# TREE CANOPY RESEARCH AND STUDENT EXPERIENCES USING THE DOUBLED ROPE CLIMBING METHOD


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## ABSTRACT

Students from the University of Central Missouri explored the tree canopies of the Great Smoky Mountains National Park in Tennessee and North Carolina, Daniel Boone National Forest in Kentucky, and Big Oak Tree State Park, Ha Ha Tonka State Park, and Pertle Springs in Missouri from the summer of 2000 to 2007. The Doubled Rope Climbing Method (DRCM) was used to climb more than 500 individual trees without injury. This included three vine species and also 49 tree species, usually exceeding 60 cm diameter at breast height, and more than 30 m in total height. Students attended a two-day mandatory tree climbing school held at Pertle Springs. The purpose of this paper is to provide information about how to obtain financial grant support and a detailed description of the DRCM and student research experiences represented by the Adventure Phase, the Laboratory Phase, and the Publication Phase. Advantages and disadvantages of the DRCM and hazards associated with climbing gear, study sites, and climbing trees are discussed in detail. The climbing gear and knots used in the DRCM are described and illustrated with color images along with the climbing procedure used to obtain bark samples, aerial reproductive structures, and cryptogams in vertical transects from near ground level to the treetop. The sampling protocol, student field experiences, discovery of a new myxomycete species (*Diachea arboricola*), tree canopy publications, media coverage, and outreach and education with seventh grade life science students at Warrensburg Middle School are included as examples of student professional scientific experiences. Multiple projects examined the occurrence and importance of cryptogams such as myxomycetes, macrofungi, mosses, liverworts, lichens, and ferns. Observations of invertebrates including insects, mollusks, nematodes, and tardigrades were also noted. Future directions for research using the DRCM are suggested in order to help the next generation of tree canopy biologists explore, ask questions, and develop hypotheses that will increase our knowledge of the biosphere.



## RESUMEN

Estudiantes de la Universidad Central de Missouri exploraron doseles de árboles en el Parque Nacional "Great Smoky Mountains" en Tennessee y Carolina del Norte, Bosque Nacional "Daniel Boone" en Kentucky y Parque Estatal "Big Oak Tree," Parque Estatal "Ha Ha Tonka" y Pertle Springs en Missouri, desde el verano del 2000 al verano del 2007. El método de cuerda doble para escalar (MECD) se usó para subir a más de 500 árboles individuales (sitios de estudio) sin accidentes graves. Estos sitios de estudio incluyen 49 especies de árboles que generalmente exceden los 60 cm de diámetro a la altura del pecho y más de 30 m de la altura total y tres especies de enredaderas. Los estudiantes asistieron a una clase obligatoria para escalar árboles. El propósito de este trabajo es el de proveer información de como obtener ayuda financiera y una descripción detallada del MECD y las experiencias de investigaciones de los estudiantes representados por una Fase de Aventura, una Fase de Laboratorio, y una Fase de Publicación. Las ventajas y desventajas del MECD y riesgos asociados con el quipo de escalar, sitios de estudios, y árboles escalados son discutidos con todo detalle. El equipo de escalar y los nudos usados en el MECD son descritos e ilustrados en color junto con el procedimiento de escalada usado para colectar las muestras de cortezas, las estructuras reproductoras aéreas, y criptógamas en transectos verticales desde el nivel del suelo hasta la copa de los árboles. El protocolo del muestro, las experiencias de campo, el descubrimiento de una nueva especie de myxomycete (*Diachea arboricola*), las publicaciones



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sobre doseles arbóreos, las coberturas periodísticas, y el alcance y educación con estudiantes de ciencias biológicas de séptimo grado del Colegio de Warrensburg son incluidos como ejemplos de oportunidades científicas profesionales estudiantiles. Este proyecto se centró en la ocurrencia y la importancia de criptógamas en su mayor parte como myxomycetes, macromicetos, musgos, hepáticas, líquenes, y helechos y observaciones de invertebrados incluidos insectos, moluscos, nematodos, y tardígrados. Direcciones futuras para la investigación usando el MECD son sugeridas para actividades investigadoras adicionales en los doseles de los árboles. Este trabajo ayudará a la próxima generación de biólogos en doseles de árboles a utilizar los métodos de conseguir acceso al dosel de árbol y para explorar, hacer preguntas, y desarrollar las hipótesis que aumentarán nuestro conocimiento de la biosfera.

Key Words: cryptogams, doubled rope climbing method (DRCM), Great Smoky Mountains National Park, Tennessee and North Carolina, Daniel Boone National Forest, Kentucky, Pertle Springs, Missouri, myxomycetes, tree canopy, tree climbing

## INTRODUCTION

This paper describes the climbing methodology, sampling protocol, and student research experiences used to survey and inventory tree canopy biodiversity in the Great Smoky Mountains National Park (GSMNP) of Tennessee and North Carolina, Daniel Boone National Forest (DBNF) in Kentucky, and Big Oak Tree State Park, Ha Ha Tonka State Park, and Pertle Springs in Missouri. This research project began the summer of 2000 and has included more than 20 undergraduate and master's degree level students at the University of Central Missouri (UCM).

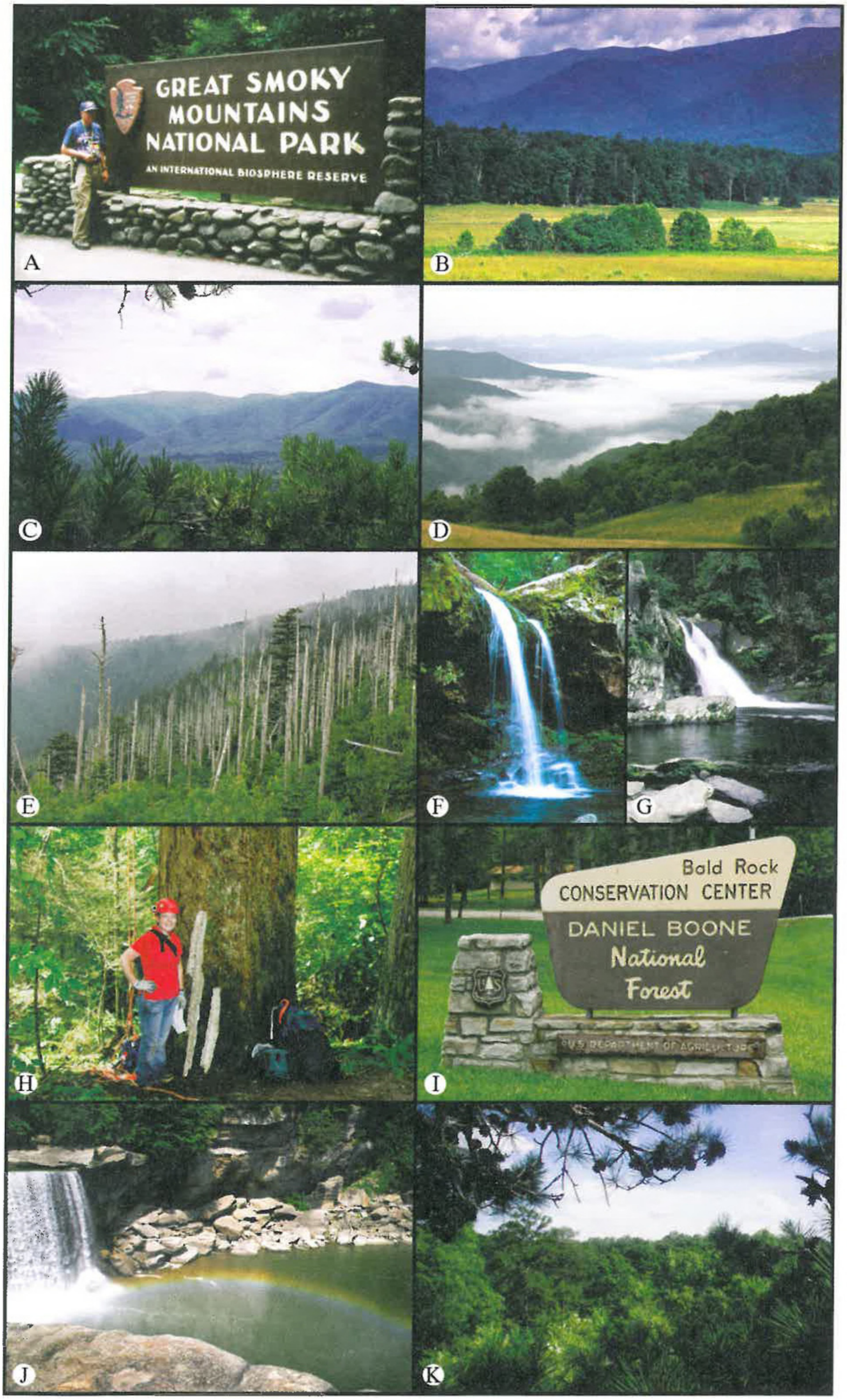
Landscape vistas in GSMNP make this the most popular national park with over 11 million visitors annually. Scenic mountains, waterfalls, valleys, and the mixed diversity of deciduous and evergreen trees highlight brilliant fall leaf colors, old growth forests host champion-size trees, and summer haze and storms create beautiful cloud fields in high elevation areas of the Park (Fig. 1A–H). Located just a short distance to the north of GSMNP, the DBNF in Kentucky has a rugged topography that features scenic land formations and waterfalls, especially at Cumberland Falls State Park (Fig. 1I–K).

The purpose of this paper is to provide information on how to obtain financial grant support and the additional narrative details and color images that document the terminology of climbing gear used to gain tree canopy access. Also provided are detailed descriptions of climbing trees using the Doubled Rope Climbing Method (DRCM), and a body of literature that describes tree canopy research in temperate forests. The field experiences designated here as the Adventure Phase used the DRCM to gain access to the tree canopy. The advantages of DRCM serve as an example of tree canopy access that will help others with planning and executing tree canopy exploration. Results are summarized and in some cases reported for the first time.

### National Science Foundation Small Grant for Exploratory Research

This research project would not have been possible without the financial support of the National Science Foundation (NSF) Small Grant for Exploratory Research (SGER) through the Biodiversity Surveys and Inventories Program, Division of Environmental Biology. When applying for such a grant the appropriate Program Officer should be contacted to determine if the project proposal idea meets the specific SGER criteria, and in our case, the application of new expertise or new approaches to established research topics. Our research idea of accessing the tree canopy using the DRCM to explore and collect myxomycetes, macrofungi, lichens, liverworts, mosses, and ferns in the Great Smoky Mountains National Park (GSMNP) appeared to match

**Fig. 1. A–H. Great Smoky Mountains National Park. A. Sign at the Gatlinburg, Tennessee entrance to the park. B. Cades Cove Valley is a low elevation open field site with mountain ridges on all sides. The Cades Cove Loop Road is a popular scenic drive for park visitors. Many trees were climbed in this area and resulted in the discovery of the new species, *Diachea arboricola*. C. Treetop view along Ridge Mountain Road overlooking Cades Cove. D. Panoramic view from the high altitude site at Purchase Knob and the Appalachian Highlands Science Learning Center. Cloud fields form in low areas after afternoon rain showers. E. Clingman's Dome, the highest point in Tennessee at 2,025 m, showing many dead spruce and Fraser fir trees caused by the Balsam wooly adelgid insect and aerial pollution. F. Grotto Falls located along the Roaring Fork Motor Nature Trail near Gatlinburg. G. Abrams Falls plunges 8 m into a large pool. One of the most popular sites in the park located off the Cades Cove Loop Road. H. Live, old growth, tulip poplar trees grow to tremendous size. Note the slabs of bark that fell while climbing this tree. I–K. Kentucky sites. I. Daniel Boone National Forest Bald Rock Conservation Center that was the source of *Pinus echinata* bark and cone samples obtained by limbwalking. J. Cumberland Falls plunges 21 m into the Cumberland River and forms a beautiful rainbow in the misty spray at the base shown here with full sunlight at midday. K. Panoramic view taken from the top of a *Pinus echinata* at the Holly Bay area DBNF.**


GREAT SMOKY MOUNTAINS NATIONAL PARK
AN INTERNATIONAL BIOSPHERE RESERVE
Bald Rock CONSERVATION CENTER
DANIEL BOONE National Forest
U.S. DEPARTMENT OF AGRICULTURE
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this criterion. We proposed to go where no one had gone before in the tree canopy at GSMNP and to make observations and collections of targeted groups of cryptogams (Keller 2005a, 2005b).

The program officer requested that HWK prepare a proposal, limited to five pages, entitled "SGER-RUI: Tree Canopy Biodiversity (myxomycetes, macrofungi, mosses, liverworts and lichens) in the Great Smoky Mountains National Park." Also included, was a clear statement of why this proposed research should be considered exploratory and high risk, and the significance of its potential impact on the discipline or field. It was important that the applicant work closely with the program officer since the SGER proposals undergo an internal merit review by NSF staff. In our case the draft narrative, budget details, and biographical sketch were previewed before submission by the NSF program officer. The maximum budget was $100,000, but the usual average amount was less for a project period of one to two years. Certain promising SGER projects approved by the program officer and division director may be extended for up to six additional months and supplemented with up to $50,000 in additional funding. Most of the budget supported student wages, climbing equipment and supplies, travel, and meals. In most cases lodging was provided by Discover Life in America in the GSMNP and the United States Forest Service in the DBNF.

