scale USGS topographic maps to obtain these map layers. Data were in Universal Transverse Mercator (UTM) Zone 17 coordinates.
2. Elevation data (see Figure 1.2) in ERDAS raster format. GRSM employees created these from USGS Digital Elevation Model data. All data were in UTM coordinates (cell size = 30m x 30m).
3. Smoky Mountains Exotic Plant Survey (SMEPS) daily field trip summaries and a list of the *D. batatas* sites from the SMEPS database. The database included the UTM coordinates, elevation, and estimated infestation area for 125 sites. (Other SMEPS materials exist but were unavailable.)
4. Other GIS data in ERDAS format were collected, but were not used in this study: geology (Figure 1.4), vegetation (Figure 1.5), and logging history (Figure 1.6).

MAPPING SMEPS SITE LOCATIONS

Two GIS software packages were used to locate and map the SMEPS sites. ARC/INFO was used for the Fall 1994 sites and IDRISI for the Summer 1995 sites.

Since ARC/INFO was readily available in the fall of 1994, the existing GIS data were reformatted from ERDAS to ARC/INFO. Having the data in ARC/INFO format also benefited GRSM personnel who had recently acquired ARC/INFO.

The ERDAS raster elevation data converted easily using a built-in ARC/INFO function. For the ERDAS vector data, however, it was necessary to write a C language reformatting program before the line feature data could be converted. Appendix A contains a listing of this routine. After converting the stream, trail, and road vector data, the UTM coordinates were used from the SMEPS site listing to generate an ARC/INFO map layer containing the site locations as point features. It was not necessary to reproject any map layers since all map layers were then in UTM coordinate space.

Next, the site, road, trail, stream, and elevation map layers were overlayed (Figure 4.1) within ARC/INFO on a Sun workstation. Referring to the map layers on the computer screen, I marked the site locations on photocopies of USGS 1:24,000 scale topographic maps for field use. These field maps were used in conjunction with the SMEPS daily field trip summaries to relocate SMEPS sites in the field.

Since IDRISI was to be used for the potential-spread modeling, a copy of IDRISI was purchased in the summer of 1995. All data were then converted to IDRISI format and stored on an IBM-compatible PC. IDRISI, instead of ARC/INFO, was used to create the field maps for the remaining Summer 1995 sites.

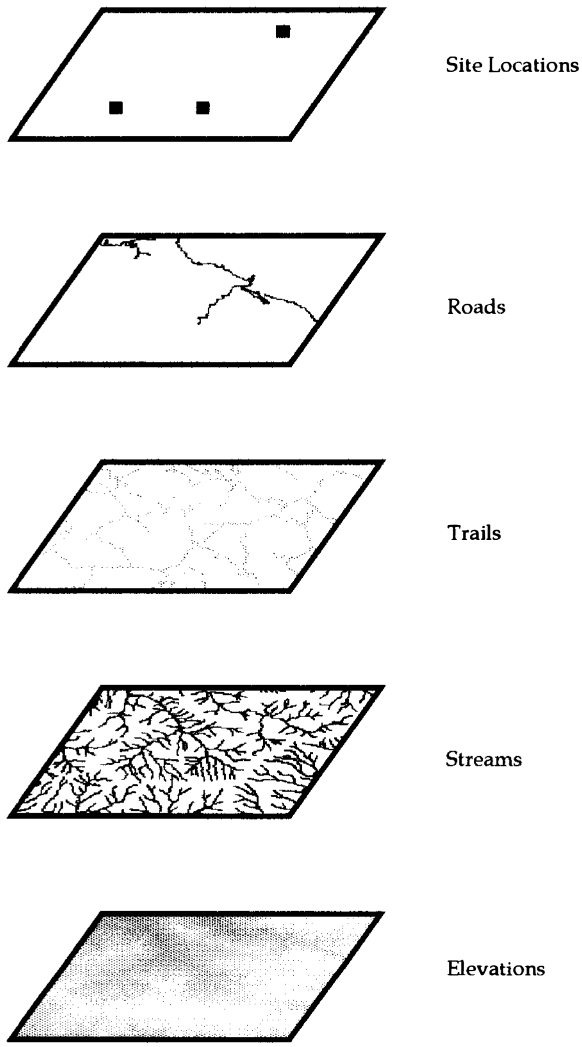


Figure 4.1: Map Layer Overlays

REVISITING SMEPS SITES

I relocated the original SMEPS sites using the field maps and a compass. Most sites were accessible by road or trail. I was less likely to revisit remote sites. Approximately 40% of the 125 sites were revisited in October 1994. The remaining sites were revisited from June through August 1995. In addition, I revisited a subset of sites periodically from October 1993 through September 1995 to note seasonal floristic changes.

The following sections discuss data collected at each site (see Appendix B for an example field data sheet). In addition, herbarium specimens were collected at a few sites and deposited in the herbaria of the University of Tennessee and GRSM.

LOCATION

I recorded directions to each revisited site and observations along the way. In the case of new sites, or if I found considerable discrepancy with the original SMEPS UTM coordinates, new coordinates were estimated. I also categorized each *D. batatas* site according to its disturbance zone location. These zones were previously determined by the GRSM Exotics Crew to aid in prioritizing exotic pest site locations (Remaley, 1994):

Zone 1) Boundary Areas,
Zone 2) Heavily Visited Areas, and
Zone 3) Backcountry Areas.

Boundary areas include roadsides and the national park boundary. These areas have the lowest priority because they have the highest rate of ongoing disturbance and are the most susceptible to continual exotic pest invasions. Heavily visited areas include locations with heavy visitor usage (subjectively determined). All other locations are considered backcountry areas and are the most important for maintaining a native flora and fauna free from exotic invasions. I used USGS topographic maps to estimate the disturbance zones for sites that I did not revisit. Sites for which this could not be determined were placed into an additional "No Data" category.

CONTINUED PRESENCE

If any *D. batatas* plants were found at a site, *D. batatas* was recorded as being "Present." If no plants were found a site, *D. batatas* was recorded as being "Absent." For sites that were not revisited or could not be positively identified, the presence of *D. batatas* was recorded as "Uncertain."

SURVIVAL

Procedures for ranking the survival status of *D. batatas* were adopted from Clements et al. (1989) with slight modification and the addition of a "No Data" category:

Category 0: No Data — no data were available.

Category 1: Declining/Not Establishing — populations that will not become established or plants that are declining.

Category 2: Persisting — populations that are persisting where they are presently established.

Category 3: Slowly Expanding — populations that are slowly expanding into surrounding areas.

Category 4: Rapidly Expanding — populations that are rapidly expanding into surrounding areas.

Survival status was subjectively determined by evaluating the number and density of single-leafed plants in the peripheral zone away from the central cluster of vines. I also examined *D. batatas* patch shapes to help determine whether a population was declining or expanding. According to Forman and Godron (1986), a convex shape is an indication of expansion, and a concave shape is an indication of decline. In some cases I consulted the area of infestation previously recorded by Clements et al. to determine whether the patch size had increased or decreased.

IMPACT

Procedures for ranking the impact of *D. batatas* on surrounding vegetation were adopted from Clements et al. (1989) with the addition of a "No Data" category:

Category 0: No Data — no data were available.

Category 1: No Observable Impact — "no observable impact on local habitats." I placed small populations with only single-leafed plants into this category.

Category 2: Low Impact — "low impacts on local habitats or floras." I placed populations with single-leafed plants and mostly non-climbing vines into this category.

Category 3: Moderate Impact — "moderate impact on local habitats and floras." I placed populations with many climbing vines into this category.

Category 4: Severe Impact — "severe impacts on local habitats and floras." I placed populations with heavy leaf density and many climbing vines into this category.

PATCH DENSITY

Since the density of leaves and stems strongly affected my estimates of the survival and impact of *D. batatas*, I recorded the *average* patch density at each site. Late in the study, I also recorded the *maximum* density. Categories for ranking the density of *D. batatas* patches were as follows:

Category 0:	No Data — no data were available.
Category 1:	Sparse — only a few plants.
Category 2:	Moderate Density — mature plants with seedlings.
Category 3:	Heavy Density — a very thick covering of leaves and stems.

Therefore, if most of a site had mature *D. batatas* plants with seedlings, and a few places were very thickly covered by *D. batatas* leaves and vines, then the *average* density was recorded as "Moderate" and the *maximum* density was recorded as "Heavy".

PATCH CONTINUITY

Since multiple groups of *D. batatas* plants existed at many of the SMEPS sites, I recorded the approximate separation between groups. The categories for ranking the continuity of *D. batatas* patches are as follows:

Category 0:	No Data — no data were available.
Category 1:	Discontinuous — at least three meters between groups of plants.
Category 2:	Relatively Continuous — less than three meters between groups of plants, but at least one meter.
Category 3:	Continuous — less than one meter between groups of plants.

PATCH SIZE

Once a population of *D. batatas* was found at a SMEPS site, the site was examined to find each patch boundary, and a general sketch was usually drawn. Due to the complexity of patch shapes, a gross approximation of the areal extent of infestation (patch size) was made by estimating a simple enclosing rectangle. In the fall of 1994, an approximate maximum width and length were paced and noted as shown in Figure 4.2. The methods used in the summer of 1995, however, gave a quicker and closer approximation of patch size. The width of each patch was visually estimated instead of paced, and patches more than about three meters apart were measured separately (Figure 4.3). Patches of vast size were mapped directly on the field map and patch dimensions were then estimated from the topographic map.

CANOPY

The openness of the tree canopy was subjectively determined using these general guidelines:

Category 0: No Data — no data were available.

Category 1: Open Canopy —few to no tree limbs were present above most of the *D. batatas* plants. (Slight to no shade.)

Category 2: Partial Canopy — branches were present above most of the *D. batatas* plants, but were not closely knit together.

Category 3: Closed Canopy —a dense tree canopy was present above most of the *D. batatas* plants. (Virtually no breaks in the canopy. Heavy shade.)

To better estimate light levels, a Gossen Luna Pro light meter was used in the Summer of 1995. Incident light readings were taken within patches of *D. batatas*. The average of these numbers was recorded as the "Inside Patch" light level for the site. Some readings were also taken outside the perimeter of *D. batatas* patches, where it was absent. The average was recorded as the "Outside Patch Perimeter" light level for the site.

NEAREST NEIGHBORS

I also recorded the presence of certain neighboring plant species when they occurred together with *D. batatas*. The following exotic plant species were noted when present: boxwood (*Buxus sempervirens*), Japanese grass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), periwinkle (*Vinca minor*), and roses (*Rosa* spp.). Three native vine species were noted when present: wild yam (*Dioscorea* spp.), Dutchman's pipe (*Aristolochia durior*), and hog peanut (*Amphicarpaea bracteata*). Scientific names follow Peter S. White (1982).

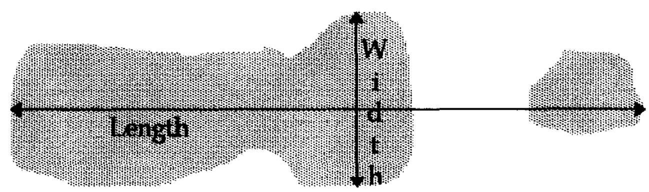


Figure 4.2: Example of Fall 1994 Patch Size Estimate

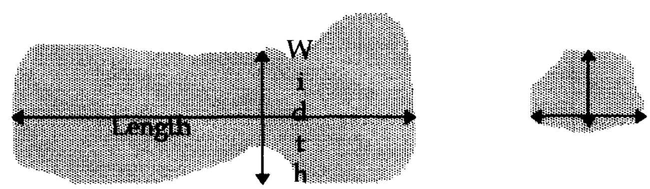


Figure 4.3: Example of Summer 1995 Patch Size Estimate

Chapter 5
DATA COLLECTION
RESULTS AND DISCUSSION

In the fall of 1994 and the summer of 1995, 78 of the original 125 sites were identified. It was difficult in some cases to determine whether the correct site had been relocated; 20 sites could not be positively identified and were labeled as "Uncertain" (Figure 5.1). The remaining 27 sites were not revisited because of time constraints, inaccessibility, or UTM coordinate errors. The following sections discuss the status of *D. batatas* at the revisited sites as well as some habitat and dispersal observations.

STATUS

CONTINUED PRESENCE

D. batatas is present at 77 of the 78 "Visited" sites (Table 5.1). However, it should be noted that if *D. batatas* was not found near a possible site location, the site was more likely to be recorded as "Uncertain". This contributed to the higher percentage marked as "Absent" among Uncertain sites. Even if we assume <u>all</u> the Uncertain sites are in fact the original SMEPS sites (which is highly unlikely), *D. batatas* would still be present at 85% of the revisited sites. Thus, *D. batatas* persists at a vast majority of the original SMEPS sites discovered in 1987-1988.

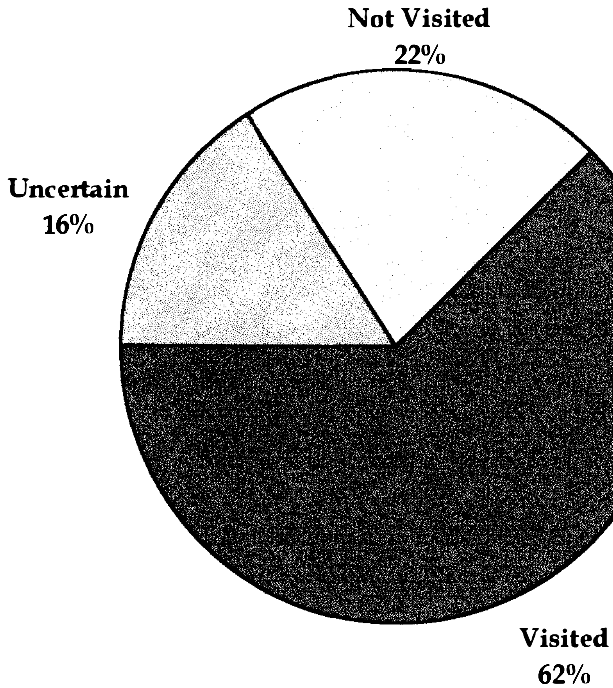


Figure 5.1: Percentage of SMEPS Sites Revisited in 1994-1995

Table 5.1 : Presence-Absence at Revisited Sites

	Visited	Uncertain	% Total
Present	77	6	85%
Absent	1	14	15%
Total	**78**	**20**	**100%**

SURVIVAL

Survival status results for *D. batatas* are shown in Table 5.2. Sixty-four percent of the Visited *D. batatas* populations are expanding, and at least 70 of the original 125 SMEPS populations are expanding or persisting.

IMPACT

The average impact of *D. batatas* on other plant species is shown in Table 5.3. Unlike many of the woody non-native vines, *D. batatas* does not strangle trees. It may, however, be a hindrance to the growth of young saplings. Their small diameter allows *D. batatas* to twine from the trunk to the top of the tree. The only mature trees *D. batatas* grows on are flowering dogwoods (*Cornus florida*) and eastern hemlocks (*Tsuga canandensis*). Unlike the reports of *D. batatas* growing 20 meters in the trees in Shawnee National Forest (Langdon, 1993), the highest level in GRSM is about 3.5 meters. Vines are usually under 2 meters. *D. batatas'* main impact comes from shading or crowding out other species in the herbaceous understory. Therefore, the situation shown in Figure 5.2 is considered severe impact.

PATCH DENSITY

The leaf density of *D. batatas* patches indicates the impact *D. batatas* has on surrounding vegetation as well as its survival and dispersal patterns. In cases of heavy leaf density (Figure 5.3), *D. batatas* may exclude other species by shading. Heavy leaf density at the ground level is usually a sign of heavy stem density, and hence the crowding out of other ground level flora.

Long vines produce more bulbils; therefore *D. batatas* sites tend to have heavier leaf and stem densities where the plants can find support for climbing. Figure 5.4 illustrates the

Table 5.2 : Survival Status at Visited Sites

	# of SMEPS Sites	% Total
Rapidly Expanding	20	26%
Slowly Expanding	30	38%
Persisting	21	27%
Declining or Not Establishing	5	6%
No Data	2	3%
TOTAL	78	100%

Table 5.3 : Impact on Other Plant Species at Visited Sites

	# of SMEPS Sites	% Total
Severe Impact	16	21%
Moderate Impact	33	42%
Low Impact	24	31%
No Observable Impact	3	4%
No Data	2	2%
TOTAL	78	100%

Figure 5.2: Severe Impact of *D. batatas*

Figure 5.3: Heavy Leaf Density of *D. batatas*

Figure 5.4: ***D. batatas*** **Climbing Flowering Dogwood**

heavy leaf density *D. batatas* can achieve by climbing a flowering dogwood (*Cornus florida*). *D. batatas* has taken advantage of the low-hanging branches, and is using other vine species as support to climb. Figure 5.4 also shows many single leafed *D. batatas* plants. These plants occur less frequently away from the central cluster of vines. Because of this clustered distribution pattern, leaf densities are not uniform within each site. Since recording only an *average* leaf density usually leads to assigning a moderate density (Table 5.4), I also recorded the *maximum* leaf density at each site (Table 5.5). Notice the high percentages of moderate to heavy leaf densities.

PATCH CONTINUITY

The distribution pattern of the majority of *D. batatas* plants is clumped. Often many patches of *D. batatas* occur within a homesite and more patches are scattered downhill along trails, roads, or streams. Table 5.6 shows the continuity of patches.

The spread of plants downhill from the original sites led to the discovery of approximately 50 new sites (Figure 5.5). The majority were found along roads or trails while traveling to and from the original SMEPS sites. The status of the plants at the new sites is similar to those at the original sites. The impact of *D. batatas*, however, is somewhat lower because the new sites usually have small patch sizes. Although this implies the new sites may be more recently established "daughter" sites, some of them may have existed in 1987-1988. Clements and co-workers may not have recorded them because they were not in a designated search region. Furthermore, I may have noticed more plants simply because I hiked most trails and roads, whereas they drove.

Table 5.4: Average Leaf Density at Visited Sites

	# of SMEPS Sites	% Total
Heavy	9	11%
Moderate	45	58%
Sparse	14	18%
No Data	10	13%
TOTAL	**78**	**100%**

Table 5.5: Maximum Leaf Density at Visited Sites

	# of SMEPS Sites	% Total
Heavy	37	47%
Moderate	18	23%
Sparse	3	4%
No Data	20	26%
TOTAL	**78**	**100%**

Table 5.6: Patch Continuity at Visited Sites

	# of SMEPS Sites	% Total
Continuous	3	4%
Relatively Continuous	5	6%
Discontinuous	63	81%
No Data	7	9%
TOTAL	**78**	**100%**

New Chinese Yam Sites (1994-1995)

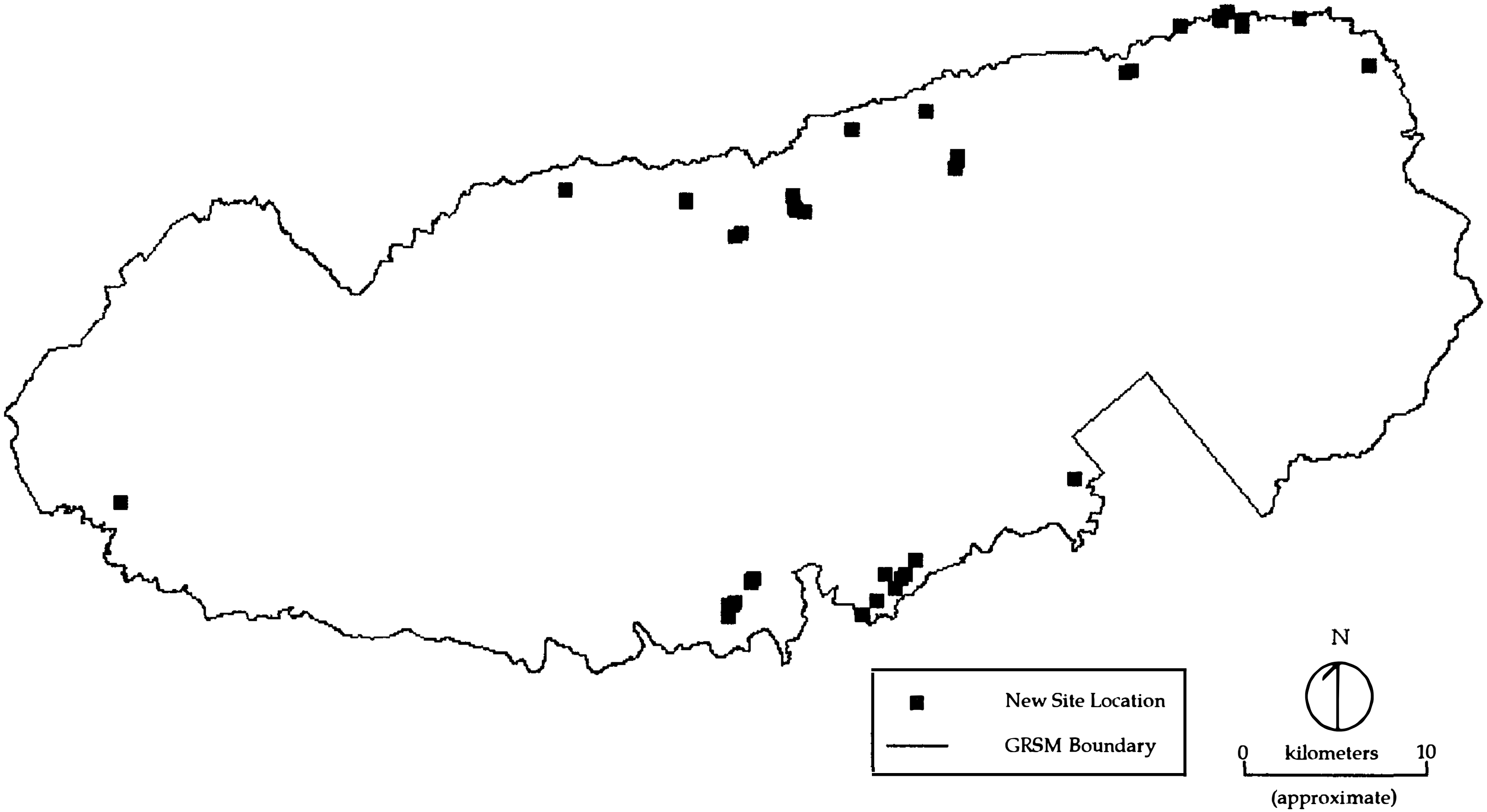


Figure 5.5: Location of New Chinese Yam Sites within the Great Smoky Mountains National Park
(Source: Boundary Data from GRSM)

AREA OF INFESTATION

In 1987-1988, Richard Clements estimated over 15,000 square meters of area infested by *D. batatas* at 125 sites (Table 5.7). In 1994-1995, over 140,000 square meters were estimated at only 62% of the original 125 sites (Table 5.7). This strongly suggests that *D. batatas* has expanded significantly over the last 6-8 years. Some discrepancy exists between estimates, however. During Fall 1994, I did not use the same methods as Clements. He visually estimated the areal extent of infestation per site; I measured the <u>maximum</u> length and width of patch sizes. This rendered a higher estimate (refer to Chapter 4). Yet, during the Summer of 1995, I used the same methods as Clements and estimated 35,000 square meters at about 45 sites. This amount is still much higher than the <u>total</u> infested area estimated by Clements.

HABITAT

ELEVATION

D. batatas occurs in the lower elevations of the Great Smoky Mountains National Park. The lowest site is at 290 meters, the highest at 1,000 meters (Table 5.8). A study of Japanese honeysuckle (*Lonicera japonica*) by Baron et al. shows similar results. The exotic honeysuckle occurs from 365 meters to 1,025 meters, and the majority is located between 425 and 610 meters (Baron et al., 1975). This implies that these two exotic vine species have an upper altitude limit near 1,000 meters. This suggests a climatic limit, but it may reflect a combination of factors. Much of the lower elevations had been farmed, logged, or burned before the park was established, thus giving exotics more opportunity. Also, these two

Table 5.7: Comparison of Infested Area Data

	# of Sites	Total Area
Visited	78	140,870 sq. m.
Uncertain	20	450 sq. m.
New Sites	49	27,550 sq. m.
Original SMEPS	125	15,420 sq. m.

Table 5.8: Elevation Range of SMEPS Sites

Elevation Range (meters)	Approx. GRSM Area (hectares)	Number of SMEPS Sites
250 - 500	8,830	23
500 - 750	48,820	88
750 - 1,000	44,510	14
1,000 - 1,250	48,560	0
1,250 - 1,500	39,050	0
1,500 - 1,750	15,940	0
1,750 - 2,000	2,350	0
2,000 - 2,250	10	0

exotic vine species were introduced near early homesites, and Baron et al. (1975) note that most homesites are below 670 meters.

CLIMATE

The hypothesis that *D. batatas* has an upper elevational (climatic) limit of 1,000 meters can be checked by comparing temperature data against its equivalent latitudinal range. The environmental lapse rate (decrease in temperature with increase in elevation) in the Great Smoky Mountains is 4°C per 1,000 meters (USDI, 1982). This was calculated using Gatlinburg, Tennessee as a base at 443 meters above sea level. Given that the January mean temperature in Gatlinburg is approximately 4.4°C, then the January mean temperature at 1,000 meters in GRSM is approximately 2.2°C. Comparing this average January temperature with global climate maps suggests that *D. batatas* should range as far north as 40° latitude in the eastern U. S. (Espenshade, 1992, p. 10). *D. batatas*, indeed, has been recorded as far north as southern Pennsylvania (just below 40° latitude) and no farther (Table 2.1).

ZONE LOCATION

I only classified about half of the Visited sites as backcountry sites (Table 5.9). As mentioned earlier, Clements et al. (1989) concentrated on backcountry areas within the park. My results may show a low percentage of backcountry sites because I classified sites into three disturbance zones, whereas Clements et al. classified SMEPS sites into two: 1) Frontcountry and 2) Backcountry (Clements, 1995).

