MANAGEMENT AND RESTORATION IN THE SOUTHERN APPALACHIANS:

APPLICATIONS FOR THE WHARTON CONSERVATION CENTER

by

KELLY ANN ROBINSON

(Under the Direction of Laurie Fowler)

ABSTRACT

The Wharton Conservation Center (WCC) is a 129 acre tract of land located on the border of Georgia and North Carolina north of Tate City in Towns County, Georgia and Clay County, North Carolina. Dr. Charles H. Wharton, scientist, naturalist and former owner of the property, envisioned it to be an “interpretive site for the Southern Highlands.” Now protected from development via conservation easement, the WCC is owned by the Georgia Wildlife Federation with management and oversight provided by an Advisory Board composed of Dr. Wharton’s colleagues and friends. The Advisory Board has developed a concept plan to achieve Dr. Wharton’s goals. This is a restoration and management plan that focuses on eastern hemlock and mountain bog habitats, invasive species, and focal species to inform the Advisory Board’s decisions in implementing the concept plan.

INDEX WORDS: restoration, ecosystem function, hemlock, hemlock woolly adelgid (HWA), riparian, brook trout, salamanders, invasive species

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DEDICATION

This plan is dedicated to Dr. Charlie Wharton whose commitment to the environment helped preserve many natural areas and inspired many people.

And to my parents. Without their generosity, kindness, love and support, this wouldn’t be possible.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Laurie Fowler, for taking me under her wing and leading me and helping me grow. Laurie always had a positive attitude during this project, even when she had to juggle many projects and students all at once.

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CHAPTER ONE

INTRODUCTION

The Wharton Conservation Center (WCC), owned by the late Dr. Charles H. Wharton from 1958 until his death in 2003, is a beautiful, biologically diverse 129-acre tract of land located on Beech Creek at the headwaters of the Tallulah River, a major tributary of the Savannah River. It is located in the Chattahoochee and Nantahala National Forests in Towns County, Georgia and Clay County, North Carolina. Naturalist and conservationist Charlie Wharton, author of *Natural Environments of Georgia*, was a key player in identifying many of the lands that are now conserved in the Southeastern United States. Before his passing, Dr. Wharton expressed his wish that the WCC, previously known as Beech Creek, would become "an interpretive site for the Appalachian highlands." Shortly before his death he began discussions with the Georgia Wildlife Federation (GWF) to make this a reality. His long-time friend and heir, Carol Miley, ultimately conveyed the property to the GWF for this purpose. An Advisory Panel comprised of Wharton's friends and colleagues provides management and guidance to the GWF. The Panel has developed a Concept Plan that identifies a vision of the future for the WCC based on Dr. Wharton's ideas. This thesis will help inform the Advisory Panel in determining how to fulfill Dr. Wharton's goal for this unique and charismatic property.

Dr. Charles H. Wharton: Scientist and Advocate

Dr. Wharton was a renowned ecological scientist, conservationist, and outdoorsman. Since boyhood, he had a love of nature and an avid sense of curiosity and wonder, which led him to excel in the field of ecology. He was born in Minneapolis, but moved to Washington D.C. as a preschooler. While there, his parents took him to the National Zoological Park, sparking his lifelong interest in wildlife. About a year later, his family moved to North Carolina where he fell in love with the Blue Ridge Mountains. When he was 15 they moved to Decatur, Georgia. His father took him hunting and fishing which allowed his interest in nature to flourish. After high school Wharton enrolled at Emory University where he majored in biology and minored in geology. In high school and college he had his first articles published in regional magazines and later became the assistant editor of the magazine *Outdoor Georgia* (Davis, 1997).

Military service in World War II interrupted his college education. As an officer in the Army Medical Administrative Corps, he was responsible for malaria control. After the Japanese were defeated, Wharton spent nearly a year in Japan and while there met one of the country's leading herpetologists (Davis, 1997). Wharton took his discharge in the Philippines living off of the money he had saved during the war. He spent 1947 on the Philippine island of Mindanao trapping rare animals. He caught a variety of small birds and reptiles, including a flying lemur and a tarsier and brought the animals back to sell at U.S. zoos. National Geographic Society commissioned him to write about the animals he brought back, and before he had graduated college he was published in *National Geographic* (Davis, 1997).

He continued to travel and write articles about exotic animals throughout college. After graduating in 1951, he was invited to go to Belem, Brazil, located at the mouth of the Amazon. He was to collect marmosets and other animals, but his mentor, Harold J. Coolidge, Jr. who was the director of the Pacific Science Board at the time, urged him to return to school to get an advanced degree. Wharton took his mentor's advice and enrolled at Cornell University where he pursued a Master's degree in zoology and minored in epidemiology and entomology. He then attended the University of Florida at Gainesville to pursue the Doctorate degree he would earn in 1958 through a dissertation on the ecology of the cottonmouth snake. Later that year he took a position at Georgia State University in Atlanta, where he taught for the next 20 years. Throughout his years at Georgia State he wrote dozens of articles for a wide array of scholarly journals, shaped numerous students' views of the natural world, and oversaw the assembly of a first-class vertebrate collection. He also taught a variety of classes such as comparative anatomy, vertebrate zoology, natural history, and ecology. Dr. Eugene Odum, for whom the Odum School of Ecology is named, considered Wharton to be "the most knowledgeable person" on Georgia's environments (Davis, 1997). In 1977 he completed *The Natural Environments of Georgia*, the first comprehensive overview of the state's habitats. This book has led to "preservation or conservation in several different areas of the state" according to James R. Wilson, former Chief Operating Officer of the Georgia Wildlife Federation (Davis, 1997).

Dr. Wharton was a long-time conservationist who could relate to all types of people from politicians to farmers (Davis, 1997). He led the fight against the channelization of the Alcovy River in Newton County in the mid 1960's into the 1970's. His research on the ecological value of river swamps played a critical role in preserving the Alcovy and helped change federal policies concerning the Soil Conservation Service's channelization of rivers and streams worldwide (Davis, 1997). Wharton conceived of, planned, and led the establishment of several natural areas including Cooper Creek Scenic Area in Union County, Shining Rock Wilderness in North Carolina, Chattooga National Wild and Scenic River in Rabun County, the Murder Creek Research Area in Jasper County, and the Ebenezer Creek State Scenic River in Effingham County. He also helped establish the Southern Nantahala Wilderness, within the Nantahala National Forest, in Georgia and North Carolina, which borders the WCC. His greatest value and influence in these projects was to impart knowledge and frame the value of sites to decision makers. He was clearly recognized as the most prolific advocate for the protection of natural areas throughout the state (McCollum, personal communication).

Wharton also devised the idea for the Georgia Natural Areas Council; the establishment of the council was the subject of the first bill ever introduced by then senator Zell Miller in 1966. Wharton was the council's first chairman and compiled in that capacity a list of natural areas worthy of preservation in Georgia. The list later became the basis for the acquisition plan of the Georgia Natural Heritage Trust Commission under Governor Jimmy Carter (Davis, 1997).

In the 1980s, Wharton started becoming less of an activist and more of a resource for other conservationists after becoming a research associate at the University of Georgia's Institute of Ecology (now the Odum School of Ecology). He served on many advisory groups that ranged from assessing the impact of proposals for channelizing streams in the 1970s to planning environmental education centers in the 1980s and 1990s (Davis, 1997). He also advised for the State Botanical Garden at the University of Georgia and continued to write magazine articles after becoming a professor emeritus at Georgia State University (Davis, 1997).

Historical Ecology of the WCC

Dr. Wharton loved Georgia's unique lands and recognized the ecological significance of the Beech Creek tract when he purchased it in 1958. The property is surrounded by the Chattahoochee and Nantahala National Forests and is bisected by the Tallulah River. Burnt Cabin Branch and Beech Creek headwaters converge on the property to meet the Tallulah River (Figs: 1.1 & 1.2). The Tallulah River later joins the Savannah River and flows into the Atlantic Ocean. The WCC is full of seepages and wetland-like areas that are home to many wildlife and plant species. In fact, the WCC has at least 20 species of salamanders (Rothermel, 2011). It is recognized as a “prime example of a mature Appalachian mountain forest” (The Conservation Fund, 2006) because of its mature hemlock-hardwood habitat which dominates the ravines and gorges on the property. This vegetation community is normally found above 1,200 m in elevation but here occurs below 900 m. These ravines and gorges provide lower elevation refuge for a huge diversity of small boreal mammals including the southern red-backed vole, the short-tailed shrew, the smoky shrew, the masked shrew, the pygmy shrew, the water shrew, and the red squirrel, all of which are normally found at higher elevations (Wharton et al., 1996). As of 1996, Beech Creek was the only documented locality for the water shrew and the hairy tailed mole in Georgia. According to Wharton, the WCC is actually “Beech Creek Low Altitude Boreal Small Mammal Refugium” because of this diversity. (Wharton et al., 1996).

The unique diversity at the WCC is the result of an ice sheet that covered most of North America approximately 20,000 years ago. The Laurentide Ice Sheet did not reach the southern part of the Appalachian Mountains but the entire region was nonetheless molded by severe periglacial effects, in particular at higher elevations around approximately 3,330 ft. (Wharton et al., 1996). One of the more lasting effects is the boulder fields on the north-facing coves in North Georgia. These resulted from alternate freezing and thawing on rock outcrops. Toward the end of this glacial period, the Southern Appalachians provided a refuge for plant and animal species driven south by the glaciers. The remnants of these so called “boreal” communities currently occur in high latitude regions of North America, including most of Canada where they make up the Boreal Life Zone. Boreal forests are dominated by various species of spruce, fir, and northern pines (Wharton, 1977). Remnants of the communities are still found in the Southern Appalachians but only occur at elevations above 4,950 ft. and in “connector areas” like the gorges and ravines that occupy the WCC. These deep shelter ravines are characterized by a cool, moist environment, dominated by northern hardwoods and hemlock. Many hardwood trees that are usually restricted to elevations above 3,960 ft. reside in these areas at the WCC (Wharton et al., 1996).

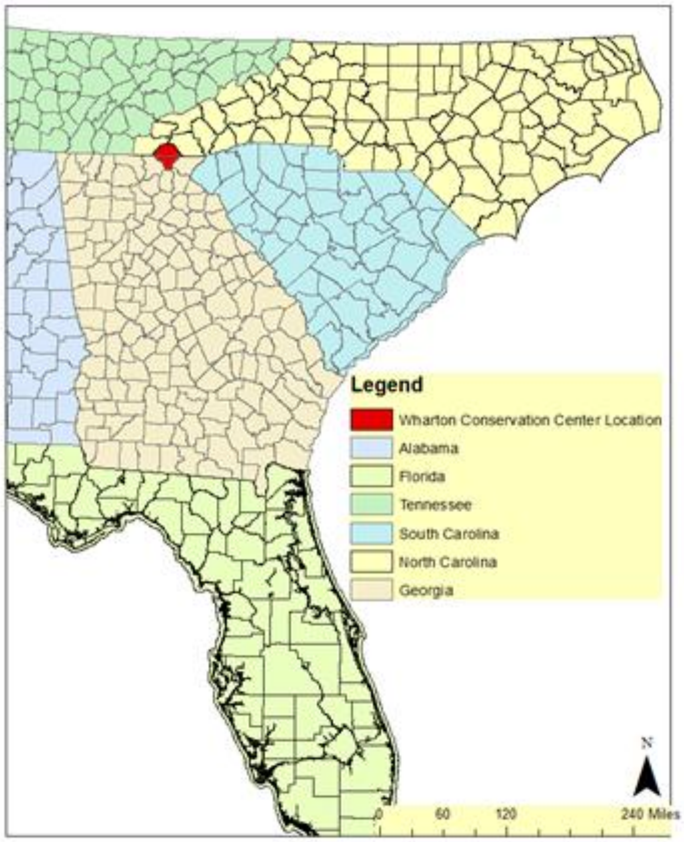

Figure 1.1: Southeastern US—Wharton Conservation Center. Map of the Towns County, Georgia and Clay County, North Carolina, the location of the WCC. Smith and Robinson March 2013. Data from State GIS Clearing House.

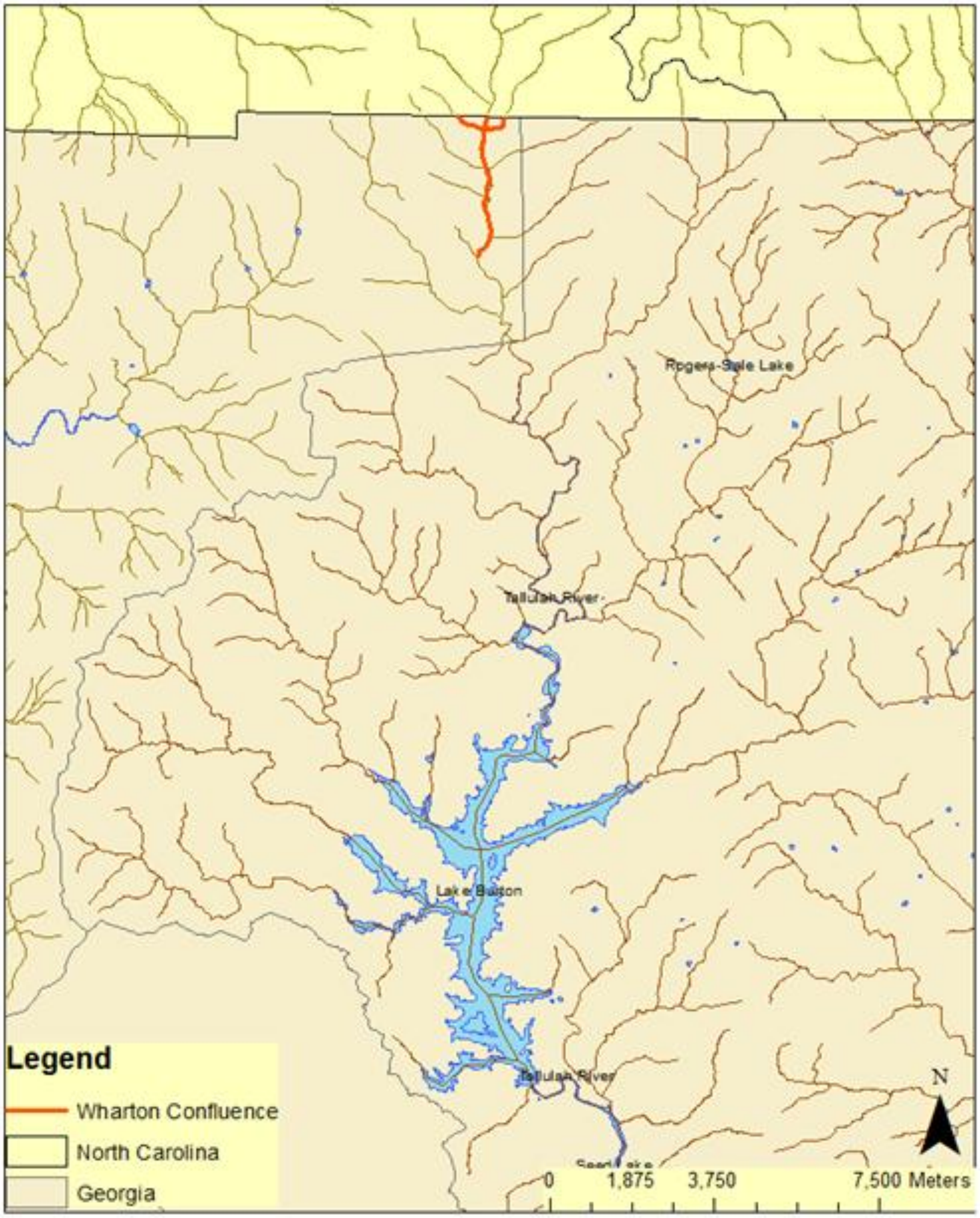

Figure 1.2: WCC drainage in the Tallulah River Watershed. Smith and Robinson 2013. Data from Georgia and North Carolina Clearinghouse

Wharton Conservation Center Preservation and Management

Before he passed away Dr. Wharton expressed his strong desire that the property be used as an interpretive site for the Southern Highlands while maintaining the integrity of the land. He met with the leadership of the Georgia Wildlife Federation (GWF) to explore possible avenues for achieving this goal (The Conservation Fund, 2006). Unfortunately, Dr. Wharton died before an easement could be placed on the land; his long-time friend and heir Carol Miley conveyed a conservation easement to the Georgia Wildlife Federation in April 2004. A conservation easement is a legally binding agreement held by a land trust that permanently protects the land and prohibits certain activity by the owner in order to achieve a conservation goal. The conservation easement was conveyed to The Conservation Fund by the GWF in March 2006 (The Conservation Fund, 2006) and property ownership was transferred to the GWF from the Wharton Estate.

The conservation easement specifies certain uses for the land:

1. To protect the natural resources of the property;
2. To use said natural resources for education and research;
3. To protect the water quality of the Tallulah River, through control of point and non-point discharges;
4. To protect the scenic and natural landscape of the Tallulah River watershed;
5. To continue the traditional use of the property for hiking, nature study, and other occasional passive recreational uses;
6. To protect the property from any uses inconsistent with those described in the Conservation Easement (The Conservation Fund, 2006).

