Social and Ecological Aspects of Managing Wildlife in Fire-dependent Forested Ecosystems

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University

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2017

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Abstract

Many species in North America are closely linked to natural disturbance processes and the habitat features created by them. As one such disturbance, wildland fire can create unique vegetation patterns on a forested landscape. Biological legacies, such as standing dead trees, dead and downed wood, and residual patches of live mature trees, can be important structures for maintaining stand-level biodiversity. Fire can also be an important tool for reducing hazardous fuels and maintaining an open condition in some ecosystems. Managing and restoring fire-dependent ecosystems can present unique challenges for managers. Two case studies are presented here, each addressing challenges to forest restoration efforts within fire-dependent ecosystems.

The first examines standing dead trees that resulted from three different treatments in the Great Lakes region of North America. Standing dead trees, or snags, are unique features of ecosystems representing post-disturbance biological legacies. As such, the abundance, volume, size and distribution of snags can affect wildlife communities and stand-level biological diversity. While the importance of snags is widely recognized, factors influencing the use of snags by wildlife are less understood. Characteristics such as the wood properties of different tree species, local environmental conditions, and the proximate cause of tree death (insects, disease, senescence, wind, fire, etc.) can influence

decomposition and subsequent use by wildlife. Building on previous research in eastern Upper Michigan, the objective of this study was to characterize the development of snag decay patterns in jack pine (*Pinus banksiana* Lam.) and correlate these to different measures of use by woodpeckers (Picidae) and subcortical insects. In 2014, woodpecker excavations in snags were measured across three treatments (girdling, n=35; prescribed fire, n=35; and topping, n=35). The topping treatment took place in 2004, the prescribed fire took place in 2003, and the girdling treatment in 2007. Principal component analysis was used to examine the relationships between snag and decay characteristics, and past insect activity. An information theoretic approach to model selection was then used to rank potential predictors of woodpecker foraging activity and cavities. Overall, girdled snags had the lowest levels of past insect activity, particularly midway up the bole where the tree was originally girdled. Topped snags were softer, or more easily penetrable, than the other two treatments and had the highest levels of past insect use. The prescribed fire treatment had the greatest number of potential cavities and the greatest number of foraging excavations. The models predicting foraging activity suggested that treatment type was the most influential variable, while the models for predicting potential cavities suggested a combination of past foraging activity and snag diameter were most influential. These results may help inform potential snag treatment options when managing for biological legacies within pine forests of the Great Lakes region.

The second case uses qualitative data from interviews with land managers to examine perceptions of management for an endangered species whose habitat requirements largely depend on frequent fire. Management of endangered species has

been criticized as emphasizing conservation of individual species, while inadvertently diverting resources from or potentially running counter to more broad-based public land management objectives. Moreover, there is concern about the long-term prognosis for species that have met their recovery goals as reduced protections may result in fewer available resources and potentially less management attention for downlisted or de-listed species. Here we investigate the case of the red-cockaded woodpecker (*Leuconotopicus borealis* Vieillot) that was listed as endangered soon after the passing of the *Endangered Species Act* in 1973. Through semi-structured interviews with natural resource professionals in the Southeast Coastal Plain region (n=32), we examine manager perspectives on conserving the red-cockaded woodpecker, how their efforts align or conflict with other objectives, and what lessons might be learned from this case to inform others. In general, managers viewed red-cockaded woodpecker habitat management (e.g., thinning and burning pine stands) as compatible with their other resource management objectives, particularly longleaf pine (*Pinus palustris* Mill.) ecosystem restoration. In some contexts, however, managers found that specific guidelines dictating the amount of habitat to be set aside for foraging per red-cockaded woodpecker group was a barrier to implementing restoration actions. Managers expected that efforts to provide habitat for red-cockaded woodpeckers would likely continue into the future regardless of the species' conservation status. Managers also believed that more intensive strategies with a single species focus, such as using artificial inserts and translocation of individuals, would likely decrease over time. Overall, these perspectives suggest that one factor likely to contribute to the sustained recovery of an endangered species is the alignment of

species recovery guidelines and objectives with broader ecosystem management or restoration objectives.

Acknowledgments

I would like to thank my advisor, Dr. Eric Toman for his guidance, direction, and support throughout the research process. He has been encouraging as I have learned to apply new research methods, and I am a better researcher for having worked with him. I would also like to thank Dr. Charles Goebel and Dr. Daniel Herms, the other members of my committee. They have been generous with their time and provided much-appreciated advice, review, and feedback throughout the data collection and analysis processes.