## METHODOLOGY

### Methods to Access the Tree Canopy

Tree canopy exploration reached new heights in the 1970s with a variety of canopy access techniques modified from mountain climbing methods including the use of polyester ropes with a high tensile strength along with various ascenders (Nadkarni 1988; Lowman 1994; Nadkarni 1995; Lowman & Wittman 1996). Early canopy access usually resulted in a solo researcher climbing a tree using a method such as the single rope technique (SRT), cherry pickers, or ladders (Lowman 2004). The single rope technique was the first rope technique used to access the canopy in the 1970s (Lowman 1994; Lowman & Bouricius 1995; Lowman 2004). This method allows a researcher to sample a vertical transect into the canopy that can be replicated at other sites (Lowman & Wittman 1996; Lowman 1999). Rope studies with single climbers generally produce small data sets (Nakarni 1995). However, ropes can be used to attach structures in the canopy such as collapsible platforms used to observe arboreal vertebrates over a period of time. This allows multiple scientists to perch in the canopy and observe animal activity with minimal disturbance. The SRT cannot be used to access the upper branches in the canopy as noted by early arborists (Nadkarni 1988; Moffet & Lowman 1995).

Information about different methods of accessing the tree canopy are described in various books and journal articles as well as part of a lecture given by H. Bruce Rinker (2004) at a symposium entitled "Tree Canopy Biodiversity in the Great Smoky Mountains National Park" presented at the Mycological Society of America 2004 annual meeting held jointly with the North American Mycological Association. Chapter 1 by Moffett and Lowman (1995) includes tree canopy access techniques used for scientific studies, and Table I evaluates the different access methods assigning an assessment value from 1 (least desirable) to 10 (most desirable). The information contained in this table will help tree canopy biologists select the best access methods for their own special research projects. Updated progress in canopy walkway construction and canopy cranes is included in Chapters 23 and 25 (Lowman & Rinker 2004) and emphasizes how canopy access techniques will impact future sampling, hypotheses testing, and facilitate ecotourism in the tree canopy.

Ground based methods of canopy research are useful in collecting data for mobile or sensitive species and demanding projects such as insect surveys. In addition, radio telemetry can be used to study arboreal animals, colorful paint can be applied to arboreal reptiles, and arthropods can be collected *en masse* using insecticidal fogging (Moffet & Lowman 1995). Traps can be hoisted in the canopy using rope and pulley systems; for example, a team of researchers from UCM used "composite flight-intercept traps" (Fig. 2A) at Big Oak Tree State Park, Missouri to survey insect biodiversity (Wilson et al. 2003).

Recent canopy research favors a more collaborative approach and focuses on methods such as towers, canopy walkways, cranes, and the canopy raft and sled, all of which can accommodate several scientists at


**Fig. 2. A. Ropes are used to tether a flight intercept trap in the tree canopy. Note the white bottle at the top and bottom filled with alcohol. This trap can be lowered, the bottles unscrewed and insects removed, and then hoisted into the canopy again. Flying insects that hit the trap netting such as Coleoptera (beetles) fold their wings and tend to fall or crawl downward into the bottle at the bottom; other insects such as Lepidoptera (moths and butterflies) and Diptera (flies) tend to fly or crawl upward into the top bottle. B. Climbing spur unit strapped to the left leg with sharp spur along the inside instep of the boot with the other spur unit unstrapped on the ground. The waist belt unbuckled at base of tree. C. Pole climbing spurs and waist belt used to climb *Pinus taeda* L. This technique is used by telephone lineman on wooden poles, loggers, and tree service arborists. The spurs penetrate deeply enough to injure the tree. Federal and state collecting permits require a detailed description of the climbing method and climbing spurs are banned. Note the power line in the background. Photograph taken circa 1966, Atlanta, Georgia.**

a time (Lowman 2004). These methods usually sample from the outer limbs or periphery of the tree, not the trunks, whereas rope climbing allows the researcher to be in direct contact with the trunk of the tree. Towers represent a permanent structure for canopy research; however, few trees are within reach from a single point. Canopy walkways and cranes are attached to towers and provide a larger sample area (Lowman 1994). Canopy walkways are often more affordable than cranes, which cost between one and five million dollars (Lowman 2004), and are often used for ecotourism and conservation (Lowman & Bouricius 1995; Lowman et al. 2002). The canopy raft is of French design and effectively creates a platform lifted by a dirigible to the treetop canopy from which scientists can study the canopy/atmosphere interface (Lowman 1994; Nadkarni 1995; Lowman & Wittman 1996; Lowman et al. 2002; Lowman 2004). A smaller raft that is trailed behind the dirigible, called a sled, is used to skim the canopy allowing scientists to collect leaves, epiphytes, various flowers and their pollinators (Lowman 1994; Nadkarni 1995; Lowman & Wittman 1996; Lowman et al. 2002; Lowman 2004). Other more daring methods of cooperative canopy exploration include ultralight planes (Lowman & Wittman 1996).

Methods to access the tree canopy have not generally complied with Occupational Safety and Health Administration (OSHA) regulations (Grushka et al. 1999). A team of researchers developed the first OSHA regulated fall arrestance canopy access system to be used by scientists at the University of Columbia Biosphere 2 Center for Research and Education in Oracle, Arizona (Grushka et al. 1999). Although risky, canopy research is essential as biologists race to survey species in dwindling forests worldwide. It is estimated that over half of the world's species of plants and animals occur in the tree canopies (Nadkarni 1995; Lowman 2004). Canopies also play an integral role in nutrient cycling, are a major source for photosynthesis, and serve as a carbon sink for atmospheric $CO_2$ (Lowman 1994; Lowman & Wittman 1996; Lowman 2004).

Canopy access methods should be considered when creating a research project. Studies can involve sessile organisms, mobile organisms, or interactions of sessile and mobile species within the tree (Lowman 1999, Lowman 2004). Sessile organisms such as epiphytes that grow along the trunk and inner branches of the tree are the easiest to study with rope methods in the canopy and represent fewer logistical constraints. However, certain plant organs such as flowers and buds produced on the tips of branches and uppermost branches of the canopy are more difficult to reach with rope climbing methods and would therefore be better sampled using a crane, walkway, or raft (Lowman 2004). Another way to access mature, aerial reproductive structures (cones and dried fruits) on branches in the outer tree canopy used limb walking with the DRCM (Kilgore 2008).

Tree canopy access is possible using dirigibles, cranes with gondolas, cherry pickers, elevated platforms or walkways, inflatable platforms, peconha, tree houses or bridges, ladders, towers, boats, sleds, pole climbing spurs and belt (Fig. 2B,C), free hand or rope climbing methods. Even so, the current literature does not include a detailed discussion of the advantages and disadvantages of the DRCM, as a useful method for conducting canopy research, the description and use of the climbing equipment (ropes, climbing saddles, knots), safety precautions as these apply to tree canopy survey research, and a stepwise "how to" approach of the climbing methodology. Previous publications include general information about the DRCM (Snell & Keller 2003; Keller et al 2003; Keller 2004a, 2004b, 2005a; Everhart & Keller 2008; Everhart et al. 2008; Kilgore 2008) used mostly in the GSMNP.

## Requirements for Climbing and the Tree Climbing School

Selection of student tree climbers first involved national recruitment efforts including posting announcements in national newsletters, on our web site: http://faculty.ucmo.edu/myxo/, on electronic bulletin boards, and making announcements at regional and national professional scientific meetings such as the Association of Southeastern Biologists and Mycological Society of America annual meetings. Local recruitment efforts involved displaying flyers and posters in university hallways showing rope climbing images and scenic color images from past field experiences, presenting departmental seminars, and delivering announcements in biology classes. Three phases of this research project were repeatedly emphasized; the Adventure Phase (tree climbing and sampling); the Laboratory Phase (sample sorting and moist chamber cultures); and Publication Phase (poster and oral platform presentations along with abstracts, team written articles for newsletters, or refereed journal papers based on individual student research projects).

Prospective students were interviewed to determine their interest and qualifications to complete all three phases of the tree canopy biodiversity research project. A student profile included the following information: field experiences such as hiking, backpacking, and camping in remote areas; athletic activities that involved team sports or activities, strength building exercises, repelling, rock or wall climbing, and tree climbing using rope systems; academic major (biology preference), undergraduate classes, grade point average, and biology courses completed; skill sets including use of computer software, database spreadsheets, microscopes, digital cameras, use of topographical maps, and global positioning systems; future career interests, and especially interest in graduate school. Strength building exercises to increase upper body arm strength and body form were important in successfully reaching upper parts of the tree canopy. Students with research projects already planned in advance that included tree and vine species targeted for sampling were more successful in the Publication Phase.

Each qualified student was required to sign a Release and Acknowledgment of Risks Agreement prior to attending the tree climbing school. This document described the risks involved in travel to, from, and


**Fig. 3.** Tree climbing school. **A.** Exercises included repetitive pullups to increase arm strength. **B.** Rope practice session at Pertle Springs using the Anchor Hitch to tie in to saddle and the Blake's Hitch tied to the climbing rope with the split tail. **C.** Finger walking an axe handle to strengthen fingers for grasping the climbing rope. **D.** Climbing instructor Charly Pottorff demonstrating the butterfly saddle with climbing rope tied into carabiner. **E.** Students practice tying the climbing rope into the climbing saddle. **F.** Instructor supervising climber using the DRCM and arm strength to ascend the climbing rope freely suspended. **G.** Three climbers in two trees. Left foreground climber resting in saddle attached by lanyard to limb, climber above standing on limb, climber in adjacent tree in resting position. This helps climbers adapt to different tree heights and builds confidence in the climbing equipment. **H.** A group picture of climbers from the first tree climbing school held at Pertle Springs the spring of 2000 "hanging out" in the tree with instructor and ground crew at base.

within forested areas, hiking in remote areas, dangers such as stinging insects, wild animals, poison ivy, and using ropes to climb trees. In addition, each student was required to be more than 18 years of age and have medical insurance. Contact information was provided in case of medical emergency. Additional optional information included any physical condition that might increase the risk of being in the field for prolonged periods of time, and the endurance required to hike long distances and climb trees. Emphasis was given to team sports and cooperative activities since the Adventure Phase was a team effort that required living and working in close quarters. We had a minimum of 4 to 8 participants in the Adventure Phase for the GSMNP and DBNF field trips.

A two-day tree climbing school was held in late April or early May at Pertle Springs, Warrensburg, Missouri (Fig. 3A–H). Charly Pottorff, a professional arborist from Manhattan, Kansas, was the first tree climbing instructor (Fig. 3A,D,E,F,H). He has been a professional arborist since 1968 and also a member of the Kansas Arborist Association and International Society of Arboriculture. His involvement for many years in popular regional Tree Climbing Jamboree competitions as an organizer, convener, and practitioner of rope climbing techniques has resulted in being on the cutting edge of climbing techniques and equipment design and safety. The combination of his physical exercise routines and tree climbing expertise allowed him to serve as a role model for the next generation of tree canopy climbers.

Instructors led training sessions that were intense and physically demanding to ensure that each student climber had developed the physical strength and conditioning to safely climb 30 m or more into the tree canopy. This included a series of exercises that helped build upper body strength. Indoor exercises included: pull ups with palms up or down on the bar, cliff hangers with hands facing one another with palms on the bar (Fig. 3A), finger tip push ups, leg lifts, and the sledge hammer – an axe handle finger walk (Fig. 3C) that increases finger strength. Outdoors everyone ran stadium steps to increase endurance and leg strength. Rope climbing practice at Pertle Springs included using the climbing equipment and gear (knot tying Fig. 3B,) and demonstrations by the instructors (Figs. 3D,E; 7A,E). Climbers were supervised by the instructor on their first climbing attempt (Fig. 3F). Once in the tree canopy, climbers practiced using lanyards, knots used in advancing, relaxing in the saddle, and standing on a branch to rest and adapt to the canopy height (Fig. 3G). A group picture was taken at the completion of the tree climbing school (Fig. 3H). Only the students who successfully completed the training course on the basic DRCM were considered for the project.

The Adventure Phase, Laboratory Phase, and Publication Phase had to be satisfactorily completed to meet the objectives of this project (Counts et al. 2001; Keller & Skrabal 2002; Keller et al. 2002; Snell 2002; Keller & Snell 2002a; Keller & Snell 2002b; Snell & Keller 2001; Snell & Keller 2003). Each student kept a daily journal of observations that in some cases were used in research papers. Students were given writing assignments as part of team-writing projects. These narratives were collated into popular articles published in different newsletters (Counts et al. 2000; Henley et al. 2000; Keller & Skrabal 2002; Keller et al. 2002; Skrabal et al. 2001; Keller & Everhart 2007; Kilgore 2007; Kilgore & Keller 2007; Keller et al. 2008; Kilgore & Keller 2008).

**Advantages and Disadvantages of the Doubled Rope Climbing Method (DRCM)**

The two basic rope climbing systems most often used are the single and doubled rope methods (Jepson 2000). Advantages and disadvantages are associated with both techniques. Advantages of the single rope technique (SRT) include quick canopy access because the rope can pass over several tree crotches without impeding climbing, and it is safe and efficient when practiced correctly using back-up ascenders and descending devices (Dunlap 2002). A disadvantage of SRT is that the climber cannot advance higher in the canopy by advancing the rope from the original installation point. The climber can only advance if a separate climbing line is used (Jepson 2000). Another disadvantage of SRT is that several pieces of equipment are needed, including ascenders, pulleys, and stir-ups, which are a more mechanized mode of ascending into the tree canopy. If any of these mechanical devices are lost the climber cannot complete the climb (Charly Potorff, pers. comm.).