The easement prohibits:

1. Development which would significantly impair or interfere with the conservation values of the property;
2. Dumping of refuse or other materials;
3. Subdivision of the property;
4. Timber harvest not necessary to maintain or protect the property;
5. Exposure of the property to use by the general public (The Conservation Fund, 2006).

Wharton Conservation Center Advisory Panel

In 2004, the GWF recruited a group to advise its board and staff regarding management of the WCC, however management decisions will ultimately be made by the GWF. Panel members were selected to represent a variety of perspectives; they all knew Dr. Wharton, and had a strong desire to honor his legacy at the WCC (Neuhauser, 2006). In 2004-2005, The Advisory Panel created a Concept Plan for the WCC based on Dr. Wharton's vision for the site. The Mission of the WCC is to:

1. Permanent preservation of land and life forms on the WCC property and encouragement of the same in the Tallulah River watershed;
2. Facilitate experiential education to all walks of life;
3. Long-term research on highlands habitats and deep ecology.

The plan identifies a vision for the future of the WCC and proposes guiding philosophies for achieving this vision (Neuhauser, 2006).

This thesis is written for the GWF Board and staff and the Advisory Panel. It is a restoration and management plan informed by literature reviews, interviews with experts, and consultation with the Advisory Panel on their priorities for the property. In addition to providing recommendations for priority restoration goals and activities, it identifies funding sources for these activities and opportunities for future research and outreach.

CHAPTER TWO

RESTORATION ECOLOGY: THE NEED FOR FLEXIBILIY

IN THE FACE OF UNCERTAINTY

Introduction: What is Restoration Ecology?

Restoration ecology is defined by the Nature Conservancy as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” frequently as a direct or indirect result of human activities (Society for Ecological Restoration International Science & Policy Working Group, 2004). Although the term “restoration” implies returning to a pristine nature, modern restoration ecology looks to the near distant past. Restoration is not striving for a perfect duplication of a former state and restored ecosystems will not necessarily recover this former state. Instead it strives to reestablish dynamics that were prevalent before degradation and that are important for ecological and social processes (Howell et al., 2012), such as biodiversity and ecological function (Benayas et al., 2009). Restoration ecology occurs on a continuum from repairing totally devastated sites, such as mines, to limited management of relatively unmodified sites, such as enhancing nature conservation values in protected lands (Hobbs et al., 1996). Although restoration and management are along the same continuum and employ similar sorts of intervention, ecological restoration aims at assisting or initiating recovery whereas ecosystem management is intended to ensure the continued well-being of the restored ecosystem thereafter (Society for Ecological Restoration International Science & Policy Working Group, 2004). Restoration can involve modifying a specific disturbance, such as dam removal, and allowing ecological processes to bring about an independent recovery but often there are many disturbances being repaired concurrently. It may require reintroducing a native species that has been lost, or eliminating and controlling harmful invasive species. Sometimes historical species and function of an ecosystem are lost beyond restoration potentials (Society for Ecological Restoration International Science & Policy Working Group, 2004). When the desired state is realized and restoration has been achieved, continued monitoring and management is needed to counteract the invasion of opportunist species, the impacts of various human activities, climate change, and other unforeseeable events (Society for Ecological Restoration International Science & Policy Working Group, 2004).

Conducting a restoration project in a future faced with challenges like global climate change, land-use change, and the spread of invasive species will require flexible and adaptive restoration plans, creative ideas, and continued monitoring. Restoration draws on a variety of different disciplines and requires communication between social and natural scientists in order to provide conditions that allow ecosystems and species to continue to thrive (Howell et al., 2012).

The History of Restoration

Restoration ecology is a field that has been developing since the early 1900s with the protection of unique lands, pioneered by people like John Muir, who founded the Sierra Club in 1892 and promoted the protection of the Yosemite Valley which became Yosemite National Park in 1896. Restorations in the U.S. have been attempted in one form or another for around 100 years but restoration ecology is a relatively new scientific field and profession that only dates back to the early 1980s. The Society of Ecological Restoration International was founded in only 1988 (Greipsson, 2011).

One of the earliest attempts to restore the function of the native plant community was carried out by Fredrick Law Olmstead, a landscape architect, in 1878. He was asked by the Boston Park Commission to design a plan for the Back Bey Fens, on a site that was a degraded salt marsh polluted by raw sewage. Olmstead used an engineering approach to redirect sewage flow, installed gates to regulate the salt water level, and carefully selected native plants to re-create a salt marsh in an urban environment (Howell et al., 2012). During the late 1800s and early 1900s, Jens Jensen, a Danish-American landscape architect, promoted and focused on the value of the native landscape in the context of preservation and renewal through landscaping. From 1870 to 1940 many horticulturalists, landscape architects, and gardeners began advocating for native plants promoting the idea that ecosystems should remain undisturbed by invasive species. Projects resulting from these writings were among the first modern restorations. Later in the 1930s at the University of Wisconsin, William G. Longnecker, Norman Fassett, and Aldo Leopold created an outdoor laboratory where students could study the ecological functions of plant and animal communities (Howell et al., 2012). This later developed into The University of Wisconsin Arboretum John T. Curtis Prairie, the world's oldest restored ecosystem. Curtis Prairie was converted from an old horse pasture to native vegetation of bluestem grass (*Schizachyrium scoparium*) and Indian grass (*Sorghastrum nutans*).

Aldo Leopold also linked the concepts of human reliance on natural systems and restoration of those systems in some writings (Palmer et al., 2009). This is demonstrated in the Report of the Committee on American Wild Life Committee (1929) where Leopold promoted healthy, reproducing ecosystems:

> Too much emphasis is placed on replanting game, and not enough on creating environments where constant replanting is unnecessary. We have still to learn the

> fundamental fact that in a favorable environment any wild species raises itself. (Meine et al., 1999).

The first explicit call for restoration of lands damaged by human activities came from George Perkins Marsh in *Man and Nature* (1965) when he urged that damaged forests be replanted and rivers be restored.

Restoration Today: A Developing Field

Currently, restoration takes place all over the world, encompassing all types of ecosystems and ranging from smaller projects such as planting vegetation within a defined riparian corridor to larger long-term projects such as the Everglades, the most expensive and comprehensive restoration attempt in history and which covers over 18,000 square miles. (Vaughn et al., 2010). Restoration is conducted by private individuals, conservation groups, and government agencies and requires cross-disciplinary thinking in order to create effective plans while dealing with limited resources. Many ecological restoration projects are locally initiated and carried out by community volunteers (Vaughn et al., 2010). These projects provide one of the most accessible opportunities for lay people to be actively involved in nature conservation and see positive outcomes (Hobbs et al., 1996). Since the 1990s the number of books, journals, and organizations devoted to restoration ecology has risen exponentially. The Society for Ecological Restoration (SER, est. 1988) holds conferences and meeting and publishes the journals *Ecological Restoration* (est. 1981) and *Restoration Ecology* (est. 1993) which are dedicated to furthering restoration knowledge and practice (Vaughn et al., 2010).

There are many challenges that restoration ecologists face in today's world. These include using ecological and social theories as a foundation for alleviating the disconnect between ecological theory and on-the-ground application, dealing with complex relationships within social and ecological systems, and identifying means to address these issues. Scientists are still learning how many types of ecosystems function, and this results in gaps in knowledge in the information needed to guide the decision-making process (Eitzel et al., 2012). Dealing with the challenges of restoration will require flexible, cross-disciplinary thinking along with adaptive monitoring (Lindenmayer et al., 2009). Opportunities in the field of restoration include protecting existing natural remnants, creating buffer areas, providing missing habitat links, creating resilient social and ecological systems, and generating new information (Howell et al., 2012).

Restoration in an Uncertain Future

Change is a normal characteristic of ecosystem responses. The ecosystems we manage and restore are complex and often have nonlinear and unpredictable behaviors (Harris et al., 2006). Both abiotic changes, such as global climate change and land use change, and biotic change, such as invasive species, are more likely to occur at a faster rate and on a larger scale in today's globally-connected world (Hobbs, 2009). Climate change will result in changes in weather patterns, increases in mean temperatures, and changes in patterns of precipitation. Considerable uncertainty remains concerning the direction and extent of these changes on a regional basis (Harris et al., 2006). Invasive species and human disturbances such as land-use change are stressors that can propagate disturbance to ecosystems (Falk et al., 2006). The combination of these stressors poses challenges for restoration and ecosystem management. Looking to the past to model restoration may not be an accurate indicator for the future (Harris et al., 2006). Our goals should be protecting species and ecosystems at risk and attempting to build resilient ecosystems (Harris et al., 2006) which are defined as "those that return to a pre-invasion trajectory soon after invasion and without human intervention" (Falk et al., 2006).

Ecological Restoration

Each dynamic ecosystem is different and must be analyzed in a situation-based approach. There is no paradigm at this time to guide this process. The use of management and restoration to effectively maintain ecosystems most resistant to invaders and most resilient to disturbances will depend on the characteristics of the ecosystem and of those invaders (Falk et al., 2006). Sometimes an ecosystem cannot recover from stressors and a novel ecosystem is created. A novel ecosystem is one in which the species composition or function has been completely transformed from the historic system (Hobbs et al., 2009). A hybrid system is defined as one that retains characteristics of the historic system but whose composition or function now lies outside the historic range of variability (Hobbs et al., 2009).

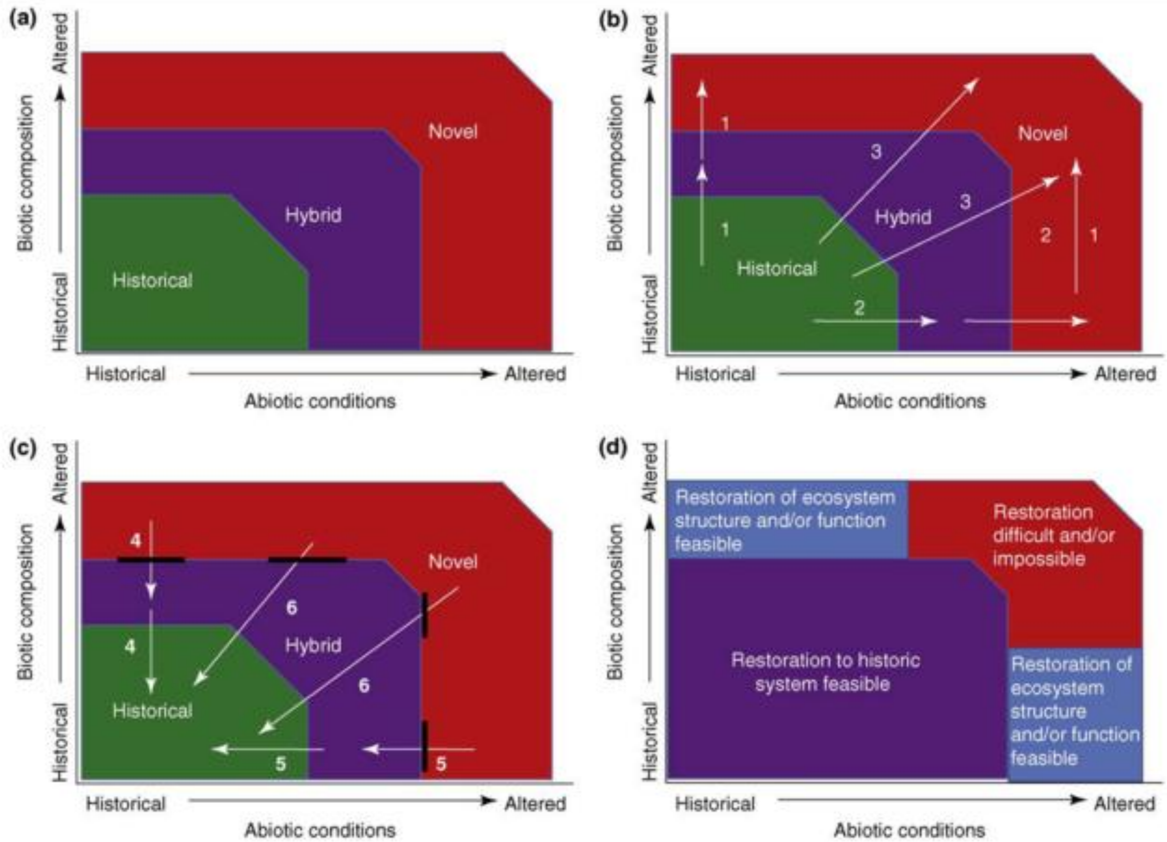

Figure 2.1: Types of ecosystems that develop with certain types of change. Reprinted from (Hobbs et al., 2009)

Figure 2.1 demonstrates ecosystem development in response to changes. When an ecosystem is still in its historic state, it may be feasible to restore the ecosystem function. When it has moved into a hybrid state, it may only be possible to restore culturally-valued species of the ecosystem. When an ecosystem has reached a novel state, it may be beyond financial and cultural feasibility to restore (Hobbs et al., 2009). Restoration practitioners and managers understand that historic conditions may not be achievable and that hybrid and novel ecosystems should be managed for cultural or ecosystem functions.

Applications to the Wharton Conservation Center

In terms of nature conservation there is no substitute for preserving good quality habitat, and maintenance of this habitat is the number one priority (Hobbs et al., 2001). At the WCC, habitat preservation requires specific restoration and management activities in order to maintain ecosystem function and resilience. The WCC has already experienced large changes in biotic composition due to decline of the foundation species eastern hemlock (Fig. 2.1a) and may be transitioning from a hybrid ecosystem to a novel ecosystem. This will make restoration difficult and focus should be on restoring ecosystem structure and function where feasible. This may be accomplished by eradicating invasive species and restoring hemlock where possible.

The 129-acre WCC is a relatively small, manageable tract of land where localized human impacts are controlled, making focused restoration feasible. The WCC has the potential to become a demonstration and educational site for restoration, and a model for mitigation and adaptive management activities, integrated with research at every step. In this thesis, I make recommendations for restoration and management options applicable to the scale of the WCC that explain how to protect species and enhance ecosystem structure and function. Specific restoration and management actions include treating select riparian hemlocks that are infected by hemlock woolly adelgid, encouraging hardwood growth on upland slopes, restoring a rare mountain bog habitat, and enhancing and maintaining brook trout habitat and monitoring healthy populations of salamanders. Within each of these actions I have outlined opportunities for research.

Along with ecological challenges, the WCC must also deal with funding constraints. The WCC is owned by the GWF, a nonprofit organization, and funds are not assured from any source. In this thesis I discuss opportunities for funding and suggest paths by which the public may be involved at the WCC. I also recommend that future research can be done that could be applicable to the Southern Appalachians on larger scales.

CHAPTER THREE

RESTORATION: FOREST COMMUNITY

Background

The Wharton Conservation Center (WCC) is dominated by the long-lived, late successional conifer tree, eastern hemlock (*Tsuga canadensis:* Coniferophyta: Pinaceae) along with hardwood trees and dense understories of rhododendron *(Rhododendron maximum)* near streams. In the past decade the hemlock woolly adelgid, (*Adelges tsuga:* Hemiptera: Adelgidae, HWA) an invasive insect, has infected and killed many of the trees in the Southern Appalachians including the WCC. HWA spreads rapidly and kills trees of all sizes and age classes within 4-10 years of infestation (Orwig, 2002). A study by Orwig and Foster at Harvard Forest in 1998 concluded that Connecticut forests were being severely impacted by HWA, which had reached the area sometime in 1985, and that forest composition and structure would become increasingly more homogeneous. The study noted that the persistence of hemlock in southern New England forests was bleak (Orwig et al., 1998). Decline of hemlock will lead to changes in ecosystem function which includes local loss of wildlife, such as associated ants (Ellison et al., 2005) and birds (Tingley et al., 2002), regional floral and faunal homogenization (Ellison et al., 2005), soil ecosystem change (Jenkins et al., 1999) and hydrological regime alteration (Ellison et al., 2005).

Hemlock trees at the WCC are currently infested and have experienced mortality due to HWA. Many of these infested trees can be treated with insecticides thus mitigating and reducing change in ecosystem function and biodiversity. In this chapter, I identify the potential effects of

HWA on hemlock stands and discuss restoration options and best management practices for the WCC.

Eastern Hemlock is a Foundation Species

Eastern hemlock is a slow-growing, shade-tolerant, and late-successional species. These characteristics create unique and important structural diversity and control ecosystem dynamics making hemlock a foundation species. The loss of a foundation species changes the local environment on which many other species depend by altering biodiversity, fluxes of energy and nutrients, and hydrology (Ellison et al., 2005).

Hemlock dominates about 1,000,000 hectares of forests in North America from the Southern Appalachians up to southern Canada (Fig 3.1), west to the central lake states (McWilliams et al., 1999).