Thank you to Dr. Greg Corace for helping to design this thesis and for providing feedback on my ideas and writing throughout the process. These projects would not have taken place or been possible without him. Additionally, I would like to thank the staff at Seney National Wildlife Refuge and the Seney Natural History Association, who were always welcoming to me and were generous in providing housing and research assistance throughout the course of this work. I especially thank Sarah Rademacher, Lyndsay Morrison, and Tayelor Gosselin for their hard work and help with data collection, and Laurie Tansy for always ensuring that things ran smoothly during the field season.

Thank you to Will McDearman, for his consultation and helpful advice at the beginning phase of this research. I would also like to thank all of the interview

participants and those who took the time to show me around some beautiful longleaf pine forests. This research would not have been possible without their help.

Finally, thank you to my friends and family. Their unwavering support and love have helped me to persevere through the challenges I have faced in graduate school and in life. Thank you for your patience and for reminding me to always keep my sense of humor in times of frustration.

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Fields of Study

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Chapter 1: Introduction

Throughout North America, natural disturbances have played an important role in characterizing and shaping ecosystems throughout time. A natural disturbance can be described as something that causes a perturbation in an ecological system or component relative to a specific reference state (Rykiel 1985). Disturbance events vary from region to region and can include windstorms, flooding, insect or disease outbreaks, and fire among others (White 1979). Although numerous vegetative communities evolved with these processes and are thus adapted to them, human communities often see natural disturbances as problematic, damaging, or catastrophic events.

Human communities and infrastructure are not typically designed to adapt to the dynamic and sometimes unpredictable nature of natural disturbances, so have often sought to implement control measures and prevent potential damage (Holling and Meffe 1996). However, in seeking to reduce or eliminate disturbance processes, ecosystems become less resilient over time and may even become more at risk to experiencing extreme events in the long term (White 1979, Holling and Meffe 1996). For example, throughout much of the 20th century, the U.S. Forest Service (USFS) enforced strict wildfire suppression policies, functionally removing this process from forests. However, doing so resulted in a buildup of fuels, which ultimately increased the risk of catastrophic wildfire (Dombeck et al. 2004).

Further, as human populations have expanded, landscapes have experienced broad-scale land use change; the expansion of agriculture and extraction of wood products and other resources from forests have had significant impacts on many landscapes. Due to a variety of past land management decisions and practices, many forestlands across North America are currently altered from their pre-European settlement conditions (Hermy and Verheyen 2007, Nowaki and Abrams 2008).

Although the idea of restoring altered or degraded lands has long been discussed, restoration ecology began to develop as a discipline in the 1980s (Davis and Slobodkin 2001). Restoration ecology is an applied science that can provide important tools for management of degraded lands (Dobson et al. 1997), often drawing on benchmarks from past ecosystem conditions to inform future goals (Swetnam et al 1999). In a world that is undergoing climate change and increased exurban development, setting these targets can be quite challenging for land managers, especially when accounting for the dynamic nature of ecosystems (Hobbs and Harris 2001). Circumstances may be unprecedented and context-specific; successes taken from one location may not always be applicable to another, making it difficult to draft guidelines or best management practices. Additionally, managers must weigh ecosystem restoration priorities with other land use or conservation policies and objectives. Despite these challenges, ecological restoration efforts provide an excellent opportunity to study ecosystem dynamics and relationships, which can contribute to foundational ecological knowledge, as well as aid managers in their future selection of strategies (Ehrenfeld and Toth 1997, Hobbs and Harris 2001).

This thesis presents two case studies, each addressing challenges to forest restoration efforts within fire-dependent ecosystems. The first case is a study of wildlife

use of standing dead trees conducted in a novel context. Standing dead trees (snags) are important components within forested ecosystems and are typically the products of natural disturbance (Franklin et al. 1987). Past studies in the western United States (U.S.) have sought to create snags to benefit wildlife as a part of broader restoration efforts; however, there are fewer studies on snag management in the Great Lakes region where there is opportunity to incorporate snag management into forest management practices on many public lands. The second case examines the decision making environment for managing an endangered species, the red-cockaded woodpecker (*Leuconotopicus borealis*; RCW), within the fire-dependent longleaf pine ecosystem of the Southeastern Coastal Plain. This region is of high priority for restoration, and RCW managers on public lands must consider federal and agency-specific policies to meet their goals for RCWs as well as any additional goals they may have to restore forest conditions on their lands. RCWs themselves are considered fire-dependent, so there is potential for overlap between these goals. In this case study, we learn from managers how they balance species-specific objectives with broader management goals.