An advantage of using the DRCM for canopy research in the backcountry is that the necessary equip-


**Fig. 4. Tree climbing hazards A.** Tree holes and crotches may house bees with a bee swarm shown here. Binoculars are needed to ensure that bees are not in the pathway of the climber. **B.** A timber rattlesnake coiled with the dark brown rattles behind the head. This venomous snake was seen in GSMNP near our climbing tree site on a cold, misty day. **C.** Lightning strikes may damage, split, weaken, or kill parts of the tree and represent a potential danger at tree climbing sites. **D.** Electrical power lines shown here in the foreground pose a special threat when shooting the throwbag. **E.** Standing dead snag located in the spruce-Fraser fir high elevation zone near Clingman's Dome, the highest point in GSMNP. Our climbing protocol excluded trees that were dead, dying, or with large dead branches and this often included champion-sized trees.

ment is minimal so that each climber can pack the entire set of climbing gear into a standard backpack. The use of additional equipment such as ascending and descending devices is optional (Adams 2007a; Adams 2007b). To minimize the necessary climbing equipment, it is recommended that the climber rely on the climbing rope, split tail, safety rope, and his or her knowledge of the proper climbing knots used to access the tree canopy. This provides more mobility when hiking over long distances and allows quick use at specific sites. In addition, the DRCM is a non-invasive method that allows the climber to advance the rope to higher branches, often reaching near the top of the tree (Keller 2004a). The DRCM requires more strength than the SRT and climbers must be in top physical condition to successfully master this technique. Some researchers may see this as a disadvantage and a hindrance to completing tree canopy research in the backcountry. However, it is never a disadvantage to be in good physical condition when conducting tree canopy research in the backcountry and using DRCM was an incentive for the students to be in excellent health and develop athletic skills.

An advantage for both rope methods is that they are more affordable than other methods such as canopy walkways, towers, or cranes (Moffett & Lowman 1995). Ropes are also easily transported to different study sites, allowing researchers to sample from trees that are geographically separated rather than grouped together as in walkways, towers, or cranes; however, several research climbers are needed to sample a large number of trees.

**Tree Climbing Hazards**

Hazards to climbers can be avoided with pre-climbing safety inspections (Fig. 4A–E). Jepson (2000) includes an entire chapter on pre-climbing safety inspections. Safety inspections should be done on equipment, the climbing site, and the tree. Possible hazards in the equipment include frayed ropes or lanyards, inconsistent diameter of ropes, heat damage on ropes or lanyards, unsealed rope ends, cracks in safety helmets or eye protection gear, holes in gloves and clothing, tears or broken stitching in the climbing saddle, elongated holes in the climbing saddle waist buckle, and cracks or distortion in D-rings or carabiners that do not lock properly. Climbing gear should be free of dirt and debris to avoid jamming carabiners and possible loosening of knots.

Each study site must be inspected for animal activity, such as bees in the trees (Fig. 4A) hornet nests in the ground, venomous snakes (Fig. 4B), and also bear activity, wild pigs, raccoons, and possibly mountain lions. When climbing in the mountains, it was important to be aware of terrain by looking for steep slopes, boulders, loose rocks, landslide areas, and mountain creeks. Poisonous plants are often common on disturbed sites, so the climber must know how to identify poison ivy, poison oak, poison sumac, and stinging nettle.

Stormy weather and lightning pose serious hazards. Lightning is a deadly threat when working in the tree canopy (Fig. 4C). Weather forecasts in the GSMNP were unreliable since they were not specific to any particular region of the park. It frequently rains heavily in one part of the park with little or no rain in other parts. At lower elevations, movement of storms can be observed at fairly long distances. This allowed the climber sufficient time to complete work and exit the tree safely. Higher altitudes made it difficult to tell exactly how far away a potential storm was located. Furthermore, rain is also a hazard because wet ropes are more likely to slip, tightening knots and making ascension more difficult. Wet branches reduce traction, making it more difficult to climb into and advance within the tree. Ground sites become wet and slippery, increasing the chance that a climber would fall. Climbing before, during, and after thunderstorms and rain should be avoided.

Climbers should be aware of any electrical hazards such as power lines and grounded electrical lines (Fig. 4D). Septic systems and drain fields should also be avoided. The climber should be careful not to launch the throwbag over a limb in the direction of any vehicles, buildings, or people. Hikers and bystanders should be kept away from the climbing area, however, public curiosity and education were encouraged, so if a hiker came into the area, all team members stopped work for the moment to explain our activities and recommend a safe distance for viewing.

The climbing tree also poses potential hazards to the climber. These include signs of damage such as lightning damage on the trunk (Fig. 4C), broken limbs, dead trees and branches (Fig. 4E,) cavities at the base of the tree, poison ivy, thorns, honey bees in cavities, presence of wood rotting fungi, and loose bark (Fig. 1H). When foliage is dense in the canopy, broken limbs may not be visible. Binoculars help locate hard to see hazards, especially dead branches or damaged sections of the tree. Prior to climbing, the climber tests the sturdiness and integrity of the limb. If the limb bends or makes a noise indicating it is damaged, the limb should be avoided.

## Tree Climbing Equipment and Gear

***The Big Shot.***—The Big Shot is an oversized slingshot that has a 2.4 m metal pole with a rubber gripper attached to the bottom end and a detachable head consisting of a forked metal frame on the top end. Attached to each end of the forked head are two strands of durable elastic rubber tubing that are joined in the middle with a sling that cradles the throw bag, similar to a slingshot. This metal pole can be separated into two 1.2 m sections that can be tied and carried on top of the backpack and assembled on site when ready to use (Fig. 5A,B). The Big Shot is used to launch the throwbag with the throwline over the desired climbing limb, thereby allowing climbing ropes to be installed in the upper canopy.

***Throwbags.***—Throwbags are made of thick woven material or leather, double stitched at the seams and filled with non-lead-based pellets. Throwbags usually come in two shapes: a tightly filled, aerodynamic torpedo-shape, and a partially filled tear-drop-shape for maneuvering through narrow crotches or inclined branches. Throwbags should be inspected before use to make sure the stitched seams have not broken. A metal O-ring is located at one end for throwline attachment. Throwbags weigh 227 g, 340 g, 397 g, or 454 g and each weight was able to reach different heights in the tree (Fig. 5D). The lightweight throwbags (227 g) were used more frequently by female tree climbers, reaching heights up to 25 m.

***Throwline.***—The throwline (also called slickline) is a small-diameter (approximately 1.75 mm), lightweight line that is yellow or multicolored (Fig. 5B; 6J; 7A–D) and is designed to be the first line installed in the tree. The throwline is tied to the throwbag O-ring with an Anchor Hitch knot that is dressed so no protruding ends wedge in crotches or hook on branches. A cloth storage bag approximately 14 cm deep and 10 cm wide is used to store the throwline to keep it from tangling. One end of the throwline is attached to the bottom of the storage bag and the other end is attached to the throwbag. Usually a throwline of 60 m is used, which means the shooter can reach a tree crotch or limb about 30 m high. Continual usage of the throwline often results in kinks that must be removed by tying and stretching the line between two trees. The ends of the throwline often frayed and this was fixed by melting the ends using a match or butane lighter.

***Climbing ropes.***—Ropes are available in different colors and lengths (Fig. 5A,B). Climbing ropes of 36 m in length are coiled in about 1 m lengths and a gasket hitch knot used to keep the rope from uncoiling (Fig. 6L). Once installed, the rope is limited to 18 m in height since it is doubled over a branch or crotch. Climbing ropes are a bright orange or a white color, 16 stranded, 1.3 cm diameter, with a tensile strength of 3,175 kg. One end has a spliced "eye" so a carabiner could be used to "tie in" (Fig. 6J) instead of tying a knot to the climbing saddle O-ring. The other end of the climbing rope has spliced ends with whipped twine to prevent the ends from fraying (Fig. 6A). Another white rope 60 m in length is used to reach a total height of 30 m after installation over a branch. The objective is to get the climbing rope installed at the highest possible point so advancing higher in the tree canopy takes less time. Split tails were approximately 1.5 m to 2 m long and were made the same as the climbing ropes (Fig. 5A).

Ropes are the climbers' lifeline and must meet minimum Occupational Safety and Health Administration standards that include abrasion resistance and a minimum breaking strength (dry test) of 2,449 kg. Ropes should be inspected before use to make sure that possible weakness due to abrasion, cuts from knife use or sharp bark edges, and accumulation of dirt have not weakened the rope and increased the risk of breakage.

***Climbing saddles.***—Two types of climbing saddles are used by students, the leather and butterfly. Leather

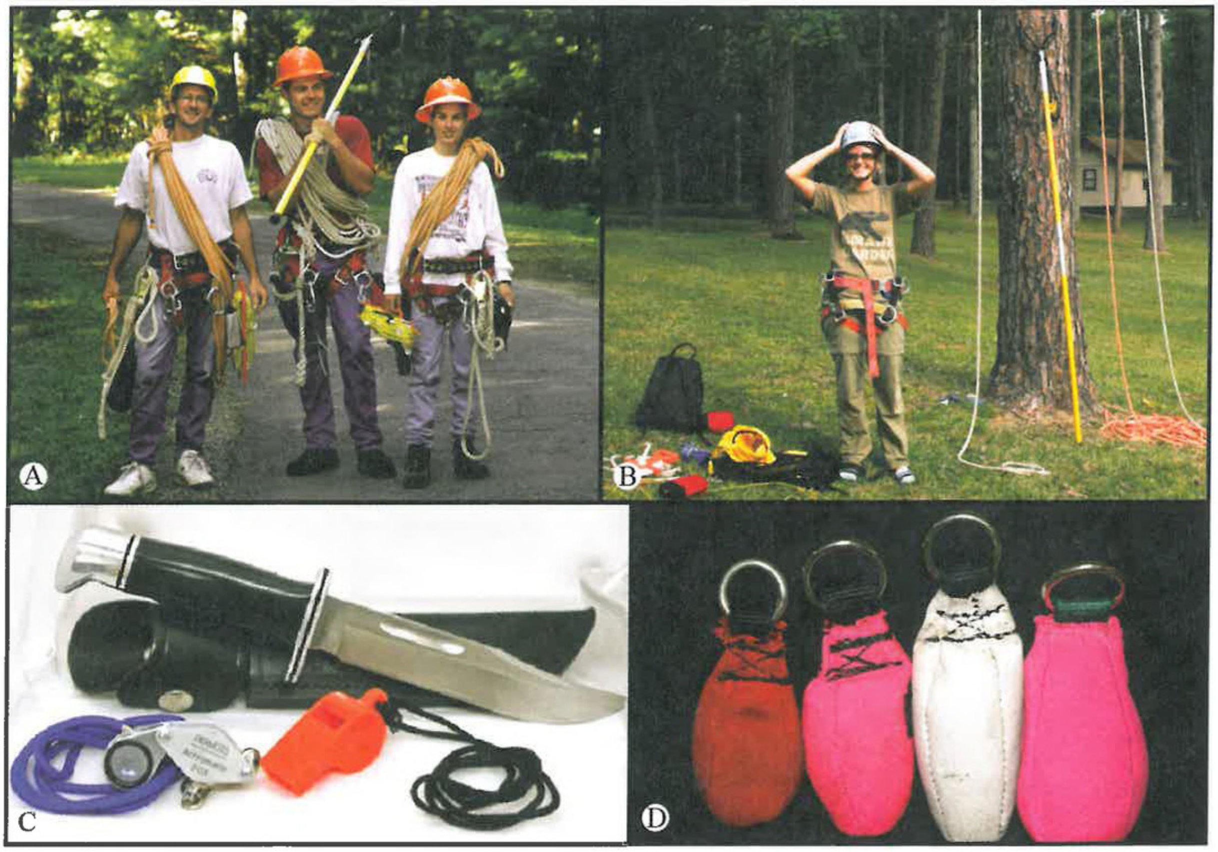

**FIG. 5. A. Climbers with collecting and tree climbing gear. Note hard hat with brim, Big Shot, climbing ropes over shoulders, and leather climbing saddles with lanyards attached at their side. Climber at far left with split tail in right hand, storage bag for throwline and elevation line on right side. Climber in middle with Big Shot over shoulder and knife in sheath attached to right side. Climber at far right with elevation line in right hand and lanyard attached to saddle on right side. B. Climber with brimless helmet, Big Shot propped against trunk of tree, two climbing ropes in tree, backpack and throwline left, and altitude line foreground. C. Collection items carried by climber included heavy bladed knife and sheath to collect bark samples, a 20× handlens with attached blue lanyard to scan bark surface for myxomycetes, and whistle to communicate with ground crew and other climbers. D. Throwbags arranged from left the lightest to right the heaviest: 227 g, 340 g, 397 g, and 454 g. Note metal O-ring at top for throwline attachment, the leather, torpedo-shaped bag second from right, and the other three teardrop-shaped, cloth bags.**

saddles have an extra wide 15.2 cm back support that is foam filled and incased in soft brown leather (Fig. 3E,F). The saddle can be adjusted to the waist and padded leg straps adjusted to the thighs with buckles. The leg straps of this saddle are sometimes uncomfortable in the groin region after prolonged periods in the tree canopy. Each saddle has two D-rings for carabiners or to tie the climbing rope and split tail, two O-rings for lanyard attachment, and also two snaps for equipment such as a knife for removing bark samples, a reel bound tape for height measurements, storage bag for throwbags and throwlines, and water bottles. Leather saddles weigh approximately 3.2 kg and increase the weight carried in the backpack.