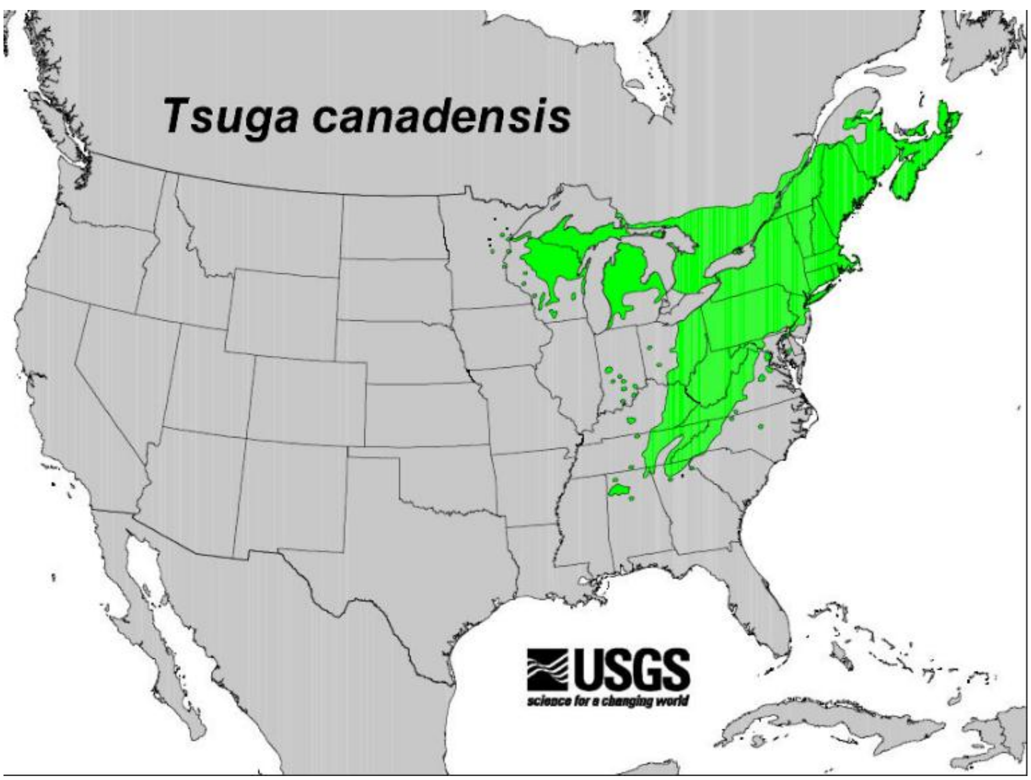

Figure 3.1: Native range of Eastern Hemlock *(Tsuga canadensis)*. Reprinted from USGS (2005).

In the northeastern U.S., hemlocks occur in largely monotypic stands with low diversity understories. In the Southern Appalachians and at the WCC, hemlocks occur in riparian zones with dense rhododendron (*Rhododendron maximum*) in the understory (Ellison et al., 2005) and are confined to moist cool valleys, moist flats, northern and eastern slopes, coves, and ravines (Carey, 1993).

Hemlocks are the most shade-tolerant tree in North America and can grow in as little as five percent sunlight (McClure et al., 2003). Thus, hemlocks may grow close together and form a dense canopy that extends almost to the ground surface. These branches provide a large amount of shady habitat and create vertical structural heterogeneity for wildlife use. Hemlock forests support up to 120 vertebrate species which includes over 90 species of birds (Ward et al., 2004).

Hemlocks not only support a huge diversity of terrestrial wildlife but also support 1.5 times more taxa on average than other streams (Snyder et al., 2002). Hemlock forests provide a more constant flow of water in streams than hardwood forests because they have lower rates of transpiration. Transpiration is essentially the release of water from plant leaves. During the growing season leaves will transpire at a much higher rate because they are using water for photosynthesis (USGS, 2013) Hardwood trees must maintain high photosynthetic rates during the summer and thus must have a constant supply of water. Because hemlocks have slower rates of photosynthesis (Catovsky et al., 2002) they have lower transpiration rates, leaving more water in streams. Organisms that live in hemlock streams are adapted to this perennial stream flow.

Hemlocks also alter nutrient and energy fluxes. They decompose slowly because of their high tannin content. The combination of shade and slow decomposition rates characteristic of hemlock-dominated stands creates a cool, damp microclimate, slow rates of nutrient cycling and nutrient-poor, acidic soil, mediate soil moisture levels, stabilize stream base flows, and decrease variation in stream temperature (Ellison et al., 2005) making hemlock an important and stable foundation species to these forests.

Hemlock Woolly Adelgid History on the East Coast

In the 20th century, Eastern forests experienced mortality and decline of american chestnut *(Castanea dentata)*, elm *(Ulmus spp.)*, oak *(Quercus spp.)*, and american beech (*Fagus grandifolia)* as the result of introduced pathogens and insect pests (Liebhold et al., 1995). Adelgids are aphid-like insects (Order Hemiptera: Superfamily Aphodidea: Family Adelgidae) that feed on trees in the family Pinaceae (Havill, 2007) which includes cedar, fir, hemlock, pine and spruce. The adelgid family is native to boreal and temperate environments (Havill, 2007). The HWA (*Adelges tsugae)* was introduced to Virginia from Osaka, Japan in the early 1950s (Havill, 2007) and is a serious threat to the eastern hemlock forest ecosystems which it invades. HWA is devastating because it is parthenogenetic and reproduces rapidly with two generations per year, and is easily transported by wind, birds, mammals, and humans (Orwig, 2002). This high rate of reproduction contributes substantially to its overall impact (Paradis et al., 2008). Once introduced it spread slowly along the east coast of the U.S and currently extends from north Georgia to southern Maine (Fig. 3.2). HWA reached the WCC in approximately 2004 (Fig 3.3). HWA attacks all sizes of hemlocks (Sullivan et al., 2006) by feeding on stored sugars in the xylem ray parenchyma cells at the base of hemlock needles (Nuckolls et al., 2009) via long stylets causing needle loss, bud mortality, and branch and tree mortality within four years (Orwig et al., 1998). There are no known predators of HWA native to the eastern U.S. and hemlock shows no resistance to it (Orwig, 2002).

HWA eggs look like white fuzz on the tree (Fig. 3.4) and can be seen on the hemlocks in the WCC. HWA is vulnerable to cold winter temperatures. In southern regions HWA experiences significantly decreased mortality rates because of warmer winter temperatures, resulting in elevated amounts of infestations. Hemlocks infested with HWA begin to die-off within four years.

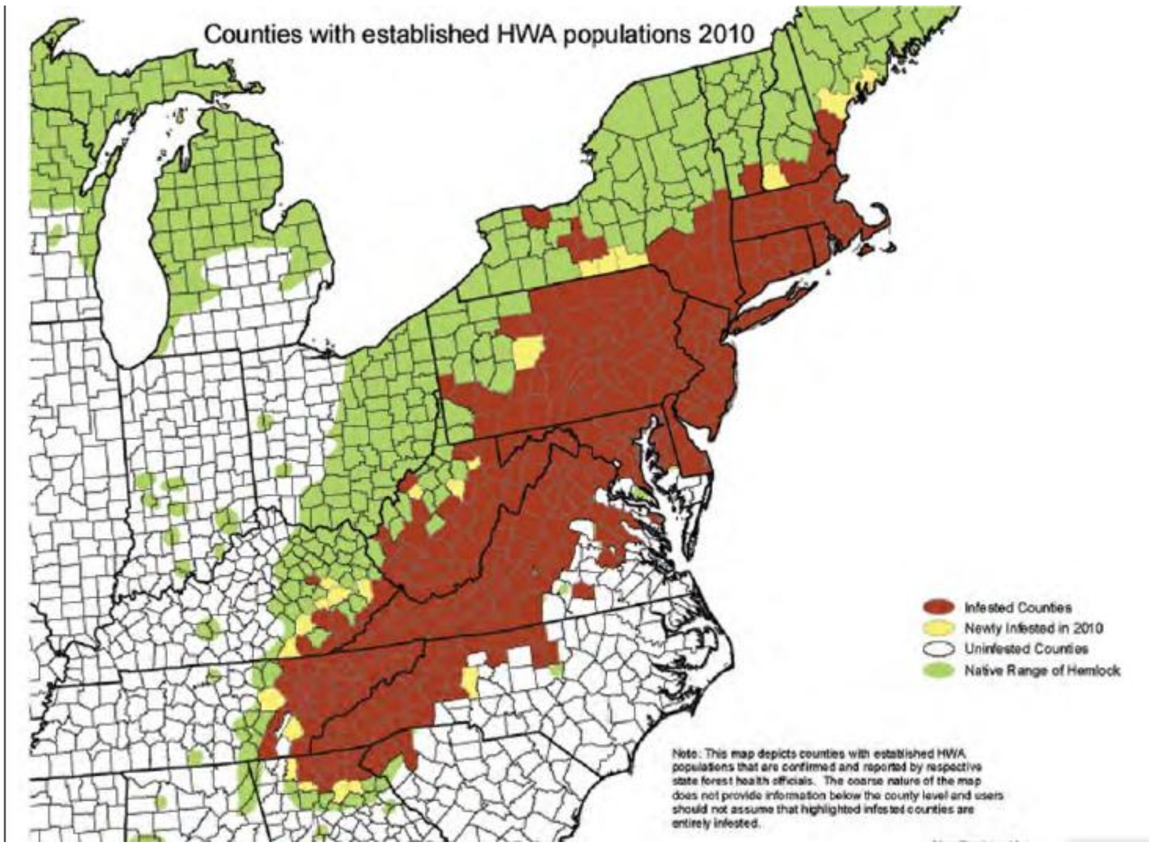

Figure 3.2: Counties with HWA populations 2010. Reprinted from (Onken et al., 2011).

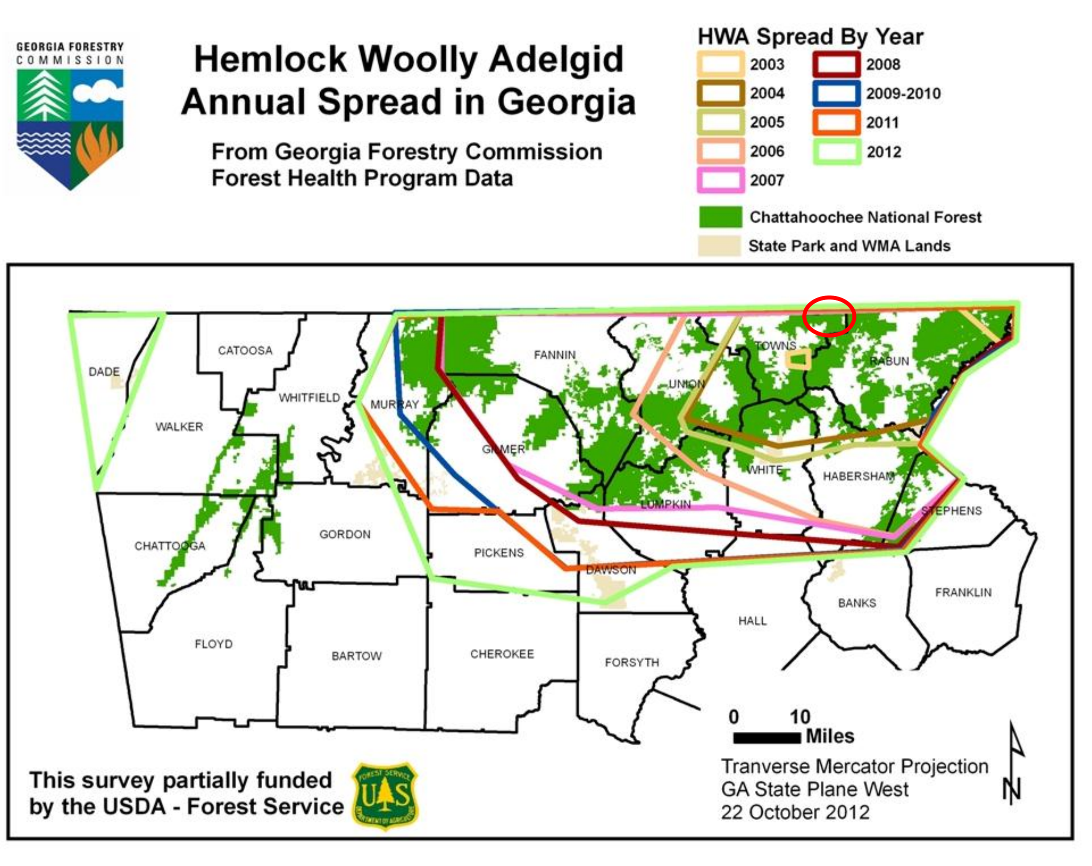

Figure 3.3: Spread of the HWA in Georgia. WCC circled in red. Reprinted from (Georgia Forestry Commission, 2012).

Figure 3.4: Overwintering hemlock woolly adelgid. Photo Credit: Gill, 2012.

Other Threats to Hemlocks

The hemlock borer (*Melanophila fulvoguttata)* is a native pest to eastern hemlock and usually acts as a secondary predator but is seldom abundant. The borer can become a primary predator when hemlock trees are stressed from HWA, drought, or excessive stand openings and increased edge habitat. Hemlock borer generally attacks larger trees (DBH > 40 cm) and damage from the borer (Fig 3.5) can be seen at the WCC on larger trees. Hemlock borers reached Georgia around 2010. Hemlock borer outbreaks generally occur on stressed trees so maintaining healthy hemlocks is the best was to minimize infestations (Evans, 2000).

Figure 3.5: Damage on hemlock tree by hemlock borer. Photo credit: Steven Katovich, USDA Forest Service

The elongate hemlock scale (*Fiorinia externa,* Ferris) is an invasive pest thought to have invaded from Japan in 1908. The hemlock scale reached Georgia in 2012, and causes damage by inserting its piercing mouthparts into the needles and withdrawing nutrients necessary for survival from the mesophyll cells. This causes needles to drop prematurely and resulting in crowns thinning. Soil-injected insecticides are not effective in controlling the scale. Maintaining healthy hemlock stands reduces the chance of scale population increases (Hoover, 2009).

An additional challenge facing hemlocks is the tip blight *(Sirococcus tsuga)* which infects the tips of branches. This pathogen is known to infect western hemlock but it is not known how the blight reached the eastern U.S. It was found in Georgia in early 2010 (Stanosz et al., 2011). The epidemiology of the blight is not yet known but tree damage in most stands seems to be light. There are currently no known effective controls for the tip blight (Miller-Weeks, 2010).

Hemlock Loss Will Alter Ecosystem Processes

There will be massive loss of hemlock trees in the next 50 years (Spaulding et al., 2010) which will have many ramifications for ecosystem functions. Insights on the ecosystem-level effects of hemlock decline may be gained by looking at the American chestnut die-off that occurred in the 1930s as a result of the chestnut blight. Chestnut was also a long-lived foundation species and die-off occurred within two years; a faster rate than the decline of eastern hemlock by HWA. Chestnut was succeeded mostly by red maple (*Acer rubrum* L.) and oaks *(Quercus spp.)* (Webster et al., 2012). The effects of hemlock decline on forest structure and function will not be as sudden as it was with American chestnut.

Hemlock forests will also be replaced with short-lived hardwoods such as red maple and oaks. There may be an invasion by several exotic tree, shrub, and herbaceous species (Orwig et al., 1998) but there is currently no empirical evidence regarding the long-term future for species composition of formerly hemlock-dominated forests in the coming decades (Albani et al., 2010). Hemlock loss will create canopy gaps and alter vegetation communities which may contribute to a loss of habitat and forage for many wildlife species. This may also contribute to the spread of other invasive species directly through disturbance impacts and indirectly by removing dispersal barriers (Eschtruth et al., 2006). Hemlock loss may increase stream bank erosion and freshwater pollution and cause shifts in resource availability and plant species distribution (Paradis et al., 2008). Further, if HWA continues to persist, there will be a decline in hemlock regeneration (Preisser et al., 2011).