Table 5.9: Site Locations of Visited Sites

	# of SMEPS Sites	% Total
Backcountry	38	49%
Heavily Visited	27	34%
Boundary	13	17%
TOTAL	78	100%

DISTURBANCE

D. batatas primarily occurs in areas of disturbance such as old homesites and the sides of roads, trails, and streams. Since most of the SMEPS sites are located at old homesites, these areas are obviously important habitat for *D. batatas*. Most homesites have canopy gaps, thus providing sufficient light. Tuliptree (*Liriodendron tulipifera*), which is often successional, frequently dominates the canopy at site locations. This coincides with findings of a previous study of Japanese honeysuckle (*Lonicera japonica*). Baron et al. (1975) note that 83% of the Japanese honeysuckle occurs in successional forest dominated by *Liriodendron tulipifera*.

Trails and roads provide important habitat for this species. It appears that *D. batatas* can spread along these corridors from the homesites where it was planted. Trails and roads provide light gaps, and the compacted trail or road surfaces increase water runoff, providing a source of moisture to the margins and a possible transport mode for bulbils. Wood piles may also play an important role in the spread of *D. batatas* along the trails and roads. Park employees and volunteers frequently clear roads and trails of brush and tree limbs, and pile the debris at the sides. Narrow diameter twigs in the piles provide excellent support for *D. batatas'* twining vines.

D. batatas also frequently occurs near streams, especially near creek crossings or debris dams. Streams are natural disturbance areas that provide gaps in the canopy. Floods provide fertile soil to the moist alluvial areas surrounding the streams. Streams in GRSM flood frequently, and these areas almost certainly provide important habitat conditions and aid in the spread of *D. batatas*. Severe flooding in the Spring of 1994 may have been a large factor influencing the spread of *D. batatas* between 1987 and 1995.

CANOPY

The majority of Visited sites have partial canopy (Table 5.10). Few entire sites are classified as Open Canopy, but small patches of *D. batatas* plants within a site frequently occur under open conditions. Rarely did *D. batatas* occur under closed canopy, and no sites are classified as such. When a few *D. batatas* plants grow under closed canopy, they usually receive morning or evening direct sunlight from a light gap nearby. This may indicate that *D. batatas* is restricted to places of canopy disturbance. No clear evidence suggests that *D. batatas* is invading farther into undisturbed areas, as does Japanese honeysuckle (Baron et al., 1975).

Table 5.10 : Canopy Results at Visited Sites

	# of SMEPS Sites	% Total
Closed Canopy	0	0%
Partial Canopy	68	87%
Open Canopy	8	10%
No Data	2	3%
TOTAL	**78**	**100%**

However, these results do not agree with Clements' findings that *D. batatas* "is very shade tolerant" (Clements, 1989). Apparently Clements' classification of closed canopy includes successional growth when it attains initial closure, even though it allows relatively high light levels (Clements, 1995). I classify closed canopy as a dense overstory which greatly reduces light levels, such as in old growth or hemlock (*Tsuga canadensis*) forests (see Chapter 4).

Average incident light readings are shown in Figure 5.6 for sites visited between 10:00 a.m. and 4:00 p.m. EDT from June through mid-August (local solar noon is approximately 1:30 p.m. EDT). Readings taken within patches of *D. batatas* ranged from 350 to over 350,000 lux-candles, the maximum limit of the light meter. Readings taken outside *D. batatas* patches, where it was absent, ranged as low as 22 lux-candles. These preliminary results may suggest that shade is limiting. However, further investigation would be necessary to adequately quantify the light requirements of *D. batatas.*

SOIL

D. batatas occurs most often in organic-rich, moist, alluvial soils. Occasionally, a few plants are found growing in gravel or clay, next to streams where the soil has a very high moisture content. *D. batatas* does not grow in highly compacted soils, such as on trails or old roads, although it does occur occasionally between the ruts where the soil is loose. It must be able to tolerate a certain amount of acidity, since it occurs on the edges of rhododendron thickets and hemlock forests. *D. batatas*, however, does not grow underneath hemlocks or rhododendron. This may be due to acidic soil or lack of sunlight. Overall, the moisture content of the soil seems to be the most important factor.

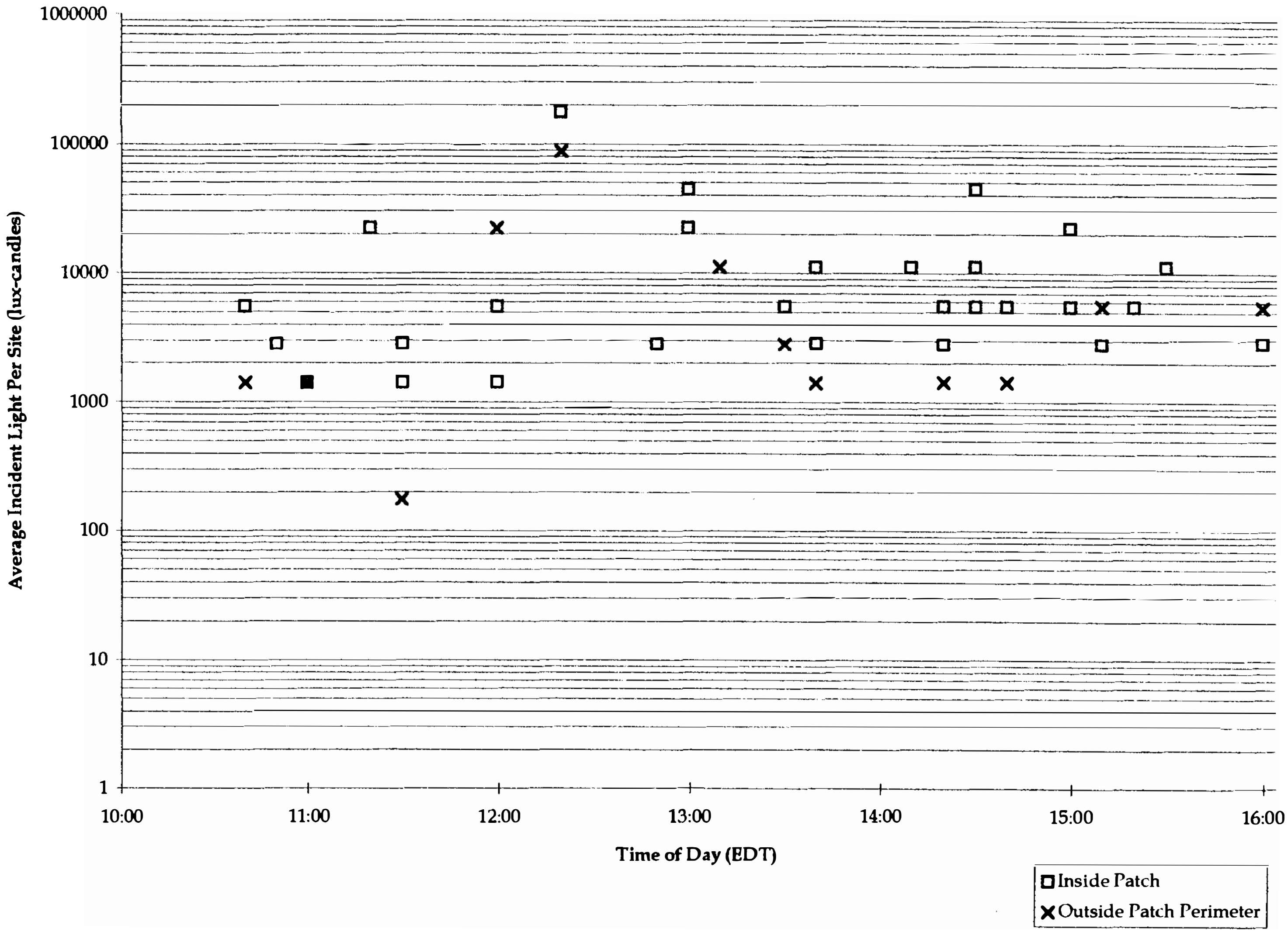


Figure 5.6: SMEPS Site Light Meter Readings

NEAREST NEIGHBORS

Other exotic species were noted at 73% of the Visited SMEPS sites. Baron et al. (1975) also observed that over one-third of the herbaceous species associated with *Lonicera japonica* are exotic. There are two reasons for this phenomenon: 1) early homeowners planted exotics near their houses, and 2) exotic plant species are known for invading disturbed areas. The following discusses some exotic species that occur with *D. batatas.*

Boxwood (*Buxus sempervirens*) was planted by early settlers as an ornamental shrub. It persists in GRSM but often does not produce viable seed. Therefore, it is a good indicator of old homesites or cemeteries.

Japanese honeysuckle (*Lonicera japonica*) occurs frequently throughout the park. My observations concur with Baron et al. who noticed *D. batatas* and *Lonicera japonica* occurring together frequently at old homesites. Japanese honeysuckle was planted in GRSM by early settlers as an ornamental. It excludes forest floor herbs with its heavy ground cover and its woody vine can strangle small trees (Baron et al., 1975). Japanese honeysuckle reproduces vegetatively by rapid layering and runners, and sexually by bird-disseminated seeds (Baron et al., 1975). It is very drought resistant and its vines can grow at a rate of 4.5 meters per year.

Japanese grass (*Microstegium vimineum*) is ubiquitous throughout GRSM. Although it may not have been recorded <u>at</u> many site locations, it occurs along most trails. The presence of Japanese grass may negatively affect the growth of *D. batatas.* The patch size, impact, and survival of *D. batatas* are lower at sites where Japanese grass is the dominant herb species.

Periwinkle (*Vinca minor*) carpets the ground to the exclusion of most other herbaceous species. *D. batatas* is one of the few species that I observed growing within periwinkle patches.

Some other important neighboring species of *D. batatas* are native vines. Figure 5.7 shows *D. batatas* in close association with poison ivy (*Rhus radicans*), greenbrier (*Smilax spp.),* and hog peanut (*Amphicarpaea bracteata*). When possible, *D. batatas* will use other vines as support for climbing. This can lead to the smothering and weighing down of the other vines. Table 5.11 shows the frequency of three native vine species occurring within the 78 Visited SMEPS sites.

Dutchman's pipe (*Aristolochia durior*) is a woody vine. Although it is rarely seen within *D. batatas* patches, it is important to note because the seedlings of this species resemble *D. batatas* (Figure 5.8). They can be distinguished by examining the leaf veination. Dutchman's pipe is a dicotyledon (veination branches off from the center vein); *D. batatas'* dominant veins are parallel.

D. batatas occasionally grows with the wild yam species (Figure 5.9). Both exotic and native may twine around each other for support. This occurs infrequently, however, because most of the wild yam taxa prefer more xeric woodland areas, distinct from *D. batatas* habitat.

Hog peanut (*Amphicarpaea bracteata*) is a ground cover that is frequently found in association with *D. batatas* (Figure 5.10). It may be the native vine species most directly affected by the invasion of *D. batatas*. Despite this, hog peanut seems prolific in the park and

Figure 5.7: ***D. batatas*** **Growing with Native Vine Species**

(poison ivy, greenbrier, hog peanut)

Table 5.11 : Native Vines Occurring at Visited Sites

	Dutchman's Pipe	Wild Yam	Hog Peanut
# of SMEPS Sites	6	8	50
% Total Visited	8%	10%	65%

Figure 5.8: *D. batatas* **Growing with Dutchman's Pipe**

Figure 5.9: ***D. batatas*** **Growing with Wild Yam**
(the majority of wild yam leaves are on the left side of the figure,
the majority of *D. batatas* leaves are on the right)

Figure 5.10: ***D. batatas*** **Growing with Hog Peanut**
(small trifoliate leaves)

in many cases the hog peanut, which has a smaller diameter stem, twines around *D. batatas* for support. Baron et al. (1975) also note that hog peanut occurs frequently in successional forests and is a nearest neighbor (spatially) of Japanese honeysuckle (*Lonicera japonica*).

HERBIVORES

Insect herbivory occurs occasionally (Figure 5.10). Leaf damage is not specific to *D. batatas*, but also includes surrounding plant species. Possible rooting by exotic wild hogs is the only other observed herbivory. Animal herbivory, however, warrants further investigation. Coursey (1967) notes wild hogs as being a problem with yam crops in Africa.

DISPERSAL

REPRODUCTION

As stated in Chapter 2, it is rare for *D. batatas* to flower in our region. A few *D. batatas* plants, however, can be observed forming inflorescences in the leaf axils as early as July. Each plant seems to need approximately one meter vine length before reaching this reproductive stage. Although the inflorescence is often too immature for verification, most plants seem to be of the male gender. Only one possible female inflorescence was noted during the field work phase of this study, and no successful flowering or seeds were observed. Therefore, the primary means of dispersal within the Great Smoky Mountains is by vegetative reproduction from the aerial tubers (or bulbils). Bulbils form on the multi-leaf vines from late July through November. A short-term experiment with ten bulbils showed that burial is not necessary for sprouting to succeed.

TRANSPORTATION

The first step in the dispersal of bulbils is dislodging them from the vine — whether by gravity, weather, animals, or people. Bulbils can then be transported farther from the parent plant by being kicked along the ground by animals or people, by rolling downslope due to gravity or sheet and rill transport, or by streams. People could also collect the bulbils within the park and transport them unknown distances.

An interesting dispersal mechanism, not mentioned in the literature, is the use of the bulbils from *D. batatas* as toys. The little miniature potatoes are quite appealing as throwing objects. They could have been frequently carried from homesite to homesite for a child's game of war, or thrown into streams. Two previous residents of GRSM said they remembered playing with them often (Beck, 1995; Ownby, 1995). This characteristic may possibly be an important dispersal mechanism in the park that is easily overlooked.

Speculation aside, it is evident that water plays the most important role in the natural dispersal of *D. batatas*. Torrential downpours are frequent in the Smoky Mountains, causing heavy sheet and rill runoff. Bulbils are easily transported by these processes. This is evident in that *D. batatas* usually occurs near a permanent or ephemeral water source and the patterns of spread usually follow drainage patterns.

Other than human intervention, the primary means of transporting bulbils long distances within the national park is by streams. Coursey (1967) suggested that *Dioscorea* bulbils are less dense than water, which assists in dispersal by flotation. However, this is not the case with *D. batatas*. Its bulbils do not float, even after drying out over the winter months, but they do move downstream by rolling, traction, and saltation. Therefore, streams and overland runoff are important factors in predicting the dispersal of *D. batatas* within the Great Smoky Mountains National Park.

Chapter 6
GIS METHODS

Using IDRISI Geographic Information System software, I developed a model to predict potential spread of *D. batatas* from established infestations. The model's results greatly facilitate comparison of different sites for management decisions, since the relative threat each poses is immediately evident. I evaluated the model by using 1987-1988 SMEPS data for its initial conditions, and comparing the model results to 1994-1995 field data from this study. (Refer to Chapter 4 concerning creation of the IDRISI map layers discussed in this chapter.)

PREDICTING SPREAD FROM THE ORIGINAL SMEPS SITES

As stated earlier, *D. batatas* is not known to produce seeds in Tennessee. Therefore, I predicted its spread by simulating the transportation of its bulbils (aerial tubers). Although humans and animals may help disperse bulbils, the extent of these modes is unknown, and no attempt was made to include them. Thus the model simulates two natural modes of bulbil dispersal:

1) local downslope dispersal near the parent plant, and
2) long-range stream transport.

LOCAL DISPERSAL

Local dispersal includes transportation by all downslope processes, such as gravity and surface water (sheet and rill) runoff. The steepness of the terrain is the primary factor influencing the dispersal of bulbils. The steeper the slope, the greater the likelihood for bulbils to move farther from the parent plant.

Because the actual spread rate of *D. batatas* is unknown, I simulated potential dispersal over an infinite time period. In other words, the model assumes that a parent plant produces bulbils which drop to the ground and move downslope; these bulbils sprout, reach reproductive stage, and produce more bulbils which also drop to the ground and move downslope. This cycle is repeated until the slope no longer favors further dispersal.

LONG-RANGE DISPERSAL

Field evidence suggests that streams are the primary long-range natural transport mechanism for bulbils. Once bulbils can reach a stream, all downstream riparian areas are at risk. Therefore, I simulated the long-range dispersal threat by mapping all stream-bank locations downstream from intersections between zones of local dispersal and streams.

CREATING THE POTENTIAL-SPREAD MAP

To model the potential spread of *D. batatas* in the park, I divided the park into 15 data processing regions (Figure 6.1). Care was taken to encompass groups of sites within adjoining drainage basins. Within each region, I created a local-dispersal map for each site. These maps were joined to form a local-dispersal map for the region. Next, I created a long-range dispersal map for each site, and these were joined to form the long-range dispersal

Figure 6.1: The Fifteen Data Processing Regions for the Great Smoky Mountains National Park

map for the same region. The two regional maps, local-dispersal and long-range dispersal, could then be overlayed to create a comprehensive potential-spread map for that region. I repeated this process for all regions shown in Figure 6.1. Finally, I concatenated all fifteen regional maps to create the full GRSM potential-spread map. To implement this procedure, I developed a series of IDRISI Macro Language (IML) routines (see Appendix C). The following two sections explain how I created the local-dispersal map and long-range map for each site with the help of IDRISI.

LOCAL-DISPERSAL ANALYSIS

I used the IDRISI SURFACE and DISPERSE functions to simulate the local dispersal of *D. batatas* from its site of origin:

- <u>SURFACE</u> uses a digital elevation input image to calculate a corresponding slope image and aspect image (Eastman, 1992).

- <u>DISPERSE</u> calculates the movement of phenomena when acted upon by a given force over time (Eastman, 1993). DISPERSE requires three input images: one containing force magnitude values, one containing force direction values, and another containing target starting locations. An additional parameter is required to determine the maximum dispersal distance. DISPERSE produces a cost surface in which each grid cell value represents the "cost" of moving an object from the nearest (in terms of cost) starting location to that cell. The greater the effort, the higher the "cost" value of the cell, or, in a probabilistic system, the higher the value, the lower the probability of reaching the cell. Therefore, the output image shows decreasing probability of occurrence radiating from each starting point in response to the force vectors.

I used the DISPERSE function to simulate the downslope dispersal of *D. batatas* from the original SMEPS sites. A basic flow diagram for creating individual local-dispersal maps is shown in Figure 6.2. The GRSM elevation data layer (Figure 1.2) was analyzed using the SURFACE function to create the force magnitude (i.e., slope) and direction (aspect) images required by the DISPERSE function (Figure 6.2). The SMEPS site data layer (Figure 1.8) provided starting point locations. I set the dispersal distance parameter to the maximum possible value, effectively allowing infinite generations of *D. batatas* establishment and propagule release.

To display results, I reclassified each local-dispersal image and created a customized color palette using the following color scheme:

Magenta:	starting point grid cell (SMEPS site location),
Brown:	highest probability of occurrence,
Yellow:	lowest probability of occurrence,
White:	zero probability of occurrence.

Intermediate probabilities were assigned interpolated colors between brown and yellow.

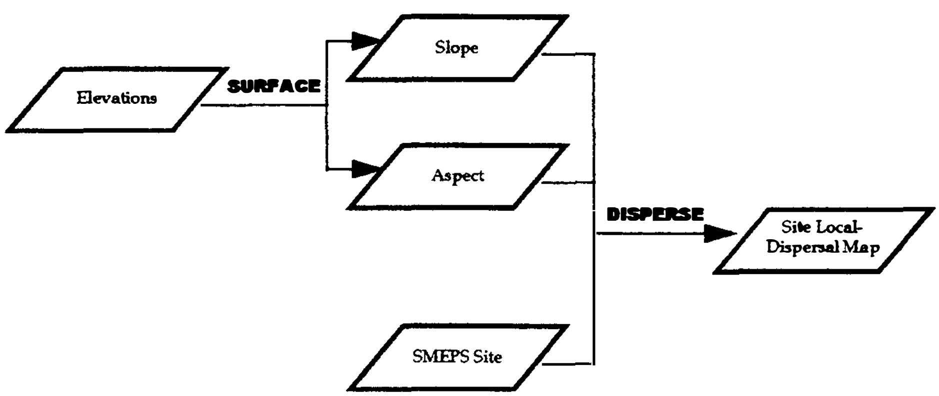


Figure 6.2: Flow Diagram for Creating an Individual Local-Dispersal Map

LONG-RANGE DISPERSAL ANALYSIS

If the local-dispersal zone for a site reached a stream, I also modeled potential long-range dispersal from the site. The IDRISI PATHWAY and COSTGROW functions were the main modules used:

- PATHWAY requires two input images: a surface image, and a starting point image (Eastman, 1992). It calculates the least-cost path across the surface from a starting point to a destination point. The lowest value in the surface image defines the destination point.
- COSTGROW also requires a surface image and a starting point image (Eastman, 1992). It creates a cost surface in which each grid cell represents the distance to the nearest starting point. This distance is determined radially from the set of starting points.

I first generated the path surface that the PATHWAY function requires (Figure 6.3). I used the GRSM stream and boundary data as input to the COSTGROW function and generated a surface on which values decrease in the downstream direction. Because streamflow in GRSM is radial from the center of the park outward (Figure 1.3), destination points can usually be defined where streams intersect the park boundary. I used the resulting path surface as input to the PATHWAY function in order to map all streambank locations below the given local-dispersal zone. To display results, I assigned the color green to locations under threat from long-range dispersal.

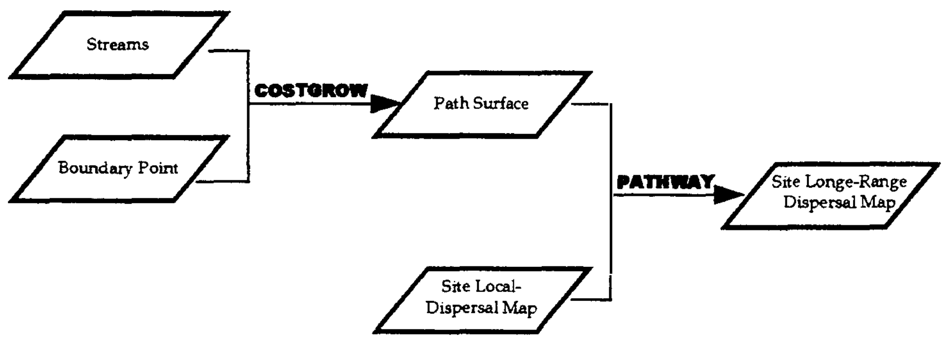


Figure 6.3: Flow Diagram for Creating an Individual Long-Range Dispersal Map

Because the resolution of the data is 30 x 30 meters and most streams are small, no attempt was made to analyze near-stream topography or over-bank transport. The model simply identifies the corridor of pixels a stream traverses. In most cases, this will include all areas of potential establishment.

DETERMINING PRIORITY SITES

I combined results from the potential-spread model with 1994-1995 field data to prioritize SMEPS sites for management purposes. Using four sets of criteria, I created four lists (results shown in Appendix E). The first list consists of SMEPS sites prioritized according to size of predicted local-dispersal area. In order to accomplish this, I used the IDRISI AREA function to compute the potential local-dispersal area in square meters. This and other IML routines are in Appendix C. I imported the data into a spreadsheet program (Microsoft Excel©), and merged it with the previous SMEPS database information.

Since streams are important to the potential spread of *D. batatas*, I created a second list containing SMEPS sites sorted by distance from streams. To achieve this, the vector streams map layer and SMEPS site map layer were first converted to raster format (see Appendix C). Then I used the IDRISI DISTANCE function to calculate the distance to the nearest stream, and the OVERLAY and EXTRACT functions to write the distance values for each site to an ASCII text file. That information was again imported into the spreadsheet and merged.

As stated earlier, the Great Smoky Mountains National Park staff have set up a priority system for taking action against infestations of aggressive exotic species based on their locations. These are:

Priority 1) Sites located in backcountry zones,
Priority 2) Sites located in heavily visited zones, and
Priority 3) Sites located in boundary zones and along roadsides.

For the third and fourth lists, I used the 1994-1995 disturbance zone data to classify sites by location. Then, within location categories, I prioritized sites by potential area to produce a third list, and by stream proximity to produce a fourth.

EVALUATING THE MODEL

As a test of the model, I compared locations of new sites discovered during 1994-1995 with the model's predicted areas of spread based on 1987-1988 site locations. First, UTM locations from all the new sites were used to create a new vector map layer (Figure

5.5). This was converted to raster and overlayed on the GRSM Potential-Spread Map to test whether the new sites fell within predicted dispersal zones. I used the IDRISI EXTRACT function to export the information from each site to an ASCII text file, which I could then sort and analyze.