The butterfly saddle is lighter weight at approximately 1.8 kg and is easier to carry (Fig. 3B,D,G; 5B; 7F–I,K,L). The padded backrest is 18 cm in height giving back support to the climber when in the saddle for longer periods of time. The belt and leg loops buckle with a smooth-action quick release. This saddle has two D-rings, two small O-rings and three cloth attachment loops on the back rest. Female student climbers prefer the butterfly saddle because it is more comfortable.

Each saddle provides freedom of movement in a horizontal or upside down position that relaxed tired legs. Both hands were free to handle a heavy-bladed knife to collect bark samples, or to use a 20X hand lens to scan the surface of the bark, or use a whistle to communicate with other climbers and the ground crew (Fig. 5C).

***Lanyards (safety ropes).***—This personal safety rope is used as an additional "tie in" while gathering bark samples or as a single tie in when advancing the climbing rope higher in the tree (Fig. 5A; 7F–I, K,L). Lanyards consist of a thick rope, connecting devices on each end with carabiners or a rope snap, and a lanyard adjuster to tighten the rope around the tree trunk. Sometimes it is difficult to secure the lanyard because of the large diameter of the tree trunk. Climbers usually use their legs to pull themselves as close to the tree trunk as possible and swing the rope around the trunk, catching the opposite snap end with their feet. The lanyard snaps are attached to the two D-rings on the climbing saddle or to carabiners.

***Head gear.***—Several types of head gear are worn, but clearly the best is a form fitting helmet without a brim or edge. Brightly colored red, blue, orange, or white helmets make it easy to track the climber high in the tree canopy, especially when thick foliage obscures the view from ground level. A helmet is worn by both the climber and ground crew members. Helmets protect the climber from falling objects such as debris from limbs, falling tree bark, and branches. Chunks of bark sometimes fall from above the climber, especially in old growth champion-sized trees, and the combination of gravity and height can result in serious injury to anyone underneath. Special tree climbing helmets made of durable hard plastic that is lightweight (approximately 0.5 kg) with an inner padded lining feature an external chin strap to prevent the helmet from becoming detached. Ventilation holes along the side prevent excessive sweating around the head band. Sometimes a bandana is worn to prevent slippage of the helmet (Fig. 5A,B; 7F–I,K).

***Gloves.***—The climbers must wear gloves to protect their hands from rope burn, to assure a firm grip on the climbing rope, to prevent scratches from sharp edges of bark, and to protect fingers when using a sharp-bladed knife when collecting bark samples. The palm is made of a latex coated, rubberized, and roughened surface and the backside from breathable cotton and polyester fibers (Fig. 6G–I; 7C,D,F,H,I,L).

**Knots used in the Doubled Rope Climbing Method**

Six basic knots are used: the Anchor Hitch, Figure Eight stopper knot, Blake's Hitch, Half Hitch, Monkey Fist, and Gasket Hitch (Fig. 6A–L). These knots, except the Half Hitch, are described in detail with illustrations in Jepson (2000). Toss (1990) presents an excellent, illustrated guide to tying knots. The website, http://www.iwillknot.com, gives animated examples of how to tie various knots and serves as a valuable resource for novice knot tyers (Hudson 2008).

***Anchor Hitch.***—This attachment knot is used to secure the throwline to the throwbag (Fig. 6A–C). It can also be used to tie one end of the rope to the D-ring or a carabiner on the climbing saddle if the climbing rope lacks an eye splice. This knot must be finished with a Figure Eight stopper knot to ensure that no creeping occurs. Creeping is the term used when the rope slowly moves through the knot, eventually untying the knot.

***Figure Eight.***—This attachment knot is a type of stopper knot (Fig. 6D–F) used as an added safety measure for the climbers to prevent the climbing rope from creeping through the attachment hitches, such as the Anchor Hitch and Blake's Hitch (Fig. 6C,F). This knot is easy to tie and resembles a figure eight when tied correctly.

***Blake's Hitch.***—This knot is a type of friction hitch, also known as a climbing hitch (Fig. 6G–I) and serves to grab the rope when it is under tension. When tension is lessened, the hitch can be moved up or down the rope. The Blake's Hitch knot is a variation of the Tautline Hitch, but is considered to move more smoothly on the rope with less friction to the climbing rope, making it more desirable as a climbing knot. The Tautline Hitch is also notorious for creeping and also binds and tightens to the rope, requiring frequent adjustments during climbing. Although the Blake's Hitch is more tedious to tie than the Tautline Hitch, it is a more functional climbing knot. A Figure Eight stopper knot is always tied to the tail of the Blake's Hitch to prevent any creeping (Fig.6F).

***Half Hitch.***—This knot is used to attach the throwline to the climbing rope before hauling the climbing line over the limb. Four or five Half Hitches are tied to one end of the climbing rope and will tighten when the throwline is pulled (Fig. 6J). Most importantly, they do not interfere with the climbing rope sliding over the crotch of a limb.

***Monkey Fist.***—This knot is considered a type of throw knot (Fig. 6K). It is used for throwing one end of the climbing rope over a limb when advancing in the canopy. Throwing this knot works best when the climber is advancing short distances in the canopy. It can be tedious and awkward to throw, as the climber is usually forced to throw the knot straight overhead. Once the knot has successfully passed over the limb it unravels sending the rope back to the climber. If the Monkey Fist knot is unsuccessful, the climber may opt to use a throwbag attached to the throwline to gain access to the upper limbs in the canopy.

***Gasket Hitch.***—This knot is used when coiling the climbing rope for storage after use (Fig. 6L) and allows the climber to hang the rope up to dry or for storage. If tied successfully, the climber should be able to toss the coiled rope without it uncoiling.

**Climbing Procedure**

The tree climbing procedure (Fig. 7A–L) began with a pre-climbing inspection to search for any dangers that might impact climbers. The buddy system was used, where each climber had a ground crew member, consisting of one or more individuals instructed in climbing techniques, safety procedures, and collecting protocols. Every member of the climbing team (climbers and ground crew members) wore a hardhat and followed proper safety procedures. Ground crew members were responsible for double-checking the pre-climbing inspection, maintaining the throwline and the climbing rope at the base of the tree, communicating with the climber, and supplying the climber with equipment such as hammers and collecting bags. Eye contact was maintained with the climber to ensure safe conditions, to recover bags of bark collected and dropped to the ground, to collect bark samples at 2 meters in height, to record data on a data sheet, and to manage the perimeter of the tree, thus keeping the area free of debris and hikers away from the hazardous zone.

Each climber wore gloves, safety glasses, and a protective helmet when climbing the tree and taking samples. Safety glasses kept debris out of the climbers' eyes and the helmet protected the climber from falling branches and limbs. The climber wore a long-sleeved shirt, long pants, sturdy hiking shoes, helmet, and a climbing saddle designed for arborists. The long-sleeved shirt and pants prevented abrasion to the skin while maneuvering in the tree, through branches, and also helped prevent insect bites. Ground crew members also wore helmets to protect them from falling branches, limbs, throwbags, collecting bags, and any equipment that needed to be tossed from the canopy by the climber.

When the tree was declared safe for climbing, a 227 to 454 g pellet-weighted throwbag was attached to a lightweight throwline and either thrown (Fig. 7A) or shot over the crotch of the desired tree limb using the "Big Shot" (Fig. 7B). The throwline must be free of knots and neatly coiled into a bag placed approximately one meter in front of the Big Shot. This area must be free of leaves, twigs, and branches to minimize drag when shooting. Preparation to shoot required the throwbag be positioned in the sling and the gripper attached to the sling pulled taut (Fig. 7B). To prevent misfire, the throwbag, throwline and O-ring must be carefully positioned in-line. There was a potential risk of backfiring and hitting the shooter in the face if the Big Shot, throw bag, and throwline were not properly aligned.

One way to ensure success when shooting the throwline and throwbag over the limb was to focus on the target and visualize the throwbag moving over the crotch. Shooting the Big Shot can be done two ways: single-hand method or double-hand method. The single-hand method is best for individuals with strong upper-body strength and allows maximum accuracy by stabilizing the pole with the free hand. The double-hand method can achieve higher shots than the single-hand method but compromises accuracy with both hands being used to pull the sling (Fig. 7B).

Even when the throwbag was successfully shot over the desired crotch of the limb, it does not always reach the ground due to friction caused by rubbing against bark, limbs, vines, and leaves. To correct for this, a variety of techniques were used to lower the throwbag to the ground. The first technique was to whip the throwline up and down in a process called "flipping." This was usually effective when the throwline was stuck in a tree "v" crotch as it lifts the throwline above the crotch, allowing the throwbag to descend. Another method was called the "strumming" technique (Fig. 7C,D). This method was akin to drawing a bow and consisted of pulling the throwline towards the torso with two fingers while keeping the line outstretched

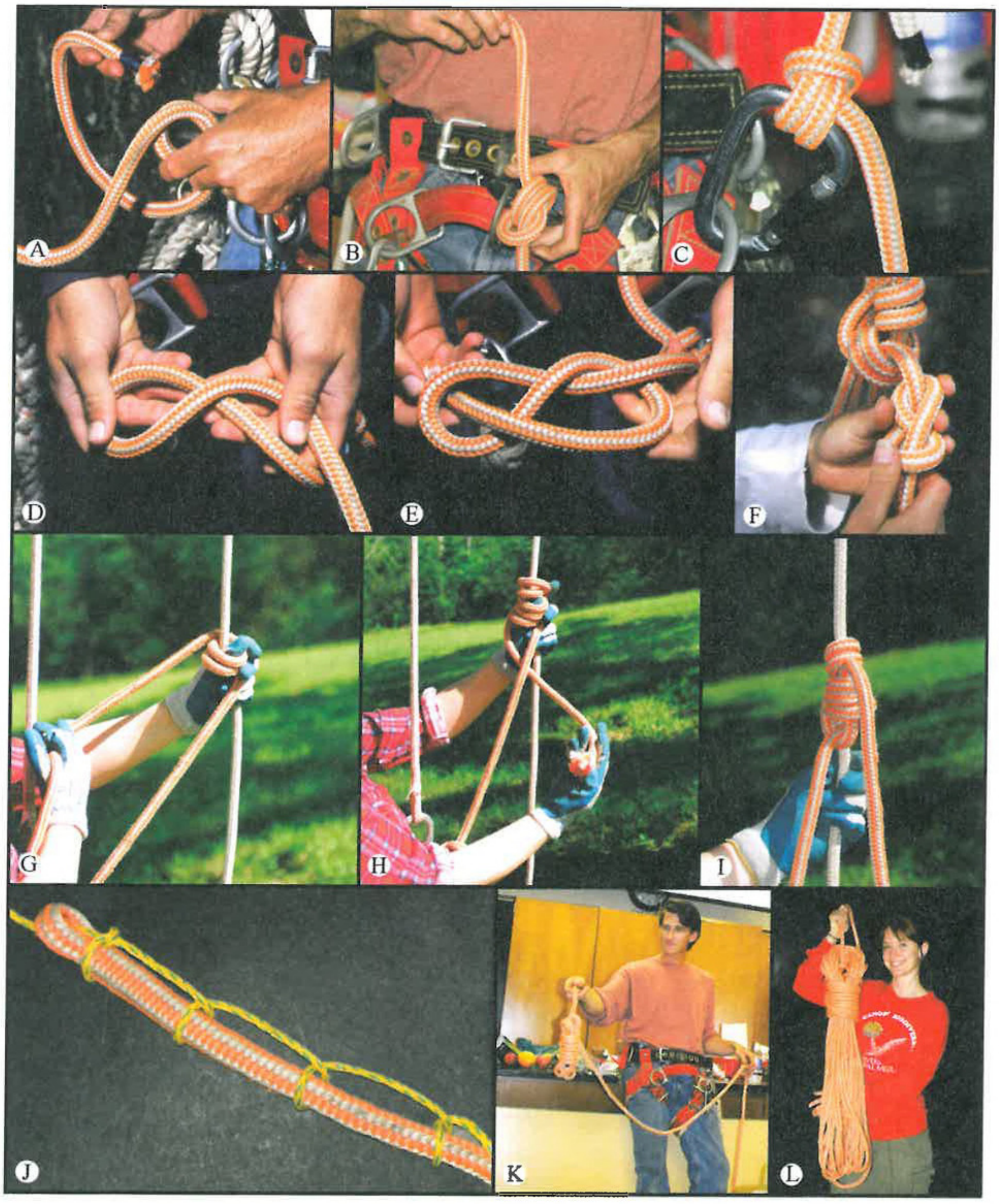


Fig. 6. A–L. Climbing knots. A–C. Anchor Hitch knot. A. Pass the working end of the rope forward over and through the carabineer twice forming two loose turns moving left to right. B. Pass the working end across the two loops from right to left then through the two loops from left to right. C. Tighten and dress the knot and add a figure eight stopper knot. D–F. Figure Eight stopper knot. D. Form the working end of the rope into a loop. Cross the working end over and under the running end forming another loop. E. Pass the working end through the first loop from the front. F. Tighten and dress the knot. G–I. Blake's Hitch Knot. G. Grab working end of rope with left hand. Use left thumb as a spacer and make four to five counter clockwise upward turns with first two or three turns over thumb. Make sure bridge between saddle and Blake's Hitch is not too long or too short. The bridge needs to be a comfortable length in a sitting position, ensure that the extra give from the climbing saddle does not lengthen the bridge to the point that the Blake's Hitch is out of reach. H. Pass the end of the split tail behind turns. Then pass the end of the split tail between bridge and working end of rope. I. Pass the end of the split tail through the lower two or three turns (depending on whether four or five total turns) held by thumb. Dress and set the knot and add a figure eight stopper knot (see F). J. Half Hitch. Pass the end of the throwline around the end of the climbing rope in a clockwise motion. Pass end of throwline over climbing rope and under throwline. Repeat Half Hitch four to five times moving down the climbing rope away from the end of rope. K. Monkey Fist. Coil 3–5 m of working end of rope. Cover the coils with several turns of rope. At end of turns form a loop and pass it through one of the loops formed by the coils. L. Gasket Hitch. Coil all but the last three to five feet of rope. While holding onto coil with one hand, make clockwise horizontal turns around the coil moving towards the head of the coil. Push a bight through and then over the head of the coil and slide bight over coil until it rests on top of the turns. Pull the end of the rope to tighten and set the knot.

with the other hand. By quickly releasing the throwline with the two fingers, a wave of vibrations was sent along the throwline causing it to move toward the ground. When the throwbag reached the ground, the throwline was moved as close to the trunk as possible by using a circular, whip-like arm movement.