Effects of Hemlock Decline on Southern Appalachian Streams

In the Southern Appalachians hemlock is one of the principle riparian species, therefore, it has direct and indirect effects on hydrological processes (Ford et al., 2007). Hemlock serves two distinct hydrological roles as: 1) an evergreen tree that has relatively stable fluxes throughout the year and 2) a tree that occupies the riparian zone and has high fluxes during the spring (Ford et al., 2007). Southern Appalachian streams are lined with hemlock and dense rhododendron as opposed to the Northeastern hemlock forest which is almost purely hemlock. These southern streams have stable annual temperatures and flows and low light input (Fig. 3.7). The effect of HWA- induced mortality on hemlock stands will be extensive (Ellison et al., 2005) and there will be dramatic changes in age, structural, and compositional attributes of the forest and altered wildlife habitat. There will also be changes in soil moisture dynamics within the riparian zone which will impact nutrient and carbon cycling processes (Ford et al., 2007). It is likely that no other single species will fill the roles that hemlock plays in the Southern Appalachian ecosystem. Some of these potential alterations are as follows:

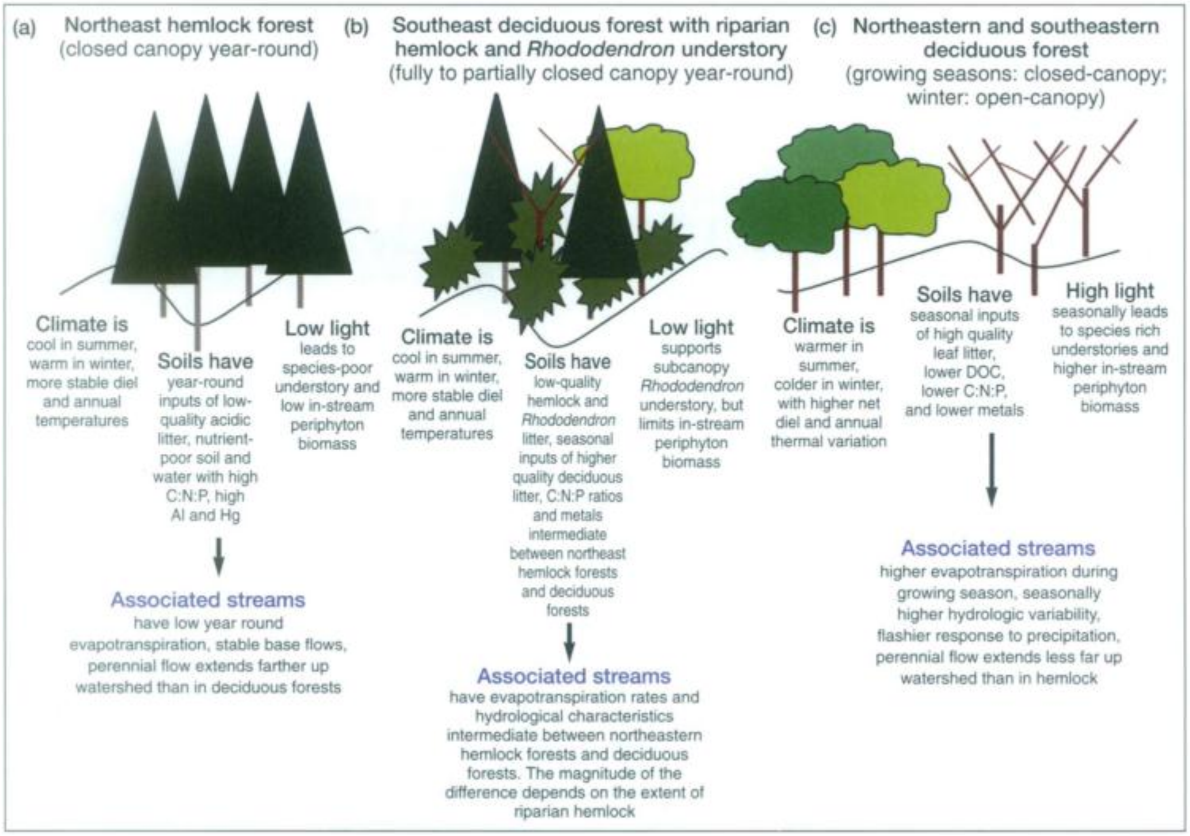

Figure 3.6: Various forests and stream associations. Type (b) is characteristic of the WCC. Loss of hemlock will cause the forest to shift to type (c) which has more hydrologic variability and lower biodiversity. Reprinted from (Ellison et al., 2005).

Woody Debris: Increased mortality of mature trees will result in substantial piles of woody debris in streams. Hemlock debris will decay more slowly than hardwood debris and persist for decades because there is a higher tannin content in the wood (Webster et al., 2012). Wood in streams slows the flow of water, causes accumulation of sediment and organic matter, and modifies geomorphology. These things provide favorable conditions for biotic processing of leaves, twigs, and dissolved nutrients (Webster et al., 2012) However, this increased stream debris and sedimentation alters important habitat for macroinvertebrates, amphibians, and other stream-dwelling organisms that require highly oxygenated water. Eventually, there will be a net loss of woody debris in streams leading to a decline in sediment retention and productivity of streams (Ellison et al., 2005).

Water Flow and Transpiration: Reductions of hemlocks will lead to reduction in water flux which may make these streams more prone to summer drought and spring flood (Webster et al., 2012). Changes in the levels of seasonal leaf area dynamics (deciduous vs. evergreen) will lead to an overall decrease in forest transpiration and decreased rates of winter and spring transpiration (Ford et al., 2007). This alteration of hydrologic regime will likely lead to an increase in soil moisture and discharge and width of variable source area and decreased diurnal amplitude of stream flow (Ford et al., 2007).

Light Availability and Temperature: Light availability and canopy openness in streams will increase (Webster et al., 2012) with hemlock decline. Space will increase above and below ground as trees and roots decline (Orwig et al., 1998). It is likely that the increased sunlight will stimulate an increase in algal production which could lead to an increase in the abundance of algal-scraping macroinvertebrates. Temperature of the streams may not change because it is more related to groundwater temperature than to light availability (Siderhurst et al., 2010). The presence of dense rhododendron thickets may have a significant effect on thermal regimes (Roberts et al., 2009).

Riparian Vegetation: In the northeastern U.S., hemlocks killed by HWA are generally replaced by hardwoods (Orwig et al., 1998). However, hemlocks in the Southern Appalachians generally occur with rhododendron which inhibits seed germination and seedling growth of many trees (McClure, 1989). There are two scenarios which may occur with the decline of hemlock. First, on sites with dense rhododendron growth, seedling recruitment of any species into the canopy will likely be low and rhododendron biomass will likely increase until resources are limited. Second, on sites with limited to no rhododendron, early successional species such as black birch (*B. lenta*) will increase in density followed by late successional species such as black gum (*Nyssa* *sylvatica*) and yellow poplar (*Liriodendron tulipifera*); (Ford et al., 2007; Webster et al., 2012). Rhododendron and hemlock leaves decompose in a similar amount of time so rhododendron growth may compensate for the lost trophic influences by hemlock.

Effects of Hemlock Decline on Wildlife

One of the best known examples of overstory loss is that of the American chestnut by the chestnut blight. There is very little known about the ecosystem response to the loss of chestnut although there is a lot known about the compositional and structural changes. Similarly, the effects of chestnut decline on wildlife are not well known, except for the anecdotal information that squirrel populations crashed with loss of chestnut mast, and that woodpecker populations increased in association with the increase in dead tree habitat (Orwig, 2002).

Unfortunately, there is also not much known about how wildlife will respond to hemlock decline but species that are hemlock specialists are predicted to decline perhaps even to the point of local extinction. The dense canopy of hemlock stands is home to more than 120 vertebrate species (Ward et al., 2004) and fish and macroinvertebrates in streams draining hemlocks are distinct from other streams. Hemlocks are dominant in riparian areas enhancing aquatic vulnerability to hemlock declines (Snyder et al., 2002). Herbivorous insects that specialize on hemlocks may be severely affected (Gandhi et al., 2010). Some bird species are highly associated with hemlock. Birds that are hemlock habitat specialists like the acadian flycatcher (*Empidonax virescens*) have been adversely affected by HWA invasion and show little adaptability to the surrounding habitat or habitat replacement (Tingley et al., 2002). The black-throated green warbler (*Dendroica virens*; Fig 3.7), which is closely associated with hemlock, exhibits mortality with hemlock decline which could lead to local extinctions (Tingley et al., 2002). Conversely the hooded warbler, a bird that prefers black birch, benefits from hemlock decline and opportunistic species such as the wood thrush increase by using canopy gaps and dead trees for habitat (Gandhi et al., 2010).

Figure 3.7: The Black-throated green warbler is highly associated with hemlock and will decline with decline of hemlock which may lead to local extinctions. Photo Credit: Marie Read.

Effect of Hemlock Declines on Nutrient Cycling

Other than from clear-cutting forests, the effects of forest disturbance and tree mortality on nutrient cycling are not well understood (Yorks et al., 2003).

Hemlock mortality may have dramatic influences on nutrient cycling rates (Hill et al., 1989). A number of processes regulate the input of inorganic nitrogen (N) into streams including (Fig 3.8) mineralization of organic N (conversion from organic forms to ammonium), vegetation uptake, immobilization of N by the microbial community, volatilization of ammonia, and denitrification (conversion of nitrate to ammonium); (Gundersen, 2006).

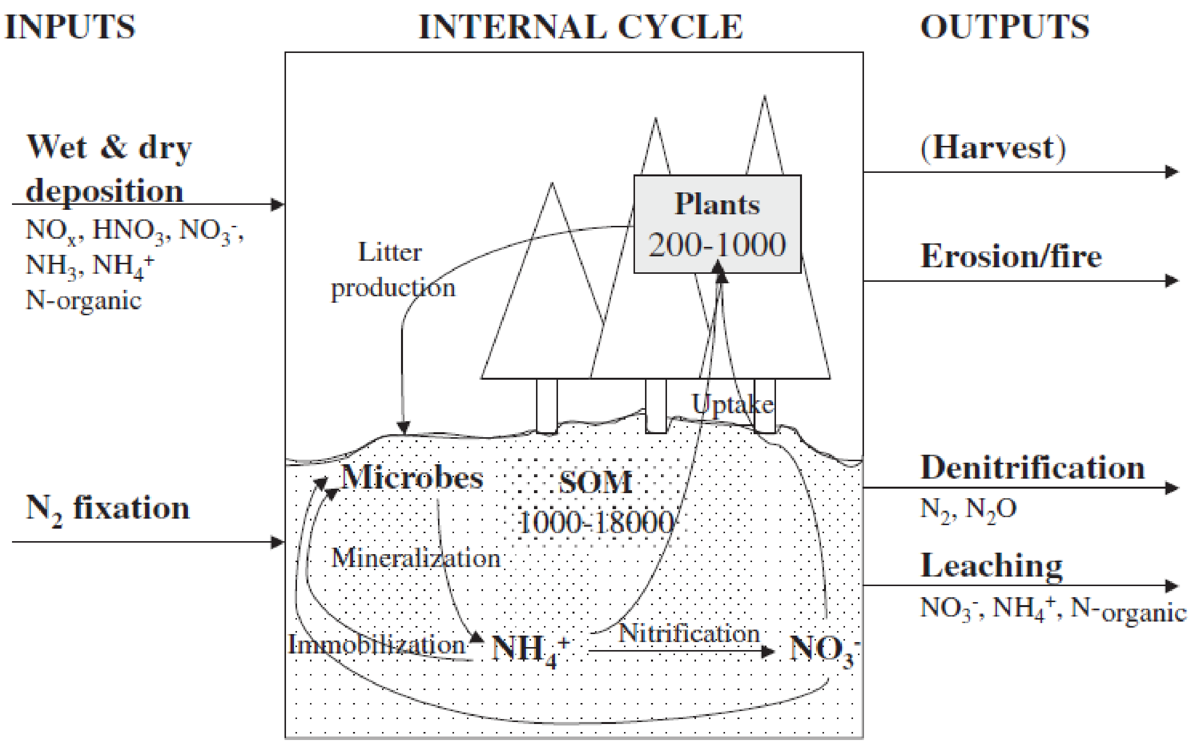

Figure 3.8: Simplified model of N cycle in forests. N enters the system through nitrogen fixation and deposition and leaves through denitrification, leaching, fire and harvest. Hemlock forests have lower N turnover than hardwood forests which have higher N content in the foliage. Reprinted from (Gundersen, 2006).

Hemlock forests usually have relatively low nitrogen (N) mineralization and nitrification rates due in part to the relatively high soil C:N and lignin:N ratios (Yorks et al., 2003). These rates increase with HWA-induced disturbance (Jenkins et al., 1999). It is likely that the combination of enhanced subsurface decomposition of roots from hemlock decline and reduced uptake of N and water by trees leads to increases in the availability of NO_3^- and NO_4^+ (Orwig, 2008). These increases in N will occur at least until the new hardwood forest canopy becomes established and begins taking up the additional inorganic N (Yorks et al., 2003). Hardwood litter has more available N and less lignin than conifer litter, and therefore, is a higher quality for microbial decay. This can lead to increases in decomposition of soil organic matter and increases in stream nutrient loads (Evans et al., 2011).

Increased mineralization and nitrification rates and reduced nutrient uptake by dead hemlocks may result in NO_3^- and NO_4^+ leaching from stands with hemlock mortality (Yorks et al., 2000). Increased leaching on NO_3^- is associated with nutrient cation (e.g., Ca^{2+}, Mg^{2+}) leaching which contributes to decreased water quality such as mobilization of toxic metals and acidification of soil and stream water (Yorks et al., 2000). The effects of disturbance on nutrient retention in vegetation and on water quality will be important to understand in order to mitigate the effects of the HWA outbreak on the Appalachians.

Hemlock stands may be particularly prone to nutrient loss after disturbance because there may be very little understory to rapidly uptake nutrients. This could be particularly important to stream water quality, as the Southern Appalachians are reliably moist, and nutrients lost to soil water may be rapidly transported to stream water (Yorks et al., 2000). Replacement of hemlock by hardwoods could result in a long-term increase in N turnover and nutrient loss rates.

Hemlock decline may lead to increased light exposure, increased N runoff, and decreased winter transpiration and storm discharge (Evans et al., 2011). Generally water from unimpacted forests is of high quality with relatively low dissolved N compared to other land uses such as agricultural land use. Leaching of N from forests may not only impair groundwater quality but may also lead to eutrophication of surface water. Increased N could cause increased acidity in soils which could reduce long-term forest productivity. It could also impact species composition in nitrogen-limited waters. However, a study by Roberts et al. 2009 found that stream nitrate concentrations, pH, hydrology and water temperatures are similar between hemlock and hardwood-dominated streams in the Great Smoky Mountain National Park but that localized and short-term turnover impacts may be severe (Roberts et al., 2009). Since hemlock decline is occurring on a large scale in the upper Tallulah watershed, the river downstream may have degraded water quality. One purpose of the conservation easement at the WCC is to "protect the water quality of the Tallulah River, through control of point and non-point discharges." Protection and restoration of riparian zones and creation of small wetlands is an option to protect aquatic systems from N leaching (Gundersen, 2006). The best option for the WCC to protect water quality is to reduce the effects of hemlock decline by saving riparian hemlocks. In areas where hemlock mortality has occurred, encouraging the establishment of hardwood canopy species to help establish intact riparian cover could mitigate the effects of hemlock decline by intercepting solar radiation, reducing energy input into stream water surfaces, taking up nutrients, and reducing levels of nitrate entering the stream (Roberts et al., 2009).

Carbon

Physical processes of mortality have a direct influence on the carbon cycle. Reductions in primary productivity, accelerated detrital inputs from leaves and roots, and alteration to the soil CO_2 efflux all affect the carbon cycle (Nuckolls et al., 2009). The understanding of belowground processes of tree decline is limited. It is predicted that hemlock decline may be locally severe but may not have large impacts on regional patterns in the carbon cycle (Albani et al., 2010). Death of eastern hemlock will result in transfer of carbon to the atmosphere as the dead trees decompose. Broad- leaved species that occur with hemlock typically have two-fold greater rates of carbon uptake than hemlock itself (Catovsky et al., 2002) and summer uptake of carbon by red maple may exceed that of the current eastern hemlock forest (Hadley et al., 2008) which may be beneficial later for climate change mitigation.

Hemlock Status at the Wharton Conservation Center

The HWA reached the WCC around the turn of the century. The majority of hemlock trees on hillsides at the WCC are completely dead. These dead zones are circled on the map below. Many of the hemlock trees in riparian areas are mostly alive but infested with HWA. These trees can be seen as green in Fig. 3.9.

Figure 3.9: WCC March 2011. Mass die-off on slopes is circled in red. The log house is boxed in white. There is not much die-off along riparian zones.

In June 2012 with the help of Angela Mech, I assessed the status of the hemlocks using the Crown-Condition Classification system developed by the Forest Service (Schomaker, 2007) which we modified for the WCC. We categorized hemlock trees into the following vigor classes: 1= moderate vigor, 2= poor vigor and 3=dead. None of the hemlocks at the WCC are completely unaffected by HWA.

Qualifications for Vigor Classes shown in Figure 3.10:

VIGOR CLASS 1 had 0-50% dieback. Damaged foliage is defined as leaves with more than 50 percent of their original surface area chewed, discolored, missing, or otherwise damaged.

VIGOR CLASS 2 had 60-90% dieback. Less than 10 percent of their leaves were undamaged.

VIGOR CLASS 3 had 95% or more dieback.