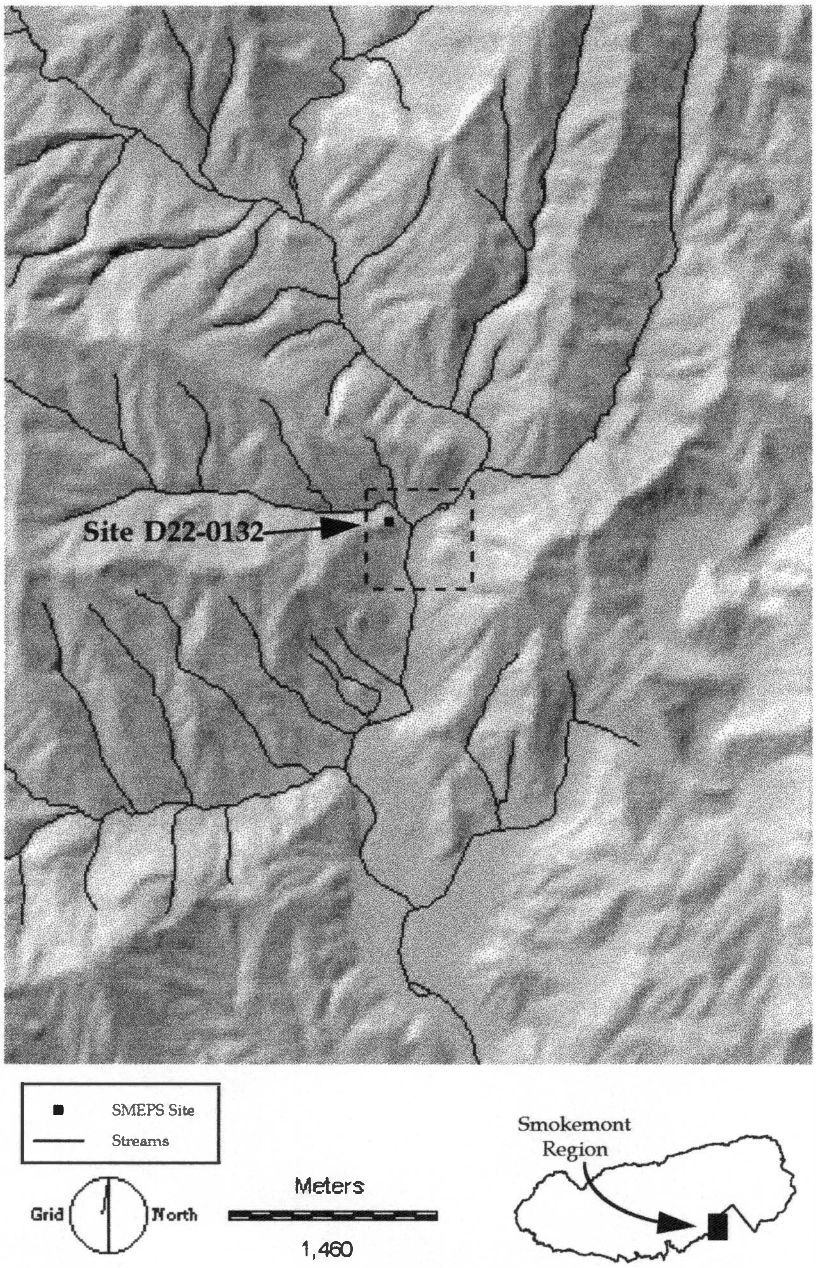
I also measured the distance between new sites and the modeled potential-spread zones (see Appendix C). By analyzing the model's potential-spread map with IDRISI's DISTANCE function, I created a data layer containing, pixel by pixel, the distance to a potential-spread zone. As before, data on new sites were extracted, sorted, and printed.

Chapter 7
GIS RESULTS AND DISCUSSION

POTENTIAL-SPREAD MODEL RESULTS

To aid in interpreting the potential-spread maps produced by the model, I include several figures to illustrate the local-dispersal and long-range dispersal from an example site. This site is near a stream on a northeast-facing hillside in the Smokemont region (Figure 7.1). Figure 7.2 is a freehand sketch of the immediate area at larger scale. Figure 7.3 is the local-dispersal map generated for this site. It is shown again in Figure 7.4 with the sketch overlain, to illustrate how the spread of *D. batatas* was predicted in accordance with the surrounding terrain. Because the site's local dispersal zone intersected with a stream, a downstream corridor was also mapped. The combined local-dispersal and long-range dispersal maps for this site are shown as Figure 7.5.

As mentioned in Chapter 6, all site maps within each region were joined to form the regional potential-spread maps. These are in Appendix D. Plate 1 is the potential-spread map for the entire Great Smoky Mountains National Park. As can be expected, regions with a high density of SMEPS sites show the greatest potential spread area (compare with Figure 1.8 or Figure 6.3). The northeastern part of the park is particularly noticeable. Because of the relatively flat terrain in this sector, local dispersal is less apt to be constricted by topography.



(Site UTM Coordinates: 3934750 N, 291050 E, Zone 17)

Figure 7.1: Location of an Example Site within the Smokemont Region of the Great Smoky Mountains National Park
(Source: Elevation and Stream Data from GRSM, Site Data from SMEPS)

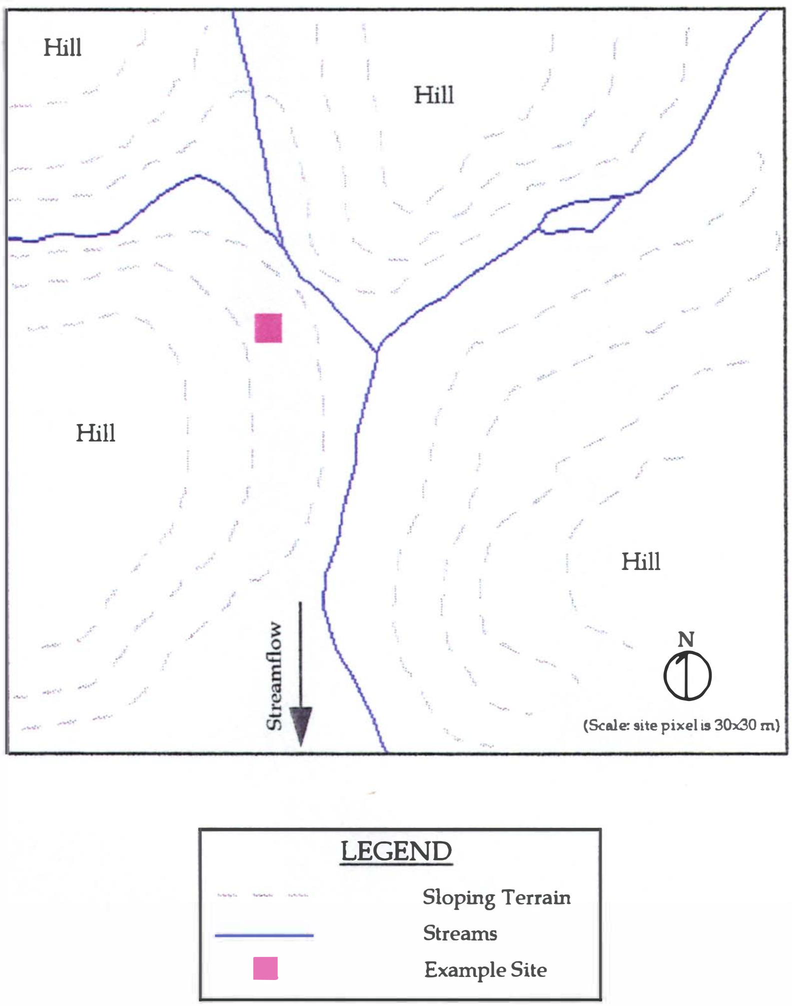


Figure 7.2: Freehand Sketch of Example Site

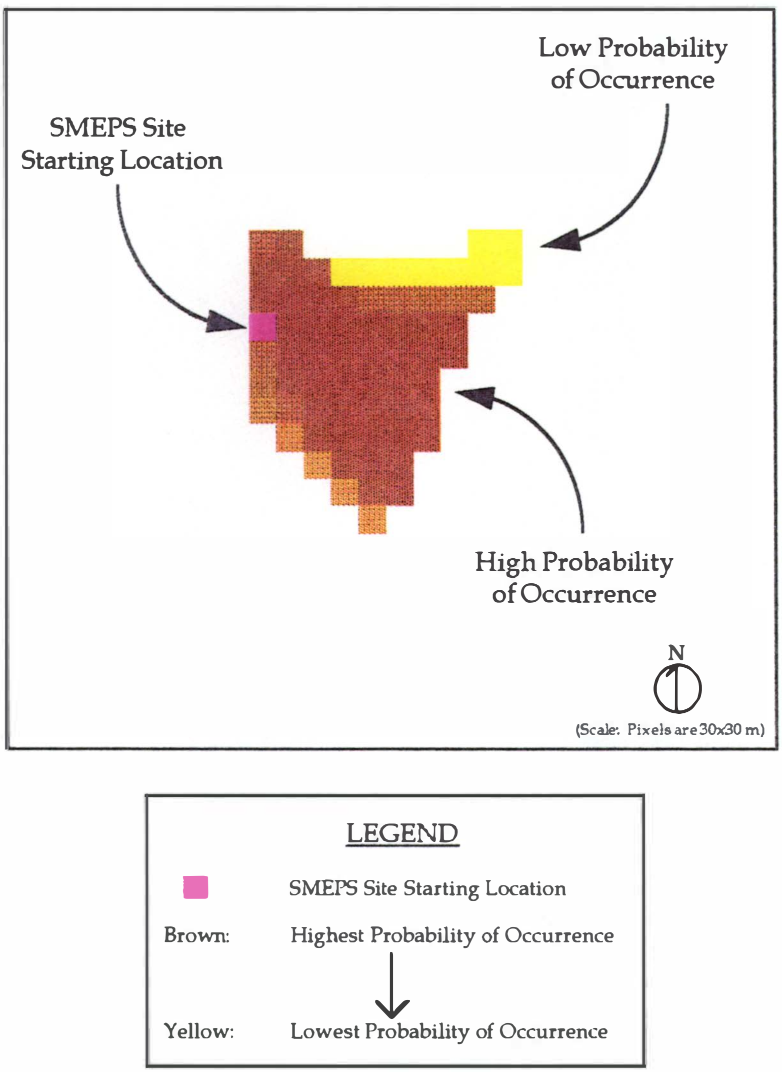


Figure 7.3: Example Site Local-Dispersal Map

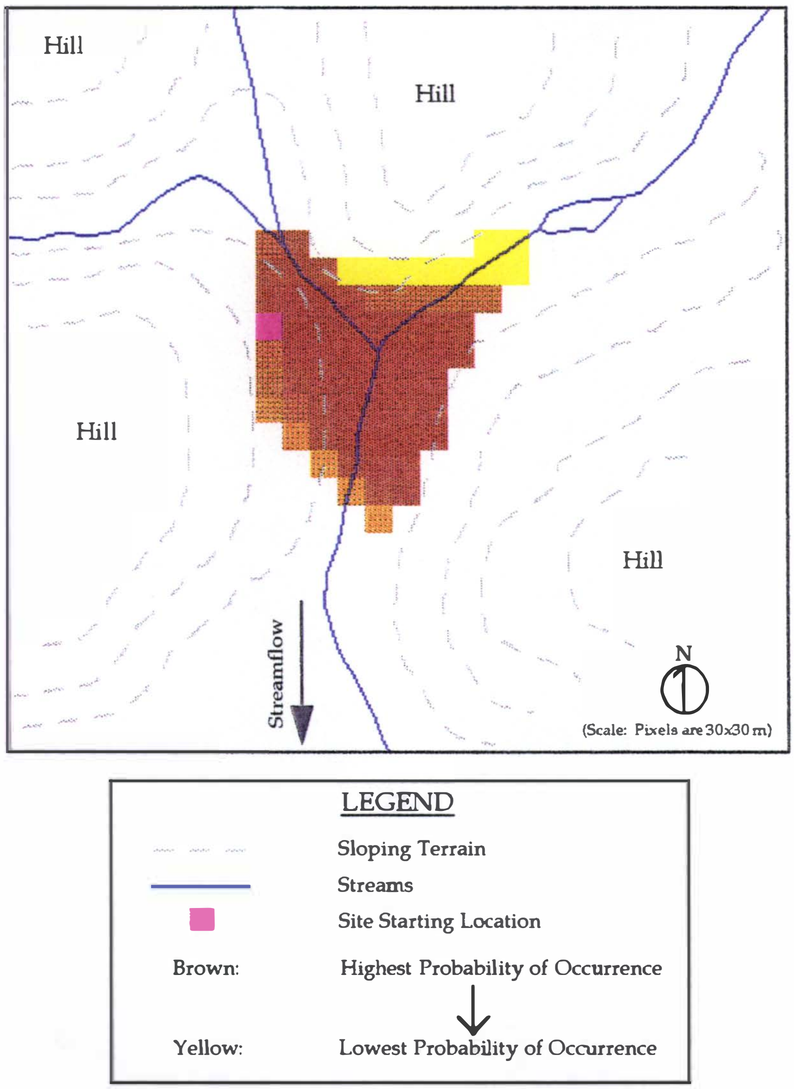


Figure 7.4: Example Site Local-Dispersal Map with Sketch Overlay

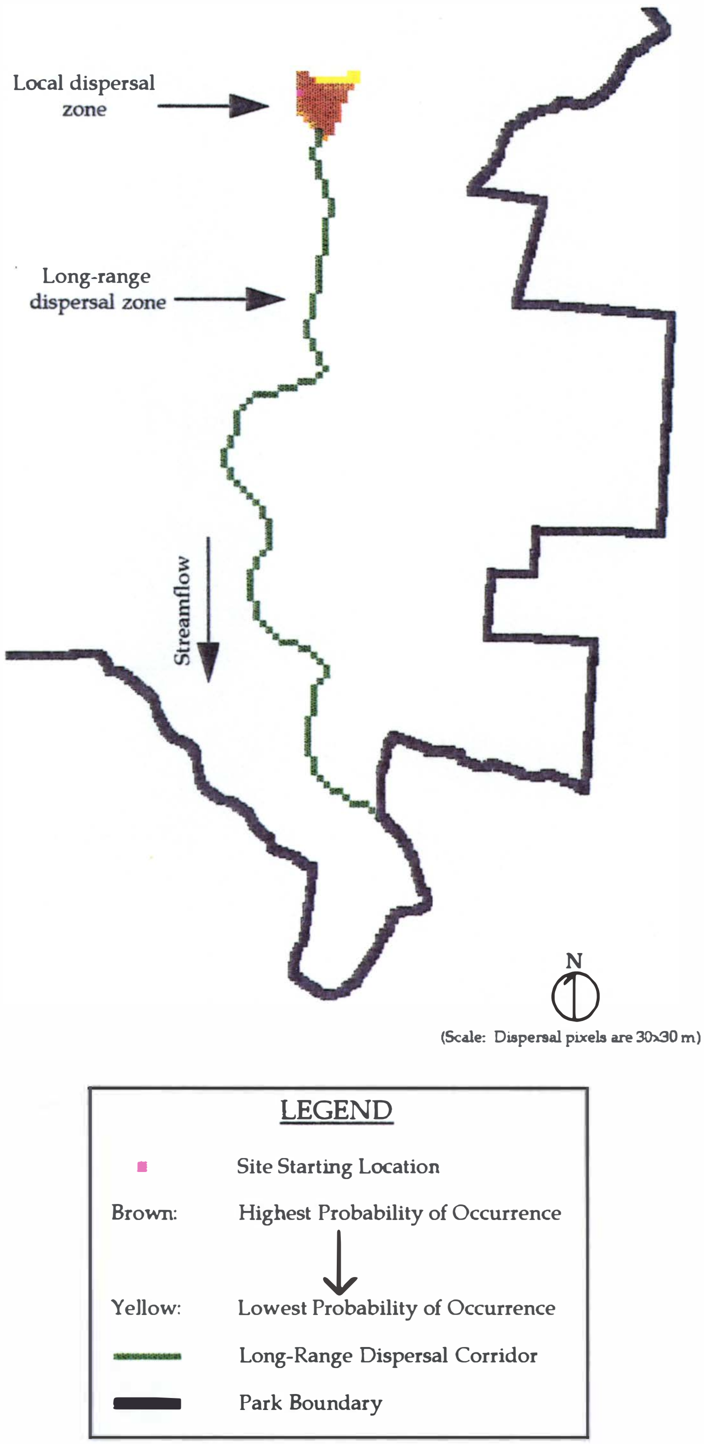


Figure 7.5: Example Site Local-Dispersal Map with Long-Range Dispersal Map

PRIORITY SITES RESULTS

Eradication of *D. batatas* in the Great Smoky Mountains is very difficult. Digging up underground tubers of one foot or more in length is very labor intensive and time consuming. Much of the surrounding vegetation is damaged and uprooted in the process. Until further research indicates otherwise, it is imperative to dig up all tuber pieces and roots. Since any part of the plant may be able to resprout, all debris may have to be disposed of outside the park. Herbicide (that is approved for usage in the park) is not adequately effective on *D. batatas* because of the large storage organs (Remaley, 1994). Spraying *D. batatas* patches with herbicide kills the surrounding native vegetation as well, and may be counter-productive since *D. batatas* may resprout and have more space to occupy. Funding is limited, so it is imperative that target sites be carefully selected for control.

Appendix E includes four prioritized site lists to aid the decision-making process. Sites are ranked by spread potential, proximity to streams, and disturbance zone locations. One hundred twenty-four sites are listed because one SMEPS site had UTM coordinates outside of GRSM and could not be mapped. Also, some of the sites have duplicate results because they fall within the same 30-meter-square grid cell.

The top ten sites in order of potential spread (List 1, Appendix E) are either near the northeastern region of the park or near Gatlinburg. Comparing these results with List 3, which ranks sites first by eradication-priority zone and then by potential spread, we see that List 3 also top-ranks many sites in the Jones Cove quadrangle, but only ranks one site in the Gatlinburg quadrangle in the top ten. Therefore, when considering the local-dispersal potential of the original SMEPS sites, the northeastern region of the national park (especially in the Jones Cove quadrangle) is a primary target sector. Note, though, that much of the predicted spread in the northeastern region extends beyond the national park boundary (Plate 1). If the potential-spread map were truncated at the park boundary, the same sites would have lower potential-spread values. Considering the very large difference between the Jones Cove sites and other backcountry sites, however, it would still be a focal region.

List 2, sites ranked by proximity to streams, shows that at least 14 of the SMEPS sites are located within 30 meters of streams (within the same grid cell). Note that a stream distance of 30 or 42 meters means the site is only one grid cell dimension away from a stream. List 2 and List 4 (sites classified first by location and then ranked by proximity to streams) do not accentuate Jones Cove sites to the same degree as List 1 and List 3, but many of the same Jones Cove sites are 30 to 60 meters (only one to two grid cells) from a stream. Overall, considering local and long-range potential dispersal from the original SMEPS sites, it appears that the northeastern regions of the park deserve early attention.

NEW SITES EVALUATION RESULTS

Only one-third of sites that were first recorded in 1994-1995 coincide with zones of predicted dispersal from 1987-1988 sites (Appendix F). A total of 49 new sites were found in 1994-1995 (Figure 5.5); however, only 41 are listed in Appendix F because in some instances more than one site fell within a single grid cell. These results suggest that the GRSM Potential-Spread Model conservatively estimates the future spread of *D. batatas*; although, as mentioned in Chapter 5, there is uncertainty about whether the new sites are newly established or newly discovered.

SUGGESTED MODEL IMPROVEMENTS

In its current form, the GRSM Potential-Spread model ignores roads and trails as dispersal corridors. I omitted roads and trails from the current model because their topology was inconsistent with the streams map layer. As mentioned in Chapter 5, roads and trails provide important habitat and dispersal corridors for *D. batatas*, and would be an important addition to make in the future. If roads and trails were added to the model, then many of the new sites would be explained. Another possible addition would be to increase the probability of *D. batatas* occurring at intersections of streams with roads or trails, a tendency observed during the field study (see Chapter 5).

The following is a list of other possible improvements to the model:

1. The GRSM Potential-Spread Map could be truncated at the national park boundary. This would make it possible to include only areas within the park boundary.
2. Bulbils are less likely to cross large streams than indicated by the model. If the model included stream order, it could assign local-dispersal barrier effects according to stream order.
3. At present, the model assumes that bulbils drop from the parent plants, sprout, reach reproductive stage, and then the cycle continues. No consideration is

given to how long bulbils stay viable while waiting to sprout, or how long plants can remain in a waiting stage for environmental factors to change, such as a tree fall or other disturbance, so that they may then go on to the reproductive stage. Further empirical evidence would be necessary before these changes could be incorporated.

4. The habitat of *D. batatas* could also be modeled. The logging history data could be used to extract only the disturbed sections of the national park, and the vegetation data to could be used to extract the Tuliptree-dominated sections. These data could be overlayed with estimated buffer zones around streams, roads, and trails to provide a habitat map. Given the current input data, however, this would allow only a very crude estimate.

5. Presently, the IDRISI macro language (IML) only consists of batch mode commands. Improvement of the macro language could decrease the amount of necessary code and would allow the implementation of the model to be more automated.

6. In the model, dispersal distances are currently represented in "grid cell equivalents." In the future, grid cell equivalents could be associated with empirical information, such as percentage of probability or rate of spread. Long-term field research on *D. batatas* propagation, however, would be necessary.

7. The input parameters to the DISPERSE function could be changed to provide a less conservative estimate of potential-spread area.

8. Currently, site locations are only represented as a single point in a 30-meter-square area. This could be changed to more realistically depict *D. batatas* patch sizes. Therefore, given more starting points, the dispersal of large patch sizes would be more accurately predicted.

9. Ideally the model should map all downstream flood areas, perhaps to the 100 year flood line, or should at least include zones where overbank flooding would most likely occur, instead of mapping only a one-pixel corridor that encompasses the stream.

MODEL APPLICATIONS

The *D. batatas* GRSM Potential-Spread Model can be used to create field maps to find *D. batatas* populations for control or study purposes. Results from the prediction model make it evident that sites at higher elevations need to be given priority over lower elevation sites. Otherwise, if lower sites are eradicated first, then the upper elevation sites may repopulate them. Therefore, when choosing a sector for management, it would be wise to check all upslope areas. This model can be used to narrow down the search locations by substituting new starting point locations, such as at the highest possible ridgeline or old homesites. Conversely, the model may be useful for predicting uphill homesites, given the known *D. batatas* site locations.

This model may also be used to predict the propagule dispersal of other plant species within GRSM. To simulate the dispersal of propagules other than in the national park, however, it would be necessary to modify the IML routines for the new input data. In this case, the modeler would also need to check the new dataset for anomalies. Digital terrain data often have erroneous "spikes" or "pits" in the dataset which greatly affect the results from surface flow models. Although it was not necessary for the current study, pits may need to be filled using ARC/INFO's FILL module or other such routines. The potential-spread model would not be recommended for use in regions with flat terrain, since the slope aspect would often be undefined, and no path could be determined.

Chapter 8
CONCLUSION

In summary, I used field methods in the first phase of this study to collect data on the status and spread of *D. batatas* since 1987-1988 (Chapter 4). Comparisons with earlier research conducted in 1987-1988 show that *D. batatas* has spread and continues to affect the herbaceous understory by shading or crowding (Chapter 5). In the second phase of this study, I used a Geographic Information System (GIS) to produce a potential-spread computer model (Chapter 6). Results from the potential-spread model show that sites in the northeastern region of the park have the highest spread potential (Chapter 7). The model was then used to generate target site lists to help set priorities for managing *D. batatas* infestations (Appendix E).

Although this model was designed specifically for the spread of *D. batatas* within GRSM, it may be used to predict the spread of other GRSM plant species with similar dispersal mechanisms. With modifications, it could also be used to model *D. batatas* or other plant species elsewhere. Even though field work is essential, I strongly encourage the use of GIS tools for managing invasive species and planning other natural resource management activities. Most GIS software provide the ability to display existing spatial patterns, to perform comparative analyses, and to model changes over time. Information from such analyses can assist in prioritizing management efforts, as well as proposing funding. To allow the most comprehensive view of a problem, I highly recommend the combination of computer analysis and field investigation, such as in this study.

Although field information collected for this study contributes to ongoing monitoring of *D. batatas* within the Great Smoky Mountains National Park, continued research is necessary to provide answers to many of the remaining questions. Why has *D. batatas* spread so much in the last 6-8 years? Is this a temporary population explosion? Do *D. batatas* experience cyclical expansions and diebacks? A previous resident of GRSM (a descendent of Wiley Oakley), commented that *D. batatas* did not previously "grow all over the place like it is now" (Ogle, 1995). Why, then, has *D. batatas* spread so much in the last 60 years? Has the spread rate increased or has it remained the same and we are noticing an accumulation over time? Do severe flooding and heavy precipitation greatly influence the spread of propagules? Has *D. batatas* increased its bulbil production in response to unsuccessful flowering or new habitat conditions? Further research on this species is necessary to better understand its role in the Great Smoky Mountains National Park. Such research would also help increase our understanding of the genus *Dioscorea*, the role of vines in the ecosystem, and the susceptibility of riparian zones to invasion, as well as the ecology of invasive species.

What can be done to prevent future biological invasions? Williams (1994) notes that the U. S. government largely ignores former President Carter's 1977 executive order to "restrict the introduction of exotic species into natural ecosystems." Legislation alone will not stop such introductions; the solution lies in public awareness. To achieve this, research must continue so that a full understanding of the problem can be achieved, and then that knowledge can be provided to the public. Such research contributes to the preservation of U. S. natural resources as well as the greater understanding of exotic pests worldwide.

LIST OF REFERENCES

LIST OF REFERENCES

Al-Shehbaz, Ihsan A. and Schubert, Bernice G. (1989). The Dioscoreaceae in the Southeastern United States. *Journal of the Arnold Arboretum* **70**, 57-95.

Baron, Jill; Dombrowski, Christine; and Bratton, Susan P. (1975). "The Status of Five Exotic Woody Plants in the Tennessee District. Great Smoky Mountains National Park Management Report No. 2." Field Research Laboratory, Great Smoky Mountains National Park.

Beck, Kate (1995). Personal interview with former resident of GRSM. Conducted on January 21 during Wilderness Wildlife Week of Nature Convention at Heartlander Country Resort, Gatlinburg, Tennessee.

Bowen, Brian (1995). Exotic Plant Species Profile: Purple Loosestrife. *TN-EPPC News* **2(1)**, 4.

Brockman, C. Frank (1986). "Trees of North America: A Field Guide to the Major Native and Introduced Species North of Mexico." Golden Press, New York.

Campbell, Carlos C. (1969). "Birth of a National Park in the Great Smoky Mountains." University of Tennessee Press, Knoxville, Tennessee.