Once the throwline was set, it was tied onto the larger climbing rope using a series of half hitches (Fig. 6J) and used to pull the climbing rope over the desired limb. A limb was strongest where it was attached to the tree trunk and therefore it was essential that the climbing rope be positioned as close to the trunk as possible. A whip-like motion was used to move the climbing rope over the limb and next to the trunk. Once the rope was installed, the climber prepared to ascend. Critical supervision by the ground crew was essential as the climber tested the safety of the limb by hanging and bouncing using full body weight with the climbing rope.

Climbing ropes were tied to a climbing saddle using an Anchor Hitch knot or attached using the eye splice to a special D-ring in a process called "tying in" (Jepson 2000) (Fig. 6A–C,G–I; 7E). The working end of the climbing rope was the end attached to the climbing saddle. For right-handed climbers, the working end of the rope was attached to the D-ring on the left side of the harness and became shorter as the climber advanced higher. The running end of the climbing rope was the end that the climber pulled down in order to advance into the tree canopy and became longer as the climber advanced higher. It ran along the right side of the climber's body and was attached to the saddle via a smaller rope, usually around 1.5 m in length, called a "split tail" (Fig. 5A; 6A–C; 7E). The split tail was attached to another D-ring using the eye splice or tied using an Anchor Hitch (on the right side of the saddle for right-handed climbers) and tied to the running end of the rope with a Blake's Hitch knot (Fig. 6G–I).

The Blake's Hitch knot was moved when the climber pulled down on the running end of the rope with the right hand and used the left hand underneath the knot and pushed up, sliding the slack split-tail upward. The climber then used his/her body to facilitate pushing up on the Blake's Hitch knot through a rhythmic thrusting motion of the hips or by bouncing his/her feet off of the tree trunk (Fig.7 G,H). Thrusting and bouncing motions lowered the tension on the climbing rope so that the Blake's Hitch was moved up the slack rope. When the climber was not advancing, the weight of his/her body caused the Blake's Hitch knot to tighten so that it did not slide.

Females on the tree canopy climbing team used a special foot loop technique that allowed them to use their lower body strength to help pull down on the running end of the climbing rope while pushing up on the Blake's Hitch knot (7F,H). The running end of the rope was curved into a loop and held in the climber's right hand. After the climber pushed the foot loop down with either foot and pulled the running end of the rope down with her right hand, she pushed up on the Blake's Hitch with her left hand. This foot loop procedure is described in greater detail in Kilgore (2008); other foot loop techniques are described in Jepson (2000).

A safety rope, also called a lanyard, was used to secure the climber to the trunk or around a branch while he/she was sampling bark or when the working end of the climbing rope is detached from the climbing saddle while the climber was advancing higher in the canopy. To "safety in" at the point of rope installation, the climber installed a short lanyard (more than two meters long), over a branch or around the trunk for an additional safety measure or while maneuvering (Fig. 7K). The lanyard was fastened onto the front attachment point or onto D-rings located on the side of the saddle. The lanyard length was easily adjusted using a mechanical locking system. Lanyards were frequently used in conjunction with the climbing rope to displace pressure points of the climbing saddle, to reduce swinging during ascension, or to pull the climber into reach of grapevines.

Advancement from lower limbs to upper limbs in the canopy required the climber to unhook the working end of the rope from the D-ring, lengthen the working end, and tie a special Monkey Fist knot in the working end (Fig. 6K). Another way was to throw the throwline and throwbag over a limb higher in the canopy much like you would from ground level and then attach the throwline to the working end of the climbing rope using a series of half hitches. Once the climber had thrown the Monkey Fist knot over the


FIG. 7. Tree climbing and collecting procedures. A. Demonstration of hand throwing the throwbag using the throwline and to reach lower heights in the tree canopy. B. Climber using Big Shot in shooting position to release throwbag. C. Climber in position to initiate the strumming technique to create vibrations that lower the throwbag. D. Climber at release point using strumming technique. Note the blue gloves that protect the hands when using throwlines or climbing ropes. E. Climber with climbing rope and split tail tied in to D-rings on bridge of saddle. F. Climber using rope wrapped around left foot creating a foot loop to increase leverage when using the Blake's Hitch. G. Climber walking the tree trunk. H. Climber bouncing off the trunk in a rhythmic thrusting movement and using the foot loop with the right foot. I. Climber in descending position. J. Climber collecting lichen sample and holding the collecting paper bag underneath the knife to catch the bark. Note that both hands are free using the DRCM. K. Climber shown in collecting position with orange climbing rope installed higher in the tree and the white lanyard tied in around the trunk of the tree. This is the proper work position to collect bark samples with knife in one hand and paper bag in the other. L. Climber limb walking on thick branches of *Pinus echinata* to collect female cones. Not shown was the climbing rope around the tree trunk and limb above the climber.

desired limb higher up in the canopy, or attached the climbing rope to the throwline and hauled it over the limb, the working end of climbing rope was reattached to the saddle.

The DRCM allowed climbers the freedom to use both hands to reach and sample tree bark in a vertical transect from near ground level to near the apex of a tree (Fig. 7J,K) It was important to remember how high the rope was secured in the tree, especially after advancing into the upper canopy. If the climber was higher than half the length of the rope, the climber ran out of rope during descent. When this happened, the climber stopped at one of the lower limbs, re-attached the rope to a lower limb and descended again. Descending from the canopy required the climber to slowly pull down on the Blake's hitch knot while holding onto the running end of the climbing rope to control speed (Fig. 7I). It was important to control speed while descending so that the rope and gloves were not burned due to friction in too rapid a descent.

Bark collection at 3 m increments up to 35 m took three hours or longer, depending on the difficulty of removing bark, maneuvering around limbs, difficulty reaching grapevines, and advancing higher to reach leaf voucher specimens from the outer canopy. Although the saddle was padded, extended periods of time hanging in the saddle caused pressure points to develop and legs to go numb. Numb legs were revitalized by inverting the body or walking up the trunk and leaning back so the body was positioned with the legs above the head. The climber could also stand on a limb or lie back on a limb to reduce pressure on the legs.

The DRCM was most efficient for sampling organisms from the trunk of the tree or from the parts of the limbs closest to the trunk. However, samples may need to be collected from the outer limb and requires the climbers to use a method called "limb walking" (Fig. 7L). This required the climber to advance to the apex of the canopy and secure the rope around the trunk of the tree and at least one limb for stability. The climber then determined the straightest path through the canopy to the target limb below. Once the climber descended to the target limb, the rope was tightened so the climber could stand on the limb. Facing the trunk of the tree, the climber proceeded to walk backwards while holding onto the rope and gradually slid the Blake's Hitch down the rope to keep tension on the rope. When the climber reached the desired distance from the trunk the targeted aerial structures near the outer canopy were sampled. To return to the trunk, the climber stood on the limb and slid the Blake's Hitch up the rope maintaining rope tension.

**Student field research experiences and activities**

This project required team effort (Fig. 8A–J). The "ground crew" included multidisciplinary experts who served as mentors for the students. These experts gave special lectures, slide shows, and field demonstrations during evenings or on rainy days on the targeted groups of organisms to aid the student climbers in the recognition and collection of specimens and suitable bark samples. Each evening, students sorted bark samples, separating mosses, liverworts, and lichens and prepared voucher herbarium specimens for the tree species (Fig. 8A). Other evening group activities that helped break the work routine and keep morale high were playing cards, baseball, Frisbee, yard darts, and inviting park personnel and friends for a group supper cooked by the students.

Field research was divided into 2 three-week sessions during the period from June to August. Students climbed for six consecutive days with one day of free time. Some students collected myxomycete specimens at night with a flashlight with a focused spotlight that enabled students to collect myxomycetes on the underside of decaying logs. Tiny myxomycete sporangia in various stages of development glisten and become more conspicuous at night when a directed light beam highlights areas of the log difficult to observe in daylight hours. This was especially true for extensive fruitings of different species of *Cribraria* and *Echinostelium minutum* de Bary on decaying conifer logs (Keller 2004a). These night-time forays with flashlights led to the first observations of slugs feeding on the immature fruiting body stages of myxomycetes (Keller & Snell 2002b). Trail excursions sometimes led to unusual observations such as a millipede feeding on an immature stage of a myxomycete fruiting body (Fig. 8B).

One of the most remarkable discoveries was a new species of myxomycete, *Diachea arboricola* H.W. Keller & M. Skrabal. Melissa Skrabal observed the myxomycete plasmodial tracks and beautiful iridescent sporangia from 9–24 meters on the bark surface and fissures of a white oak tree (Keller & Skrabal 2002;

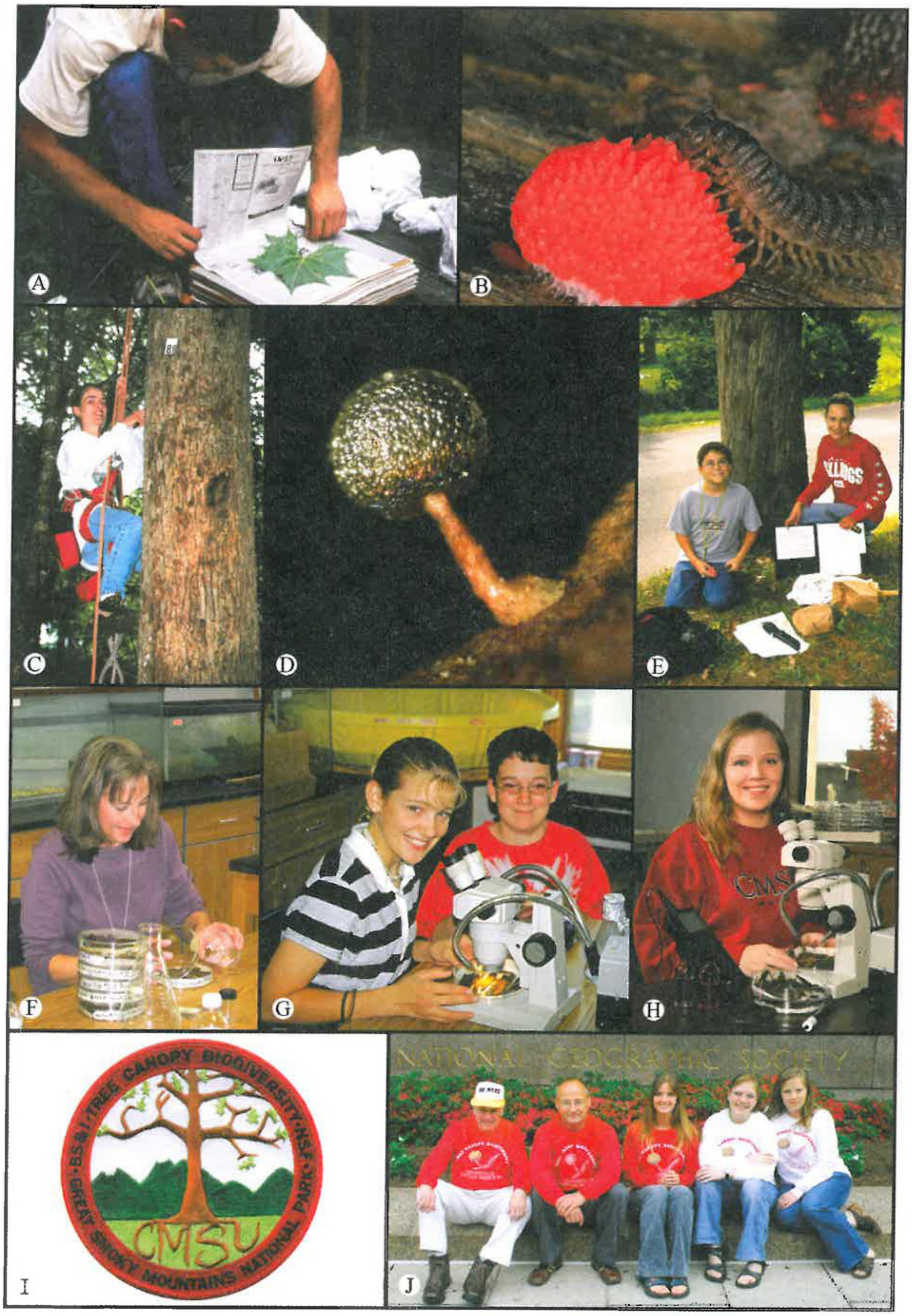


Fig. 8. A–E. Adventure Phase. A. Preparation of tree voucher specimens using plant press. B. Trail excursions resulted in the first observation of a female millipede of *Abacion magnum* (Loomis) feeding on an immature, bright red, myxomycete fruiting body of *Tubifera ferruginosa* (Batsch) J.F. Gmel. C. Climber ascending *Quercus alba* tree collecting sporangia of a new tree canopy species, *Diachea arboricola*. D. Stalked sporangium from C with iridescent peridium showing glittering silver, gold, and and bluish colors. F–H. Laboratory Phase. F. Trish Smith preparing moist chamber bark cultures for classroom study. G. Two seventh grade students scanning moist chamber bark cultures with stereomicroscope. H. Image of Angela Scarborough on front cover of the UCM McNair Journal. Note moist chamber culture with wet bark, pH meter, and stereomicroscope. I. Tree canopy biodiversity logo made into a cloth patch, color sketch by Melissa Skrabal. J. Group picture of UCM tree climbing team at the National Geographic Society Headquarters, Washington D.C.