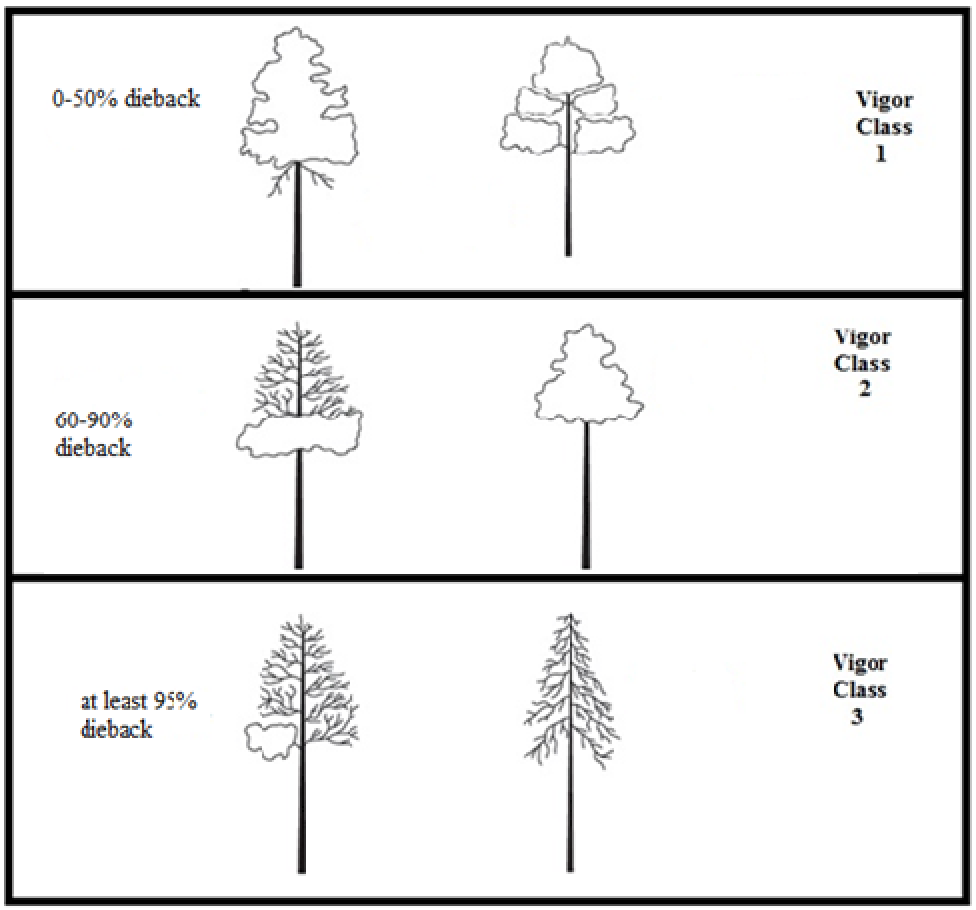

Figure 3.10: Vigor classes used in observational data collection at the WCC.

Five areas at the WCC were surveyed, identified by coordinates, and categorized into vigor classes based on the above criteria. Below is a table of our results.

Table 1.1: Hemlock Status Surveys at the Wharton Conservation Center. June 2012.

Area	Coordinates	Vigor Class 3	Vigor Class 2	Vigor Class 1	% Class 1	Notes
Log House	N 34-59.425' W -83-33.532	27	6	9	21.42%	2 near back porch mostly alive
Slope near Log House	N 34-59.383 W -83-33.586	103	3	0	0	Northwest facing slope
Tallulah River	N 34-59.462 W -83-33.465	110	52	71	30.47%	All trees in vigor class 1 are smaller than 30 cm DBH
Cabin Area	N 34-59.391 W -83-33.331	26	0	0	0	Many large dead hemlocks that could fall on cabin. Hemlock borer damage also seen
Beech Creek Near Cabin	same coordinates	50	30	1	1.23%	
Beech Creek	N 34-59.378 W -83-33.450	42	40	8	8.89%	100 ft. buffer zone

Results

The riparian zones at the WCC had relatively high levels of trees in Vigor Class 1 which can be seen in the highlighted part of the table. Areas on hillsides had extreme mortality among hemlock stands with the majority in Vigor Class 3. These stands cannot be restored and the ecosystem-level changes related to hemlock mortality may be occurring. Research should be conducted in these sites to examine the predicted effects of hemlock loss.

Hemlock Woolly Adelgid Eradication Treatments

The two primary treatment options for dealing with HWA are biological control and chemical treatments.

Biological Control

Biological control uses natural enemies to lower pest populations. There are few natural enemies of HWA that are found in North America. Native predators are generalists, and are not effective in reducing HWA populations. There are three species of beetles from Asia that are useful for biological control: a lady beetle (*Sasajiscymnus tsugae),* from Japan that specializes in eating the HWA; Scymnus lady beetles (*Scymnus spp*.) from China, which feed mostly on adelgids and sometimes aphids; and the tooth-necked fungus beetle (*Laricobius nigrinu)* from the Pacific Northwest. *Laricobius nigrinus* feed on HWA and are active during the winter, which also makes it more difficult to rear *L. nigrinus* in the lab. Winter activity is important because HWA are active during the winter.

Although biological control should be integrated into the management of HWA in the Southern Appalachians, it is not a practical option for the WCC. Most of the hemlock stands at the WCC are already dead. These biological control agents, described above, require large quantities of HWA to feed upon because most of them are adelgid specialists (Cheah et al., 2004). If control agents were released, they would not survive because there is not an ample food supply available. However, the Chattahoochee National Forest has been releasing biological control agents in the past five years which might one day reach the WCC. Biological control may be a risky tactic to use when controlling some invasive species; numerous biological control agents have negatively affected non-target native species (Simberloff et al., 1996). There is inherent unpredictability and usual irreversibility when using biological control agents that makes biological control unsafe (Simberloff et al., 1996).

Chemical Treatments

There are two main chemicals commonly used to eradicate HWA, imidacloprid and dinotefuran, which are systemic insecticides belonging to a class of chemicals called neonicitinoids. Both work well for HWA control when applied as a soil drench or a soil injection because they are soluble enough in water to be taken up by trees, but also cling to soil particles and do not wash away. Foliar spray treatments and trunk injections are two other ways to apply these chemicals. Foliar spray treatment is not an option for the WCC because of the risk of chemicals reaching nearby bodies of water. Trunk injection involves drilling holes into trees to directly inject the chemical into the trunk. Trunk injection treatment is not as effective as soil treatments.

Dinotefuran provides rapid control of HWA and can be applied by soil treatments or trunk treatments. It should be applied to trees that are on the brink of death. Results can be seen within three weeks of soil treatment; however it suppresses HWA for a shorter period of time (up to eight months) than does imidacloprid. Since dinotefuran is more water soluble than imidacloprid, it might not be safe for aquatic communities (Dalusky, 2011) and should not be used near a stream or at the WCC.

Imidacloprid is effective against a wide range of insects (Eisenback et al., 2010). Trees at the WCC in Vigor Class 1 should be treated with imidacloprid soil injection treatments. Imidacloprid is taken up by the xylem and diffuses into xylem ray parenchyma cells located within the twigs (Dilling et al., 2009). Soil treatments with imidacloprid include soil drench and soil injection techniques, and provide the longest duration of control. Soil treatments also take a longer time to control HWA than other treatment methods. It may take anywhere from six weeks to 12 months to become effective and may take years to achieve complete control. Residual efficacy can last from three to five years. Hemlock trees should be reevaluated for presence of HWA prior to retreatment as re-infestation may take several years (Dalusky, 2011). Imidacloprid can be effective on trees in advanced stages of decline but tree health will deteriorate before it improves (Dalusky, 2011). HWA mortality can last from three to five years.

Effects of Imidacloprid Treatments on the Environment

Non-target impacts of imidacloprid are of special concern because hemlock stands usually occur near streams with organisms that are sensitive to imidacloprid (Cowles, 2009). Imidacloprid is water soluble in order to be absorbed by roots and transported into tree sap. This water solubility could cause leaching into nearby groundwater or stream systems (Cowles, 2009). However, movement of imidacloprid is determined by soil absorption capacity which is determined by soil organic matter (Knoepp et al., 2012). Imidacloprid has a high organic binding capacity which should prevent leaching in areas with high soil organic matter like forests (Cowles, 2009). Forest soils have greater C content than agricultural soils. These factors limit the vertical and horizontal movement of imidacloprid within the soil (Knoepp et al., 2012) and limit the negative effects on surrounding organisms. Trees may be treated with imidacloprid any time of the year; as long as soil is not drenched (i.e., soils that puddle in your footsteps are too wet); (Dalusky, 2011). The soil at the WCC has a high organic matter content, and there is a reduced risk that imidacloprid will reach the stream (Varvoutis, 2012) if applied under unsaturated conditions (Cowles et al., 2006).

Soil injection has a lower translocation within the soil than the soil drench method (Dilling et al., 2010). Thus, the soil injection treatment should be the most effective and safe treatment for the hemlocks and the surrounding environment as absorption of imidacloprid by soil organic matter plays a large role in localizing imidacloprid and minimizing effects to the environment (Knoepp et al., 2012).

Table 3.2: Costs to Remove Hemlock Trees Threatening Built Structures and Treat Hemlocks in Vigor Class 1

Location	Action	Number of Trees	Cost	Notes	Total
Cabin	removing	20	$300 per tree		$6,000
House	removing	4	$300 per tree		$1,200
Tallulah River	treatment	~75	$2 per ince DBH	DBH varies	
House	treatment	12	$2 per inch DBH 234 inches		$468
				Total Costs	=$7,668

Rough estimates for treating and removing hemlocks were provided on October 2, 2012 by Hemlock Healers, Inc., certified arborists. This estimate does not include all other trees with smaller DBH along the stream that should be treated.

As discussed in Chapter Two, there is sometimes a complex relationship between social and ecological aspects of a restoration project. Determining if imidacloprid is allowed in the conservation easement is an example of this relationship. Since imidacloprid will not cause harm to the environment if properly applied, the conservation easement on the WCC should allow it. It will have many positive effects on water quality and biodiversity at the WCC in preventing further hemlock death.

These hemlocks may need to be re-treated if HWA returns to infest trees. In the future, new chemicals for treatment may be developed. These chemicals may be appropriate for use as they have similarly low levels of toxicity, low water solubility, and high effectiveness as imidacloprid.

Post-Treatment Restoration Options

Many hemlock trees near the streams can be treated with imidacloprid soil injection treatments thereby mitigating the effects of hemlock loss on streams at the WCC. Most of the hemlock trees on the steep slopes of the WCC are dead. On these slopes, I recommend letting hardwood trees set in by allowing hemlock stands to die. Reducing the transition period from a mixed forest to a hardwood forest will reduce the nutrient input into the stream.

Planting alternative evergreen trees in riparian zones where hemlock is lost and rhododendron does not occur will restore some of the ecological value of the property and help prevent invasive plants from spreading. Trees should not be planted in areas with dense rhododendron because it is allelopathic and prevents the growth of other species. The ability of other conifer species to provide the same ecosystem function of hemlock is unknown (Evans et al., 2011). It is important to plant many species of trees, so disease or other exotic insects do not destroy entire stands. Potential native species for planting include eastern white pine *(Pinus strobus*), American holly (*Ilex opaca*), red spruce (*Picea rubens*), eastern redcedar (*Juniperus virginiana*), northern white-cedar (*Thuja occidentalis*), and atlantic white-cedar (*Chamaecyparis thyoides*). Some alternate conifers like eastern white pine may have the leaf area index required to moderate stream temperatures and provide habitat for shade-tolerant understory species (Evans et al., 2011). They may also create acidic soil conditions, slow decomposition rates of soil organic matter, and reduce leaching of N (Evans et al., 2011). However, white pine is experiencing die-back in the North Georgia Mountains due to a scale and pathogen complex (Mech, unpublished data). Conifers near riparian zones should be maintained, in order to maintain aquatic ecosystem function. Riparian areas should be restocked with hemlock seedlings and saplings to protect water quality (Evans et al., 2011).

There are also three Asian hemlock species that are resistant to HWA that have been grown in the Eastern United States; these are northern Japanese hemlock (*Tsuga diversifolia),* southern Japanese hemlock (*Tsuga sieboldii*), and Chinese hemlock *(Tsuga chinensis*) (Ward et al., 2004). These trees are non-native but could fill the ecological niche of eastern hemlock. However, it is not the preferred alternative because it involves non-native species which could alter the ecosystem in unpredictable ways.

Management of Fallen Hemlocks

There may be threats to the public visiting the WCC, particularly near roadways and walkways with substantial hemlock mortality. The WCC should remove hemlocks that pose a threat to public safety. Georgia Power has funding for public safety and may be willing to remove these trees if approached. They operate five dams downstream of the WCC so they are interested in water quality, and watershed health and maintenance. Their “boom trucks”, which may be used for tree removal, have been used in other conservation priorities such as assessing osprey nests on the coast of Georgia. The WCC should consult an expert to help ensure the removal causes as little damage as possible to the site. Removing these trees would prevent a safety hazard for visiting researchers and volunteers. Salvaging the hemlocks is unlikely to yield material profits as hemlock is a relatively low value tree.

Threats of Surrounding Development and Public Involvement

The WCC is surrounded in part by the Chattahoochee and Nantahala National Forests, but the private property bordering to the west may be sold soon and subsequently developed. There is some interest on the part of the GWF to secure this property or secure a conservation easement in order to maintain water quality and ensure important habitat is protected. Development of this property may result in habitat fragmentation and loss leading to further ecosystem degradation. Landscape development is one of the biggest threats facing wildlife in particular for salamanders. Potential funding source for purchasing the land for restoration is the USDA Forest Service which grants available in order to promote forest stewardship.

Restoration of the forest ecosystem at the WCC will be an ongoing effort. A certified arborist should be hired to remove the hemlock trees that threaten built structures and to treat hemlock trees in Vigor Class 1. Hemlocks may need to be treated every five years depending on re-infestations. Citizen scientists and volunteers could help plant evergreen trees that will help fill the niche of the dead hemlock stands. The GWF could host a volunteer day for citizen scientists at the WCC in order to get large numbers of volunteers needed to plant many trees. The National Science Foundation provides funding for citizen science projects.

Potential Research Opportunities

Little is known about the long-term effects of hemlock decline on ecosystem processes. Usually, processes affecting biodiversity are not studied in depth until species become endangered. The WCC would be an appropriate place to study these ecosystem effects and experiment with restoration effects which focus on maintaining ecosystem function. Potential partnerships for research are the University of Georgia, USDA Forest Service's Coweeta Hydrologic Laboratory, and Archbold Biological Station which has already partnered with the WCC on an amphibian monitoring program.

Some research suggestions include:

- Determining the effects of population decline of hemlock on current stands and potential founder effects for healthy individuals

- Long-term monitoring of woody debris nutrient input related to hemlock decline
- Determining if rhododendron will survive in areas without hemlock
- Monitoring the nutrient inputs into streams as hardwood trees appear on slopes
- Determining if hemlock-associated birds such as the black-throated green warbler will persist at the WCC
- Determining the effects increases in light reaching streams versus groundwater on stream temperatures
- Determining the effects of hemlock decline on habitat for aquatic organisms (e.g., salamanders, macroinvertebrates, fish)
- Monitoring the changes in algae abundance and macroinvertebrate species
- Monitoring which organisms colonize the hemlocks at which state during decomposition

CHAPTER FOUR

RESTORATION AND MANAGEMENT: PLANT COMMUNITIES

Mountain Bog Restoration

Mountain bogs are the most critically endangered habitat in the Blue Ridge Mountains and occur in high elevation flat areas with deep, black soils fed by streams and small springs (Georgia Plant Conservation Alliance, 2012). Due to development and suppression of natural systems, and a decreased rate of bog creation, mountain bog habitats are increasingly rare. There are only two originally intact mountain bogs left in Georgia. All other mountain bogs are restoration sites used for safeguarding some of the most critically endangered species, such as pitcherplants (*Sarracenia spp*.). Currently, there are no bogs at the WCC. There is however, a site that was likely once a bog, as indicated by sphagnum moss (*Sphagnum spp*.) that could be restored to a bog. Bog habitat should be a priority for the WCC because it is representative of rare Southern Appalachian habitat, could help protect aquatic systems from nitrogen leaching, and could be used for education purposes (Gundersen, 2006).

Natural History of Bogs

There are many different types of bogs: swamps, marshes, and pitcherplant bogs are the ones that are most familiar to the public. Groups like The Nature Conservancy have trouble defining bog in common terms as they attempt to protect significant habitats throughout the world. In general terms, bog-like habitats are wetlands characterized by peat accumulation. Peat is partly decayed vegetation. The different wetland habitat categories arise from different soil types, vegetation, and water flow types. Bogs tend to be acidic, have slow-flowing water, and are nutrient-poor environments (Determann, 2013). Deep, fluffy moss mats slow and dispense the surface water in sheets in the bog (GPCA, 2012). At the WCC we are specifically interested in pitcherplant bog restoration. Pitcherplant bogs can be further divided into: coastal plain bogs, mountain bogs, and cataract bogs. A mountain bog being what likely once occurred at the WCC. Sphagnum moss is always found in pitcherplant bogs and it therefore a good indicator of potential mountain pitcherplant bog habitat.

Mountain bogs are early successional habitats that naturally succeed to forested communities and have important conservation value, as they provide critical habitat for populations of rare, endemic, and disjunct plants and animals (Rossell, 2009). Historically, greater equilibrium existed between bog succession and creation through natural disturbance. However, bog succession now greatly exceeds bog creation because many bog habitats have been drained or filled by humans in areas where private property is concentrated in the Georgia mountains. The flat bog habitat is ideal for towns, roads, reservoirs, and farms (Resources, 2012). Stream impoundment, beaver removal, and fire suppression also prevent bog creation. Some estimates say that there may be fewer than 500 acres of mountain bog remaining in North Carolina. Animals that depend on bog habitat are forced to seek out new sites once previous ones become densely forested, hydrologically unsuitable, or displaced by human infrastructure.

Bog Restoration Actions

This plan was developed in collaboration with Ron Determann, a mountain bog expert from the Atlanta Botanical Garden, and Jennifer Ceska, Plant Conservation Coordinator from the State Botanical Garden of Georgia. The restoration phase can range from 1-15 years depending on how much the site is degraded. One USFS site near Clayton took 10-15 years to restore because it was highly degraded and rhododendron had invaded.