In examining these cases, our goal was to provide insights that can inform discussions of restoration and conservation practices: in the Great Lakes region with snags and of endangered species management within the context of landscape-scale ecosystem restoration in the Southeast U.S.

Chapter 2: Wildlife Implications Across Snag Treatment Types in Jack Pine Stands of Upper Michigan

Introduction

Dead material serves numerous ecological functions and contributes to the overall structural complexity and biodiversity within forests (Harmon et al. 1986, Franklin 1988). For example, dying trees release resources such as light, nutrients, and moisture, providing structure and food resources for a wide range of taxa (Franklin et al. 1987). Diverse groups of fungi, plants, and animals utilize both standing dead trees (snags) or trees that have fallen to the forest floor (downed wood) (Boddy 2001, Jonsell and Weslien 2002, Jonsson et al. 2005, Lonsdale et al. 2008), further contributing to the decomposition of dead wood (Farris et al. 2004, Jackson and Jackson 2004). For instance, bark beetles (Scolytinae) are pursued by avian predators (e.g., Picidae) whose foraging and nest excavations further facilitate decomposition and other processes. Overall, understanding the dynamics of snags and downed wood can have important implications for management of forests and for associated wildlife (Farris and Zack 2005, Drapeau et al. 2009).

Within conifer forests of the Great Lakes region and boreal forests farther north, past management activities have, in some instances, homogenized stand structure and

diversity, with implications for resiliency within forest ecosystems (Bergeron et al. 1998, Perry 1998, Drever et al. 2006). Additionally, wide-spread fire suppression, combined with land use change has altered many forests. This has resulted in reduced complexity and diversity within forests relative to pre-European settlement conditions (Schulte et al. 2007, Tucker et al. 2016). When natural disturbances (e.g., fire) do occur, landowners, including managers on public lands, will often engage in salvage harvesting practices to recoup some of their financial loss (Lindenmeyer and Noss 2006). Removal of these biological legacies (features on the landscape left behind following a disturbance, such as snags) effectively removes would-be habitat for users of deadwood and alters ecosystem processes (Imbeau et al. 2000, Niemelä 1996, Lindenmeyer and Noss 2006).

Although forest management aimed at timber production has often been implicated in forest simplification, even forest management specifically directed at producing wildlife habitat may not include all of the structural features that would have been produced from natural disturbance regimes (Corace et al. 2010). For instance, jack pine (*Pinus banksiana* Lam.) stands on lands owned by the U.S. Fish and Wildlife Service (USFWS), USFS, and Michigan Department of Natural Resources (MDNR) are managed for the recovery of the endangered Kirtland's warbler (*Setophaga kirtlandii* Baird). Breeding habitat is primarily produced through clear-cutting mature stands of jack pine followed by artificial regeneration (hand or machine planting of jack pine seedlings) in an opposing wave pattern (MDNR et al. 2015). While these practices have been credited with contributing to population increases of this neotropical migrant songbird, these species-specific treatments have resulted in patterns of regeneration (Kashian et al.

2017) and levels of snags and downed wood that fall outside the natural range of variation (Spaulding and Rothstein 2009, Corace et al. 2010).

Following the development of the ecosystem management concept in the late 1980s (Robbins 2012), recommendations were made for greater retention of biological legacies in managed forests (Franklin et al. 1987, Harmon 2001, Dudley and Vallauri 2005, Jonsson et al. 2005, Mason and Zapponi 2015). Grumbine (1994) defined ecosystem management as "integrat[ing] scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term." This focus on ecological relationships and ecosystem integrity were important in that they shifted the focus from individual components of ecosystems to more broad scale ecosystem health. Within this framework, biological legacies, such as snags, were viewed as important features of ecosystems that provide greater structural complexity, improve ecosystem function, and ultimately increase overall biodiversity (Franklin et al. 2002, Lindenmayer and Noss 2006).