Keller et al. 2002; Keller et al. 2004) (Fig. 8 C,D). This was an example of a woman in science doing fieldwork that required strength, agility, and athleticism. She represents a role model for other young women to follow in her footsteps. She also designed and sketched our tree canopy biodiversity logo which was made into a cloth patch to provide research team members, volunteers, park personnel and interns, reporters, and friends with a memento of our tree canopy biodiversity research project. The logo recognizes the support of NSF and BS&I and our home institution Central Missouri State University (now UCM). More than 100 of these patches were distributed and are posted on bulletin boards, worn on blazers or jackets, or to help identify gear bags or backpacks (Fig. 8I). A book entitled *Fungi* introduces a new series of Ranger Rick Books for children in grades 3–5. Including a section entitled *Exploring for Fungi* that features Melissa Skrabal collecting lichens and *Diachea arboricola* high in the tree tops in GSMNP (Carson 2003).

The NSF-Research Experience for Teachers Program facilitates professional development of K–12 teachers on the cutting edge of science through partnerships between local school districts and universities (Keller et al. 2005). Trish Smith, a Warrensburg Middle School seventh grade life science teacher, along with students and faculty from UCM, participated in a summer tree canopy biodiversity project in the GSMNP (Fig. 8F). The project created a website at http://warrensburg.k12.mo.us/iadventure/GSMNPiadventure/ where the field Adventure Phase "Exploring Life in the Forest Canopy," represented the first tier of the iAdventure website. This innovative website enabled students and teachers to experience tree canopy research and learn about the All Taxa Biodiversity Inventory as part of the Adventure Phase (Fig. 8E). This was followed by the Laboratory Phase where students observed moist chamber cultures with wet bark that enabled students to observe a living miniature ecosystem composed of myxomycetes, fungi, lichens, mosses, liverworts, green algae, cyanobacterial algae, myxobacteria, tardigrades, insects, nematodes, and possibly other invertebrates (Fig. 8G). The students found several rare myxomycete species such as *Echinostelium arboreum* H.W. Keller & T.E. Brooks, known only from a few locations in the world.

The second tier of the website at http://warrensburg.k12.mo.us/iadventure/whatis.html was an iAdventure problem solving activity. Students determined the direction and outcome of a content-rich storyline, using resources available on the Internet, including resources that provided real-world data and primary literature sources. This activity was designed to help students discover how to use and access data and information on the Internet, and to solve problems and make choices. Students were expected to develop their own research questions, design their own experiment or investigation using the specimens and collected data. This subsequently led them to the Publication Phase, where they were expected to create poster presentations shared with parents and the school community. These classroom activities and website experiences encouraged secondary students to choose field biology as their future career (Smith & Keller 2004).

**Student Research Special Recognition**

Kenneth (Kenny) L. Snell was a graduate of the first tree climbing school and served as an instructor in later years (Fig. 6K, 7E). His leadership and mentorship in the field was a valuable resource for future student climbers. He was the project leader beginning the summer of 2000 and created the tree and myxomycete database for future research projects. His master's thesis (Snell 2002) resulted in the first tree canopy paper published on Myxomycetes (Snell & Keller 2003). Discover Life in America highlighted his accomplishments at UCM in the lead article published in the All Taxa Biodiveristy Inventory Quarterly (Keller 2002b). Kenny received two UCM awards, the Reid Hemphill Outstanding Scholar for his scholarship, research, and citizenship; and the university-wide Graduate Thesis Award for the best graduate thesis for the year 2002.

Erica E. Parker was a McNair Scholar Award Recipient at UCM. This program prepares first-generation, low-income, undergraduate college students for doctoral study. Approximately 24 students were selected as eligible McCAP participants. She was awarded first place for the best research paper (Parker & Keller 2003).

Angela R. Scarborough was selected as a McNair Scholar that resulted in her being featured on the front cover of the McNair Journal (Scarborough 2005) (Fig. 8H); and her research paper presented at the

Association of Southeastern Biologists (ASB) 2006 Annual Meeting won the Outstanding Microbiology Award (Scarborough 2006a) and her poster won the Elsie Quarterman-Catherine Keever Award for the best ecological poster (Scarborough 2006b).

Sydney E. Everhart, a UCM graduate student, won the Outstanding Microbiology Award for the best paper presentation at the ASB 2007 Annual Meeting (Everhart et al. 2007a), and also the Elsie Quarterman-Catherine Keever Award for the best ecological poster (Everhart et al. 2007b). Her master's thesis (Everhart 2007) submitted to UCM was recognized by the University Research Council as the best graduate student thesis in 2008.

Courtney M. Kilgore received the Nahm Award for the Outstanding Graduate Student from the UCM College of Science and Technology. The selection criteria included a major in a graduate program within the College and demonstrated performance in leadership, scholarship, and citizenship. She also was the winner of the Mycological Society of America official conference t-shirt design for the annual 2008 meeting held at Pennsylvania State University. Four edible, mushroom cultivars were included in the winning design, Shiitake (*Lentinula edodes*), Hen of the Woods (*Grifola frondosa*), button mushroom and Portabella white and brown variety (*Agaricus bisporus*), and the velvet foot mushroom (*Flammulina velutipes*), and five molds around the circular border: *Alternaria, Aspergillus, Fusarium, Penicillium,* and *Trichoderma*. The design style was reminiscent of early taxonomical drawings and scientific illustration with a classic art nouveau border to frame the design.

## Special Media Highlights

One of the objectives of this tree canopy project was to involve volunteers, park interns, undergraduate and graduate students, in interpretive exhibits, news media coverage (print and television), publication of technical articles in peer reviewed journals and also in popular magazines that sent a powerful conservation message for biodiversity. The grants acknowledged here for the period 2000 to 2008 resulted in 20 refereed papers in scientific journals, 15 articles published in newsletters, mostly in the Mycological Society of America newsletter *"Inoculum,"* the *"ATBI Quarterly"* from Discover Life in America, and *"What's Up"* from the International Canopy Network. The majority of these articles were on the front cover as the lead article. Abstracts (74) were represented by power point and poster presentations given at many different professional meetings. Four master's degree theses were completed during this period.

The media coverage gave the public a better understanding of the occurrence and importance of mostly cryptogams such as myxomycetes, macrofungi, mosses, liverworts, lichens, and ferns and observations on invertebrates, including insects, mollusks, and tardigrades. Media attention highlighted the DRCM and reporters interviewed students and project team members. Interpretive exhibits, newspaper articles, popular books for children, and television feature stories based on our tree canopy exploration and discoveries in the GSMNP were described by Keller (2004a).

Rock Creek National Park, located in Washington D.C., hosted the first 24-hour BioBlitz held May 18–19, 2007, jointly sponsored by the National Geographic Society (NGS) and the National Park Service (NPS); Fig. 8J). Student climbers demonstrated the use of the DRCM when sampling bark for myxomycetes. The BioBlitz which began in 2007, will be held annually in urban areas of NPS units for the next 10 years with the goal of increasing public awareness through the documentation of species inventory, public outreach activities, and science education for all age groups (Kilgore 2007; Kilgore & Keller 2007). This first BioBlitz drew media coverage that resulted in a photo of Sydney E. Everhart on the front page of the Metro section of the May 19th, 2007 issue of the Washington Post. Perched in her climbing saddle in the top of a white oak tree canopy, she collected bark samples that were later transported to the laboratory and cultured in moist chambers for myxomycetes and other organisms. Video of this event is available for viewing at this URL address: http://video.nationalgeographic.com/video/player/specials/films-specials/. The NGS video page will load and the featured video will begin to play. In the dialogue box that says "search all videos" enter "Rock Creek Bioblitz" and press "GO."

More recently, National Geographic Television produced two films "BioBlitz Rock Creek Park 2007" and "Smoky Mountains Treetop Exploration," that appeared as part of the *Wild Chronicles* series on Public Broadcasting Stations (PBS) nationwide. The former as Episode #236, August, 2007 and the latter as Episode #318, February, 2008, and had a running time of seven minutes for each episode. Boyd Matson was the host and narrator. National Geographic Society Mission Programs supports pioneering research and field expeditions through programs such as the Committee for Research and Exploration.

During July of 2007, National Geographic Television Producer Jason Orfanon shot 10 hours of film footage over a five-day period in the GSMNP. The storyline documented the exploration of the tree canopy using the DRCM by a research team of two University of Central Missouri graduate student climbers, SEE and CMK, who demonstrated how to access, climb, and gather bark samples with myxomycetes, macrofungi, lichens, mosses, and liverworts from the tree canopy. Harold W. Keller coordinated the ground crew and served as the principal investigator for the research project entitled "RUI: Biodiversity and Ecology of Tree Canopy Biota in the Great Smoky Mountains National Park." Video is available for viewing at this URL address: http://video.nationalgeographic.com/video/player/specials/films-specials/. The NGS video page will load and the featured video will begin to play. In the dialogue box that says "search all videos" enter "Smoky Mountain Tree Canopy" and press "GO." Films will appear as blocks. Click the second block that is called "In Search of Slime" which has a beautiful color image of a sessile, densely netted, plasmodiocarpous fruiting body with a conspicuous bluish iridescence of the rare myxomycete *Didymium perforatum* Yamash.

In addition to the video, Matson also conducted a 20-minute interview with CMK and HWK about their tree canopy adventures, which aired on *National Geographic Weekend*. This is a new radio program hosted by Boyd Matson that highlights stories of "exploration to the far corners of the planet and the hidden corners of your own backyard." It airs on radio stations on Saturdays and Sundays.

## RESULTS

### Tree and Vine Species Climbed and Sampled

Tree and vine species represented 52 taxa and more than 500 individual trees were climbed over the eight year period of this project. Some species of trees are represented by many individual trees, for example, *Acer rubrum, A. saccharum, Fraxinus americana, Juniperus virginiana, Liquidambar styraciflua, Liriodendron tulipifera, Picea rubens, Pinus echinata, P. strobus, Platanus occidentalis, Tsuga canadensis,* and grapevines, *Vitis aestivalis,* and *V. vulpina*. Some of the tree species were scattered, fewer in number, and difficult to find, but the species given here occurred in greater numbers, were closer together, easier to locate and climb, and larger. These trees met our climbing criteria for bark sampling. Trees were located using trail guides, vegetation maps, consultation with local residents, park and state officials, and questioning hikers on the trail (Keller 2006).

Tree and vine species listed alphabetically: *Abies fraseri* (Pursh) Poir., *Acer negundo* L., *A. rubrum* L., *A. saccharinum* L., *A. saccharum* Marsh., *Aesculus flava* Aiton, *A. octandra* Marsh, *Ampelopsis cordata* Michx., *Betula alleghaniensis* Britton. *B. lenta* L., *Carya alba* (L.) Nutt., *C. cordiformis* (Wangenh.) K. Koch., *C. glabra* (Mill.) Sweet, *C. illinoinensis* (Wangenh.) K. Koch., *Cercis canadensis* L., *Cornus florida* L., *Diospyros virginiana* L., *Fagus grandifolia* Ehrh., *Fraxinus americana* L., *F. pennsylvanica* Marsh., *F. profunda* (Bush) Bush, *Halesia carolina* L., *Juglans nigra* L., *Juniperus virginiana* L., *Liquidambar styraciflua* L., *Liriodendron tulipifera* L., *Magnolia acuminata* (L.) L., *Nyssa sylvatica* Marsh., *Picea rubens* Sarg., *Pinus echinata* Mill., *P. strobus* L., *Platanus occidentalis* L., *Populus deltoides* Bartram ex Marsh., *Prunus serotina* Ehrh., *Quercus alba* L., *Q. falcata* Michx., *Q. michauxii* Nutt., *Q. montana* Wild., *Q. muehlenbergii* Engelm., *Q. prinus* L., *Q. rubra* L., *Q. velutina* Lam., *Robinia pseudoacacia* L., *Sorbus americana* Marsh., *Taxodium distichum* (L.) Rich, *Tilia americana* L., *T. heterophylla* Vent., *Tsuga canadensis* (L.) Carr., *Ulmus americana* L., *U. rubra* Muhl., *Vitis aestivalis* Michx., and *V. vulpina* L.