At the WCC, the restoration phase will be complete when sphagnum moss expands and pitcherplants can flower, fruit, and reproduce without assistance. There is little readily available scientific literature on bog creation restoration. This might be the thesis subject of a future student collaboration with the WCC. I suggest the following measures to most effectively restore or create a mountain pitcherplant bog:

Step 1: Remove Plant Competition

Bogs should be open habitats in full sun so the nutrient-poor environment can persist (Determann, 2013). In order to do this, plant competition from the site and the surrounding area must be removed. Removal of plant competition should be done by hand-cutting and removing woody debris during the winter every year of the restoration phase. Mowing can be done when the soil is dry. At some sites trees should be removed in order to promote the growth of sphagnum moss and to allow more water to access the site (Determann, 2013). Fertilizers should be avoided when working with bogs because of the many resident sensitive aquatic species (e.g., amphibians). Fertilizers also encourage weed growth, which can be more difficult to eradicate in the South. At the WCC, sphagnum moss and the potential bog restoration site is next to the amphibian ponds at the field near Tate City Road (Fig. 4.1); (Ceska, 2013; Determann, 2013). There are many tulip poplars (*Liriodendron tulipifera)* on the site; The tulip poplars on the west side of the site should be removed. The trees should be removed slowly to prevent flooding, as trees intercept substantial amounts of water. Initially, ten tulip poplars should be removed. The rest of the trees should be girdled so the hydrology is not dramatically altered (Ceska, 2013) as girdling kills trees more slowly. Girdling involves removing a strip of bark around the circumference of a tree and results in the death of the wood tissues about the damage. The site should then be left to marinate and settle and girdled trees should be removed when they are dead.

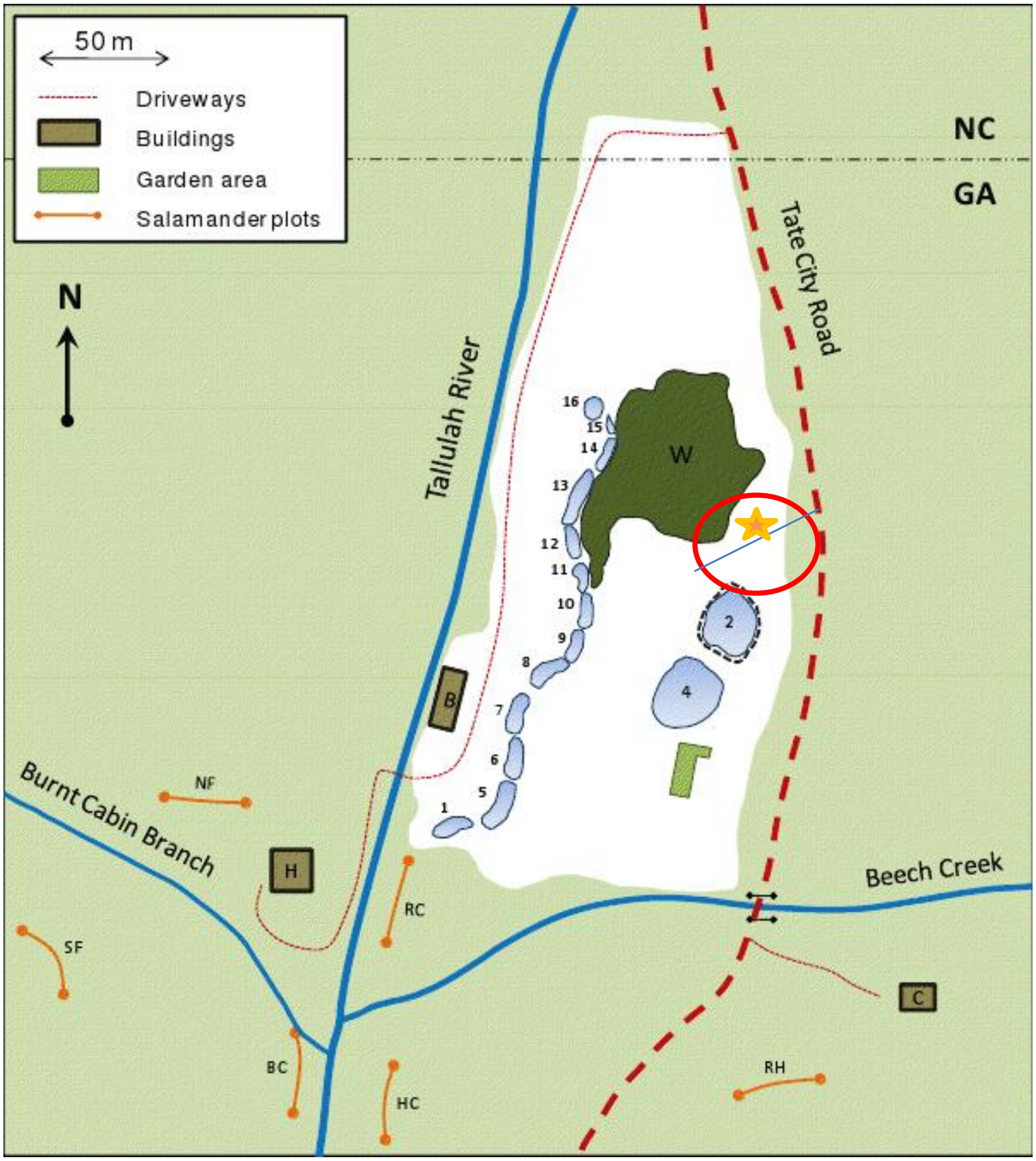

Figure 4.1: Map of the WCC. Circle indicates bog restoration site. Line in circle indicates where tulip poplars should be removed north of the line in circle (Rothermel, 2011).
★ = Sphagnum moss

Step 2: Restore Hydrological Systems

Bogs need a clean source of water and barriers to reduce nutrient input may be needed in some areas. Bogs may not be wet all year long and may dry up to the point that the exposed soil cracks in some seasons (Orwig et al., 1998). At the WCC there is a currently a small stream on the potential bog restoration site. Making small changes over time such as removing trees in stages, will help the water cover the site like a sheet (Ceska, 2013). A series of check dams made of logs should be installed in the creek to slow the water flow (Determann, 2013).

Step 3: Reintroduce rare plants

The site at the WCC may be responsive to rare pitcherplants. After plant removal and hydrological system restoration, the site should be reassessed for the planting of pitcherplants (Determann, 2013). Ron Determann grows pitcherplants *ex situ* at the Atlanta Botanical Garden and transplants them to restored, safeguarding sites, usually on protected land. At the WCC he believes Purple Pitcherplant (*Sarracenia purpurea ssp montana*), a federally endangered species, may be successfully grown. According to Determann, the Atlanta Botanical Gardens is willing to provide pitcherplants to the WCC as long as the project is a sanctioned alliance with the Georgia Plant Conservation Alliance (GPCA) and the GWF. The GWF is a member of the GPCA and an alliance can be formed easily. Jennifer Ceska, a member of the WCC Advisory Panel and Project Coordinator of the GPCA has agreed to lead the alliance and this project.

Invasive Species

Invasive plants have been recognized as a significant economic and ecological threat to management and restoration (Falk et al., 2006). Invasion of nonnative plants into southern forests continues to go largely unchecked. These infestations erode forest productivity, hinder forest use and management activities, and degrade wildlife habitat. While it is hard to quantify how much invasive species can cost, it is estimated that the federal government spends $1.2 billion a year (Bond, 2006). Disturbances such as turned up soil, release resources and creates open spaces promoting invasion by early successional plant seeds which will invade the soil and germinate (Falk et al., 2006). Hemlock decline may contribute to the spread of invasive species due to direct disturbances or removal of dispersal barriers (Eschtruth et al., 2006). Restoration is also a disturbance which initially makes habitats vulnerable to establishment of invasive species in the surrounding habitats. If we do not consistently monitor these species, we will likely pay a larger price later.

Invasive Plants

There are a number of invasive plants at the WCC. In this plan, I focus on Category I and II invasive species. Category I is defined as an exotic plant that is a serious problem in Georgia natural areas because it extensively invades native plant communities and displaces native species. Category II is defined as an exotic plant that is a moderate problem in Georgia natural areas (Georgia Exotic Pest Plant Council, 2006).

Japanese Honeysuckle (*Lonicera japonica* Thunb.) **Category I:** Honeysuckle (Fig 4.2) is an evergreen woody vine occurs both in the upper or lower canopies. It creeps along the forest floor seeking opportunities to climb trees for more sunlight. This plant flowers from April-August and then fruits and seeds from June-March. Honeysuckle covers and smothers native plants. These vines consume trees and ultimately result in tree death and are also know to release a chemical that keeps other seeds from germinating (Miller, 2010). If honeysuckle seeds contaminate the headwaters at the WCC they could flow downstream to reproduce and spread, so it is important to control this invasive species not only for the WCC but for downstream communities as well.

Honeysuckle should be removed by pulling up the whole plant and disposing of it into trash bags. It should be cut from trees so that it will not flower or fruit.

Figure 4.2: Japanese Honeysuckle: *Left:* Troy Evans, Great Smokey Mountains National Park, Bugwood.org. *Right:* Chuck Bargeron, University of Georgia, Bugwood.org

Nepalese Browntop (*Microstegium vimineum* (Trin.) A. Camus**) Category I:** Browntop (also called Japanese Stiltgrass; Fig 4.3) is a sprawling annual grass that grows from a ½ foot to three feet high. It has flat, short, off center leaf blades. Browntop is very shade tolerant and produces prolific seeds August-December. Each plant can produce 100-1,000 seeds that can remain viable in the soil for three years. It spreads on trails and recreational areas by hitchhiking on shoes and clothes (Miller, 2010). Browntop is already prevalent along the side of Tallulah River Road and Tate City Road. It is easy to pull and spray but it must be regularly monitored. When removing invasive plants it is important not to disturb the soil. Soil turnover provides a place for invasive seeds to enter or expose invasive seeds already in the soil. Browntop should be pulled or sprayed or mowed every year between August and October before seeds germinate. The WCC should consider planting the tough native grass called upland seaoats *(Chasmanthium latifolium*) to hinder the invasion of Browntop onto the property.

Figure 4.3: ***Left:*** **Nepalese Browntop a) James H. Miller, USDA Forest Service.** ***Right:*** **Chris Evans, Illinois Wildlife Action Plan. Bugwood.org**

Japanese Spiraea (*Spiraea japonica*) Category II: Spiraea (Fig 4.4), native to eastern Asia, is a small deciduous plant that can reach up to six feet tall. It invades a variety of habitats in the Eastern U.S. Once established it can form dense stands that displace native plants and over vegetate open areas (Center for Invasive Species and Ecosystem Health et al., 2010). This plant invades flood areas at the WCC, such as in the bottomlands and open woodland areas where it replaces spring wildflowers. Spiraea at the WCC should be removed by pulling up the whole plant, including the roots when it is flowering in late spring so seeds are not dispersed throughout the property. Soil disturbance should be kept to a minimum. Plant pullings should be placed into trash bags and taken to a landfill.

Figure 4.4: ***Left:*** **Flowering Japanese Spiraea. Great Smoky Mountains National Park Resource Management Archive, USDI National Park Service, Bugwood.org.** ***Right:*** **Japanese Spiraea. James H. Miller, USDA Forest Service Bugwood.org**

Silvergrass (*Miscanthus sinensis* Andeersson**) Category II**: Silvergrass (Fig 4.5) is a tall perennial grass that reaches from five to ten feet. Extensive infestations occur from ornamental plantings that escape to roadsides, forest margins, and adjacent disturbed sites (Miller, 2010). Silvergrass is not currently an invasive at the WCC but it is being planted in the nearby valley of Tate City by landowner. Tate City landowners should be informed that planting silvergrass may cause harm to the ecosystem and that it would be wise to remove silvergrass from their property.

Figure 4.5: Silvergrass. Photo credit: James H. Miller, USDA Forest Service, Bugwood.org

Chinese privet *(Ligustrum sinesnse)*: Another concern is a small patch of Chinese privet *(Ligustrum sinesnse)* on the property that should be eradicated immediately.

Eradication Techniques

Most of the above invasive species can also be removed manually by pulling the plants or by cutting with a lawnmower or weed whacker. Pulling up or mowing an invasive plant should occur before the seeds set (when the plant is in early stages of flowering). This is the preferred method of removal.

All of these plants may also be sprayed with herbicide. Timing of spraying herbicides is very important because absorption effectiveness is dependent on temperature. Herbicides should be sprayed a couple days after a rain when plants will be taking up water. If invasive plants are near a wetland, herbicide mixed with a surfactant soap should be prohibited as it is very harmful to amphibians (Ceska, 2013).

Potential Outreach Opportunities

The WCC and the residents of Tate City should be informed to plant responsibly. An outreach program should be implemented to encourage residents of the Blue Ridge Mountains to remove invasive species and to replant native species within gardens. Landowners should also be discouraged from planting non-native ornamental plants such as silvergrass. Invasive plants at the headwaters of the Tallulah River have a greater chance of spreading quickly downstream than they would elsewhere. Many of the residents of Tate City may not know which plants are invasive or how to deal with them. This is an opportunity for the WCC to reach out to the community and provide information on identifying invasive species and how to deal with them. The WCC could also host a volunteer day where volunteers help eradicate invasive species, develop and distribute a pamphlet on invasive plant species specific to the Blue Ridge, or host a speaker to discuss the topic.

Feral Hogs

Feral hogs (*Sus scrofa*) in Georgia include pure Eurasian or Russian hogs, free-ranging domestic hogs, or a hybrid of the two. Feral hogs prefer the cover of dense brush for protection but can also be found in mature woodlands or grassy areas. They are non-native invasive pests that compete directly for food with other wildlife such as deer, quail, and wild turkey. They can damage and eliminate rare or endangered plants and animals. Feral hogs feed on almost anything and consume roots, invertebrates, livestock, small vertebrates and ground nests. They can have serious diseases that can be transmitted to humans and domestic animals. When it is hot they prefer wading in wetlands or in streams close to protective cover. Hogs can reproduce from an early age and have large litters of up to 13 young (Resources, 2003). Feral hog damage has been seen at the WCC (Jerry McCollum, Committee meeting 8/11/2012) but at this time is not a threat. If feral hogs do become a threat, GWF personnel will reduce the problem with trapping and shooting. Trail cameras should also be installed in tandem with an aggressive hog management program.

CHAPTER FIVE

FOCAL SPECIES MANAGEMENT

History and Decline of the Brook Trout in the Eastern United States

Brook trout (*Salvelinus fontinalis*; Fig 5.1) are part of the trout and salmon (Salmonid) family and the Char (*Salvelinus*) genus that include bull trout, lake trout and arctic char. They are native to the eastern U.S. and can live in many types of water bodies such as lakes, larger rivers, small streams, and estuaries. Brook trout are known as an indicator species for water quality because they have very specific water habitat requirements. Brook trout prefer temperatures below 68 degrees Fahrenheit and cannot survive in temperatures that exceed 77 degrees Fahrenheit. They can live in water with a pH as low as 5 and require a high dissolved oxygen level. Historically, brook trout have thrived in the eastern U.S. and in the Southern Appalachians. Georgia and North Carolina are home to a genetically distinctive subspecies called the Southern Appalachian brook trout. Brook trout populations in hemlock forests are three times greater than in hardwood forests (Ross et al., 2003). Current data suggest there are over 150 miles of brook trout streams in Georgia. Most of the streams are quite short, usually less than one mile in length.

The exact historical range of brook trout in Georgia is unknown due to losses of habitat and population declines before this information was collected (Eastern Brook Trout Joint Venture, 2008). The first large losses of brook trout were in the early 19th century when primitive logging techniques destroyed much of the brook trout habitat. At the same time, brook trout populations were decimated by overfishing and an increase in water temperatures due to loss of canopy cover (King, 1942). Fishing stocks were replenished with non-native rainbow trout and brown trout, which were selected because of their higher tolerance for warmer temperature. Rainbow and brown trout prevented brook trout from reestablishing in streams where they once existed and continue to out-compete brook trout. Brook trout also face challenges from impaired water quality such as sedimentation from gravel roads and development that impair brook trout habitat.

Figure 5.1: Brook Trout *(Salvelinus fontinalis)* Photo Credit: (Petty, 2012).

In Georgia, it is estimated that 58% of watersheds containing brook trout no longer support viable populations. The vast majority of brook trout populations are at high elevations on USFS land, where they are more protected from disturbance, creating stable populations.