Tree Death and Decay

Processes associated with tree decay are complex and may be dependent on a variety of interacting factors. Decay processes often begin while a tree is still "living," with many trees becoming susceptible to fungi, pathogens, or insects prior to death (Boddy 2001). Franklin et al. (1987) described tree death as "an arbitrary point on a continuum;" while in some cases tree death appears sudden and the cause seems apparent (e.g., falling on a windy day), other less obvious factors may contribute to the probability

of such a sudden event occurring (e.g., suppression and resulting reduction in root strength).

Decay itself can occur in a variety of ways within a tree. Harmon et al. (1986) identified six unique types of tree decay: leaching (materials dissolving as water seeps into and through wood), fragmentation (the physical breaking apart of materials by gravity or biological organisms), collapse and settling (internal weakening, generally within material already fallen on the forest floor), seasoning (the shrinking or hardening of material upon drying), respiration (carbon loss by microbes), and biological transformation (material metabolized by microbes or invertebrates). These types of decay interact and depend on site-specific factors, such as temperature and moisture. For example, very low or very high water content within woody material can limit the activity of organisms. Moreover, while respiration and feeding activity often increases with temperature, activity may reach a threshold and drop off at especially high temperatures (Harmon et al. 1986). Such complex interactions make it difficult to pinpoint single causal factors to tree death and drivers of decay. However, in studying decay patterns across ecosystem types in the U.S., researchers have begun to tease apart these processes, noting differences in decay among tree species, tree characteristics, and the proximate causes of tree death (Morrison and Raphael 1993, Angers et al. 2010, Corace et al. 2013, Seedre et al. 2013).

Features such as bark thickness and snag diameter have been shown to influence the decay process in dead or dying trees. Previous work in eastern Upper Michigan found that there was a positive association between snag diameter and more advanced classes of decay (associated with breaking) in jack pine snags (Corace et al. 2013). Everett et al.

(2000) looked at snag decay across a wildfire chronosequence in Washington and found that snags smaller in diameter and of thinner-barked species (e.g., black spruce, *Picea mariana*) fell at slower rates than larger, thicker-barked species. This finding is not consistent across all studies, however, and within forests in the Sierra Nevada, larger diameter snags were found to remain standing longer following a fire (Morrison and Raphael 1993).

Proximate cause of tree death can influence the rate and manner in which a tree decays, as well as its effects on the surrounding environment (Franklin et al. 1987, Farris and Zack 2005). Past studies have examined tree decay in a variety of contexts following disturbances (Morrison and Raphael 1993, Angers et al. 2010, Corace et al. 2013). Morrison and Raphael (1993) looked at burned and unburned plots in the Sierra Nevada and found that snags created by fire fell more quickly than unburned snags. Corace et al. (2013) found categorical rates of decay classes were influenced by the cause of death (e.g., mechanical topping, mechanical girdling, or fire) in eastern Upper Michigan, with a greater percentage of girdled trees developing into more advanced classes of decay faster than snags created through other treatments.

Complex processes of tree decay can be difficult to tease apart; influential factors often interact and are subject to site-specific variables. The studies summarized above were varied in their design and context, so differing results are not unexpected. Despite sometimes contradictory findings, the cause of tree death, as well as individual snag characteristics, such as bark thickness and size, have been found to influence decay patterns, and these likewise influence the subsequent colonization of snags by subcortical insects and use by birds as foraging or nesting habitat. Variation in the effects of these

factors in different regions prompt further region-specific investigation in locations where such processes are less well-studied.

Snag Use by Insects

Saproxylic insects, or those insects that depend on dead or dying wood for part of their life cycle, utilize dead wood at various stages of decomposition (Howden and Vogt 1951, Jonsson et al. 2005, Saint-Germain et al. 2007). These insects vary widely in their life histories and many are host-specific, colonizing trees of a certain species or at a specific stage of decay (Byers 1995, Saint-Germain 2007). Bark and ambrosia beetles (Scolytidae) and woodborers (Cerambycidae, Buprestidae) leave behind observable features on a dead or dying tree as they complete their life cycles. The life cycle of a bark beetle generally consists of: 1) adults burrow into a host tree/snag to deposit eggs, 2) hatched larvae consume woody tissue, creating larval mines or galleries, 3) after pupation, adults emerge from the tree/snag through exit holes, then mate with other adults (Wood 1982). Ambrosia beetles undergo a similar life cycle, but are different in that when they burrow into a host tree, they cultivate and feed on fungi that grow within the galleries they create (Byers 1995). Both bark and ambrosia beetles usually target host trees that are recently dead or are declining in health (Wood 1982). Different from bark beetles, members of Cerambycidae and Buprestidae--commonly referred to as longhorn beetles and jewel beetles respectively--usually hatch from eggs laid within cracks or crevices on the surface of the tree. Once hatched, larvae then burrow into the tree to feed on woody tissues. Larvae develop and pupate within the tree before finally emerging as adults. Both species groups typically target weakened or recently dead trees (Linsely 1959, Evans et al. 2007).