### Myxomycete Species on Trees and Vines

Corticolous myxomycetes complete their entire life cycle only on the bark of living trees and vines (Keller

& Braun 1999; Everhart & Keller 2008). Some corticolous myxomycete species were collected in the field directly on the bark of living trees and vines and some were harvested from laboratory moist chamber cultures. Bark characteristics and pH were important factors in the occurrence and distribution of myxomycetes on living, healthy trees and vines (Snell & Keller 2003; Keller 2004a; Parker & Keller 2004; Scarborough 2006a; Keller & Everhart 2008; Everhart et al. 2008). The more productive trees for corticolous myxomycete species are included here with the total number of species found to date. These numbers were compiled from previous publications (Martin & Alexopoulos 1969; Keller & Braun 1999; Parker & Keller 2003; Parker & Keller 2005; Scarborough 2005; Scarborough 2006b; Snell & Keller 2003; Snell et al. 2003; Everhart & Keller 2008; Everhart et al. 2008; Kilgore 2008). The number of different myxomycete species on trees and vines are listed from highest to lowest, with number of species in parentheses: *Juniperus virginiana* (54), *Acer rubrum* (49), *Quercus alba* (43), *Liriodendron tulipifera* (41), *Vitis aestivalis* (39), *Fraxinus americana* (31), *Vitis vulpina* (25), *Pinus strobus* (24), *Ulmus americana* (20), *Acer saccharum* (17), *Tsuga canadensis* (17), and *Pinus echinata* (14). All other trees had fewer species than listed here and *Abies fraseri* had no myxomycete species above diameter at breast height.

The mean pH is given for the above listed tree species from the highest pH to the lowest. *Juniperus virginiana* had the highest pH (7.3) bark values, highest water absorption capacity, and the highest corticolous myxomycete species diversity based on our field and laboratory tree canopy studies to date (Keller & Braun 1999; Keller 2004a). *Ulmus americana* (7.0) and *Fraxinus americana* (6.7) also had thick bark with high water absorption capacity (Parker & Keller 2003). *Quercus alba* (5.7), *Vitis vulpina* (5.5), *Acer saccharum* (5.5), *Liriodendron tulipifera* (4.9), *Vitis aestivalis* (4.8), *Acer rubrum* (4.7), *Tsuga canadensis* (4.1), *Pinus strobus* (3.8), and *Pinus echinata* (3.8) represent the rest of the tree and vine species (Snell & Keller 2003; Everhart et al. 2008; Kilgore 2008). The last three tree species had the lowest pH and lower number of myxomycete species in part due to the lower pH and lower water absorbing capacity. This trend of a lower pH range associated with especially resiniferous gymnosperm tree bark, resulted in the lowest number of myxomycete species.

## FUTURE DIRECTIONS

The results and scope of this project demonstrate that the DRCM is an alternative way to study tree canopy biota. Nevertheless, additional research is needed to answer questions about organisms in hard to reach places. For example, limb walking using the DRCM facilitates sampling from the trunk axis to the outer periphery of the tree. Studies using DRCM and limb walking are capable of sampling aerial reproductive structures, such as gymnosperm female cones (*Pinus* spp.), pods from *Cercis canadensis*, ball-like fruiting structures of *Liquidambar styraciflua* and the long pods of *Catalpa speciosa* (Warder) Warder ex Engelm. (Kilgore 2008).

Further research in the tree canopy is needed to document the vertical distribution of lichen growth forms (crustose, foliose, and fructicose) and lichen species among these three growth habits from the tree base at ground level to the treetop (Ciegler et al. 2003; Lumbsch et al. 2005; Fanning et al. 2007; Keller et al. 2007).

Little is known about the distribution of mosses and liverworts (bryophytes) from vertical transects along tree trunks. Most of the species found to date in the tree canopy also occur on ground sites. This is another group that should be targeted for more tree canopy survey and inventory (Davison & Keller 2004).

The presence of basidiomycetes and ascomycetes on the bark surface and in tree crotches should be targeted for collection and identification. No ascomycetes were collected and identified in our bark cultures, but they were present nevertheless. Only five basidiomycetes were collected on healthy living trees-certainly a scanty harvest.

The total height and diameter of the tree should be supplemented with core samples to determine the actual age by counting tree rings. The actual age of the tree is lacking in most studies and this piece of data would match size and age of trees and the time needed for organisms to colonize the bark surface. This invasive technique would require special permission from the National Park Service or the United States Forest Service, or be conducted on private property.

Bark samples were prepared in moist chamber cultures immediately or within several months after field collection. Laboratory protocols should include exactly how old the bark samples were when first wetted in moist chamber cultures. Storage at room temperature in sample bags enclosed inside of a large paper bag and tightly sealed for 12 to 24 months or longer increases the chances of filamentous mold contaminants, especially species of *Trichoderma*, mucoraceous species, *Aspergillus* species, and unidentified white molds.

Myxobacteria appear quite frequently in moist chamber cultures of bark from living trees and vines and represent a group of understudied organisms with potentially unidentified species which are strictly arboreal. Bark and grapevine samples from the tree canopy also have nematodes and tardigrades, and these organisms mostly are known from ground level sites. The role of nematode interactions with myxomycete plasmodia needs further study based on recent results (Kilgore & Keller 2008).

Observation and collection of snails and slugs along the tree trunk was possible using the DRCM. Slugs, *Philomycus carolinianus* (Bosc) and *P. flexuolaris* Rafinesque, were documented at heights up to 14 m on the trunk and around a treehole filled with water (Keller & Snell, 2002b). Snails with shells, for example, *Mesodon normalis* (Pilsbry) about the size of a quarter, and *Anguispira jessica* Kutchka about the size of a dime, appeared to move from ground level up to 15 m in the former and 24 m in the latter. The DRCM is the best way to record slug and snail movements in the tree canopy and determine if any species are arboreal. Little is known about tree canopy slugs and snails (Thomas Watters and Dan Dourson, pers. comm.).

Epiphytic plants in the tree canopy should also be studied. *Pleopeltis polypodioides* (L.) Andrews & Windham (the resurrection fern), was found in large conspicuous clumps along the trunk and branches at lower heights on a national champion tree, *Fraxinus profunda* (Bush) Bush in Big Oak Tree State Park, Missouri (Keller pers. obs.). This fern was observed easily with the unaided eye, and other epiphytes may be seen with ground-based binoculars higher in the canopy. In some cases the location of epiphytes eludes even the sharpest eyes and binoculars, and only the DRCM made it possible to see these plants higher in the tree canopy. The typically lithophilic *Polypodium appalachianum* Haufler & Windham (Rock Cap Fern) was discovered as a tree canopy epiphyte 35–40 m above ground on a horizontal branch in a champion-sized *Liriodendron tulipfera* in the GSMNP. Even though this fern had leaves up to 16 cm long and 5 cm wide, it could not be seen with ground-based binoculars because of the height and location on the upper side of a horizontal branch (Keller et al. 2003). Tiny epiphytic plants that include orchids and other vascular plants may represent arboreal species that can be detected only by using the DRCM. Vertical transects of the bark surface can be scanned from the base to the top of the tree canopy visually or using a 20× hand lens for tiny organisms.

Certain corticolous myxomycetes only are known from the tree canopy such as *Trabrooksia applanata* H.W. Keller. This myxomycete species and many others should be cultured from spore to spore and DNA analysis determined to correctly classify and develop phylogenetic relationships instead of morphospecies concepts (Keller 1996; Keller 2005c; Keller & Everhart 2008).

Many more studies using rope climbing methods are needed to determine if arboreal biota exist in the tree canopy of temperate forests. Research projects using the DRCM will help the next generation of tree canopy biologists to explore, ask questions, and develop hypotheses that will increase our knowledge of the biosphere.

## ACKNOWLEDGMENTS

Our sincerest gratitude goes to all of the student climbers who participated in this project. Faculty and student colleagues in the Department of Biology and Earth Science at UCM provided encouragement and logistical support that made this project possible. The success of this tree canopy project depended on numerous individuals, including local residents who knew where to find a champion tree or grapevine and professionals who offered their expertise in taxonomic identification and reviewing papers for publication.

Ricardo Perez translated the English abstract into Spanish. Keith Langdon and Paul Super from GSMNP gave assistance in obtaining collecting permits, maps and directions where to find trees, and facilitated permission for National Geographic to produce a television film about our tree canopy biodiversity research project. Jeanie Hilten assisted with equipment needs, logistics, park directions, and lodging at GSMNP as part of Discover Life in America. Carolyn and Reid Franks generously offered their home and friendship to us on numerous occasions while we conducted research in GSMNP. David Taylor, botanist for the USFS at DBNF, assisted in obtaining collecting permits, lodging facilities, and finding suitable tree climbing sites. John Perry, Glen Dandeneau, and the maintenance crew at the Berea College of Forestry helped us locate tree sites in the Berea College Forest. Tim Smith at the Missouri Department of Conservation and Mike Currier at the Missouri Department of Natural Resources assisted with obtaining collecting permits for collecting sites in Missouri.

Many individuals accompanied the tree canopy team on expeditions to GSMNP or DBNF, offered their expertise in a particular field, and participated as ground crew members. These individuals included: Alex Ciegler, Paul Davison, Uno Eliasson, Thomas Gaither, Diane Nelson, Kenneth Nelson, Jay Raveill, Trish and Stan Smith, and Ted Stampfer. Stephen Wilson assisted with canopy flight-intercept insect traps in GSMNP and Big Oak Tree State Park, served on graduate student thesis committees, edited theses, and reviewed papers for publication.

Trish Smith involved seventh grade life science students at Warrensburg Middle School with the Research Experience for Teachers project by culturing myxomycetes in the classroom, developed an interactive website for students to participate in their own tree canopy adventure, and invited members of the UCM tree canopy team to visit the classroom to help identify organisms in moist chamber cultures. Jean Gerrath and Jay Raveill assisted students in identifying grapevine and trees vouchers respectively. Gabriel Moreno produced valuable scanning electron micrographs of myxomycete species that had unusual characteristics. Uno Eliasson aided in collecting and identifying myxomycete specimens that were new records or had unusual characteristics, and he reviewed papers for publication. Karl and Jeanne Braun and Ted Stampfer reviewed numerous papers for publication.

Robert Breshears, Mike Ferro, Jim Murray, and Glenda Carmack volunteered their photographic skills and accompanied team members into the field on numerous occasions to visually record the DRCM. Many of their photographs appear in publications produced by the tree canopy team. Photo credits: James Murray = Figs. 1A,B,F,G, 3H, 5A, 7E,J, 8A,C; Courtney M. Kilgore = Figs. 1C,K, 4C; Harold W. Keller = Figs. 1D–E,H–J, 3G, 4D–E, 5B,D, 6J,L, 7F–I,L, 8F–G,I; Glenda Carmack = Figs. 2A, 3B,D,F; 4A, 5C, 6A–F,K, 7A, 8E; Jerry Coule = Fig. 2B–C; Mike Ferro = Fig. 3A,C,E; Kenny L. Snell = Fig. 4B; Robert Breshears = Figs. 6G–I, 7B–D,K, 8J; Stan Smith = Fig. 8B; Sydney E. Everhart = Fig. 8D; Bryan Tebbenkamp = Fig. 8H.

Lisa Schmidt and Terry McNeeley of Instructional Design at UCM contributed many hours of their technical expertise and support assisting with posters, power point presentations, web site construction, and other media for professional conferences. Mike Griefe highlighted our projects through University Relations at UCM.

Nalini Nadkarni and Scott Hollis of the International Canopy Network regularly published articles in the ICAN newsletter "*What's UP*"? Jinx Campbell, Current Editor of the Mycological Society of America's newsletter "*Inoculum*" along with past editors Richard Baird, Donald Ruch, and Lorelei Norvell all featured our tree canopy articles. Jason Orfanon, NGS television producer, spent time in the field with us in GSNNP to film our research for the television series "*Wild Chronicles.*" Boyd Matson interviewed two of the authors on the radio show "*National Geographic Weekend.*"

This project was financially supported in part by the National Science Foundation Division of Environmental Biology Awards #0079058 and #0343447, Discover Life in America Awards #2001-26, #2002-17, and #2004-6, National Geographic Society Committee for Research and Exploration Award #7272-02, the Missouri Department of Natural Resources for the tree canopy research in Big Oak Tree State Park, Missouri, the United States Department of Education McNair Scholars Program, and the UCM Summer Undergraduate Research and Creative Projects Program.

The authors wish to thank H. Bruce Rinker, Lafayette Frederick, and Dennis L. Miller for their careful and meticulous reviews of an earlier version of the manuscript.

REFERENCES


Adams, M. 2007a. Safe and efficient tree ascent: doubled rope techniques (DdRT). Arborist News 16(3):50–54.

Adams, M. 2007b. Safe and efficient tree ascent: doubled rope techniques (DdRT), Part Two. Arborist News 16(4):50–53.

Carson, M.K. 2003. Fungi. Newbridge Educational Publishing, New York, New York.