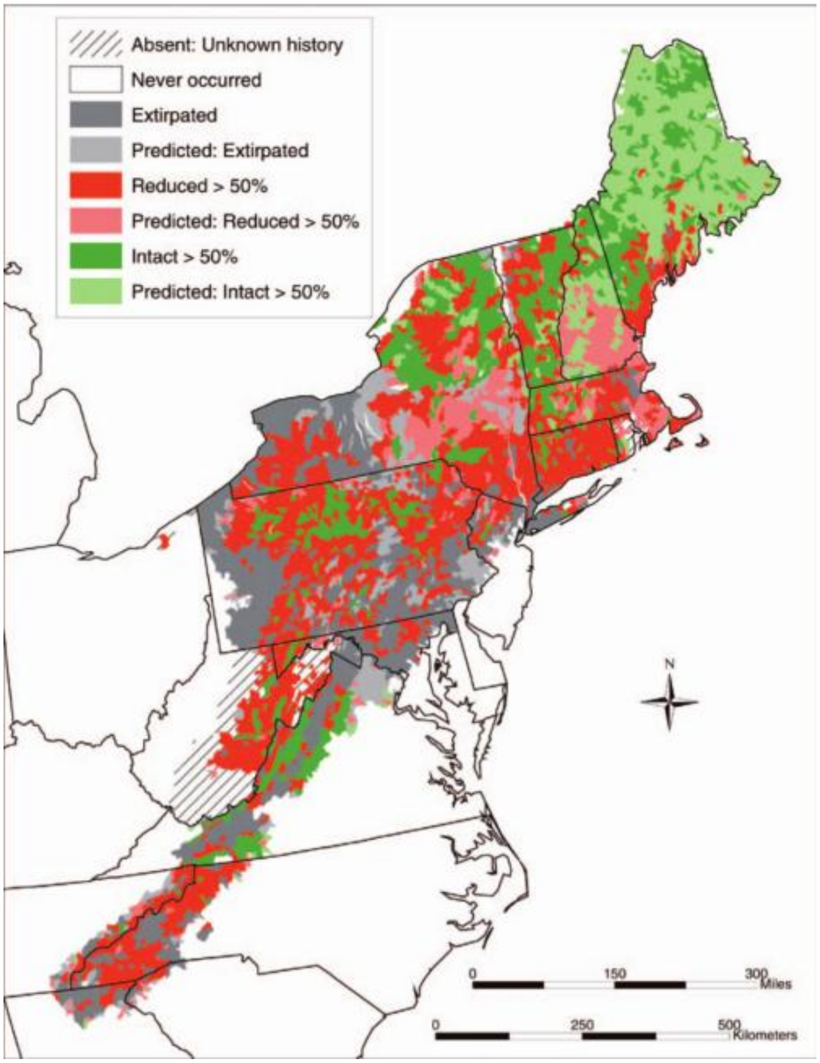

Figure 5.2: Distribution of brook trout classifications. Photo credit: (Hudy et al., 2008).

Rainbow Trout and Brown Trout

The Wildlife Resources Division of the Georgia Department of Natural Resources stocks streams in the Upper Tallulah River Basin with rainbow trout, brown trout, and brook trout from late March-August. Non-native rainbow trout and brown trout have been identified as important contributors to brook trout decline. The brown trout originally inhabited Europe, North Africa, and Eastern Asia but they are now found globally. Brown trout are able to survive in warmer waters than brook trout, making a more broadly successful species. Rainbow trout often invade on brook trout streams, sometimes resulting in brook trout populations to inhabit only the highest headwater streams, such as above waterfalls (Petty, 2012).

> "Seasonal" streams are open to fishing only during the trout season dates (last Saturday in March to October 31 each year). "Year-round" streams are open to trout fishing all year. The Tallulah is a heavily stocked year round trout fishing stream (Fig 5.3). Brown trout, rainbow trout, and brook trout probably reside in these streams. In order to have a viable population at the WCC, brown trout and rainbow trout populations should be reduced. Dispersal barriers can be constructed to halt upstream movement of non-native trout.

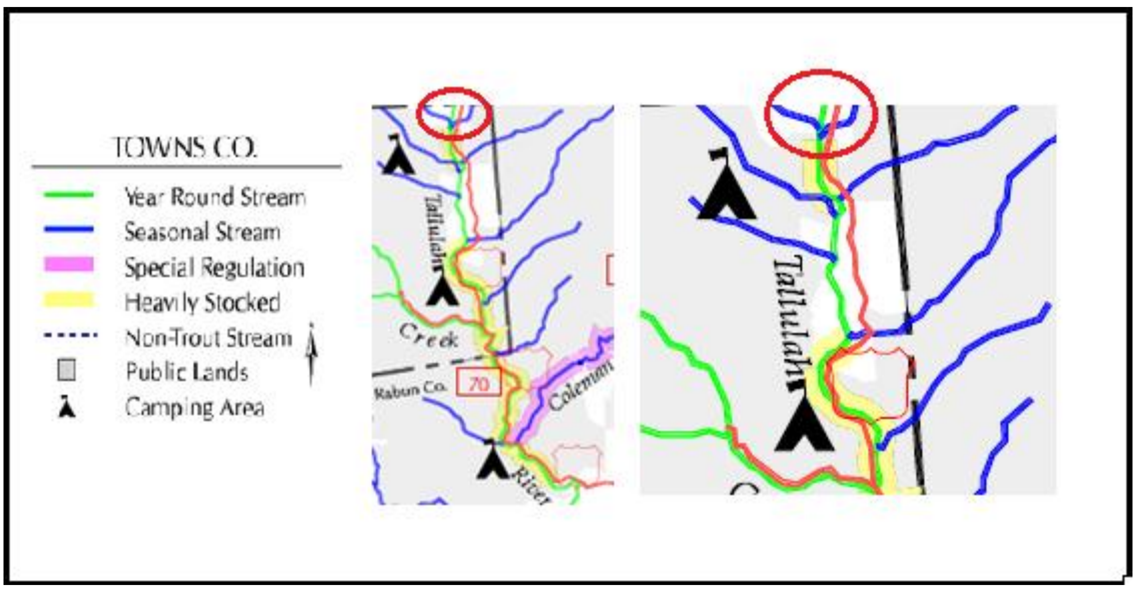

Figure 5.3: Fishing and stocking regulations at the WCC (circled in red). Beech Creek and Burnt Cabin Branch (in blue) are seasonally fished streams. The Tallulah (green) is a year-round stream. The Tallulah is heavily stocked with brown, rainbow and brook trout.

Interest in protecting native species has increased recently, and the Eastern Brook Trout Joint Venture, a collaboration of many stakeholders formed in 2005, has made it a goal to conserve and restore native trout species. A study done in 2008 has shown that brook trout are extirpated at the WCC (Fig 5.2). However, most of the brook trout currently in Georgia are located on USFS lands including the Nantahala Forest, which borders the WCC. The trout in these areas, although secluded, are thriving because of USFS protection (Eastern Brook Trout Venture, 2006). The WCC is characteristic of important spawning habitat for brook trout. This habitat should be enhanced and protected with the future goal of supporting a brook trout population.

Riverscapes and Microhabitat Protection

The riverscape, the entire spatially heterogeneous scene of the river environment, is the essential tool for conservation and management for fishes because it allows for conservation of each habitat type (Fausch et al., 2002).Appalachian streams exhibit high spatial and temporal variability. During their life cycle, fish utilize different critical stream habitats for foraging and cover, which requires movement to different parts of a stream ecosystem.

The WCC, at the headwaters of the Tallulah and at the convergence of three tributaries, has very important brook trout habitat but cannot sustain a brook trout population alone. Brook trout move into larger reaches of river when they are more mature and use tributaries during younger stages. Tributaries are also important for brook trout spawning and reproduction. Brook trout restoration requires conservation and restoration cooperation by the entire riverscape, so brook trout may use different the different stream sections needed for their respective life cycle stage. Identification of areas critical to reproduction is needed to focus recovery efforts (Petty, Lamothe, et al., 2005). Members of the Salmonid family, particularly the brook trout, exhibit high levels of movement and habitat use throughout different life stages (Curry et al., 2002) and the movement of trout between habitats is critical for trout populations (Petty et al., 2012). Brook trout populations have sedentary fractions that remain in tributaries most of the time and mobile fractions that utilize the main branch of the stream as foraging habitat (Petty, Lamothe, et al., 2005).

Managers believe that watershed-level management of brook trout is essential. While watershed level management is required, microhabitats are important in dictating brook trout movement. The microhabitats at the WCC, like tributary confluences and deep pools, are important for reproduction, refuge, and foraging and should be prioritized conservation and restoration sites. Headwater streams may be preferred spawning areas for brook trout because they protect larvae and juveniles from potential predators and competition (Petty & Thorne, 2005). Tributaries are likely to have updwelling groundwater, which is predicted to be important in brook trout reproduction. Tributary confluences have high levels of large woody debris which creates pools (Hartman et al., 2010) and support high invertebrate productivity (Benke et al 1985).

Many studies have shown that brook trout and other salmonids use cold water sources such as tributaries, seeps, and groundwater updwellings to avoid thermal stress (Baird et al., 2003; Breau et al., 2007; Goniea et al., 2006). Brook trout access these thermal refuge when summer stream temperatures reach stressful levels (Petty et al., 2012). Larger stream reaches are used as supplementary feeding habitats by larger trout. Management plans should protect these coldwater headstreams and promote the formation of pools with large woody debris in order to protect important habitat for brook trout.

Stream water chemistry plays a large role in the reproductive success of brook trout. Brook trout eggs have decreased survival in environments with low pH (Wigington et al., 1996). Timing and duration of acidic episodes play a critical role in the survivorship of brook trout eggs, larvae and juveniles (Dewalle et al., 1995). Acidic episodes of long duration (> 24 hours) can cause mortality rates that are significantly higher than shorter episodes (Van Sickle 1996). Southern Appalachian mountain streams, in particular, are prone to intense acidic episodes which can harm brook trout populations. Spawning brook trout can be attracted to small streams with low alkalinity and higher pH conditions to spawn. However during acidic episodes, the buffering capacity can become overwhelmed and the pH drops below 5, a dangerous level for brook trout, as trout can experience reproductive failure (Petty, Lamothe, et al., 2005).

There are many ways of treating streams for pH imbalances, but treating acidified streams with large quantities of limestone is the most common approach. Adding limestone can dramatically improve water quality and help diverse fish and macroinvertebrate communities recover from acidification (Petty & Thorne, 2005). Management plans should include limestone (Clayton 1998) placed in small streams where acidic conditions are likely to occur in order to protect important spawning habitat at the WCC. Placing limestone in upstream reaches is likely to have positive effects on larger bodies of water downstream (Petty & Thorne, 2005). This acid remediation should be placed in headwater streams accessible by roads.

The important microhabitats that lie on the WCC, such as tributary confluence in the headwaters and pools, are important for brook trout spawning, feeding, and thermal protection. A management plan for brook trout should include a larger watershed area beyond the WCC boundaries because brook trout populations are mobile throughout certain life stages and utilize different parts of a river to survive and reproduce. The WCC should focus on enhancing the priority habitat on the property as it is crucial to the recovery of brook trout in the area.

Predicted Effects of Hemlock Decline and Climate Change on Brook Trout Restoration

With the massive loss of eastern hemlock due to HWA, reductions in canopy cover in riparian areas will result in increasing temperatures as previously discussed. However this reduction in shading due to hemlock loss may not be the primary factor in determining stream temperature. Groundwater inputs have stronger influence on stream water temperature than shading (Siderhurst et al., 2010). Hemlock loss will also increase large woody debris in the water. Large woody debris creates habitat in pools and brook trout prefer pools with large woody debris (Flebbe, 1999). Both of these factors are predicted to not have adverse effects on brook trout and may in fact provide beneficial habitat for brook trout survival.

These habitat at the WCC will face even more challenges in the future due to the threat of climate change resulting in increasing temperatures in these streams. The effects that air temperature increases due to climate change have on lake, river, and stream temperatures is still unknown (Velasco-Cruz et al., 2012). In the eastern U.S., differences in rainfall patterns and increased temperatures will likely have effects on aquatic systems (Flebbe et al., 2006). It is predicted that brook trout will survive the most pessimistic climate change predictions due to localized riverscape conditions (Velasco-Cruz et al., 2012). Some aquatic system may experience increases in temperature whereas systems supplied mostly by groundwater may remain cool enough to support brook trout. In areas like the Southern Appalachians, where brook trout are near their temperature limit, further increases in temperature could exceed thermal limits, resulting in losses of brook trout from certain sites. Only small refuges in the headwaters may remain (Flebbe et al., 2006).

Enhancement of Critical Brook Trout Habitat

The habitat at the WCC is ideal for brook trout reproduction. Protecting small headwater tributaries (Petty, Lamothe, et al., 2005) and existing cold water sources which are important for spawning and juvenile recruitment is essential for recovery of the brook trout. Creation of new coldwater sources like pools with large woody debris is also important especially in the face of climate change (Flebbe et al., 2006). Brook trout restoration at the WCC should be done in tandem with the whole Tallulah River Basin as movement and utilization of different habitat types is essential for brook trout populations.

Specific actions for population and habitat restoration that can be taken at the WCC are: acid remediation using limestone, structural habitat enhancement, riparian zone management, dispersal barrier and removal of exotic species, and native species re-introduction. The Eastern Brook Trout Joint Venture (EBTJV) was formed in 2005 to implement strategies to improve brook trout habitat and restore brook trout to its historical range and has funding for projects contributing to the restoration of brook trout.

Acid remediation by applying limestone to headwaters neutralizes acid as it moves downstream within the bed load. This is proven to improve water chemistry such as pH and alkalinity, which can cause reproductive failure in brook trout. Streamwater at the WCC may become more acidic with hemlock decline. Usually after this treatment, brook trout reproduction, biomass, and density are enhanced (McClurg et al., 2007). Unfortunately, this technique does not treat the source of the problem, so reapplication of limestone may be required (Petty et al., 2012).

Stream habitat enhancement can often help brook trout survival. As discussed earlier brook trout prefer pools with large woody debris. An increase in large woody debris has been shown to increase biomass and density (Roni, 2002) by increasing benthic invertebrate production and providing more prey for upper trophic levels (Evans et al., 2012) like brook trout. In the northeastern U.S., the USDA Forest Service has been using the “chop and drop” method of trout habitat creation since 1988 which involves placing large woody debris into streams to create habitat (McKinley et al., 2012). Loss of the eastern hemlock at the WCC may be beneficial to brook trout populations as it will put large amounts of woody debris into the stream creating more refuge, pools, and cold water areas for trout to occupy.

Riparian zone management is crucial to brook trout populations. The riparian zone at the WCC will likely have more rhododendron or hardwood trees in the future, which will change stream processes. Riparian zone restoration includes treating infested hemlocks and encouraging the growth of hardwood trees where hemlock mortality has occurred (Roberts et al., 2009).

Dispersal barrier construction combined with removing exotic trout from the WCC could ensure that brook trout remain isolated from the competing trout species. It is unclear whether this is helpful for brook trout, but there is evidence of success with cutthroat trout (*Oncorhynchus clarkia*); (Shepard, 2004). However, putting up a dispersal barrier would prohibit brook trout from moving downstream which creates a barrier within a regional network making them less productive and may cause local populations to be more susceptible to local extirpation (Kruse and Hubert 2004). Creating barriers may be an option for the future at the WCC after there has been more research.

Reintroduction efforts have been taking place in certain areas in order to re-establish brook trout populations. The purpose of these efforts is to re-establish brook trout populations that are able to sustain themselves through *in-situ* survival, growth, and reproduction (Petty et al., 2012). Reintroduction has the potential to negatively affect regional population genetics, by creating a bottleneck effect that reduces restoration effectiveness. There is a lack of published data on this and more research is needed on the potential long-term effects and success of brook trout re-introductions.

Future Implications

In the past, brook trout restoration in the form of Trout Unlimited's "Bring Back the Brookie" program was met with much resistance due to suggestions of eradicating rainbow trout. In the past the WCC decided to focus on brook trout restoration (which could be a valuable amenity) which would require much outreach and education. Reintroduction would present many opportunities for future ecological research, for example, one suggestion is determining how non-native fish have displaced native fish and how they partition and compete for resources.

Amphibian Biodiversity at the Wharton Conservation Center

The Southern Appalachians are the world's hotspot for salamander diversity, and the WCC lies in the middle of this hotspot. Indeed, many salamanders can be found in the seepages, on the slopes of hillsides, and in the streams and ponds that are characteristic of the WCC (Fig 5.3). At least 20 species of amphibians occur at the WCC including three species of salamander identified by the Georgia Comprehensive Wildlife Conservation Strategy as high-priority species of conservation concern (Rothermel, 2011). The amphibian ponds support species such as the eastern newt (*Notophthalmus viridescens*), and large streams support black-bellied (*Desmognathus quadramaculatus*) and shovel-nosed salamanders (*Desmognathus marmoratus*). Most salamanders at the WCC, four genera in fact, are members of the family Plethodontidae which are indicators of overall biodiversity and forest ecosystem health (Welsh et al., 2001). Currently, the biggest threat that salamanders face worldwide is land development. Abundance of salamanders is correlated with late successional forest and increased woody debris (Hicks et al., 2003) and linked to cool, moist, montane climates. Salamanders could experience restricted habitat with climate change but the majority of species native to Southern Appalachia are not predicted to go extinct (Milanovich et al., 2010). Although there is an exceptionally high diversity and abundance of amphibians in the Southern Appalachians, there is a lack of information regarding long-term population monitoring data making it difficult to develop conservation strategies. Occupancy-based approaches to detect salamander abundance and diversity are a method that citizen scientists could be involved in. The WCC could play an important role in collecting these data, using citizen science for monitoring. Initial amphibian monitoring was conducted at the site by Betsie Rothermel and Emilie Travis of the Archbold Biological Station from 2008-2010 (Rothermel, 2011). This study, surveyed ten species of pond-breeding amphibians, documented successful recruitment of juveniles, and determined levels of different pathogens in these populations (Rothermel, 2011). This research was done in conjunction with the WCC Advisory Panel and GWF and provides a good model for future research efforts.