In northern conifer forests of North America, these species are thought to proceed in a type of successional colonization consisting of two “waves” as described by Boulanger and Sirois (2007). The first wave occurs soon after death of the tree and is led by a subset of insects feeding on subcortical tissues and fungi as well as the insect predators of subcortical feeders. The second wave initializes when the snag falls to the forest floor, where a different subset of epigeic (crawling or growing on the surface of soil) species begins to use the material (Boulanger and Sirois 2007).

Insects may select a host tree for a variety of reasons. Some species of bark beetles, for instance, will begin colonizing healthy or weakened trees and do so through “mass attack”, using pheromones to attract other individuals to effectively bypass the trees’ defenses and girdle it (Byers 1995). Secondary bark beetle species, however, will bore into the tree after it has recently died and are likely attracted to monoterpenes or ethanol that is released by the dying tree, or they may come upon a suitable tree in a more random fashion (Byers 1995). Insects may also favor specific sections of a snag they colonize. Foit (2010) found that insect species assemblages within dead trees differed by height along the bole of the snag. Overall, species richness and diversity have been found to concentrate near the base of trees, with fewer species using tree tops or thin branches. These differences may be due to species preferences related to bark thickness and truck diameter (Saint-Germain et al. 2004, Foit 2010).

Forest disturbances that result in tree mortality provide feeding opportunities for saproxylic insects. The characteristics of a disturbance may influence the probability and longevity of a stand being occupied by snag-users. Some post-fire studies have found that severely scorched snags (particularly thin-barked species, such as black spruce) were

used less by saproxylic insects. The thought is that charred, thinner-barked species more readily lose bark and retain less moisture, which are not ideal conditions for many early-colonizing insect species (Saint-Germain et al. 2004). Wildland fires often produce a patchy mosaic of burn severities, resulting in affected trees progressing at different rates of decay within the same burn area. For example, trees within a less severely burned patch may experience a delay in mortality (or no mortality) compared to patches that were severely burned. This results in an extended period of insect use as snags reach their peak suitability for insects at alternating points in time (Nappi et al. 2010).

Snag Use by Wildlife

Snags are used by a variety of wildlife species. Some species of bats (Chioptera) roost in snags beneath exfoliating or loose bark (Foster and Kurta 1999). Other mammalian species such as flying squirrels (*Glaucomys* spp.) or black bears (*Ursus americanus*) are known to use cavities in decayed snags for nests or dens (Johnson and Pelton 1981, Holloway and Malcolm 2006). Additionally, herpetofauna benefit from the cover that dead material in forests provides; on snags, species may take refuge beneath loose bark, and when snags fall to the forest floor, this material becomes important shelter as well (Bull 2002).

While a variety of taxa benefit from snags, our study here focuses on species of birds that depend on snags for foraging habitat, for roosting (cover), for nesting, or for a combination of these uses. We focus here on two types of use: 1) use of a snag for a cavity (be it cover or nesting) and 2) use of a snag for foraging. While cavity-nesters include species that do not excavate their own cavities, of particular interest to this research are primary cavity-nesters, or those species that initiate the development of

cavities in trees or snags. Often, these primary cavity-nesters also forage for saproxylic insects present on and within snags and leave behind smaller and shallower foraging excavations in pursuit of insects present within the wood.