Campbell, Carlos C.; Hutson, William F.; and Sharp, Aaron J. (1992). "Great Smoky Mountains Wildflowers." University of Tennessee Press, Knoxville, Tennessee.

Chester, Edward W.; Wofford, B. Eugene; Kral, Robert; DeSelm; and Evans, A. Murray (1993). "Atlas of Tennessee Vascular Plants, Volume 1. Pteridophytes, Gymnosperms, Angiosperms: Monocots." Austin Peay State University, Clarksville, Tennessee.

Clebsch, Edward E. C. (1995). Professor Emeritus in Biology Department at the University of Tennessee at Knoxville. Notes on personal interview conducted at Arnold Air Force Base, Tullahoma, Tennessee.

Clements, Richard (1988). GRSM Exotics Crew Plant Manual. Unpublished manual of identification aids for exotic plants in the Great Smoky Mountains National Park. Kept on file at Exotics Crew headquarters at Twin Creeks Upland Research Center, Gatlinburg, Tennessee.

Clements, Richard; Clebsch, Edward E. C.; and Wofford, B. Eugene (1989). *Final Report: Survey and Documentation of Exotic Plants in Great Smoky Mountains National Park.* Sub-agreement No. 7, Cooperative Agreement No. CA-5460-5-8004 between National Park Service / Great Smoky Mountains National Park and The University of Tennessee, Knoxville.

Clements, Richard (1995). Phone conversation conducted on October 10.

Coursey, Donald G. (1967). "Yams: An Account of the Nature, Origins, Cultivation, and Utilisation of the Useful Members of the Dioscoreaceae." Longmans, London.

Cox, C. Barry; and Moore, Peter D. (1993). "Biogeography: An Ecological and Evolutionary Approach." Blackwell Scientific Publications, Boston.

Cruze, Relda and Cruze, Ed (1995). Personal interview with relatives of former GRSM resident. Conducted on January 21 during Wilderness Wildlife Week of Nature Convention at Heartlander Country Resort, Gatlinburg, Tennessee.

de Waal, Louise C.; Child, Lois E.; Wade, P. Max; and Brock, John H. (Eds.) (1994). "Ecology and Management of Invasive Riverside Plants." John Wiley & Sons, New York.

Doku, E. V. (1982). Sterility in Female White Yams *Dioscorea rotundata* Poir. *In* "Yams" (J. Miège and S. N. Lyonga, Eds.), pp. 37-43. Clarendon Press, Oxford.

Eastman, J. Ronald (1992). "IDRISI Technical Reference Manual, Version 4.0 Revision 3." Clark University Graduate School of Geography. Worcester, Massachusetts.

Eastman, J. Ronald (1993). "IDRISI Update Manual, Version 4.1 Revision 1." Clark University Graduate School of Geography. Worcester, Massachusetts.

Eastman, J. Ronald (1995). "IDRISI for Windows User's Guide, Version 1.0 Revision 1." Clark Labs for Cartographic Technology and Geograpic Analysis. Worcester, Massachusetts.

Elton, Charles S. (1977). "Ecology of Invasions by Animals and Plants." Chapman and Hall, London.

Environmental Systems Research Institute (1995). "Understanding GIS: the ARC/INFO® Method, Version 7 for UNIX® and OpenVMS™." John Wiley & Sons, Inc. New York, New York.

Espenshade, Edward B. (Ed.) (1992). "Goode's World Atlas." Rand McNally & Company, Chicago.

Gentry, Alwyn H. (1991). The Distribution and Evolution of Climbing Plants. *In* "The Biology of Vines" (F. E. Putz and H. A. Mooney, Eds.), pp. 3-49. Cambridge University Press, New York.

Gleason, Henry A. (1968). "The New Britton and Brown Illustrated Flora of the Northeastern United States and Adjacent Canada, Volume 1: The Pteridophyta, Gymnospermae and Monocotyledoneae." Hafner Press, New York.

Haragan, Patricia D. (1991). "Weeds of Kentucky and Adjacent States: A Field Guide." The University Press of Kentucky, Kentucky.

Hegarty, Elwyn E.; and Caballé, Guy (1991). Distribution and Abundance of Vines in Forest Communities. *In* "The Biology of Vines" (F. E. Putz and H. A. Mooney, Eds.), pp. 313-335. Cambridge University Press, New York.

Hiebert, Ronald D.; and Stubbendieck, James (1993). "Handbook for Ranking Exotic Plants for Management and Control." Natural Resources Report NPS/NRMWRO/NRR-93/08. U. S. Department of the Interior, National Park Service, Natural Resources Publication Office, Denver.

Hunt, Charles B. (1967). "Physiography of the United States." W. H. Freeman and Company, San Francisco.

Johnson, Kristine (1995). Exotic Plant Management Techniques in Great Smoky Mountains National Park. *TN-EPPC News* **1(2)**, 4.

Johnson, Kristine; Remaley, Tom; and Gibbs, Douglas (1995). "Inventory, Control, and Monitoring of Exotic Plants in the Great Smoky Mountains National Park." Oral presentation with accompanying literature, *Great Smoky Mountains National Park Exotic Plant Ranking key to Exotic Species.* Tennessee Exotic Pest Plant Symposium held on April 7 at Scarritt-Bennett Center, Nashville, Tennessee.

Kartesz, John T. (1990). "The Biota of North America Program International Plant Data Base: Synonymized Checklist of the Vascular Flora of the United States, Canada, and Greenland." Timber Press, Portland, Oregon.

Kemp, Steve (Ed.) (1994). Park Service Fights Back Against Invasion of Non-Native Plants. *Smokies Guide: The Official Newspaper of Great Smoky Mountains National Park,* Spring Edition, p. 6. Great Smoky Mountains Natural History Association, Gatlinburg, Tennessee.

Kemp, Steve (Ed.) (1995). The Seven Wonders of the Smoky Mountains. *Smokies Guide: The Official Newspaper of Great Smoky Mountains National Park,* Spring Edition, p. 1. Great Smoky Mountains Natural History Association, Gatlinburg, Tennessee.

Kennedy, Lisa (1993). D. batatas *in the Great Smoky Mountains Natonal Park.* Unpublished seminar paper for Research Design (504), Geography Department, University of Tennessee, December 7.

King, Philip B.; and Stupka, Arthur (1950). The Great Smoky Mountains: Their Geology and Natural History. *Scientific Monthly* **71**, 31-43.

Knight, Victor M. (1993). "Vic Knight's Florida." Pelican Publishing Company, Gretna, Louisiana.

Langdon, Keith (1993). Unpublished cassette recording of a personal interview with Natural Resources Supervisory Bioligist on October 8 at Twin Creeks Research Center, Gatlinburg, Tennessee.

Larson, Helen H. (1990). Hiking Map & Guide: Great Smoky Mountains National Park. Earthwalk Press, Eureka, California. 1:62,500.

Matthews, William H. (1973). "A Guide to the National Parks: Their Landscape and Geology." Doubleday / Natural History Press, Garden City, New York.

Maatsuura, H.; Oda, H.; and Ishizaki, H. (1985). Damage of Chinese Yam by African Mole Cricket, *Gryllotalpa africana* Palisot de Beauvois, and Its Control by Chemicals. *Japanese Society of Applied Entomology and Zoology* **29(1)**, 36-40.

Nabors [Woodcock], Pamela J. (1993). *The Spread of Chinese Yam (*D. batatas*) in the Great Smoky Mountains National Park.* Unpublished seminar paper for Research Design (504), Geography Department, University of Tennessee, December 7.

Newsome, A. E.; and Noble, I. R. (1986). Ecology and Physiological Characters of Invading Species. *In* "Ecology of Biological Invasions." (R. H. Groves and J. J. Burdon, Eds.), pp. 1-20. Cambridge University Press, New York.

Ogle, Lucinda [Oakley] (1995). Personal interview with former resident of GRSM and daughter of Wiley Oakley. Conducted on January 21 during Wilderness Wildlife Week of Nature Convention at Heartlander Country Resort, Gatlinburg, Tennessee.

Onwueme, I.C. and Haverkort, A.J. (1991). Modelling Growth and Productivity of Yams (*Dioscorea* Spp.): Prospects and Problems. *Agricultural Systems* **36**, 351-367.

Osagie, Anthony U. (1992). "The Yam Tuber in Storage." Postharvest Research Unit, Benin City, Nigeria.

Ownby, Janavee (1995). Personal interview with former resident of GRSM. Conducted on January 21 during Wilderness Wildlife Week of Nature Convention at Heartlander Country Resort, Gatlinburg, Tennessee.

Purseglove, John W. (1992). "Tropical Crops, Monocotyledons." John Wiley & Sons, New York.

Pyle, Charlotte. (1988). The Type and Extent of Anthropogenic Vegetation Disturbance in the Great Smoky Mountains Before National Park Service Acquisition. *Castanea* **53(3)**, 183-196.

Pyne, Milo (1995). "The Quest for a List of the Most of the Worst: Developing a Methodology for Ranking Invasive Exotic Plants." Notes taken at oral presentation given by representative of TN-DEC Natural Heritage Program. Tennessee Exotic Pest Plant Symposium held on April 7 at Scarritt-Bennett Center, Nashville, Tennessee.

Quinn, James F. (1996). NPFlora database for the U.S. National Park Service. Published on World Wide Web at: http://ice.ucdavis.edu/US_National_Park_Service. Search Path: gopher://ice.ucdavis.edu/77/NPS/.index/plantlists?'Dioscorea batatas'. E-mail: jfquinn@ucdavis.edu.

Radford, Albert E.; Ahles, Harry E.; and Bell, C. Ritchie (1981). "Manual of the Vascular Flora of the Carolinas." University of North Carolina Press, Chapel Hill.

Raitz, Karl B.; and Ulack, Richard (1984). "Appalachia, A Regional Geography: Land, People, and Development." Westview Press, Boulder.

Redington, Robert J. (1978). "Survey of the Appalachians." Taconic Publishers, Massachusetts.

Remaley, Tom (1994). Personal interview with Exotics Crew Team Leader on September 29 at Sugarlands Headquarters, Gatlinburg, Tennessee.

Roberts, Leslie (1990). Zebra Mussel Invasion Threatens U.S. Waters. *Science* **249**, 1370-1371.

Steward, Albert N. (1958). "Manual of Vascular Plants of the Lower Yangtze Valley, China." Oregon State College, Corvallis.

Stupka, Arthur (1964). "Trees, Shrubs, and Woody Vines of Great Smoky Mountains National Park." University of Tennesse Press, Knoxville, Tennessee.

Underwood, J. K. (1965). Tennessee Weeds: Bulletin 393. University of Tennessee Agricultural Experiment Station, Knoxville, Tennessee.

United States Department of the Interior, National Park Service (1981). "General Management Plan: Great Smoky Mountains National Park." The Denver Service Center, Denver.

United States Department of the Interior, National Park Service (1982). "Final Environmental Impact Statement for the General Management Plan: Great Smoky Mountains National Park." The Denver Service Center, Denver.

United States Department of the Interior, National Park Service (1994). Great Smoky Mountains Trail Map.

van der Pijl, Leendert (1982). "Principles of Dispersal in Higher Plants." Springer-Verlag, New York.

Vietmeyer, Noel D. (1975). The Beautiful Blue Devil. *Natural History* **84(9)**, 65-72.

White, Peter S. (1982). "The Flora of the Great Smoky Mountains National Park: An Annotated Checklist of the Vascular Plants and a Review of Previous Floristic Work." National Park Service Research/Resources Management Report SER-55. U. S. Department of the Interior, Atlanta.

Williams, Ted (1994). Invasion of the Aliens. *Audubon* **96(5)**, 24 - 32.

Wofford, B. Eugene (1989). "Guide to the Vascular Plants of the Blue Ridge." The University of Georgia Press, Athens.

Zomlefer, Wendy B. (1994). "Guide to Flowering Plant Families." North Carolina Press, Chapel Hill.

APPENDICES

APPENDIX A

ERDAS TO ARC/INFO REFORMATTING PROGRAM

```
/**************************************************************************/
/* NAME:      dig2lin.c                                                   */
/* PURPOSE:   Convert ERDAS .DIG formatted (vector) files to              */
/*            ARC/INFO generate line file.                                */
/*                                                                        */
/* USAGE:     dig2lin <inputname> <-DIR | -FILE>                          */
/*                                                                        */
/* Example:   dig2lin outline.dig outline.lin                             */
/*                                                                        */
/* CREATED BY:   PJ (Woodcock) Nabors    July 1994                        */
/*                                                                        */
/**************************************************************************/
#include "stdio.h"
#include "stdlib.h"
#define RECLEN 80

FILE                    *lisfp, *infp, *genfp, *attfp;

/* Function declarations */
void SingleFile(char*);
void WholeDir();
void Dig2Gen();
void Format_Coord();


void main(argc, argv)
 int argc;
 char *argv[];

{
 /* Error check user inputs */
 if(argc!=3)
 {
  printf("Usage: dig2lin <erdas_filename | erdas_dirname> <-FILE | -DIR> \n");
  exit(1);
 }

 /* Open Generate output file */
 if((genfp = fopen("xxdigtemp.gen","w"))== NULL)
 {
  printf("ERROR: Opening Generate output file \n");
  exit(1);
 }

 /* Open Attribute output file */
 if((attfp = fopen("xxdigtemp.att","w")) == NULL)
 {
  printf("ERROR: Opening Attribute output file \n");
  exit(1);
 }

 if(strcmp(argv[2],"-FILE")==0)
  SingleFile(argv[1]);
 else if(strcmp(argv[2], "-DIR") == 0)
  WholeDir();
 else
  {
   printf("ERROR: Invalid second parameter: %s \n",argv[2]);
   exit(1);
  }

 /* Write out final EOF marker */
 fprintf(genfp,"END\n");

 fclose(genfp);
 fclose( attfp);

} /*end dig2lin*/
```

```
/*************************************************************************
FUNCTION SINGLEFILE()
            This routine generates files for a single filename.
_________________________________________________________________________/
void SingleFile(char *inputname)
{
 /* Open input file */
 if((infp = fopen(inputname,"r")) == NULL)
 {
  printf("ERROR: Opening input file: %s \n",inputname);
  exit(1);
 }

 Dig2Gen();    /* Convert data and create the generate file */

 fclose(infp);

} /*end SingleFile*/

/*************************************************************************
FUNCTION WHOLEDIR()
            This routine generates files for a whole directory.
*************************************************************************/
void WholeDir()
{
 char filename[RECLEN];


 /* Create file list */
 system("ls -1 *.dig > xxdigtemp.lis");

 /* Open file list */
 if((lisfp = fopen("xxdigtemp.lis","r")) == NULL)
 {
  printf("ERROR: Opening listing of files: xxdigtemp.lis \n");
  exit(1);
 }

 while (!feof(lisfp))
 {
  /* Get input filename */
  if(fgets(filename,RECLEN,lisfp))
  {
   /* Open input file */
   if((infp = fopen(filename,"r"))== NULL)
   {
    printf("ERROR: Opening input file: %s \n",filename);
    exit(1);
   }

   printf("Getting input from %s \n", filename);

   Dig2Gen();             /* Convert data and create the generate file */

   fclose(infp);

  }
 } /*while*/

} /*end WholeDir*/
```

ERDAS TO ARC/INFO REFORMATTING PROGRAM (cont'd)

```
/*********************************************************************
FUNCTION DIG2GEN()
This routine inputs and reformats an ERDAS vector file (.DIG)
and writes it out in ARC/INFO GENERATE format
*********************************************************************/
void Dig2Gen()
{
 char      inputstr[RECLEN];
 int       numpts, gisval,munits,mode, numrecs;     /* ERDAS hdr values */
 int       idnum=1, i=0;


 /* Read in ERDAS graphics header */
 if((fgets(inputstr, RECLEN, infp))
  sscanf(inputstr, "%d%d%d%d%d", &numpts,&gisval,&munits,&mode,&numrecs);

 while (i < numpts)
 {
  /* Skip header x,y info (ll,ul,ur,lr) */
  if(fgets(inputstr, RECLEN, infp));
  i++;
 }

 while (!feof(infp))
 {
  /* Read in ERDAS element header */
  if(fgets(inputstr, RECLEN, infp))
  {
   sscanf(inputstr, "%d%d%d%d", &numpts,&gisval,&munits,&mode);
   fprintf(genfp, "%d\n",idnum);            /* Write out id number for this arc */

   /* Read and write coordinate pairs */
   i = 0;
   while (i < numpts)
   {
    Format_Coord();
    i++;
   }

   fprintf(genfp,"END\n");    /* Write out end of arc marker */
   idnum++;
  }/*if*/
 } /*while*/

}/*end Dig2Gen*/


/*********************************************************************
This routine reads in the next coordinate pair from the input
file and strips the semicolon. The new string is written out to
the output file.
*********************************************************************/
void Format_Coord()
{
 char str[RECLEN];
 int newlen;

 if(fgets(str, RECLEN, infp))
 {
  newlen = strcspn(str, ";");
  if(newlen != strlen(str))
  {
   str[newlen] = '\0';
   fprintf(genfp, "%s\n", str);
  }
  else fprintf(genfp, "%s", str);
 }


}/*end Format_Coord*/
/*********************************************************************/
```

APPENDIX B

SAMPLE FIELD SHEET
(next two pages)

FIELD DATA SHEET for *Dioscorea batatas*

PREVIOUS 1987-1988 Exotic Plant Survey INFORMATION

EPS Drainage: ____ EPS Occurrence: ____ EPS Field Notes Date: ____

EPS Quadrangle: ____ UTM1: ____ E

EPS Quad Section: ____ UTM2: ____ N

EPS Area: ____ sq. m. EPS Elevation: ____ ft.

EPS Description: ____ EPS Status: ____

D = Declining E = Expanding P = Persistent
S = Seed V = Veg.

PJ Nabors Summer 1996 Survey INFORMATION

PJN Site #: ____ Current Date: ____

Correct Quad: ____ PJN UTM1: ____ E

Quad Page #: ____ PJN UTM2: ____ N

PJN Elevation: ____ m.

New Site?
- Yes
- Unsure
- No

Presence:
- Present
- Unsure
- Absent

Visited:
- Yes
- Unsure
- No

Starting Notes:

Travel Remarks:

Location Notes:

Location:

0	No Data
1	Boundary Areas (park boundary and roads)
2	Heavily Visited Areas
3	Backcountry

Survival:

0	No Data
1	Declining/Not Establishing
2	Persisting
3	Slowly Expanding
4	Rapidly Expanding

Impact on local habitats or floras:

0	No Data
1	No Observable Impact
2	Low Impact
3	Moderate Impact
4	Severe Impact

Surrounding Natives:	Other POSSIBLE Exotics:		
Dioscorea spp.	Buxus sempervirens	Microstegium vimineum?	Vinca minor?
Dutchman's Pipe	Lonicera japonica?	Rosa?	
Hog Peanut			

Average Density:

No Data	
Sparse	(only a few plants)
Moderate	(mature plants with seedlings)
Heavy	

Highest Density:

No Data	
Sparse	(only a few plants)
Moderate	(mature plants with seedlings)
Heavy	

PJN Site #:

Canopy:

No Data
Open
Semi-Open
Semi-Closed
Closed

Continuity of Coverage:

No Data	
Discontinuous	(> 3 m. between groups of plants)
Relatively Continuous	(< 3 m. between groups of plants)
Continuous	(< 1 m. between groups of plants)

Estimated Length: m.

Estimated Width: m.

Estimated Area: sq. m.

Scaled Light Meter Numbers

Inside Infested Area	*Outside*
Time:	Time:
Inside Ave:	**Outside Ave:**

Other Remarks:

Site Sketch:

APPENDIX C

IDRISI MACRO LANGUAGE (IML) ROUTINES

FOR POTENTIAL-SPREAD MODEL

MAIN LEVEL ROUTINES

DISPMAIN.IML

```
BRANCH BC_Main
BRANCH CC_Main
BRANCH CW_Main
BRANCH GB_Main
BRANCH HF_Main
BRANCH JC_Main
BRANCH KS_Main
BRANCH MG_Main
BRANCH ML_Main
BRANCH NC_Main
BRANCH SM_Main
BRANCH WC_Main
BRANCH WV_Main
BRANCH Disp_Cat
```

DISP_CAT.IML

```
INITIAL x grsmref 1 1 255 1 bigdem units GRSM Disperse Model (Potential Spread) Final Output
CONCAT x grsmref 4 bigndisp 1 gbfinal 1 1425 505 mlfinal 1 1660 330 mgfinal 1 2245 200 jcfinal 1 2130 280
CONCAT x bigndisp 3 bigsdisp 1 smfinal 1 2110 1020 bcfinal 1 1775 1250 ncfinal 1 1495 1340
CONCAT x bigsdisp 3 bigedisp 1 ccfinal 1 2825 605 hffinal 1 2440 160 wvfinal 1 2625 215
CONCAT x bigedisp 5 grsmdmap 1 ksfinal 1 500 595 wcfinal 1 845 505 cw1final 1 195 790 cw2final 1 294 1115 cw3final 1 110 1075
```

LOW LEVEL ROUTINES (used by regional IMLs)

SITEDISP.IML

```
SURFACE x 3 %1 XXslp XXasp d
RECLASS x i %2 XXsite 2 1 1 125 -9999
DISPERSE x XXsite XXslp XXasp 10000 none %3 1 2
```

SITEPATH.IML

```
RECLASS x i %1 XXptgt 2 0 255 256 1 0 255 -9999
PATHWAY x %2 XXptgt %3
```

DISP_MAP.IML

```
RECLASS x i %1 XXd1 3 dmap3a
RECLASS x i XXd1 XXd2 3 dmap3b
RECLASS x i XXd2 %2 3 dmap3c
```

DMAP3A.RCL

```
255   -1       0
0     0        0.0001
1     0.0001   6
2     6        12
3     12       18
4     18       24
.
.     (cont'd)
85    504      510
-9999
```

DMAP3B.RCL

```
86    510      516
87    516      522
88    522      528
.
.     (cont'd)
170   1014     1020
-9999
```

DMAP3C.RCL

```
171   1020     1026
172   1026     1032
173   1032     1038
.
.     (cont'd)
249   1488     1494
250   1494     1500
252   1500     10001
-9999
```

SMOKEMONT REGION POTENTIAL-SPREAD ROUTINES
(other regional IMLs are similar)

SM_MAIN.IML
```
BRANCH SM_DSet
BRANCH SM_Run1
BRANCH SM_Run2
BRANCH SM_PSet
BRANCH SM_Run3
BRANCH SM_Run4
OVERLAY x 8 smdmap smpmap smfinal
```

SM_DSET.IML
```
WINDOW x bigdem smelev 1 2110 1020 2300 1290
INITIAL x sminit 1 1 0 1 smelev units
COPY x sminit.img D22-0072.img
COPY x sminit.doc D22-0072.doc
POINTRAS x D22-0072 D22-0072 1
COPY x sminit.img D22-0076.img
COPY x sminit.doc D22-0076.doc
POINTRAS x D22-0076 D22-0076 1
COPY x sminit.img D22-0089.img
COPY x sminit.doc D22-0089.doc
POINTRAS x D22-0089 D22-0089 1
COPY x sminit.img D22-0095.img
COPY x sminit.doc D22-0095.doc
POINTRAS x D22-0095 D22-0095 1
COPY x sminit.img D22-0118.img
COPY x sminit.doc D22-0118.doc
POINTRAS x D22-0118 D22-0118 1
COPY x sminit.img D22-0127.img
COPY x sminit.doc D22-0127.doc
POINTRAS x D22-0127 D22-0127 1
COPY x sminit.img D22-0132.img
COPY x sminit.doc D22-0132.doc
POINTRAS x D22-0132 D22-0132 1
```

SM_RUN1.IML
```
BRANCH SiteDisp smelev D22-0072 s112disp
BRANCH SiteDisp smelev D22-0076 s113disp
BRANCH SiteDisp smelev D22-0089 s114disp
BRANCH SiteDisp smelev D22-0095 s115disp
BRANCH SiteDisp smelev D22-0118 s116disp
BRANCH SiteDisp smelev D22-0127 s117disp
BRANCH SiteDisp smelev D22-0132 s118disp
```

SM_RUN2.IML
```
BRANCH Disp_Map s112disp s112dmap
BRANCH Disp_Map s113disp s113dmap
BRANCH Disp_Map s114disp s114dmap
```

(continued)
```
BRANCH Disp_Map s115disp s115dmap
BRANCH Disp_Map s116disp s116dmap
BRANCH Disp_Map s117disp s117dmap
BRANCH Disp_Map s118disp s118dmap
RECLASS x i sminit smdmap 2 255 0 1 -9999
OVERLAY x 8 s112dmap smdmap XXfnl1
OVERLAY x 8 s113dmap XXfnl1 XXfnl2
OVERLAY x 8 s114dmap XXfnl2 XXfnl3
OVERLAY x 8 s115dmap XXfnl3 XXfnl4
OVERLAY x 8 s116dmap XXfnl4 XXfnl5
OVERLAY x 8 s117dmap XXfnl5 XXfnl6
OVERLAY x 8 s118dmap XXfnl6 smdmap
```

SM_PSET.IML
```
COPY x sminit.img smstart.img
COPY x sminit.doc smstart.doc
UPDATE x smstart 1 256 256 104 104
COPY x sminit.img smstrm.img
COPY x sminit.doc smstrm.doc
LINERAS x streams smstrm
RECLASS x i smstrm XXsurf 2 -1 0 1 1 1 10000 -9999
CONVERT x XXsurf XXsurf i 2 2 2
COSTGROW x smstart XXsurf 1000 smcostg 1
RECLASS x i smcostg XXovrlay 2 10000 -1 0 0 1 1001 -9999
OVERLAY x 9 XXovrlay smcostg smpsurf
```