Figure 5.3: The Ocoee Salamander (*Desmognathus ocoee)* found in small streams and seepages at the WCC have unique coloring. Photo Credit: Todd Pierson, University of Georgia.

Occupancy Based Approaches and Citizen Science Volunteers

Site occupancy is a metric that is often used to assess changes in amphibian systems. For management and conservation purposes, estimates of animal and plant populations serves three purposes: 1) to inform management decisions, 2) evaluate these decisions, and 3) help predict what will happen in a system (MacKenzie et al., 2005). Occupancy is defined as the proportion of areas, patches, and sample units that are occupied by a species (MacKenzie et al., 2005). Basic sampling protocol involves visiting sites and spending time within each one looking for an individual of a species or for evidence that the species is present; Importantly, for secretive animals like salamanders, imperfect detection rates are incorporated into the occupancy models (MacKenzie et al., 2005). Appropriate detection/non-detection data can be collected without much effort (Bailey et al., 2004) and tend to require much less effort than programs designed to estimate abundance (MacKenzie et al., 2005). Small-scale studies are important for monitoring amphibian populations in the face of climate change and land-use change. It is important to monitor the amphibian populations at the WCC because it is a hotspot for diversity, the habitat is changing, and it may be affected by climate change in the future.

Citizen science refers to volunteers that participate as field assistants in scientific studies (Cohn, 2008) but are not paid for their assistance nor are they necessarily trained scientists. Citizen science dates back to the National Audubon's Society Annual Christmas Bird Count that began in 1900 (Cornell University, 2013). Citizen science requires that an expert explain how to use equipment, collect accurate data, and interpret results. The WCC could incorporate citizen science monitoring programs in a few different ways. In her report on amphibian diversity from the WCC, Dr. Betsy Rothermel suggested hiring a paid coordinator to recruit, train, and schedule volunteers, to supervise fieldwork between March and August (Rothermel, 2011) to monitor populations of amphibians.

An annual 'BioBlitz', a rapid biological survey, brings groups of scientists and naturalists within a short period (generally one day or a week) to conduct multiple inventories of the wildlife community in an area (Lundmark, 2003). The GWF could organize an Annual BioBlitz for the WCC that brings stakeholders and donors together in order to gather data on amphibians and other wildlife. BioBlitz's can be community assessments of flora and fauna or can have a taxonomic focus. A BioBlitz could also be conducted by trained citizen scientists who are interested in learning more about natural history. Additionally, the WCC could host to summer undergraduate interns to participate in long-term ecological research (LTER's) in tandem with the GWF and individual professors and could gather data.

eDNA Monitoring

Environmental DNA (eDNA) uses traces of DNA extracted from environmental samples that are used to determine if a target species has been in the vicinity using specific molecular markers. The reliable detection of vertebrates in water using eDNA was recently confirmed in wetlands and in a large river system (Goldberg et al., 2011). Using eDNA to test for rare or sensitive species in streams could decrease costs, increase accuracy, and increase the number of sample sites per unit area (Goldberg et al., 2011). Currently species-specific and more general eDNA assays are under development for use in detecting and monitoring Appalachian salamander populations, and tentative plans have been made for the WCC to serve as a focal point for their implementation (Todd Pierson, personal communication).

CHAPTER 6

SUMMARY AND CONCLUSION

The Wharton Conservation Center (WCC) is a spatially and ecologically-significant tract of land located in the headwaters of the Tallulah River in the Southern Appalachians. Due to the Laurentide Ice Sheet that covered most of North America during the Pleistocene, it has ravines and gorges that are unique habitat for many boreal species. Dr. Charlie Wharton, renowned scientist and conservationist, called this land home and envisioned it as "an interpretive site for the Southern Highlands." The Advisory Panel for the WCC is committed to helping achieve his vision. This thesis helps the Advisory Panel, and ultimately the GWF Board, implement their concept plan by identifying priority management and restoration goals and activities. I make recommendations based on a synthesis of literature review, interviews with experts, and consultations with the Advisory Panel.

The WCC faces an uncertain ecological future. Global climate change, potential land-use change, and degradation from invasive species are all threats to ecosystem function at the WCC. However, the exact effect of these stressors is unknown. Wherever possible, the WCC should be restored and managed for ecosystem function and resiliency as opposed to striving for a historic state. When not possible, the effects of degradation should be reduced. The WCC has the potential to become a demonstrative restoration site because it is a small, privately-owned tract of land, so restoration techniques can be tested here with little political resistance. The restoration and management strategies that I recommend for the WCC are applicable on this scale. Certain techniques, such as hemlock treatments and invasive species eradication, are much harder to implement on a larger scale. Other goals, such as brook trout restoration, are only achievable on a larger scale, with the cooperation of many stakeholders.

Some degradation of ecosystem structure and function has already occurred at the WCC as the decline of the foundation species of eastern hemlock is occurring by the invasive insect, hemlock woolly adelgid (HWA). The WCC is transitioning into a hybrid ecosystem, shifting into a more hardwood-dominated forest; research to monitor these effects should be conducted. Restoration efforts should focus on restoring ecosystem functions (such as nutrient and energy cycling) and structure (such as canopy cover). After basic data collection and observation, I determined that most of the hemlocks on the slopes at the WCC are dead. Hardwoods will eventually start to grow in these areas and growth should be promoted. Promoting a quick turnover from hemlock to hardwood on these slopes will reduce nutrient inputs into streams and maintain water quality during this transition. These disturbed areas should be monitored for invasive plant species and managed appropriately, as disturbances such as hemlock mortality make the ecosystem less resilient and more prone to invasion. Another threat to ecosystem resilience is potential development of bordering private lands which will lead to habitat fragmentation. It is essential for the habitat at the WCC to remain continuous with the surrounding forest. This threat may be largest for salamander species, which are highly sensitive to land-use change and environmental degradation.

I determined that many hemlocks in riparian areas can be treated with the insecticide imidacloprid, using the soil injection technique. This technique will reduce the possibility of imidacloprid contaminating streams and negatively affecting wildlife. Maintaining healthy hemlocks in riparian areas will mitigate ecosystem changes on streams. Healthy hemlock trees will also create ecosystem resilience which will help deter other threats to hemlocks, such as the tip blight, the elongate hemlock scale, and the hemlock borer. In riparian areas where hemlock mortality has occurred, rhododendron may be the primary vegetation. It is also possible that riparian vegetation will be comprised of hardwoods in these areas and little rhododendron will persist. Planting selected evergreen trees in areas with hemlock loss may also help maintain ecosystem function, but the specific effects are unknown. Some of the effects of hemlock decline have been predicted such as nitrogen leaching, decline in hemlock-associated species, and an excess of large woody debris entering streams but long-term effects are not well known. The WCC could be a model site for quantifying these effects and monitored change over time.

At the WCC, mountain bog restoration is a priority. Sphagnum moss has been found which indicates a suitable site for restoration. Mountain bog habitat is the most rare habitat in the Blue Ridge Mountains as it is being destroyed by human activities much more quickly than it is being created. These bogs provided habitat for rare pitcherplants and other species. Mountain bog restoration will require removing common trees such as tulip poplars so the area can receive direct sun. This should be done slowly so the area does not flood and so sphagnum moss growth is promoted. Sphagnum moss will help spread the water into sheets which is required for mountain bog habitat. When the area is opened to full sun and the water has dispersed, rare pitcherplants grown at the Atlanta Botanical Gardens can be planted, which must be done as an alliance with the Georgia Plant Conservation Alliance. The management phase will begin when pitcherplants can flower and reproduce without assistance.

Controlling invasive plants should also be a priority for the WCC. Invasive plants can outcompete native plants, altering ecosystems and costing landowners. Invasive plant removal and control is feasible as long as landowners stay vigilant, remove plants carefully, and remove at lower risk times when plant seeds cannot be dispersed. The WCC and surrounding areas have a responsibility to monitor invasive plants and to not plant invasive species. Areas near headwaters have a higher risk of transporting these plant seeds downstream where they can invade further. Volunteer groups or herbicides can assist with eradication of these plants. The WCC should create pamphlets to distribute and deliver programs to Blue Ridge property owners describing specific threats to these areas.

The WCC has pristine habitat for brook trout reproduction and foraging in the headwaters of the Tallulah, and the Advisory Panel is interested in enhancing brook trout populations at the WCC. Brook trout restoration must occur at a larger scale than just at the WCC; however, the WCC can play a significant role in the preservation, enhancement, and maintenance of pristine stream habitat used for spawning and feeding. Hemlock decline will most likely create more brook trout habitat, as large woody debris will create pools and cold water refuge. pH levels at the WCC should be monitored and limestone should be placed in streams as needed if acid levels get too high. The Eastern Brook Trout Joint Venture has funding for projects like these and research should be continued on habitat effects on the populations of trout at the WCC.

The WCC is in the world’s greatest hotspot for amphibian diversity. Amphibians such as salamanders may experience shifts in range due to climate change. It will be important for conservation and management of salamanders to know which species inhabit the WCC and utilize which habitat types, and how may change overtime. These data could be used to inform future managers on critical habitat for salamander species. Monitoring of these species can be done by using occupancy-based approaches and by recruiting the help of citizen scientists or undergraduate researchers. The WCC could also be a focus site for the new eDNA technique which could revolutionize the way salamanders are detected.

Climate change and invasive species may have severe effects on Southern Appalachian habitat and diversity. The WCC could play a critical role in monitoring these changes by setting up experimental plots of land with lower elevation species. These plots could be mesocosms, which are experimental communities, that could be monitored by students over the years and provide insight into which species may migrate into higher altitude sites and persist (Carroll, personal communication).

Charlie Wharton understood how unique the WCC was when he purchased it in 1958. Although the WCC faces challenges, it will continue to be an ecologically important tract of land and can be more resilient to the uncertain future if these restoration and management strategies are implemented. The Wharton Conservation Center can enhance ecosystem function on a local scale, be a site for model restoration research in the future, and involve the community in restoration and management of the Southern Appalachians that Dr. Wharton so loved.

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APPENDIX A

Restoration and Management Options at the Wharton Conservation Center

Focus Area	Actions
Hemlock	Treat infested hemlocks with imidacloprid soil injection treatments Plant rhododendron and white pine to replace dead hemlocks in riparian zones Encourage hardwood set-in on slopes with hemlock mortality
Bog	Remove competing plant species in bog site (tulip poplars) Restore hydrological systems- create check dams with wood Introduce pitcherplants species-Sarracenia purpurea ssp montana.
Invasive Plants	Japanese Honeysuckle and Japanese Spiraea- pull up and dispose of in trash bags Nepalese Browntop- mow once a year in October Spray herbicides on invasive plants seasonally
Feral Hogs	Install trip cameras on site Eradicate any hogs on premises by shooting or trapping
Brook Trout	Enhance brook trout habitat -----Create more cool pools areas with strategically placed woody debris -----Remediate acid by placing limestone in streams -----Restore riparian zone by planting rhododendron and white pine -----Erect a dispersal barrier to keep rainbow and brown trout out
Salamanders	Monitor populations with occupancy based approaches (BioBlitz's or citizen science) Conduct research using eDNA

APPENDIX B

Proposed Research Activities for the Wharton Conservation Center

Focus Area	*Future Research*	*Potential Partnerships*
Eastern Hemlock Restoration	~Determine the effects of population decline of hemlock on current stands and potential founder effects for healthy individuals	~University Graduate Student/s, Coweeta LTER, USDA Forest Service, Archbold Biological Station
	~Establish plots to determine the rate of regrowth of different species	"
	~Monitor woody debris nutrient input related to hemlock decline	"
	~Determine if rhododendron will survive in areas without hemlock	"
	~Monitor the nutrient inputs into streams as hardwoods appear on slopes	"
	~Determine if hemlock-associated birds such as the Black-throated Green warbler will continue to survive at the WCC	"
	~Determine effects of hemlock decline versus groundwater on stream temperatures	"
	~Determine effects of hemlock decline on habitat for aquatic organisms (e.g. salamanders, macroinvetebrates, fish)	"
	~Monitor changes in algae abundance and macroinvertebrate species	"
Mountain Bog Restoration	~Determine how mountain bog restoration effects amphibian populations	~Archbold Biological Station, UGA Herpetological Society
	~Determine if fire regime is needed for bog restoration	~Atlanta Botanical Gardens, Coweeta LTER, Georgia Plant Conservation Alliance (GPCA)
	~Monitor timeline for bog restoration on a small scale	~GPCA, Georgia Wildlife Federation (GWF)
	~Determine how bog restoration effects water flow at the WCC	~Odum School of Ecology at UGA, Coweeta LTER
Invasive Species	~Determine speed at which invasive plants proliforate with hemlock decline	~University Graduate Student/s, Coweeta LTER, GPCA
	~Monitor plant biodiversity with the removal of invasive plants	"
Brook Trout	~Monitor resource allocation between non-native trout species and brook trout	~Eastern Brook Trout Joint Venture (EBTJV), GA Department of Natural Resouces (DNR)
	~Monitor the presence of brook trout at the WCC	~University Graduate Student/s
	~Survey the public to determine interest in native trout restoration	~GWF, GA DNR, EBTJV, University Graduate Student/s
	~Determine the effects of restoration on non-native trout species in addition to brook trout populations	~Coweeta LTER, University Graduate Student/s, EBTJV
Amphibian Monitoring	~Conduct population research using eDNA techniques	~University Graduate Student/s
	~Monitor populations using occupancy based approaches	~Archbold Biological Station, UGA Herpetology Club, Coweeta LTER
	~Determine how nutrient input from hemlock decline effects salamanders	~University Graduate Student/s, Coweeta LTER
	~Determine how continued drought will effect salamanders	~University Graduate Student/s, Coweeta LTER

APPENDIX C

Proposed Outreach Activities for the Wharton Conservation Center

Focus Area	*Outreach & Education*	*Potential Partners*
Eastern Hemlock Restoration	~Conduct a seminar on how to reduce the spread of invasive species	~GPCA ~Coweeta LTER
Mountain Bog Restoration	~Use the bog habitat as a demonstration site for bog restoration	~GPCA
Invasive Species	~Design and distribute a pamphlet on invasive plants specific to Blue Ridge Mountains ~Host a BBQ dinner and outreach session focused on feral hogs ~Education on planting Silvergrass in gardens	~GPCA
Brook Trout	~Allow limited fishing of native brook trout and hold sessions advocating for native species	~EBTJV
Amphibian Monitoring	~Host an annual BioBlitz Involve citizen scientists in monitoring efforts	~University of Georgia ~Coweeta LTER ~Archbold Biological Station

APPENDIX D

Price per Management and Restoration Action

Action	*Price per item*	*Number of Items*	*Cost*	*Possible Donations*	*Notes*
Treat hemlocks with imidacloprid	$2 per inch DBH	234 total inches	$468		Hemlocks may need to be retreated every 3-5 years
Remove hemlock threatening built structures	$300 per tree or free with Georgia Power's assistance	24 trees	$7,200	Georgia Power	Estimate from Hemlock Healers Inc.
Plant white pine	~$17 per 10 seedlings	100	$170	GPCA	
Remove tulip poplars	$300 per tree	20	$600	GPCA	Estimate from Hemlock Healers Inc.
Introduce pitcherplant species	$10	10	$100	Atlanta Botanical Gardens	These items will be donated by the Atlanta Botanical Gardens
Remove invasive plants manually ~Remove nepalese browntop in Fall ~Remove japanese spiraea in Spring ~Remove japanese honeysuckle in Spring	$1,200 per acre	15 acres	$18,000	GPCA and volunteers	This should be no cost from volunteer days
Remove invasive plants with herbicide	1 quart of non-surfactant soap is $10.95 (Alligare 90)	Number depends on reinfestation level. Purchase 10 immediately	$109.50	GPCA and volunteers	Estimate from Keystone Pest Solutions Inc. Mix 1 quart with 100 gallons of water
Install trail camera for hogs	$170	5	$850		
Eradicate feral hogs	No cost	TBD	no cost	GWF members	GWF has members who enjoy hunting and will eradicate hogs
Apply limestone to streams to reduce acid	$80-$150 per ton	3	$240-450	EBTJV	Insert limestone as pH drops below 5
eDNA research techniques	Graduate student research	1	Annual stipend around $15,000	Potential for professors to fund via grant	WCC should provide housing
Monitor salamanders ~Graduate student/s research ~BioBlitz ~Citizen science	~Graduate student research ~GWF staff supervisor to organize volunteers	1	Annual stipend around $15,000	Potential for professors to fund via grant	WCC should provide housing
			Without Donations Total= $57,747.50	With Donations Total = $2,636	
Priority 1	**Priority 2**	**Priority 3**			