Likely cuing in on saproxylic insect abundance, many woodpeckers utilize snags along predictable patterns corresponding to tree decay (Farris and Zack 2005). Factors that may impact the utility of a snag for these species include mode of death, time since death, snag diameter, and level of decay or deterioration. Generally, studies have shown that cavity excavators preferentially target larger diameter trees that are “softer” or have experienced a certain level of heart rot (Conner et al. 1976, Lehmkuhl et al. 2003, Nappi et al. 2003, Farris and Zack 2005, Bagne et al. 2008). In the case of foraging however, snags may become less suitable after they are heavily deteriorated. In their foraging, birds also accelerate the breakdown of sapwood by mechanically breaking apart portions of the stem in search of insects, sometimes introducing fungi in the process. Indeed, wood-inhabiting fungi have been found on the bills of cavity-nesters at higher levels than the bills of non-cavity-nesting species (Farris et al. 2004). With time and further decay, the snag where foraging occurred previously becomes softer and more suitable for cavity excavation. In this way, woodpeckers foraging for sub-cortical insects may also be creating future nesting substrates.

Disturbances within forests often provide an influx of snags for wood-foraging and inhabiting birds. Syncing up with the colonization patterns of saproxylic insects, birds engage in much of their foraging activity within one to three years following a disturbance (Farris et al. 2002, Farris and Zack 2005). Similarly aligned with the findings of Saint-Germain et al. (2004) for bark beetles in black spruce, more severely burned

snags were found to be preferred less by woodpeckers for foraging, likely because this resulted in bark falling off and subsequent drying of the sapwood (Nappi et al. 2003). It should be noted, however, that certain species, such as the black-backed woodpecker (*Picoides arcticus*), have been found to target severely burned areas for foraging opportunities soon after fire (Hutto 2008).

Creating Snags to Benefit Wildlife

Past studies have examined potential approaches to incorporate snags into management for a broad range of objectives, including provision of wildlife habitat. Studies, primarily completed in western U.S. forests, have also assessed the artificial production of snags and how these treatments affect cavity-nesting species (quantifying woodpecker use). Snag creation methods assessed in this prior work include girdling snags, removing the tops of trees (topping), applying herbicide, inoculating trees with fungi, and sometimes a combination of these strategies (Bull and Partridge 1986, Chambers et al. 1997, Hallett et al. 2001, Brandeis et al. 2002, Shea et al. 2002, Filip et al. 2004, Arnett et al. 2010). Across these studies, some consistent findings have surfaced. For example, in conifer forests, snags that have had their tops removed by breaking or by mechanical removal have been shown to display accelerated rates of decay and subsequent greater use by cavity nesters compared with other tested treatments (Bull and Partridge 1986, Hallett et al. 2001, Filip et al. 2002, Lehmkuhl et al. 2003). In Oregon, Bull and Partridge (1986) concluded that out of six methods of creating snags, including girdling, girdling with fungal inoculation, topping with a chainsaw, topping with dynamite and fungal inoculation, herbicide, and insect pheromones, trees topped with a chainsaw were most frequently used by cavity nesters for foraging and nesting

while also having the lowest fall rates. It is thought that through topping or breaking, a large cross-section of the tree is exposed to fungi and bacteria that then becomes saturated with water leading to further decay (Hallett et al. 2001, Jackson and Jackson 2004). In contrast, mechanical girdling has resulted in snags that are generally in a lesser stage of decay when compared with other treatments (Bull and Partridge 1986, Parks et al. 1999, Hallett et al. 2001, Shea et al. 2002). Hallett et al. (2001) compared girdling versus topping trees and subsequent use by cavity nesters and found that after seven years, none of the girdled snags had cavities while cavities were noted on topped snags within three years.

Objectives

In sub-boreal, mixed-pine ecosystems of the Great Lakes region, snag decay processes and wildlife responses to the same have been less well studied than elsewhere. Corace et al. (2013) evaluated decay rates of snags that were created by girdling, topping, and prescribed fire, which provided an important first step in understanding snag decay processes in this region; however, the effects of snag creation treatments on wildlife have yet to be evaluated. Moreover, recent proposals to list the northern long-eared bat (*Myotis septentrionalis*) and other bat species that utilize snags under the *Endangered Species Act* have heightened the need for research that investigates snag management in this region within an ecological context. The goal of this chapter is to build upon previous research from the Great Lakes region and inform future snag management in this region. Specifically, we address the following questions:

1. How do snag characteristics associated with decay patterns and environmental variables differ across snag treatment types in jack pine-dominated forests of Upper Michigan?
2. How does accumulated woodpecker use relate to these environmental, insect, and decay variables?

Understanding the interactions between snag decay, insects, birds, and the environment can contribute to better understanding the outcomes of restoration treatments that aim to retain biological legacies and provide complexity in mixed-pine forests, while accounting for multiple wildlife taxa that may use snags.