SM_RUN3.IML
```
UPDATE x smpsurf 0 256 256 104 104
BRANCH SitePath s112dmap smpsurf s112path
BRANCH SitePath s113dmap smpsurf s113path
BRANCH SitePath s114dmap smpsurf s114path
BRANCH SitePath s115dmap smpsurf s115path
BRANCH SitePath s116dmap smpsurf s116path
BRANCH SitePath s117dmap smpsurf s117path
BRANCH SitePath s118dmap smpsurf s118path
```

SM_RUN4.IML
```
OVERLAY x 7 s112path sminit XXfnl1
OVERLAY x 7 s113path XXfnl1 XXfnl2
OVERLAY x 7 s114path XXfnl2 XXfnl3
OVERLAY x 7 s115path XXfnl3 XXfnl4
OVERLAY x 7 s116path XXfnl4 XXfnl5
OVERLAY x 7 s117path XXfnl5 XXfnl6
OVERLAY x 7 s118path XXfnl6 XXfnl7
RECLASS x i XXfnl7 smpmap 2 255 0 1 254 1 2 -9999
```

IML ROUTINES (cont'd)

FOR CALCULATING POTENTIAL-SPREAD AREA

FINDAREA.IML

```
BRANCH CalcArea s001disp s001area
BRANCH CalcArea s002disp s002area
BRANCH CalcArea s003disp s003area
BRANCH CalcArea s004disp s004area
BRANCH CalcArea s005disp s005area
.
.        (continued)
.
BRANCH CalcArea s120disp s120area
BRANCH CalcArea s121disp s121area
BRANCH CalcArea s122disp s122area
BRANCH CalcArea s123disp s123area
BRANCH CalcArea s124disp s124area
BRANCH CalcArea s125disp s125area
```

CALCAREA.IML

```
RECLASS x i %1 XXreclas 2 0 -1 0 1 0 10001 -9999
AREA x XXreclas 2 4 %2
```

FOR CALCULATING STREAM DISTANCE

STRMDIST.IML

```
INITIAL x bigsite 1 1 0 1 bigdem units
POINTRAS x epssite bigsite 1
RECLASS x i bigsite bigsiter 2 1 1 126 -9999
INITIAL x bigstrm 1 1 0 1 bigdem units
LINERAS x streams bigstrm
RECLASS x i bigstrm bigstrmr 2 1 1 6000 -9999
DISTANCE x bigstrmr strmdist
RECLASS x i strmdist strmdisr 2 -1 0 1 -9999
OVERLAY x 3 bigsiter strmdisr epsstrm
EXTRACT x bigsite epsstrm 1 1 epsstrm
```

FOR NEW SITE ANALYSIS

NEWCALC.IML

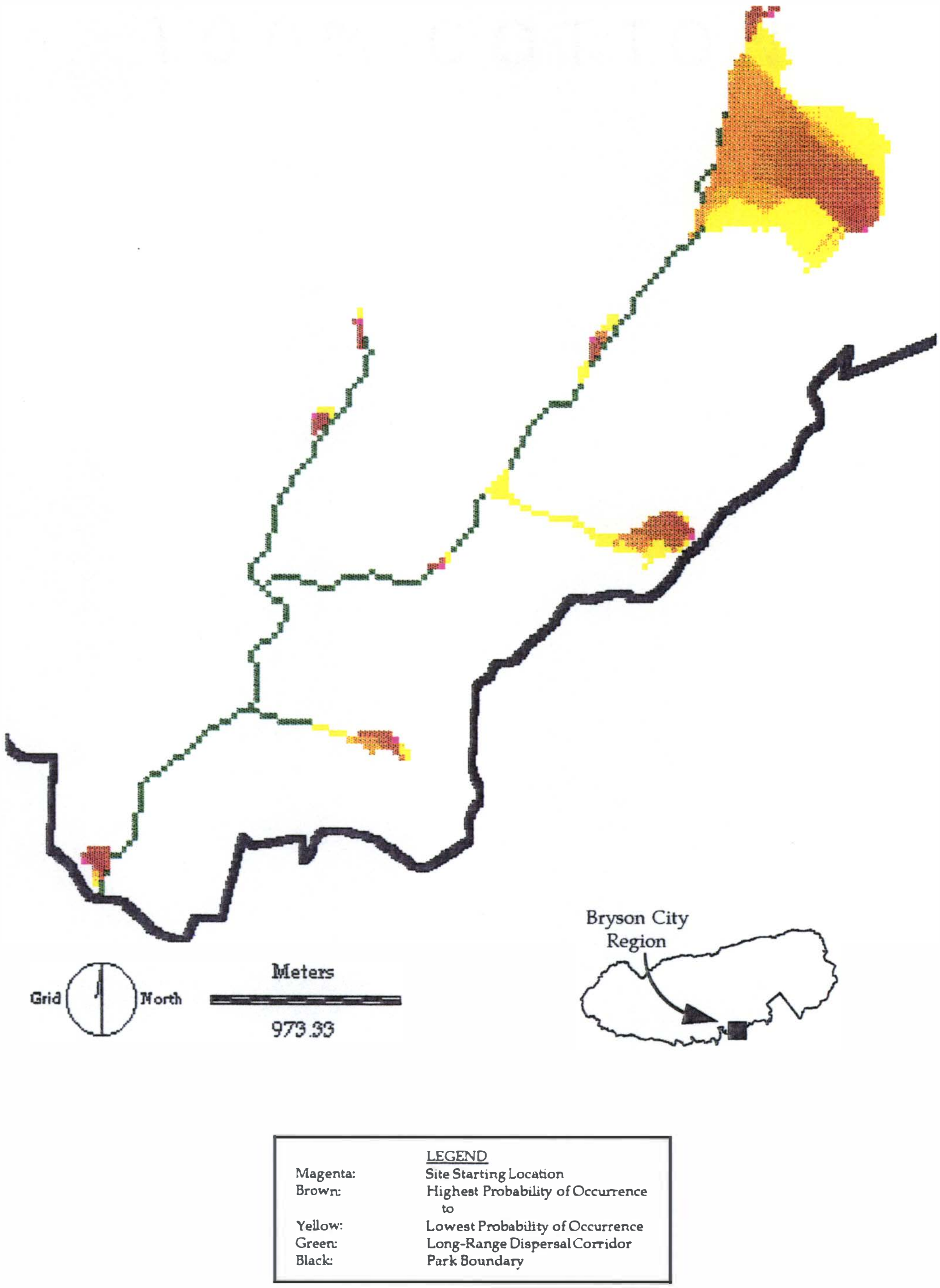
```
INITIAL x newsites 1 1 0 1 bigdem units
POINTRAS x newsite newsites 1
RECLASS x i newsites newsiter 2 1 1 50 -9999
OVERLAY x 3 newsiter grsmdmap newout
EXTRACT x newsiter newout 1 1 newout
```

NEWDIST.IML

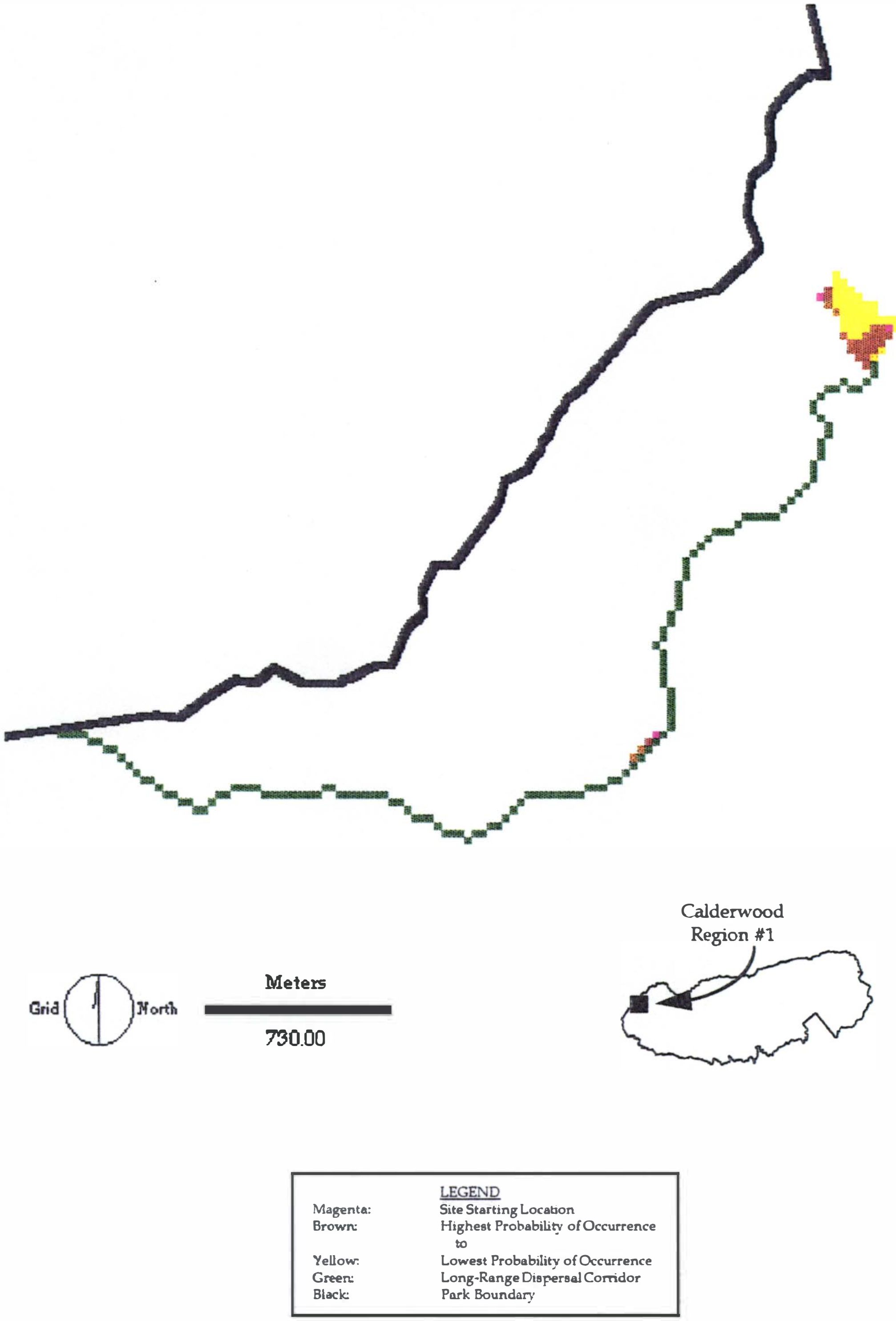
```
RECLASS x i grsmdmap bigdmap 2 0 255 256 1 0 255 -9999
DISTANCE x bigdmap dispdist
RECLASS x i dispdist dispdisr 2 -1 0 1 -9999
OVERLAY x 3 newsiter dispdisr newdist
EXTRACT x newsites newdist 1 1 newdist
```

APPENDIX D

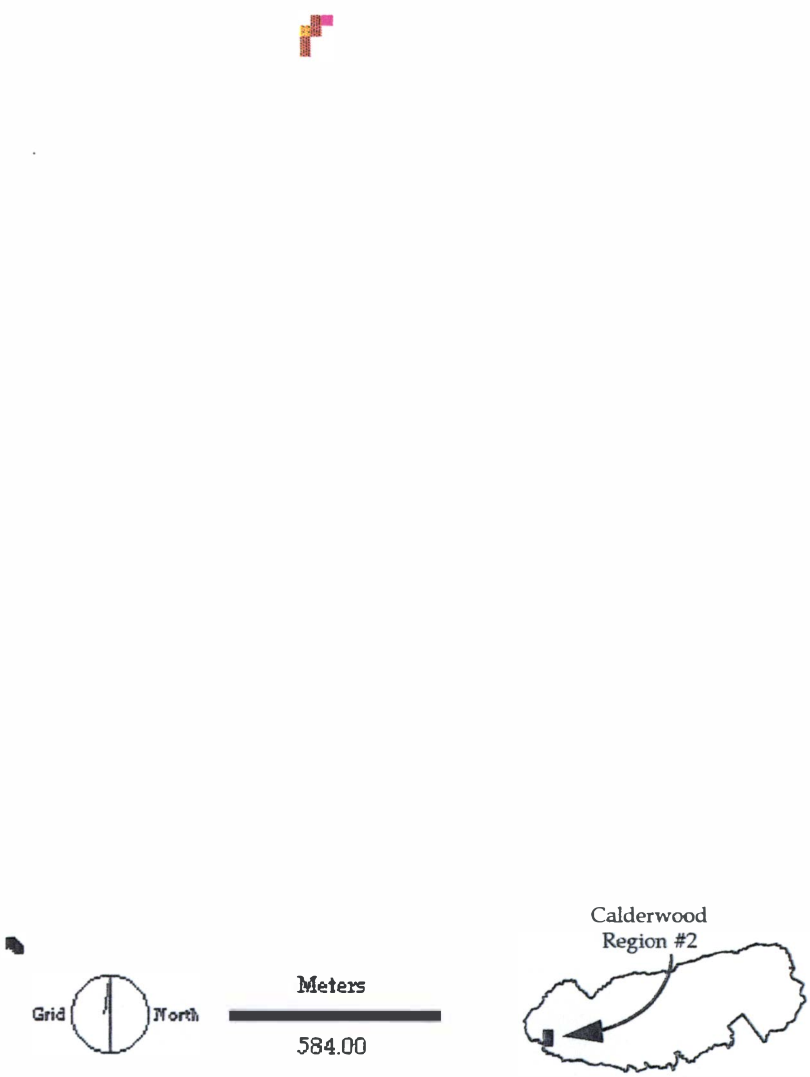
REGIONAL POTENTIAL-SPREAD MAPS
(following pages)



Bryson City Region Potential-Spread Map

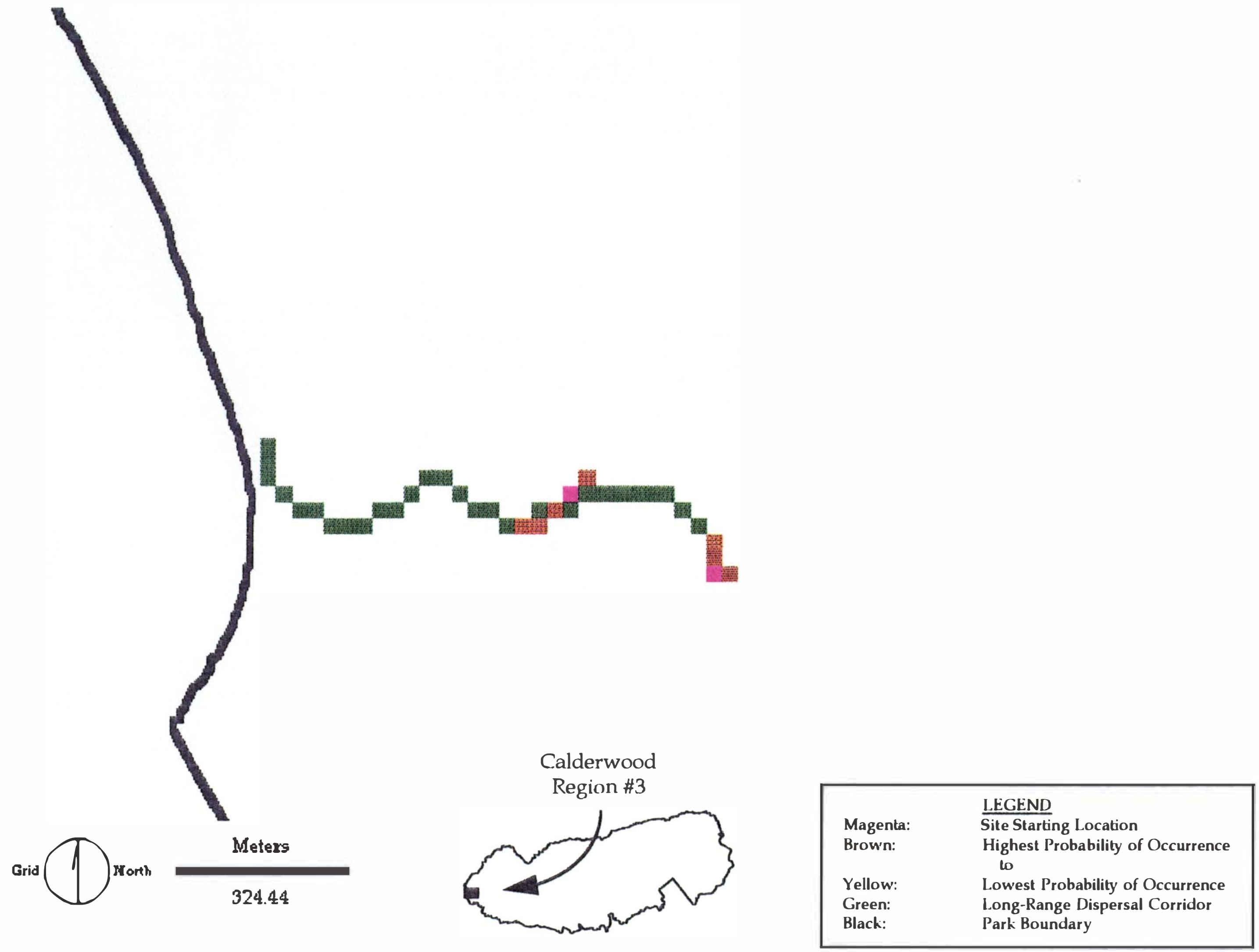


Calderwood Region 1 Potential-Spread Map

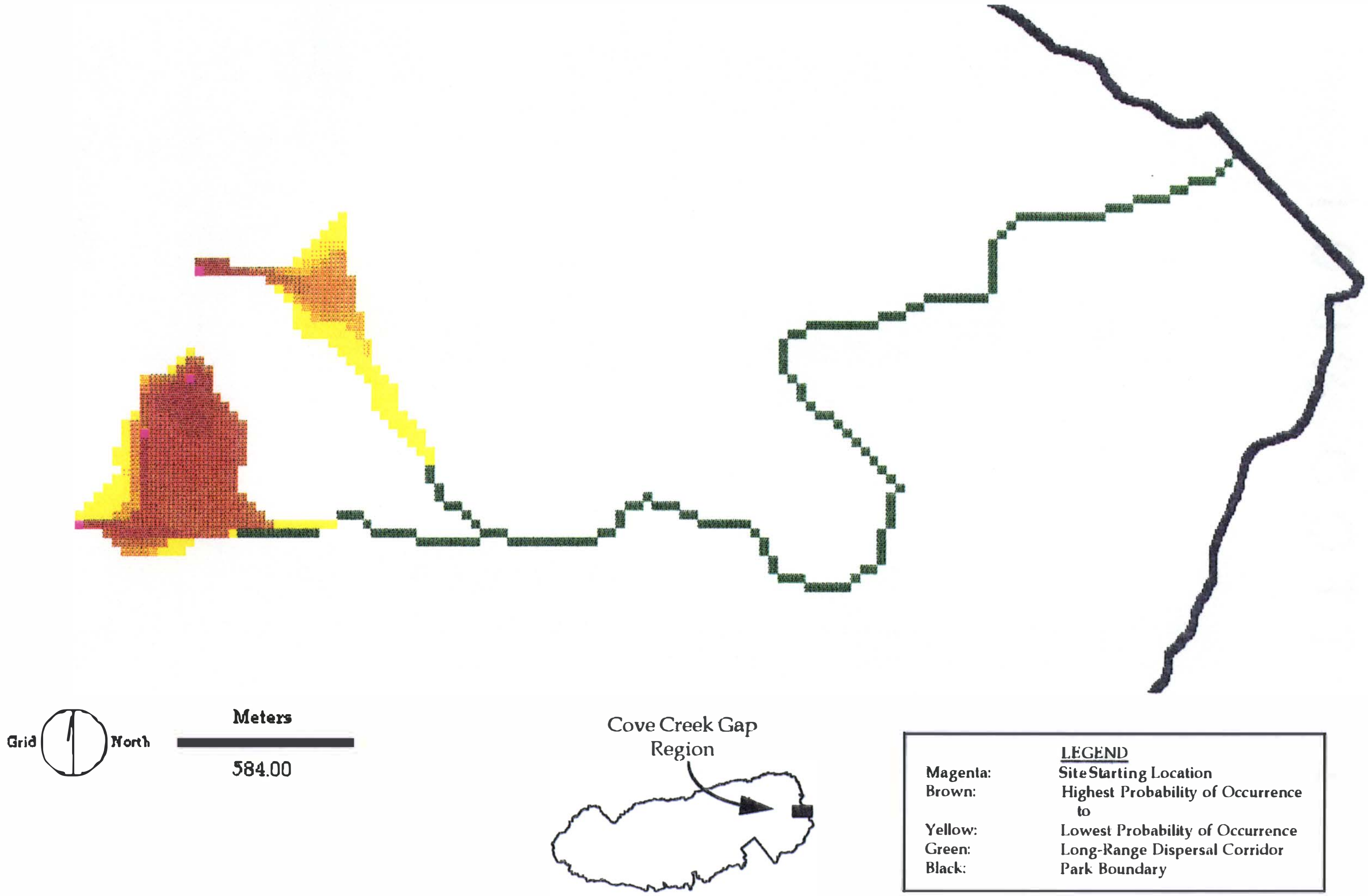


	LEGEND
Magenta:	Site Starting Location
Brown:	Highest Probability of Occurrence
	to
Yellow:	Lowest Probability of Occurrence
Green:	Long-Range Dispersal Corridor
Black:	Park Boundary

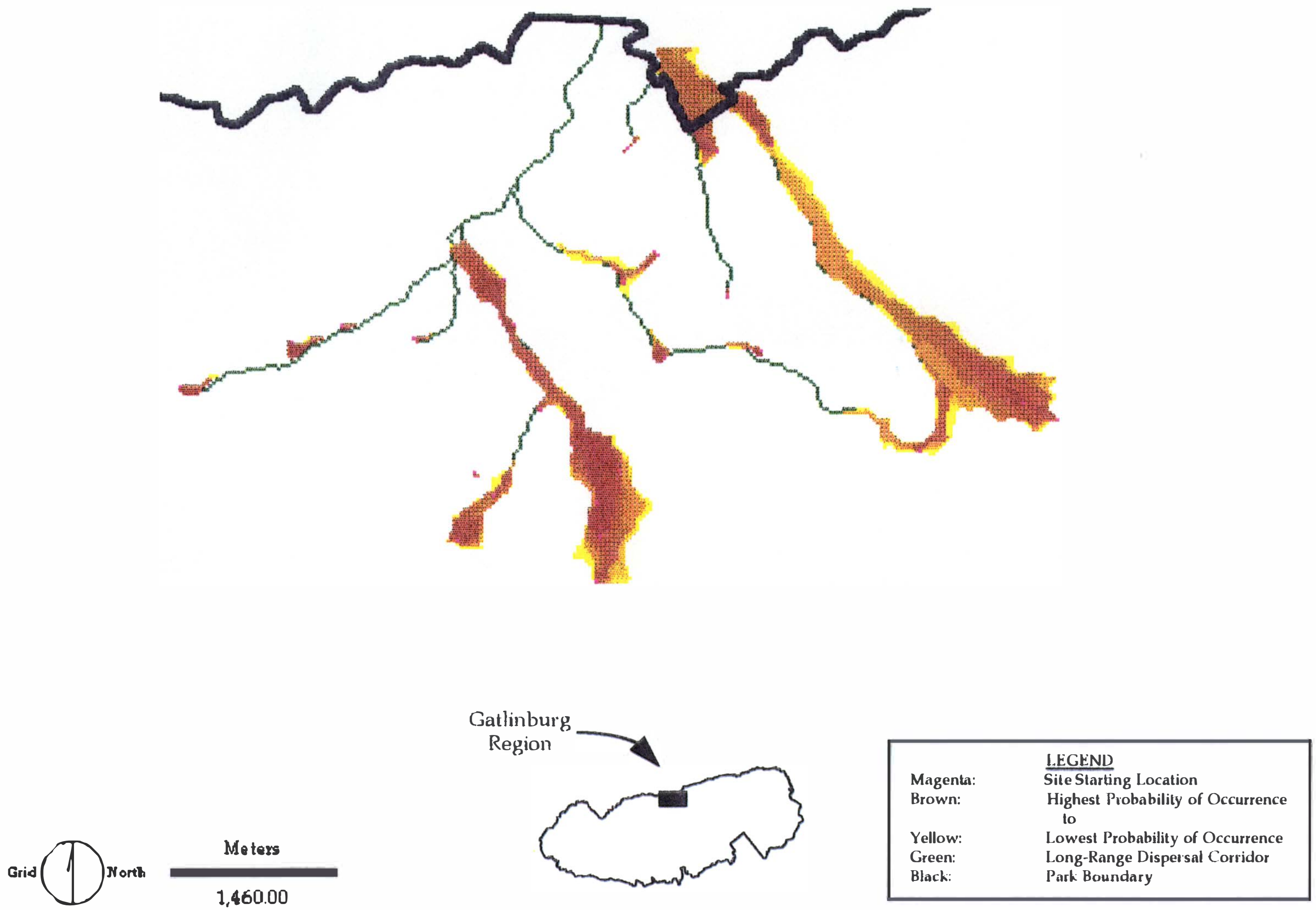
Calderwood Region 2 Potential-Spread Map