Ciegler, A., U.H. Eliasson, and H.W. Keller. 2003. Tree canopy lichens of the Great Smoky Mountains National Park. Evansia 20(4):114–131.

Counts, J., L. Henley, M. Skrabal, and K.L. Snell. 2000. Tree canopy biodiversity in the Great Smoky Mountains National Park. Inoculum 50:1–5.

Counts, J., L. Henley, M. Skrabal, and H.W. Keller. 2001. Biological jewels in tree canopies. Transactions of the Missouri Academy of Science. Collegiate Division, 35:70.

Davison, P.G. and H.W. Keller. 2004. Vertical distribution of liverworts within the forest canopy in the Southern Appalachians: contributions to the all taxa biodiversity inventory of the Great Smoky Mountains National Park. Evansia 21:79–87.

Dunlap, T. 2002. The single rope technique. Tree Care Industry 13(9):32–36.

Everhart, S.E. 2007. Assemblages and distribution of corticolous myxomycete species in the tree canopy of selected forests in Kentucky and Tennessee. (Master's thesis) University of Central Missouri.

Everhart, S.E., H.W. Keller, and J.S. Ely. 2007a. Ecology of canopy myxomycetes (true slime molds) on trees and grapevines (*Vitis aestivalis* and *V. vulpina*). S.E. Biol. 54:275.

Everhart, S.E., H.W. Keller, and J.S. Ely. 2007b. Role of bark characteristics and epiphyte cover in the abundance, distribution, and succession of corticolous Myxomycetes (true slime molds). S.E. Biol. 54:312.

Everhart, S.E. and H.W. Keller. 2008. Life history strategies of corticolous myxomycetes: the life cycle, fruiting bodies, plasmodial types, and taxonomic orders. Fungal Diversity 29:1–16.

Everhart, S.E., H.W. Keller, and J.S. Ely. 2008. Influence of bark pH on the occurrence and distribution of tree canopy myxomycete species. Mycologia 100:191–204.

Fanning, E.F., J.S. Ely, H.T. Lumbsch, and H.W. Keller. 2007. Vertical distribution of lichen growth forms in tree canopies of Great Smoky Mountains National Park. The Great Smoky Mountains National Park all taxa biodiversity inventory: a search for species in our own backyard. S.E. Naturalist 6:83–88.

Grushka, M.M., J. Adams, M. Lowman, G. Lin, and B.D.V. Marino. 1999. The Biosphere 2 canopy access system. Ecol. Eng. 13:313–320.

Henley, L., M. Skrabal, K.L. Snell., J. Counts, and H.W. Keller. 2000. Life in the treetops at Great Smoky Mountains National Park. Newslett. ICAN What's Up? 7:(1):6–7.

Hudson, P. 2008. I Will Knot! (http://www.iwillknot.com/)

Jepson, J. 2000. The tree climber's companion, a reference and training manual for professional tree climbers, ed. 2. Beaver Tree Publishing, Longville, Minnesota.

Keller, H.W. 1996. Biosystematics of Myxomycetes: a futuristic view. Invited Plenary Address. In: C. Lado and J.C. Hernandez eds. Second International Congress on the Systematics and Ecology of Myxomycetes. Abstract Volume. 23–37. Madrid. Real Jardin Botánico, CSIC, Madrid, Spain.

Keller, H.W. 2002a. Tree canopy and corticolous myxomycetes. In: J. Rammelloo and A. Bogaerts eds. Fourth International Congress on the Systematics and Ecology of Myxomycetes. Abstracts. Scripta Bot. Belg. 22:48.

Keller, H.W. 2002b. Tree canopy Myxomycetes: outstanding scholar and thesis award. ATBI Quart. 3(3):1.

Keller, H.W. 2004a. Tree canopy biodiversity and student research experiences in Great Smoky Mountains National Park. Syst. Geogr. Pl. 74:47–65.

Keller, H.W. 2004b. Tree canopy biodiversity in Great Smoky Mountains National Park. Newslett. MSA. Inoculum 55(4):20.

Keller, H.W. 2005a. Undergraduate research field experiences: tree canopy biodiversity in Great Smoky Mountains National Park and Pertle Springs, Warrensburg, Missouri. CUR Quart. 25(4):162–168.

Keller, H.W. 2005b. Tree canopy Myxomycetes in Great Smoky Mountains National Park and in Big Oak Tree State Park, U.S.A. ICSEM 5. Tlaxcala, Mexico, Universidad Autonoma de Tlaxcala. Pp. 43–44.

Keller, H.W. 2005c. What is a myxomycete species. 5th International Congress on Systematics and Ecology of Myxomycetes. ICSEM5. Tlaxcala, Mexico, Universidad Autonoma de Tlaxcala. Pp. 45–46.

Keller, H.W. 2006. Tree canopy biota in the Great Smoky Mountains National Park. Symposium entitled "All Taxa Biodiversity Inventory: A search for species in our own "backyard." S.E. Biol. 53:144.

Keller, H.W. and K.L. Braun. 1999. Myxomycetes of Ohio: Their systematics, biology, and use in teaching. Ohio Biol. Surv. Bull. New Ser. 13:1–182.

Keller, H.W., P. Davison, C. Haufler, and D.B. Lesmeister. 2003. *Polypodium appalachianum*: an unusual tree canopy epiphyte in the Great Smoky Mountains National Park. Amer. Fern. J. 93:36–41.

Keller, H.W., J.S. Ely, H.T. Lumbsch, and S.B. Selva. 2007. Great Smoky Mountains National Park first lichen bio-quest. The Great Smoky Mountains National Park All Taxa Biodiversity Inventory: A Search for Species in Our Own Backyard. S.E. Naturalist 6:89–98.

Keller, H.W. and S.E. Everhart. 2007. Fossil myxomycetes: do they really exist? Inoculum 58(6):33.

Keller, H.W. and S.E. Everhart. 2008. Myxomycete species concepts, monotypic genera, the fossil record, and additional examples of good taxonomic practice. Rev. Mex. Micol. 27:18–27.

Keller, H.W., C.M. Kilgore, S.E. Everhart, G.J. Carmack, C.D. Crabtree, and A.R. Scarborough. 2008. Myxomycete plasmodia and fruiting bodies: unusual occurrences and user friendly study techniques. Fungi 1(1):24–37.

Keller, H.W. and M. Skrabal. 2002. Discovery of a new obligate tree canopy myxomycete in the Great Smoky Mountains National Park. Newslett. MSA. Inoculum 53(2):1–4.

Keller, H.W., M. Skrabal, U.H. Eliasson, and T. Gaither. 2002. A new tree canopy myxomycete in the Great Smoky Mountains National Park. In: J. Rammeloo and A. Bogaerts eds. Fourth International Congress on the Systematics and Ecology of Myxomycetes. Abstracts. Scripta Bot. Belg. 22:49–50.

Keller, H.W., M. Skrabal, U.H. Eliasson, and T.W. Gaither. 2004. Tree canopy biodiversity in the Great Smoky Mountains National Park: ecological and developmental observations of a new myxomycete species of Diachea. Mycologia 96:537–547.

Keller, H.W. and K.L. Snell. 2002a. Cryptogam tree canopy biodiversity in the Great Smoky Mountains National Park. In: J. Rammeloo and A. Bogaerts eds: Fourth International Congress on the Systematics and Ecology of Myxomycetes. Abstracts. Scripta Bot. Belg. 22:51–52.

Keller, H.W. and K.L. Snell. 2002b. Feeding activities of slugs on Myxomycetes and macrofungi. Mycologia 94:757–760.

Keller, H.W., S.W. Wilson, and P.A. Smith. 2005. Research Experience for Teachers-National Science Foundation: biodiversity survey (myxomycetes and insects) of Pertle Springs, Warrensburg, Missouri, by 7th grade life science students. 5th International Congress on Systematics and Ecology of Myxomycetes. ICSEM5. Tlaxcala, Mexico, Universidad Autonoma de Tlaxcala. Pp. 47–48.

Kilgore, C.M. 2007. Bioblitz reaches new heights in Washington, DC. What's Up? The Newsletter of the International Canopy Network 13(4):354.

Kilgore, C.M. 2008. Aerial reproductive structures on vascular plants as a microhabitat for myxomycetes. (Masters thesis) University of Central Missouri. 97 p.

Kilgore, C.M. and H.W. Keller. 2007. Rock Creek Park BioBlitz. Newslett. MSA. Inoculum 58(5):15–16.

Kilgore, C.M. and H.W. Keller. 2008. Interactions between myxomycete plasmodia and nematodes. Newslett. MSA. Inoculum 59(1):1–3.

Lowman, M.D. 1994. Accessing forest canopies. American Orchid Society Bulletin 1252–1255.

Lowman, M.D. 1999. Life in the treetops, adventures of a woman in field biology. Yale University, Press, New Haven & London.

Lowman, M.D. 2004. Tarzan or Jane? The history of canopy ecology. In: M.D. Lowman, H.B. Rinker eds. Forest Canopies ed. 2. Elsevier Press, San Diego. Pp. 453–464.

Lowman, M.D. and B. Bouricius. 1995. The construction of platforms and bridges for forest canopy access. Selbyana 16:179–184.

LOWMAN, M., M. HUNTER, B. RINKER, T. SCHOWALTER, AND S. CONTE. 2002. Canopy walkways-highways in the sky. In: A.W. Mitchell, K. Secoy, and T. Jackson, eds. The global canopy handbook: techniques of access and study in the forest roof. Global Canopy Programme. Oxford, UK. Pp. 35–41.

LOWMAN, M.D. AND H.B. RINKER (eds.). 2004. Forest canopies. ed. 2. Elsevier Academic Press, San Diego.

LOWMAN, M. AND P.K. WITTMAN. 1996. Forest canopies: methods, hypotheses, and future directions. Annu. Rev. Ecol. Syst. 27:55–81.

LUMBSCH, H.T., E.R. FANNING, J.S. ELY, AND H.W. KELLER. 2005. New additions to the lichen biota of Great Smoky Mountains National Park. 52(2):200–201.

MARTIN, G.W. AND C.J. ALEXOPOULOS. 1969. The Myxomycetes. University of Iowa Press, Iowa City.

MOFFETT, M.W. AND M.D. LOWMAN. 1995. Canopy access techniques. In: M.D. Lowman and N.M. Nadkarni, eds. Forest Canopies 3–26. Academic Press, San Diego.

NADKARNI, N.M. 1988. Use of a portable platform for observation of animal behavior in tropical tree canopies. Biotropica 20:350–51.

NADKARNI, N.M. 1995. Good-bye, Tarzan: the science of life in the treetops gets down to business. Sciences (New York) 35:28–33.

PARKER, E.E. AND H.W. KELLER. 2003. Correlation of pH with assemblages of corticolous myxomycetes. Journal of the McNair Central Achievers Program, University of Central Missouri. Vol. 12 (Issue 1):4–8.

PARKER, E.E. AND H.W. KELLER. 2004. Correlation of pH with assemblages of corticolous myxomycetes in Big Oak Tree State Park. S.E. Biol. 51:290.

PARKER, E.E. AND H.W. KELLER. 2005. Tree canopy myxomycetes: correlation with bark pH in Big Oak Tree State Park, Missouri, U.S.A. ICSEM5. Tlaxcala, Mexico, Universidad Autonoma de Tlaxcala. Pp. 74–75.

RINKER, H.B. 2004. Ecology from the treetops: Accessing the 8th continent. Inoculum 55(4):32.

SCARBOROUGH, A.R. 2005. Ecological distribution of tree canopy myxomycetes sampled from Great Smoky Mountains National Park and Pertle Springs, Johnson, County, Missouri. McNair J. Fall 2005:27.

SCARBOROUGH, A.R. 2006a. Species assemblages of tree canopy myxomycetes related to bark pH. S.E. Biol. 53(2):79–80.

SCARBOROUGH, A.R. 2006b. Tree canopy myxomycetes: patterns of distribution. S.E. Biol. 53(2):299–300.

SKRABAL, M., K.L. SNELL, L. HENLEY, J. COUNTS, AND H.W. KELLER. 2001. Fungi in the canopy - Great Smokies survey. Newslett. NAMA. The Mycophile 42(1):6,7,13.

SMITH, P.A. AND H.W. KELLER. 2004. National Science Foundation Research Experience for Teachers (RET). Newslett. MSA. Inoculum 55(6):1–5.

SNELL, K.L. 2002. Vertical distribution and assemblages of corticolous myxomycetes on five tree species in the Great Smoky Mountains National Park. (Masters thesis) Central Missouri State University.

SNELL, K.L. AND H.W. KELLER. 2001. Biodiversity of tree canopy cryptogams in the Great Smoky Mountains National Park. Trans. Missouri Acad. Sci. 35:53.

SNELL, K.L. AND H.W. KELLER. 2003. Vertical distribution and assemblages of corticolous myxomycetes on five tree species in the Great Smoky Mountains National Park. Mycologia 95:565–576.

SNELL, K.L., H.W. KELLER, AND U.H. ELIASSON. 2003. Tree canopy myxomycetes and new records from ground sites in the Great Smoky Mountains National Park. Castanea 68:97–108.

TOSS, B. 1990. Chapman's nautical guides to knots. Hearst Marine Books, New York.

WILSON, S.W., N.M. SVATOS, AND H.W. KELLER. 2003. Canopy insect biodiversity in a Missouri state park. Newslett. ICAN What's Up? Vol. 10(1):4–5.