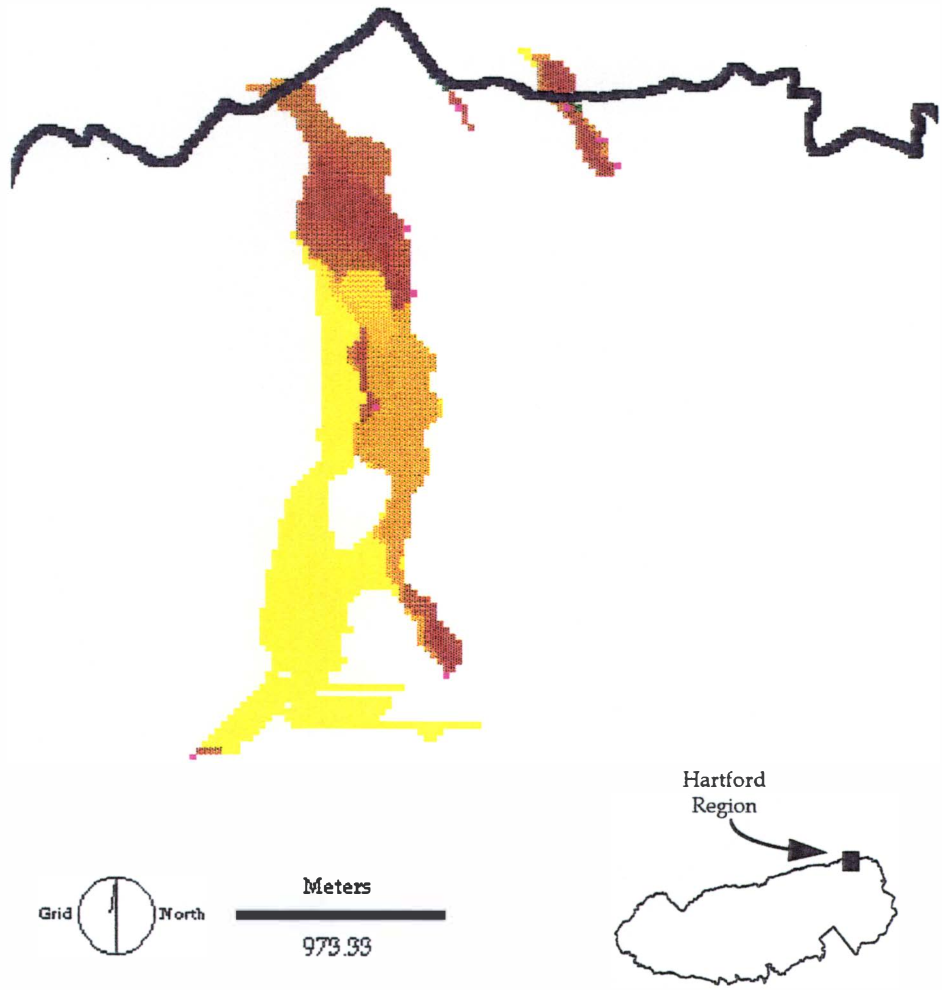
Calderwood Region 3 Potential-Spread Map



Cove Creek Gap Region Potential-Spread Map

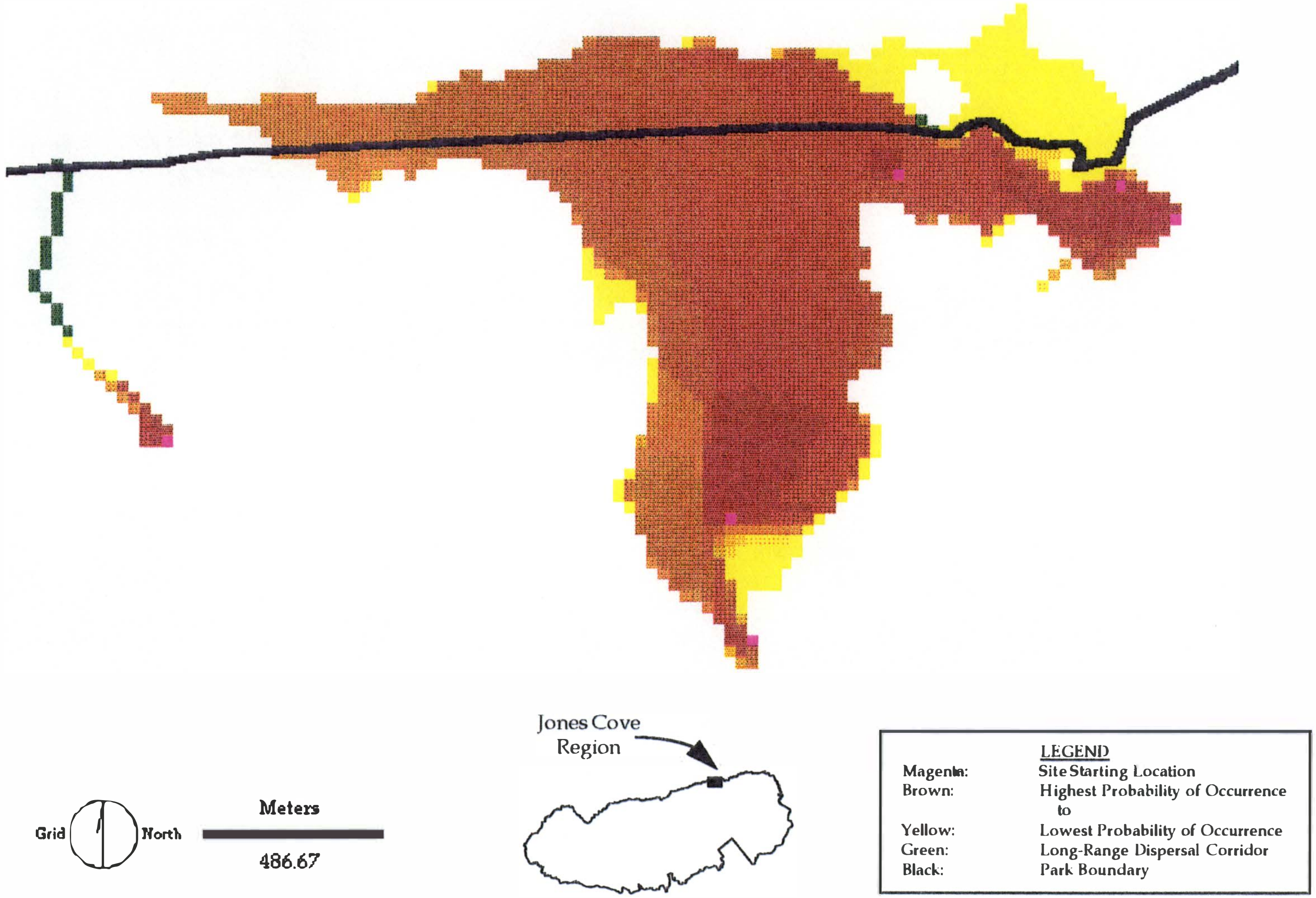


Gatlinburg Region Potential-Spread Map

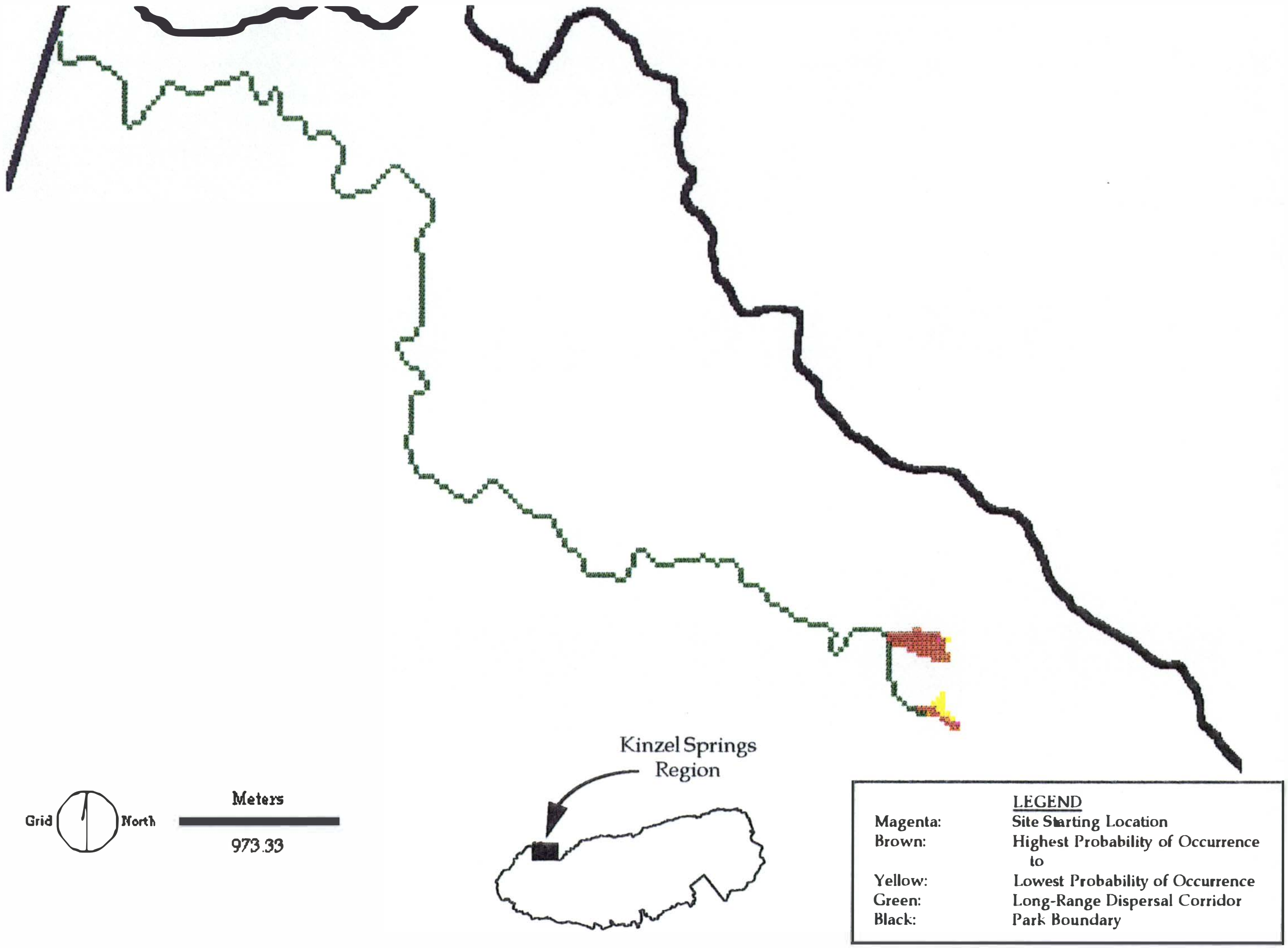


	LEGEND
Magenta:	Site Starting Location
Brown:	Highest Probability of Occurrence
	to
Yellow:	Lowest Probability of Occurrence
Green:	Long-Range Dispersal Corridor
Black:	Park Boundary

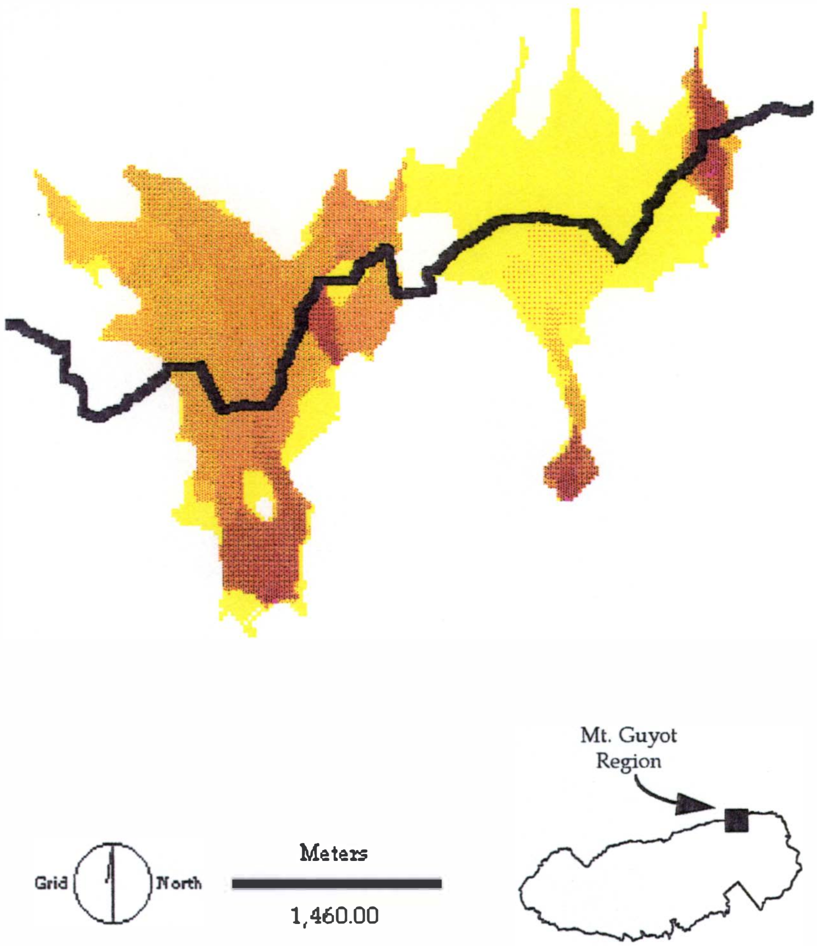
Hartford Region Potential-Spread Map



Jones Cove Region Potential-Spread Map

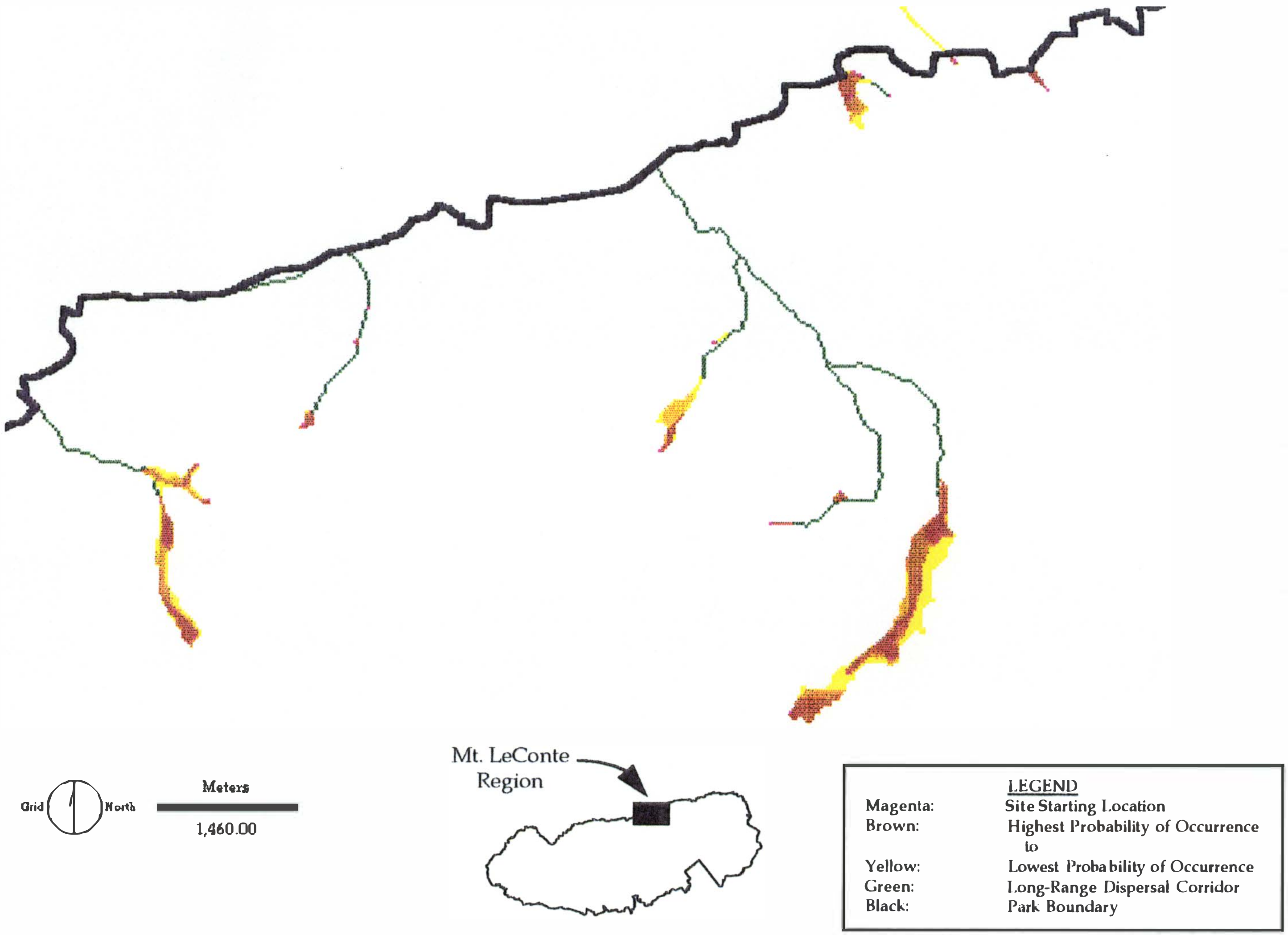


Kinzel Springs Region Potential-Spread Map

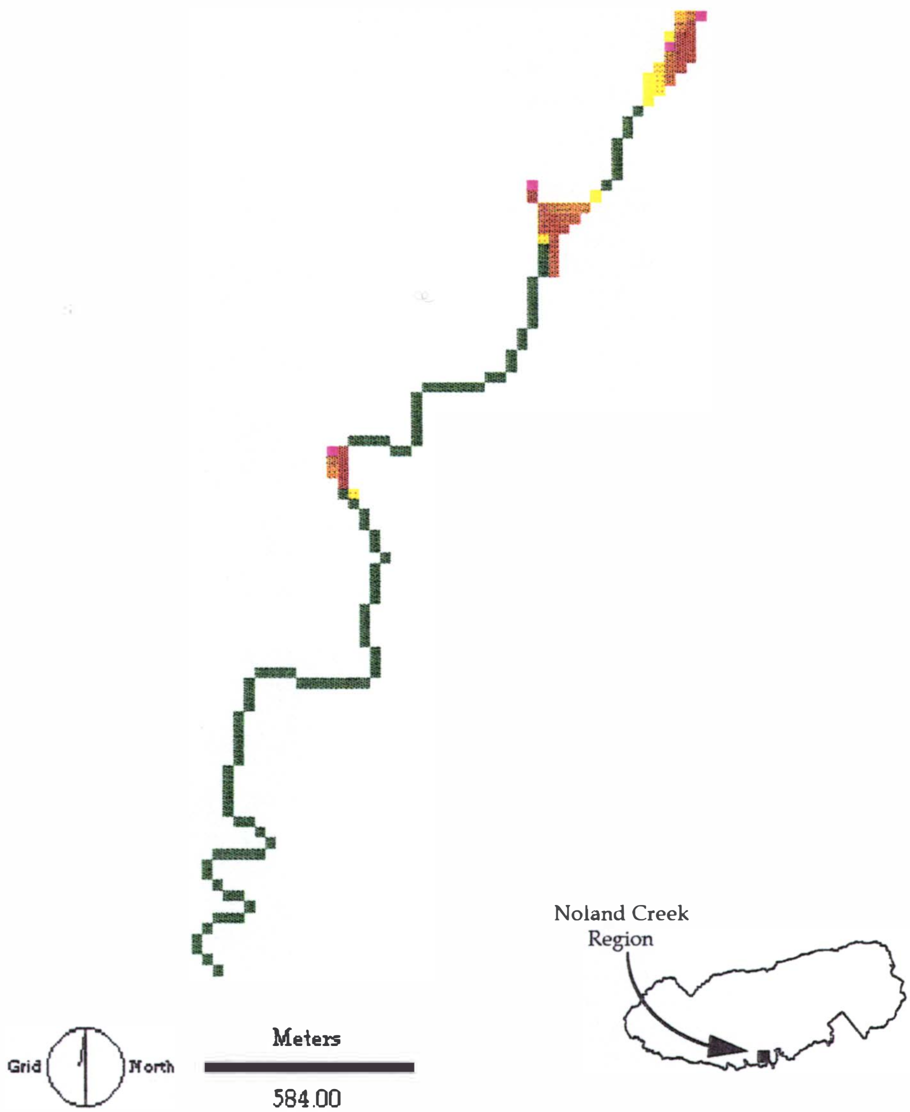


LEGEND	
Magenta:	Site Starting Location
Brown:	Highest Probability of Occurrence
	to
Yellow:	Lowest Probability of Occurrence
Green:	Long-Range Dispersal Corridor
Black:	Park Boundary

Mount Guyot Region Potential-Spread Map



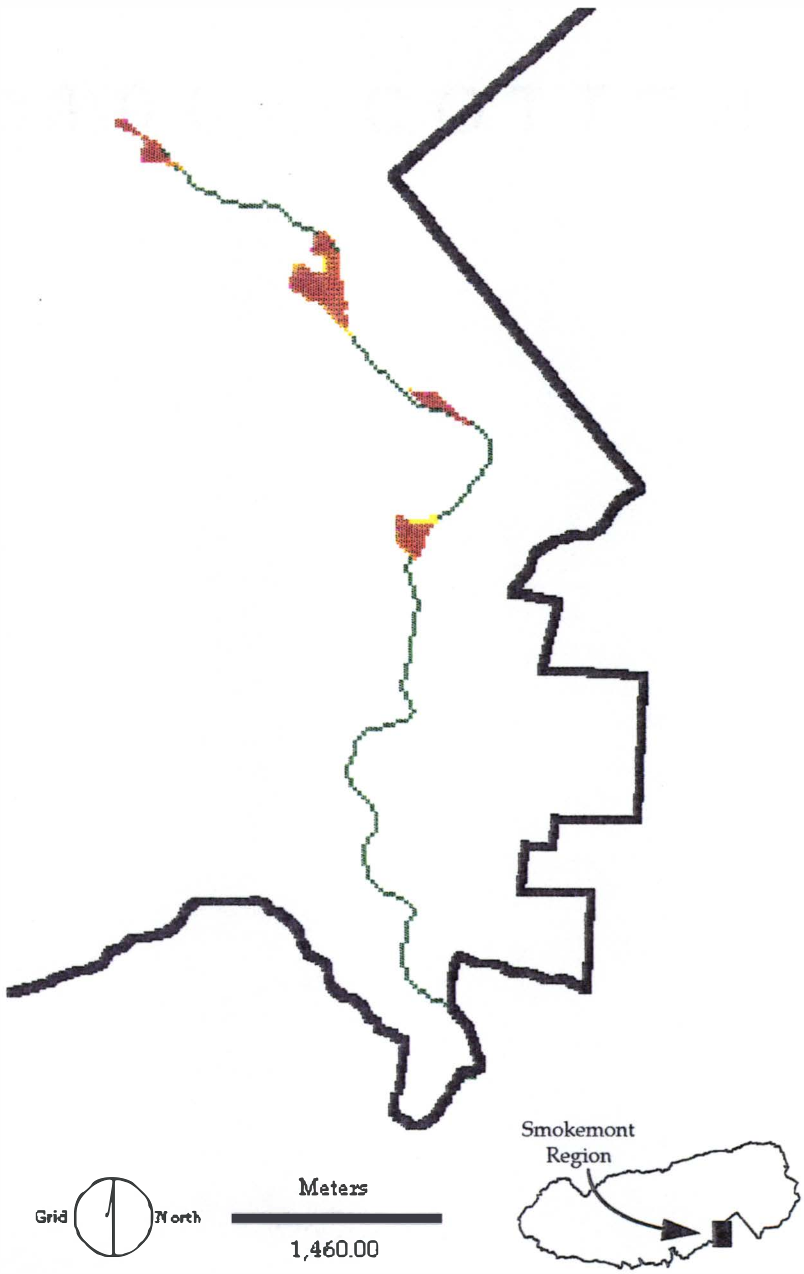
Mount LeConte Region Potential-Spread Map



(Note: Long-Range Dispersal Corridor ends at Fontana Lake)

	LEGEND
Magenta:	Site Starting Location
Brown:	Highest Probability of Occurrence
	to
Yellow:	Lowest Probability of Occurrence
Green:	Long-Range Dispersal Corridor

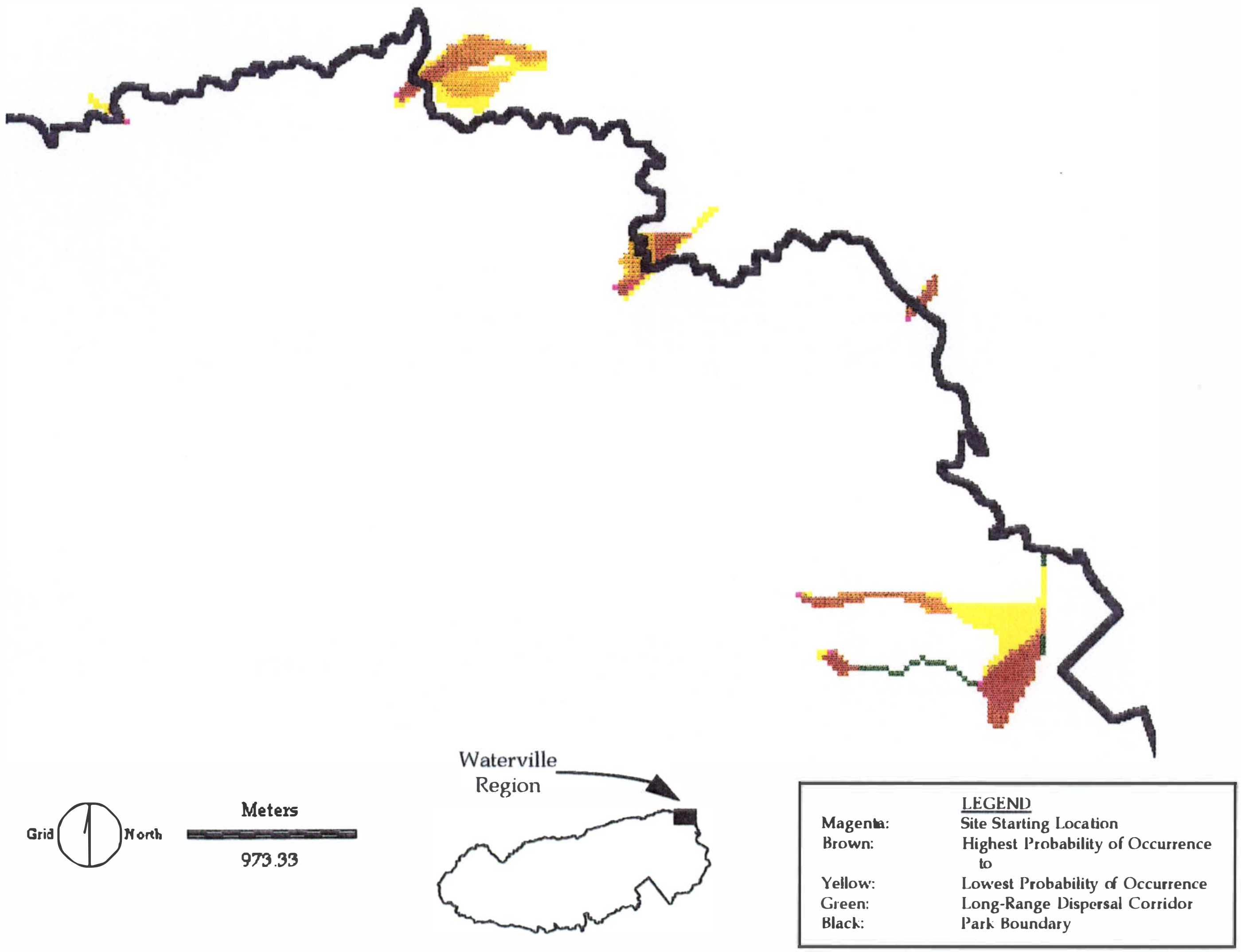
Noland Creek Region Potential-Spread Map



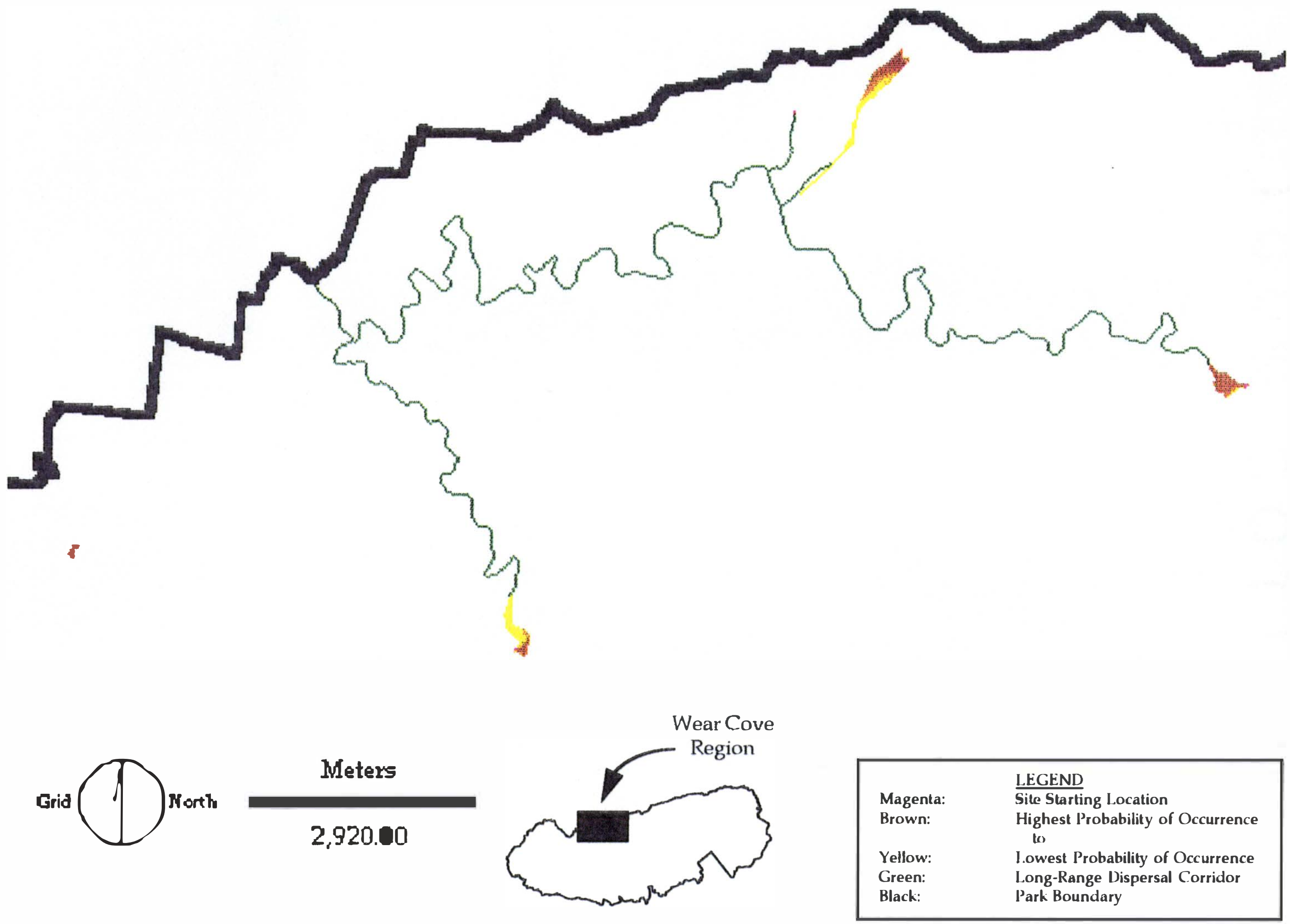
LEGEND

Magenta:	Site Starting Location
Brown:	Highest Probability of Occurrence to
Yellow:	Lowest Probability of Occurrence
Green:	Long-Range Dispersal Corridor
Black:	Park Boundary

Smokemont Region Potential-Spread Map



Waterville Region Potential-Spread Map



Wear Cove Region Potential-Spread Map

APPENDIX E

PRIORITIZED LISTS

LIST 1: SORTED BY POTENTIAL-SPREAD AREA

Potential Area (sq. m.)	IDRISI ID	SMEPS Drainage	SMEPS Occurrence	SMEPS Area (sq. m.)	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
3,820,500	23	2	13	75	JONES COVE	294230	3958100
3,820,500	24	2	16	500	JONES COVE	294230	3958100
2,885,400	25	2	17	20	JONES COVE	296300	3958830
1,279,800	15	1	61	50	HARTFORD	299030	3958950
1,258,200	57	5	44	5	GATLINBURG	275570	3950620
1,216,800	30	3	27	10	JONES COVE	290910	3958480
1,085,400	29	3	24	10	JONES COVE	290840	3958800
1,077,300	58	5	49	15	GATLINBURG	275270	3950750
1,051,200	80	6	84	75	GATLINBURG	274390	3950350
742,500	21	2	3	25	JONES COVE	294700	3959780
742,500	22	2	7	25	JONES COVE	294700	3959780
712,800	110	20	87	100	BRYSON CITY	282700	3929790
661,500	13	1	54	15	HARTFORD	300250	3959350
629,100	74	6	31	30	GATLINBURG	271570	3949210
496,800	26	3	6	15	JONES COVE	292050	3959600
491,400	42	4	24	4	MOUNT LE CONTE	283950	3952400
436,500	39	4	15	15	MOUNT LE CONTE	282890	3951850
401,400	27	3	12	50	JONES COVE	291900	3959700
364,500	75	6	37	10	GATLINBURG	271600	3949600
351,900	12	1	47	15	HARTFORD	300100	3961150
303,300	55	5	27	1000	GATLINBURG	272610	3952950
297,900	20	1	83	150	HARTFORD	297400	3960700
283,500	19	1	81	50	HARTFORD	297400	3960800
267,300	11	1	43	50	HARTFORD	300050	3961450
257,400	119	27	12	1	COVE CREEK GAP	310400	3949620
227,700	41	4	22	2	MOUNT LE CONTE	283940	3952600
206,100	59	5	50	25	MOUNT LE CONTE	276750	3952610
206,100	60	5	53	50	MOUNT LE CONTE	276750	3952610
204,300	40	4	20	3	MOUNT LE CONTE	284000	3952750
204,300	125	28	16	250	WATERVILLE	308300	3959120
198,900	4	1	15	50	HARTFORD	306000	3962020
198,000	86	7	82	5	WEAR COVE	261990	3952980
180,900	18	1	77	100	HARTFORD	297330	3961100
180,900	76	6	40	10	GATLINBURG	271550	3949890
178,200	56	5	33	50	GATLINBURG	273090	3953010
160,200	17	1	75	50	HARTFORD	297370	3961150
149,400	72	6	22	20	GATLINBURG	270370	3949570
147,600	16	1	71	150	HARTFORD	297350	3961200
140,400	78	6	57	60	GATLINBURG	270850	3951450
137,700	79	6	72	5	GATLINBURG	271780	3950160
131,400	61	5	56	1000	MOUNT LE CONTE	276550	3952900
128,700	116	22	118	10	SMOKEMONT	290300	3936450
126,000	28	3	22	10	JONES COVE	291300	3959740
126,000	122	27	52	25	COVE CREEK GAP	310450	3949990
124,200	123	28	9	10	WATERVILLE	309360	3958610
119,700	77	6	50	5	GATLINBURG	270750	3951850
107,100	69	6	7	20	GATLINBURG	271070	3950700
102,600	87	8	15	10	WEAR COVE	256980	3945400
100,600	109	20	82	120	BRYSON CITY	281800	3928200
97,200	47	4	57	10	MOUNT LE CONTE	281550	3954550
92,700	50	5	8	10	GATLINBURG	272080	3952080
90,900	35	3	59	25	MOUNT LE CONTE	283500	3958200
89,100	3	1	12	100	WATERVILLE	307250	3960900
88,200	43	4	28	5	MOUNT LE CONTE	284410	3953610
86,400	84	7	7	100	GATLINBURG	266500	3948800
85,500	49	5	4	10	GATLINBURG	272100	3952050
81,000	67	5	101	25	MOUNT LE CONTE	276780	3954400
68,400	7	1	22	100	HARTFORD	301050	3961750
67,500	6	1	20	50	HARTFORD	301000	3961850
60,300	118	22	132	50	SMOKEMONT	291050	3934750
53,100	66	5	98	15	MOUNT LE CONTE	276900	3954020
52,200	8	1	28	20	HARTFORD	300950	3961850
52,200	92	11	23	25	CALDERWOOD	234350	3944050
50,400	90	10	4	25	KINZEL SPRINGS	245670	3947320
45,900	62	5	58	50	MOUNT LE CONTE	276440	3958570

Potential Area (sq. m.)	IDRISI_ID	SMEPS Drainage	SMEPS Occurrence	SMEPS Area	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
43,200	51	5	10	25	GATLINBURG	271810	3951800
42,300	120	27	14	1000	COVE CREEK GAP	310250	3949450
35,100	9	1	30	25	HARTFORD	300820	3962000
33,300	115	22	95	1	SMOKEMONT	290450	3936720
31,500	2	1	9	100	WATERVILLE	307350	3960900
31,500	112	22	72	40	SMOKEMONT	291270	3935700
31,500	121	27	25	5	COVE CREEK GAP	310050	3949150
30,600	71	6	20	10	GATLINBURG	270650	3949950
30,600	82	6	97	100	GATLINBURG	268900	3951300
30,600	108	20	59	1000	BRYSON CITY	280250	3927150
27,900	114	22	89	500	SMOKEMONT	289250	3937350
25,200	38	4	8	10	MOUNT LE CONTE	283500	3952250
25,200	52	5	18	30	GATLINBURG	272150	3951150
24,300	14	1	57	250	HARTFORD	299900	3960600
24,300	36	3	66	50	MOUNT LE CONTE	284550	3958570
24,300	83	6	100	50	GATLINBURG	267900	3950900
22,500	89	10	3	250	KINZEL SPRINGS	245800	3946800
19,800	1	1	7	50	WATERVILLE	308950	3960730
19,800	98	19	35	5	NOLAND CREEK	271800	3928350
19,800	99	19	39	5	NOLAND CREEK	271800	3928350
19,800	104	20	31	5	BRYSON CITY	281270	3929230
19,800	111	20	93	10	BRYSON CITY	278650	3926520
18,900	53	5	20	20	GATLINBURG	272990	3951220
18,000	102	19	70	50	NOLAND CREEK	271420	3927950
18,000	124	28	12	50	WATERVILLE	308500	3958800
17,100	31	3	31	30	JONES COVE	289330	3959000
17,100	105	20	38	3	BRYSON CITY	282210	3930890
16,200	65	5	88	20	MOUNT LE CONTE	277900	3954800
15,300	32	3	39	100	MOUNT LE CONTE	283530	3958430
15,300	37	3	72	100	MOUNT LE CONTE	285500	3958250
14,400	88	9	5	5	WEAR COVE	251200	3946600
12,600	5	1	19	25	HARTFORD	304450	3961850
11,700	106	20	46	10	BRYSON CITY	279830	3928830
10,800	44	4	40	5	MOUNT LE CONTE	283410	3954120
10,800	117	22	127	10	SMOKEMONT	289150	3937620
9,000	113	22	76	10	SMOKEMONT	291420	3935620
7,200	10	1	32	300	HARTFORD	300300	3962000
7,200	45	4	44	5000	MOUNT LE CONTE	282700	3953800
7,200	81	6	89	10	GATLINBURG	269350	3951450
7,200	97	19	14	5	NOLAND CREEK	270850	3927200
7,200	107	20	51	5	BRYSON CITY	280070	3929300
6,300	46	4	49	250	MOUNT LE CONTE	282090	3955650
6,300	68	6	3	1	GATLINBURG	269970	3951320
5,400	48	5	1	20	GATLINBURG	271820	3952970
5,400	94	12	1	10	CALDERWOOD	234710	3934800
5,400	103	20	16	2	BRYSON CITY	280500	3928050
4,500	91	11	14	10	CALDERWOOD	234100	3944150
4,500	95	13	4	5	CALDERWOOD	229370	3935840
3,600	64	5	84	10	MOUNT LE CONTE	278390	3955660
3,600	93	11	35	40	CALDERWOOD	233400	3942400
3,600	96	13	8	10	CALDERWOOD	229660	3935700
2,700	54	5	23	2	GATLINBURG	272700	3951700
2,700	70	6	18	5	GATLINBURG	270500	3950150
1,800	85	7	58	2	WEAR COVE	260600	3952420
900	33	3	43	25	MOUNT LE CONTE	283600	3958400
900	34	3	49	20	MOUNT LE CONTE	283900	3958200
900	63	5	81	5	MOUNT LE CONTE	278540	3956010
900	100	19	44	500	NOLAND CREEK	271900	3928450
900	101	19	49	150	NOLAND CREEK	271900	3928450

NOTE: There are only 124 sites listed because one site did not have UTM coordinates inside GRSM.

PRIORITIZED LISTS (cont'd)

LIST 2: SORTED BY STREAM DISTANCE

Stream Distance (m.)	Potential Area (sq. m.)	IDRISI_ID	SMEPS Drainage	SMEPS Occurrence	SMEPS Area (sq. m.)	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
0	227,700	41	4	22	2	MOUNT LE CONTE	283940	3952600
0	126,000	28	3	22	10	JONES COVE	291300	3959740
0	124,200	123	28	9	10	WATERVILLE	309360	3958610
0	50,400	90	10	4	25	KINZEL SPRINGS	245670	3947320
0	31,500	121	27	25	5	COVE CREEK GAP	310050	3949150
0	15,300	37	3	72	100	MOUNT LE CONTE	285500	3958250
0	7,200	10	1	32	300	HARTFORD	300300	3962000
0	7,200	81	6	89	10	GATLINBURG	269350	3951450
0	5,400	48	5	1	20	GATLINBURG	271820	3952970
0	4,500	95	13	4	5	CALDERWOOD	229370	3935840
0	1,800	85	7	58	2	WEAR COVE	260600	3952420
0	900	63	5	81	5	MOUNT LE CONTE	278540	3956010
0	900	100	19	44	500	NOLAND CREEK	271900	3928450
0	900	101	19	49	150	NOLAND CREEK	271900	3928450
30	2,885,400	25	2	17	20	JONES COVE	296300	3958830
30	742,500	21	2	3	25	JONES COVE	294700	3959780
30	742,500	22	2	7	25	JONES COVE	294700	3959780
30	401,400	27	3	12	50	JONES COVE	291900	3959700
30	364,500	75	6	37	10	GATLINBURG	271600	3949600
30	351,900	12	1	47	15	HARTFORD	300100	3961150
30	283,500	19	1	81	50	HARTFORD	297400	3960800
30	204,300	40	4	20	3	MOUNT LE CONTE	284000	3952750
30	204,300	125	28	16	250	WATERVILLE	308300	3959120
30	198,900	4	1	15	50	HARTFORD	306000	3962020
30	137,700	79	6	72	5	GATLINBURG	271780	3950160
30	128,700	116	22	118	10	SMOKEMONT	290300	3936450
30	126,000	122	27	52	25	COVE CREEK GAP	310450	3949990
30	97,200	47	4	57	10	MOUNT LE CONTE	281550	3954550
30	89,100	3	1	12	100	WATERVILLE	307250	3960900
30	53,100	66	5	98	15	MOUNT LE CONTE	276900	3954020
30	31,500	2	1	9	100	WATERVILLE	307350	3960900
30	30,600	71	6	20	10	GATLINBURG	270650	3949950
30	30,600	82	6	97	100	GATLINBURG	268900	3951300
30	30,600	108	20	59	1000	BRYSON CITY	280250	3927150
30	25,200	52	5	18	30	GATLINBURG	272150	3951150
30	24,300	14	1	57	250	HARTFORD	299900	3960600
30	22,500	89	10	3	250	KINZEL SPRINGS	245800	3946800
30	19,800	98	19	35	5	NOLAND CREEK	271800	3928350
30	19,800	99	19	39	5	NOLAND CREEK	271800	3928350
30	18,000	102	19	70	50	NOLAND CREEK	271420	3927950
30	17,100	31	3	31	30	JONES COVE	289330	3959000
30	9,000	113	22	76	10	SMOKEMONT	291420	3935620
30	7,200	45	4	44	5000	MOUNT LE CONTE	282700	3958800
30	7,200	97	19	14	5	NOLAND CREEK	270850	3927200
30	7,200	107	20	51	5	BRYSON CITY	280070	3929300
30	6,300	68	6	3	1	GATLINBURG	269970	3951320
30	5,400	103	20	16	2	BRYSON CITY	280500	3928050
30	3,600	64	5	84	10	MOUNT LE CONTE	278390	3955660
30	3,600	93	11	35	40	CALDERWOOD	233400	3942400
30	3,600	96	13	8	10	CALDERWOOD	229660	3935700
30	2,700	54	5	23	2	GATLINBURG	272700	3951700
30	900	33	3	43	25	MOUNT LE CONTE	283600	3958400
30	900	34	3	49	20	MOUNT LE CONTE	283900	3958200
42	1,279,800	15	1	61	50	HARTFORD	299030	3958950
42	1,216,800	30	3	27	10	JONES COVE	290910	3958480
42	1,085,400	29	3	24	10	JONES COVE	290840	3958800
42	491,400	42	4	24	4	MOUNT LE CONTE	283950	3952400
42	297,900	20	1	83	150	HARTFORD	297400	3960700
42	206,100	59	5	50	25	MOUNT LE CONTE	276750	3952610
42	206,100	60	5	53	50	MOUNT LE CONTE	276750	3952610
42	180,900	76	6	40	10	GATLINBURG	271550	3949890
42	178,200	56	5	33	50	GATLINBURG	273090	3953010
42	149,400	72	6	22	20	GATLINBURG	270370	3949570

LIST 2: SORTED BY STREAM DISTANCE (cont'd)

Stream Distance (m.)	Potential Area (sq. m.)	IDR ID	SMEPS Drainage	SMEPS Occurrence	SMEPS Area (sq. m.)	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
42	107,100	69	6	7	20	GATLINBURG	271070	3950700
42	52,200	8	1	28	20	HARTFORD	300950	3961850
42	45,900	62	5	58	50	MOUNT LE CONTE	276440	3953570
42	35,100	9	1	30	25	HARTFORD	300820	3962000
42	24,300	36	3	66	50	MOUNT LE CONTE	284550	3958570
42	18,000	124	28	12	50	WATERVILLE	308500	3958800
42	12,600	5	1	19	25	HARTFORD	304450	3961850
60	496,800	26	3	6	15	JONES COVE	292050	3959600
60	140,400	78	6	57	60	GATLINBURG	270850	3951450
60	131,400	61	5	56	1000	MOUNT LE CONTE	276550	3952900
60	102,600	87	8	15	10	WEAR COVE	256980	3945400
60	88,200	43	4	28	5	MOUNT LE CONTE	284410	3953610
60	86,400	84	7	7	100	GATLINBURG	266500	3948800
60	43,200	51	5	10	25	GATLINBURG	271810	3951800
60	25,200	38	4	8	10	MOUNT LE CONTE	283500	3952250
60	17,100	105	20	38	3	BRYSON CITY	282210	3930890
60	15,300	32	3	39	100	MOUNT LE CONTE	283530	3958430
60	10,800	117	22	127	10	SMOKEMONT	289150	3937620
60	6,300	46	4	49	250	MOUNT LE CONTE	282090	3955650
60	5,400	94	12	1	10	CALDERWOOD	234710	3934800
67	661,500	13	1	54	15	HARTFORD	300250	3959350
67	198,000	86	7	82	5	WEAR COVE	261990	3952980
67	147,600	16	1	71	150	HARTFORD	297350	3961200
67	67,500	6	1	20	50	HARTFORD	301000	3961850
67	60,300	118	22	132	50	SMOKEMONT	291050	3934750
67	24,300	83	6	100	50	GATLINBURG	267900	3950900
67	19,800	104	20	31	5	BRYSON CITY	281270	3929230
67	19,800	111	20	93	10	BRYSON CITY	278650	3926520
85	119,700	77	6	50	5	GATLINBURG	270750	3951850
85	18,900	53	5	20	20	GATLINBURG	272990	3951220
85	11,700	106	20	46	10	BRYSON CITY	279630	3928830
90	160,200	17	1	75	50	HARTFORD	297370	3961150
90	68,400	7	1	22	100	HARTFORD	301050	3961750
90	31,500	112	22	72	40	SMOKEMONT	291270	3935700
90	19,800	1	1	7	50	WATERVILLE	308950	3960730
90	16,200	65	5	88	20	MOUNT LE CONTE	277900	3954800
90	10,800	44	4	40	5	MOUNT LE CONTE	283410	3954120
90	4,500	91	11	14	10	CALDERWOOD	234100	3944150
95	90,900	35	3	59	25	MOUNT LE CONTE	283500	3958200
108	180,900	18	1	77	100	HARTFORD	297330	3961100
108	27,900	114	22	89	500	SMOKEMONT	289250	3937350
120	1,077,300	58	5	49	15	GATLINBURG	275270	3950750
124	267,300	11	1	43	50	HARTFORD	300050	3961450
124	33,300	115	22	95	1	SMOKEMONT	290450	3936720
127	1,258,200	57	5	44	5	GATLINBURG	275570	3950620
150	436,500	39	4	15	15	MOUNT LE CONTE	282890	3951850
150	52,200	92	11	23	25	CALDERWOOD	234350	3944050
150	14,400	88	9	5	5	WEAR COVE	251200	3946600
175	303,300	55	5	27	1000	GATLINBURG	272610	3952950
180	3,820,500	23	2	13	75	JONES COVE	294230	3958100
180	3,820,500	24	2	16	500	JONES COVE	294230	3958100
216	100,800	109	20	82	120	BRYSON CITY	281800	3928200
216	2,700	70	6	18	5	GATLINBURG	270500	3950150
256	629,100	74	6	31	30	GATLINBURG	271570	3949210
268	81,000	67	5	101	25	MOUNT LE CONTE	276780	3954400
272	42,300	120	27	14	1000	COVE CREEK GAP	310250	3949450
362	257,400	119	27	12	1	COVE CREEK GAP	310400	3949620
376	92,700	50	5	8	10	GATLINBURG	272080	3952080
390	85,500	49	5	4	10	GATLINBURG	272100	3952050
466	712,800	110	20	87	100	BRYSON CITY	282700	3929790
492	1,051,200	80	6	84	75	GATLINBURG	274390	3950350

NOTE: There are only 124 sites listed because one site did not have UTM coordinates inside GRSM.

PRIORITIZED LISTS (cont'd)

LIST 3: SORTED BY LOCATION AND POTENTIAL-SPREAD

Location	Potential Area (sq. m.)	SMEPS Drainage	SMEPS Occurrence	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
Backcountry	3,820,500	2	13	JONES COVE	294230	3958100
Backcountry	3,820,500	2	16	JONES COVE	294230	3958100
Backcountry	2,885,400	2	17	JONES COVE	296300	3958830
Backcountry	1,216,800	3	27	JONES COVE	290910	3958480
Backcountry	1,085,400	3	24	JONES COVE	290840	3958800
Backcountry	1,051,200	6	84	GATUNBURG	274390	3950350
Backcountry	742,500	2	3	JONES COVE	294700	3959780
Backcountry	742,500	2	7	JONES COVE	294700	3959780
Backcountry	712,800	20	87	BRYSON CITY	282700	3929790
Backcountry	496,800	3	6	JONES COVE	292050	3959600
Backcountry	491,400	4	24	MOUNT LE CONTE	283950	3952400
Backcountry	401,400	3	12	JONES COVE	291900	3959700
Backcountry	351,900	1	47	HARTFORD	300100	3961150
Backcountry	303,300	5	27	GATUNBURG	272610	3952950
Backcountry	297,900	1	83	HARTFORD	297400	3960700
Backcountry	283,500	1	81	HARTFORD	297400	3960800
Backcountry	257,400	27	12	COVE CREEK GAP	310400	3949620
Backcountry	227,700	4	22	MOUNT LE CONTE	283940	3952600
Backcountry	204,300	28	16	WATERVILLE	308300	3959120
Backcountry	198,900	1	15	HARTFORD	306000	3962020
Backcountry	198,000	7	82	WEAR COVE	261990	3952980
Backcountry	180,900	1	77	HARTFORD	297330	3961100
Backcountry	160,200	1	75	HARTFORD	297370	3961150
Backcountry	149,400	6	22	GATUNBURG	270370	3949570
Backcountry	147,600	1	71	HARTFORD	297350	3961200
Backcountry	128,700	22	118	SMOKEMONT	290300	3938450
Backcountry	126,000	3	22	JONES COVE	291300	3959740
Backcountry	126,000	27	52	COVE CREEK GAP	310450	3949990
Backcountry	107,100	6	7	GATUNBURG	271070	3950700
Backcountry	102,600	8	15	WEAR COVE	256980	3945400
Backcountry	100,800	20	82	BRYSON CITY	281800	3928200
Backcountry	97,200	4	57	MOUNT LE CONTE	281550	3954550
Backcountry	90,900	3	59	MOUNT LE CONTE	283500	3958200
Backcountry	89,100	1	12	WATERVILLE	307250	3960900
Backcountry	81,000	5	101	MOUNT LE CONTE	276780	3954400
Backcountry	68,400	1	22	HARTFORD	301050	3961750
Backcountry	60,300	22	132	SMOKEMONT	291050	3934750
Backcountry	53,100	5	98	MOUNT LE CONTE	276900	3954020
Backcountry	52,200	11	23	CALDERWOOD	234350	3944050
Backcountry	50,400	10	4	KINZEL SPRINGS	245670	3947320
Backcountry	42,300	27	14	COVE CREEK GAP	310250	3949450
Backcountry	33,300	22	95	SMOKEMONT	290450	3936720
Backcountry	31,500	27	25	COVE CREEK GAP	310050	3949150
Backcountry	31,500	1	9	WATERVILLE	307350	3960900
Backcountry	30,600	6	20	GATUNBURG	270650	3949950
Backcountry	25,200	5	18	GATUNBURG	272150	3951150
Backcountry	24,300	3	66	MOUNT LE CONTE	284550	3958570
Backcountry	19,800	19	35	NOLAND CREEK	271800	3928350
Backcountry	19,800	19	39	NOLAND CREEK	271800	3928350
Backcountry	19,800	20	31	BRYSON CITY	281270	3929230
Backcountry	18,900	5	20	GATUNBURG	272990	3951220
Backcountry	18,000	19	70	NOLAND CREEK	271420	3927950
Backcountry	18,000	28	12	WATERVILLE	308500	3958800
Backcountry	17,100	3	31	JONES COVE	289330	3959000
Backcountry	17,100	20	38	BRYSON CITY	282210	3930890
Backcountry	15,300	3	72	MOUNT LE CONTE	285500	3958250
Backcountry	15,300	3	39	MOUNT LE CONTE	283530	3958430
Backcountry	14,400	9	5	WEAR COVE	251200	3946600
Backcountry	11,700	20	46	BRYSON CITY	279830	3928830
Backcountry	10,800	4	40	MOUNT LE CONTE	283410	3954120
Backcountry	7,200	1	32	HARTFORD	300300	3962000
Backcountry	7,200	4	44	MOUNT LE CONTE	282700	3953800
Backcountry	7,200	19	14	NOLAND CREEK	270850	3927200
Backcountry	7,200	20	51	BRYSON CITY	280070	3929300
Backcountry	6,300	6	3	GATUNBURG	269970	3951320
Backcountry	6,300	4	49	MOUNT LE CONTE	282090	3955650
Backcountry	5,400	5	1	GATUNBURG	271820	3952970

LIST 3: SORTED BY LOCATION AND POTENTIAL-SPREAD (cont'd)

Location	Potential Area (sq. m.)	SMEPS Drainage	SMEPS Occurrence	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
Backcountry	5,400	20	16	BRYSON CITY	280500	3928050
Backcountry	4,500	13	4	CALDERWOOD	229370	3935840
Backcountry	3,600	11	35	CALDERWOOD	233400	3942400
Backcountry	3,600	13	8	CALDERWOOD	229660	3935700
Backcountry	2,700	5	23	GATLINBURG	272700	3951700
Backcountry	2,700	6	18	GATLINBURG	270500	3950150
Backcountry	900	19	44	NOLAND CREEK	271900	3928450
Backcountry	900	19	49	NOLAND CREEK	271900	3928450
Backcountry	900	3	43	MOUNT LE CONTE	283600	3958400
Backcountry	900	3	49	MOUNT LE CONTE	283900	3958200
Heavily Visited	1,279,800	1	61	HARTFORD	299030	3958950
Heavily Visited	1,258,200	5	44	GATLINBURG	275570	3950620
Heavily Visited	661,500	1	54	HARTFORD	300250	3959350
Heavily Visited	629,100	6	31	GATLINBURG	271570	3949210
Heavily Visited	436,500	4	15	MOUNT LE CONTE	282890	3951850
Heavily Visited	364,500	6	37	GATLINBURG	271600	3949600
Heavily Visited	267,300	1	43	HARTFORD	300050	3961450
Heavily Visited	180,900	6	40	GATLINBURG	271550	3949890
Heavily Visited	140,400	6	57	GATLINBURG	270850	3951450
Heavily Visited	137,700	6	72	GATLINBURG	271780	3950160
Heavily Visited	131,400	5	56	MOUNT LE CONTE	276550	3952900
Heavily Visited	119,700	6	50	GATLINBURG	270750	3951850
Heavily Visited	92,700	5	8	GATLINBURG	272080	3952080
Heavily Visited	86,400	7	7	GATLINBURG	266500	3948800
Heavily Visited	85,500	5	4	GATLINBURG	272100	3952050
Heavily Visited	45,900	5	58	MOUNT LE CONTE	276440	3958570
Heavily Visited	43,200	5	10	GATLINBURG	271810	3951800
Heavily Visited	31,500	22	72	SMOKEMONT	291270	3935700
Heavily Visited	30,600	6	97	GATLINBURG	268900	3951300
Heavily Visited	25,200	4	8	MOUNT LE CONTE	283500	3952250
Heavily Visited	24,300	1	57	HARTFORD	299900	3960600
Heavily Visited	19,800	20	93	BRYSON CITY	278650	3926520
Heavily Visited	16,200	5	88	MOUNT LE CONTE	277900	3954800
Heavily Visited	9,000	22	76	SMOKEMONT	291420	3935620
Heavily Visited	7,200	6	89	GATLINBURG	269350	3951450
Heavily Visited	4,500	11	14	CALDERWOOD	234100	3944150
Heavily Visited	3,600	5	84	MOUNT LE CONTE	278390	3955660
Heavily Visited	900	5	81	MOUNT LE CONTE	278540	3956010
Boundary / Roads	1,077,300	5	49	GATLINBURG	275270	3950750
Boundary / Roads	206,100	5	50	MOUNT LE CONTE	276750	3952610
Boundary / Roads	206,100	5	53	MOUNT LE CONTE	276750	3952610
Boundary / Roads	204,300	4	20	MOUNT LE CONTE	284000	3952750
Boundary / Roads	178,200	5	33	GATLINBURG	273090	3953010
Boundary / Roads	124,200	28	9	WATERVILLE	309360	3958610
Boundary / Roads	67,500	1	20	HARTFORD	301000	3961850
Boundary / Roads	52,200	1	28	HARTFORD	300950	3961850
Boundary / Roads	35,100	1	30	HARTFORD	300820	3962000
Boundary / Roads	30,600	20	59	BRYSON CITY	280250	3927150
Boundary / Roads	24,300	6	100	GATLINBURG	267900	3950900
Boundary / Roads	22,500	10	3	KINZEL SPRINGS	245800	3946800
Boundary / Roads	19,800	1	7	WATERVILLE	308950	3960730
Boundary / Roads	12,600	1	19	HARTFORD	304450	3961850
Boundary / Roads	10,800	22	127	SMOKEMONT	289150	3937620
Boundary / Roads	5,400	12	1	CALDERWOOD	234710	3934800
Boundary / Roads	1,800	7	58	WEAR COVE	260600	3952420
No Data	88,200	4	28	MOUNT LE CONTE	284410	3953610
No Data	27,900	22	89	SMOKEMONT	289250	3937350

NOTE:
1) Drainage #6, Occurrence #29 had UTM coordinates outside GRSM and is not listed.
2) Location status was determined by the author.

PRIORITIZED LISTS (cont'd)

LIST 4: SORTED BY LOCATION AND STREAM DISTANCE

Location	Stream Distance (m)	Potential Area (sq. m.)	SMEPS Drainage	SMEPS Occurrence	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
Backcountry	0	227,700	4	22	MOUNT LE CONTE	283940	3952600
Backcountry	0	126,000	3	22	JONES COVE	291300	3959740
Backcountry	0	50,400	10	4	KINZEL SPRINGS	245670	3947320
Backcountry	0	31,500	27	25	COVE CREEK GAP	310050	3949150
Backcountry	0	15,300	3	72	MOUNT LE CONTE	285500	3958250
Backcountry	0	7,200	1	32	HARTFORD	300300	3962000
Backcountry	0	5,400	5	1	GATLINBURG	271820	3952970
Backcountry	0	4,500	13	4	CALDERWOOD	229370	3935840
Backcountry	0	900	19	44	NOLAND CREEK	271900	3928450
Backcountry	0	900	19	49	NOLAND CREEK	271900	3928450
Backcountry	30	2,885,400	2	17	JONES COVE	296300	3958830
Backcountry	30	742,500	2	3	JONES COVE	294700	3959780
Backcountry	30	742,500	2	7	JONES COVE	294700	3959780
Backcountry	30	401,400	3	12	JONES COVE	291900	3959700
Backcountry	30	351,900	1	47	HARTFORD	300100	3961150
Backcountry	30	283,500	1	81	HARTFORD	297400	3960800
Backcountry	30	204,300	28	16	WATERVILLE	308300	3959120
Backcountry	30	198,900	1	15	HARTFORD	306000	3962020
Backcountry	30	128,700	22	118	SMOKEMONT	290300	3936450
Backcountry	30	126,000	27	52	COVE CREEK GAP	310450	3949990
Backcountry	30	97,200	4	57	MOUNT LE CONTE	281550	3954550
Backcountry	30	89,100	1	12	WATERVILLE	307250	3960900
Backcountry	30	53,100	5	98	MOUNT LE CONTE	276900	3954020
Backcountry	30	31,500	1	9	WATERVILLE	307350	3960900
Backcountry	30	30,600	6	20	GATLINBURG	270650	3949950
Backcountry	30	25,200	5	18	GATLINBURG	272150	3951150
Backcountry	30	19,800	19	35	NOLAND CREEK	271800	3928350
Backcountry	30	19,800	19	39	NOLAND CREEK	271800	3928350
Backcountry	30	18,000	19	70	NOLAND CREEK	271420	3927950
Backcountry	30	17,100	3	31	JONES COVE	289330	3959000
Backcountry	30	7,200	4	44	MOUNT LE CONTE	282700	39[illegible]800
Backcountry	30	7,200	19	14	NOLAND CREEK	270850	3927200
Backcountry	30	7,200	20	51	BRYSON CITY	280070	3929300
Backcountry	30	6,300	6	3	GATLINBURG	269970	3951320
Backcountry	30	5,400	20	16	BRYSON CITY	280500	3928050
Backcountry	30	3,600	11	35	CALDERWOOD	233400	3942400
Backcountry	30	3,600	13	8	CALDERWOOD	229660	3935700
Backcountry	30	2,700	5	23	GATLINBURG	272700	3951700
Backcountry	30	900	3	43	MOUNT LE CONTE	283600	3958400
Backcountry	30	900	3	49	MOUNT LE CONTE	283900	3958200
Backcountry	42	1,216,800	3	27	JONES COVE	290910	3958480
Backcountry	42	1,085,400	3	24	JONES COVE	290840	3958800
Backcountry	42	491,400	4	24	MOUNT LE CONTE	283950	3952400
Backcountry	42	297,900	1	83	HARTFORD	297400	3960700
Backcountry	42	149,400	6	22	GATLINBURG	270370	3949570
Backcountry	42	107,100	6	7	GATLINBURG	271070	3950700
Backcountry	42	24,300	3	66	MOUNT LE CONTE	284550	3958570
Backcountry	42	18,000	28	12	WATERVILLE	308500	3958800
Backcountry	60	496,800	3	6	JONES COVE	292050	3959600
Backcountry	60	102,600	8	15	WEAR COVE	256980	3945400
Backcountry	60	17,100	20	38	BRYSON CITY	282210	3930890
Backcountry	60	15,300	3	39	MOUNT LE CONTE	283530	3958430
Backcountry	60	6,300	4	49	MOUNT LE CONTE	282090	3955650
Backcountry	67	198,000	7	82	WEAR COVE	261990	3952980
Backcountry	67	147,600	1	71	HARTFORD	297350	3961200
Backcountry	67	60,300	22	132	SMOKEMONT	291050	3934750
Backcountry	67	19,800	20	31	BRYSON CITY	281270	3929230
Backcountry	85	18,900	5	20	GATLINBURG	272990	3951220
Backcountry	85	11,700	20	46	BRYSON CITY	279830	3928830
Backcountry	90	160,200	1	75	HARTFORD	297370	3961150
Backcountry	90	68,400	1	22	HARTFORD	301050	3961750
Backcountry	90	10,800	4	40	MOUNT LE CONTE	283410	3954120
Backcountry	95	90,900	3	59	MOUNT LE CONTE	283500	3958200
Backcountry	108	180,900	1	77	HARTFORD	297330	3961100
Backcountry	124	33,300	22	95	SMOKEMONT	290450	3936720
Backcountry	150	52,200	11	23	CALDERWOOD	234350	3944050
Backcountry	150	14,400	9	5	WEAR COVE	251200	3946600
Backcountry	175	303,300	5	27	GATLINBURG	272610	3952950
Backcountry	180	3,820,500	2	13	JONES COVE	294230	3958100
Backcountry	180	3,820,500	2	16	JONES COVE	294230	3958100

LIST 4: SORTED BY LOCATION AND STREAM DISTANCE (cont'd)

Location	Stream Distance (m)	Potential Area (sq. m.)	SMEPS Drainage	SMEPS Occurrence	SMEPS Quadrangle	SMEPS UTM1	SMEPS UTM2
Backcountry	216	100,800	20	82	BRYSON CITY	281800	3928200
Backcountry	216	2,700	6	18	GATLINBURG	270500	3950150
Backcountry	268	81,000	5	101	MOUNT LE CONTE	276780	3954400
Backcountry	272	42,300	27	14	COVE CREEK GAP	310250	3949450
Backcountry	362	257,400	27	12	COVE CREEK GAP	310400	3949620
Backcountry	466	712,800	20	87	BRYSON CITY	282700	3929790
Backcountry	492	1,051,200	6	84	GATLINBURG	274390	3950350
Heavily Visited	0	7,200	6	89	GATLINBURG	269350	3951450
Heavily Visited	0	900	5	81	MOUNT LE CONTE	278540	3956010
Heavily Visited	30	364,500	6	37	GATLINBURG	271600	3949600
Heavily Visited	30	137,700	6	72	GATLINBURG	271780	3950160
Heavily Visited	30	30,600	6	97	GATLINBURG	268900	3951300
Heavily Visited	30	24,300	1	57	HARTFORD	299900	3960600
Heavily Visited	30	9,000	22	76	SMOKEMONT	291420	3935620
Heavily Visited	30	3,600	5	84	MOUNT LE CONTE	278390	3955660
Heavily Visited	42	1,279,800	1	61	HARTFORD	299030	3958950
Heavily Visited	42	180,900	6	40	GATLINBURG	271550	3949890
Heavily Visited	42	45,900	5	58	MOUNT LE CONTE	276440	3953570
Heavily Visited	60	140,400	6	57	GATLINBURG	270850	3951450
Heavily Visited	60	131,400	5	56	MOUNT LE CONTE	276550	3952900
Heavily Visited	60	86,400	7	7	GATLINBURG	266500	3948800
Heavily Visited	60	43,200	5	10	GATLINBURG	271810	3951800
Heavily Visited	60	25,200	4	8	MOUNT LE CONTE	283500	3952250
Heavily Visited	67	661,500	1	54	HARTFORD	300250	3959350
Heavily Visited	67	19,800	20	93	BRYSON CITY	278650	3926520
Heavily Visited	85	119,700	6	50	GATLINBURG	270750	3951850
Heavily Visited	90	31,500	22	72	SMOKEMONT	291270	3935700
Heavily Visited	90	16,200	5	88	MOUNT LE CONTE	277900	3954800
Heavily Visited	90	4,500	11	14	CALDERWOOD	234100	3944150
Heavily Visited	124	267,300	1	43	HARTFORD	300050	3961450
Heavily Visited	127	1,258,200	5	44	GATLINBURG	275570	3950620
Heavily Visited	150	436,500	4	15	MOUNT LE CONTE	282890	3951850
Heavily Visited	256	629,100	6	31	GATLINBURG	271570	3949210
Heavily Visited	376	92,700	5	8	GATLINBURG	272080	3952080
Heavily Visited	390	85,500	5	4	GATLINBURG	272100	3952050
Boundary / Roads	0	124,200	28	9	WATERVILLE	309360	3958610
Boundary / Roads	0	1,800	7	58	WEAR COVE	260600	3952420
Boundary / Roads	30	204,300	4	20	MOUNT LE CONTE	284000	3952750
Boundary / Roads	30	30,600	20	59	BRYSON CITY	280250	3927150
Boundary / Roads	30	22,500	10	3	KINZEL SPRINGS	245800	3946800
Boundary / Roads	42	206,100	5	50	MOUNT LE CONTE	276750	3952610
Boundary / Roads	42	206,100	5	53	MOUNT LE CONTE	276750	3952610
Boundary / Roads	42	178,200	5	33	GATLINBURG	273090	3953010
Boundary / Roads	42	52,200	1	28	HARTFORD	300950	3961850
Boundary / Roads	42	35,100	1	30	HARTFORD	300820	3962000
Boundary / Roads	42	12,600	1	19	HARTFORD	304450	3961850
Boundary / Roads	60	10,800	22	127	SMOKEMONT	289150	3937620
Boundary / Roads	60	5,400	12	1	CALDERWOOD	234710	3934800
Boundary / Roads	67	67,500	1	20	HARTFORD	301000	3961850
Boundary / Roads	67	24,300	6	100	GATLINBURG	267900	3950900
Boundary / Roads	90	19,800	1	7	WATERVILLE	308950	3960730
Boundary / Roads	120	1,077,300	5	49	GATLINBURG	275270	3950750
No Data	60	88,200	4	28	MOUNT LE CONTE	284410	39[illegible]610
No Data	108	27,900	22	89	SMOKEMONT	289250	3937350

NOTE: 1) Drainage #6, Occurrence #29 had UTM coordinates outside GRSM and is not listed.
2) Location status was determined by the author.

APPENDIX F

NEW SITE EVALUATION LIST

Distance from Potential Spread Area (m.)	PJN Site #	PJN UTM1	PJN UTM2
0	PJN061495-A	274660	3951410
0	PJN062595-A	291150	3934700
0	PJN070595-H	271070	3927350
0	PJN070695-A	279510	3927570
0	PJN072595-E	300120	3962280
0	PJN072595-F	299630	3962020
0	PJN072595-G	299810	3961780
0	PJN072595-H	299730	3961920
0	PJN072695-B	297430	3961420
0	PJN080295-A	294170	3958580
0	PJN080295-B	294480	3958690
0	PJN080595-A	284110	3952950
0	PJN080595-B	284160	3953470
0	PJN080595-C	284230	3953690
0	PJN102794-A	271610	3949250
30	PJN070595-I	270900	3927270
30	PJN070695-F	281230	3929090
30	PJN070695-G	281790	3929890
30	PJN072495-A	308400	3959130
30	PJN072595-A	304420	3961930
30	PJN102194-D	282420	3956390
30	PJN102594-A	268410	3951050
42	PJN070595-G	271260	3927450
42	PJN081495-A	261150	3951830
42	PJN102094-B	274750	3950660
42	PJN102194-C	278100	3955250
60	PJN070595-B	270900	3926610
60	PJN070695-B	280050	3929100
67	PJN070695-H	280600	3928250
67	PJN102194-A	275310	3950490
85	PJN070695-C	280910	3928660
90	PJN081595-A	278730	3926670
108	PJN102094-A	274890	3950620
120	PJN072595-C	300970	3961600
120	PJN102394-B	268400	3951150
335	PJN070595-F	272190	3928590
360	PJN072595-B	300960	3961350
361	PJN102794-B	271250	3949000
433	PJN070595-D	272240	3928660
618	PJN070595-C	272370	3928830
1261	PJN060895-A	234710	3933460

VITA

Pamela Jean (Woodcock) Nabors was born on April 27, 1966 in Winter Garden, Florida. She attended local elementary schools and graduated from West Orange High School in 1984. Afterwards, she attended the University of Central Florida and received a Bachelor of Science degree in Computer Science in May, 1988. She then worked as an Engineer in the Image Processing Laboratory at Martin Marietta in Orlando, Florida. She resigned from Martin Marietta in October 1992 and moved to Knoxville, Tennessee to pursue a Master of Science degree in Geography at the University of Tennessee. She has chosen a career in Geographic Information Systems and biogeography because she desires to combine her computer skills with her interests in ecological conservation. Her conservation philosophy comes from the belief that God has called us to be good stewards of the earth. She and her newlywed husband presently live in Alcoa, Tennessee.

Potential Spread of *Dioscorea batatas* in the Great Smoky Mountains National Park

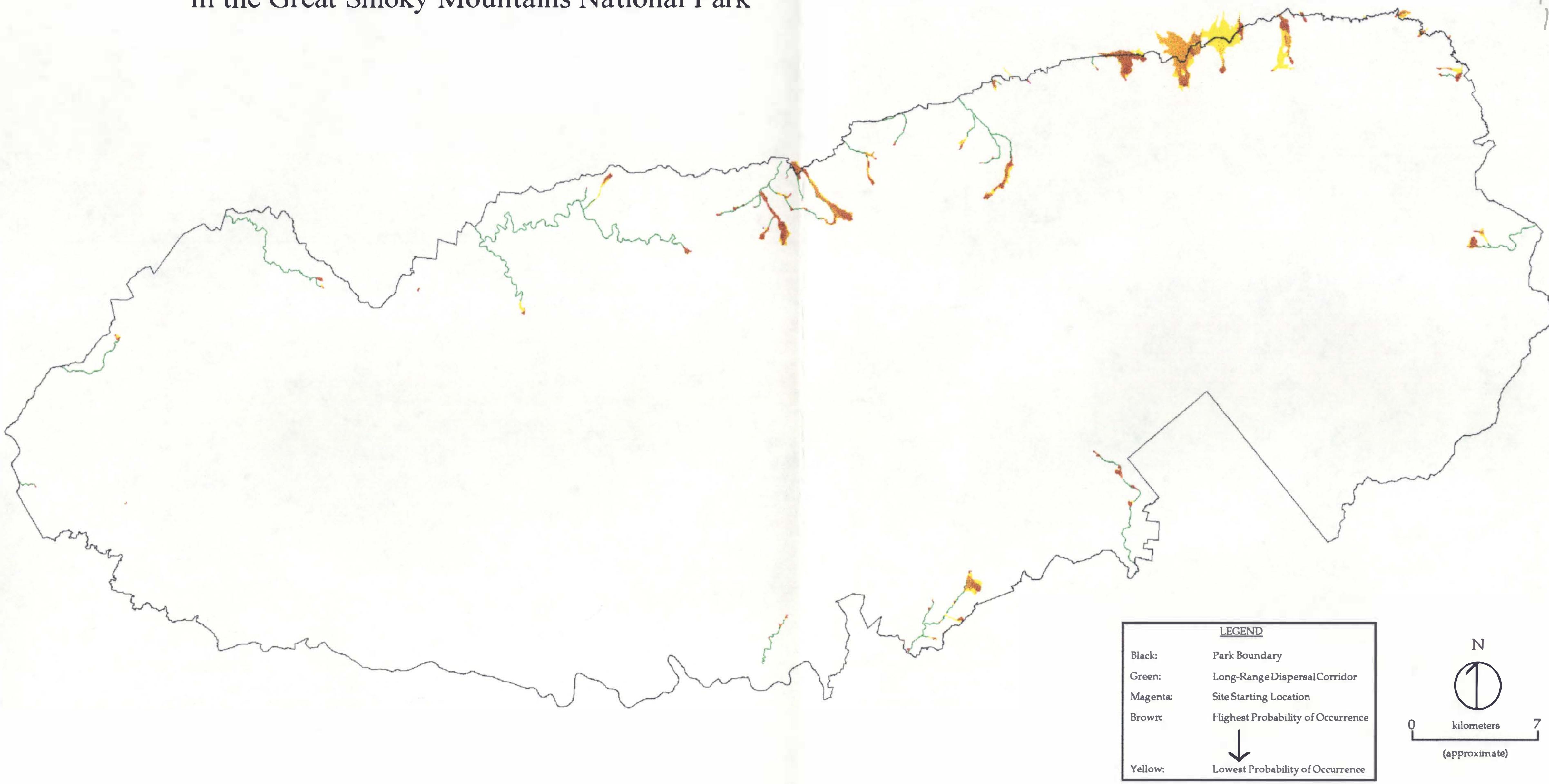


Plate 1: GRSM Potential-Spread Map

Pamela J. Nabors
May 1996