Research Methods

Study Site

Seney National Wildlife Refuge (SNWR) is located in the eastern Upper Peninsula of Michigan (46.288069, -85.945192). A priority of management for SNWR is the restoration of fire-dependent mixed-pine ecosystems historically dominated by red pine (*P. resinosa* Ait.) and white pine (*P. strobus* L.) (Corace et al. 2009, USFWS 2009, Nyamai 2013). Proximity to the Great Lakes influences the local climate; winds are typically from the southwest to the northwest, the area experiences 81 cm of annual precipitation on average with the average daily humidity 50-60% (USFWS 2003a). Temperatures typically range from -14 to 26 degrees Celsius (MRCC 2017). Intensive logging and subsequent wildfires outside of the natural range of variation altered the structure and composition of these forests starting in the late 19th century (Drobyshev et al. 2008a). Currently, these forests are dominated by jack pine and deciduous species

(Drobysheve 2008b, Corace et al. 2012). Land managers have used several methods to produce snags in jack pine-dominated stands receiving restoration treatments (Nyamai 2013).

Creation and Selection of Snags

In this study, snags used by Corace et al. (2013) were re-analyzed. In brief, snags were created mechanically in two stands that were harvested, and in an additional stand during a prescribed fire. For mechanical treatments, trees were “topped” or “girdled” with logging equipment. Most created snags were jack pine as this was the tree species primarily targeted for harvest. Sampled snags were scattered throughout each stand; on average spaced 28.6 m (±38.4 m) between sampled snags in the topped treatment, 51.7 m (±30.2 m) in the girdled treatment, and 8.25 m (±4 m) in the fire treatment. Snags created through mechanical treatment were selected for creation prior to timber harvest and were spaced to allow mechanized equipment to move about the stand unimpeded. The topping treatment was completed in 2004 and consisted of snags being cut at approximately 3 m in height (maximum height equipment was able to reach). The girdling treatment took place in 2007 and was performed by using a processor to scrape the bark off of the middle sections of trees. Lastly, the prescribed fire treatment took place in 2003, resulting in an area with high jack pine mortality. We address the differences in the timing of treatments in our methods of analysis. All stands studied were growing on the *Pinus strobus*/*Vaccinium angustifolium-Epigaea repens* habitat type of the soil classification of Burger and Kotar (2004).

Sampling Strategy

Based on the expected needs of cavity nesting birds, Thomas et al. (1979) defined a snag as > 10.2 cm in diameter and as > 1.8 m in height. These cutoffs were applied when sampling snags and live trees across our treatments. In 2014, 105 (n=35 per treatment) snags were sampled for woodpecker excavations, herein defined as any obvious penetration of the wood from either foraging or nest creation. In 2016, these same snags were sampled for past subcortical insect activity. From the girdled treatment, 35 jack pine snags were randomly selected from those documented and measured by Corace et al. (2013). From the topped treatment, 22 jack pine snags were selected from those previously measured. There were a limited number of previously sampled jack pine to include from this treatment (previous sampling included several different species) and so we sampled an additional 13 topped jack pine snags not previously measured but selected randomly within the treatment area. From the prescribed fire treatment, 29 jack pine and six red pine snags were sampled along a transect. Twelve sampling points were located every 10 m and at each location, three of the closest snags to the transect were sampled. We chose to include six red pine snags due to the limited number of jack pine snags available for sampling within this fire treatment area. In 2016, we also measured 35 live jack pine trees for comparison purposes in a separate jack pine-dominated forest stand at SNWR and sampled trees at three different distances (20 m, 40 m, and 60 m) from a forest road at intervals of 161 m.

Measurements

In June and July of 2014, diameter at breast height (DBH) and snag height (m) were collected from snags within each of the three treatment groups. If woodpecker

excavations were present, these were documented with photographs. Height from the ground and the dimensions (height, width, depth) of each excavation were measured. When excavations were inaccessible due to the height on the snag, these values were estimated. Later on, photos and dimensions were reviewed to distinguish between cavity and foraging excavations. Determinations on which excavations could be considered potential cavities were made based on reported cavity characteristics of woodpeckers known to occur at SNWR (Table 1).

In June and July of 2016, these previously sampled snags were relocated using GPS coordinates and specific decay characteristics and effects of past subcortical insect activity were measured. Snag decay characteristic metrics were adapted from Angers et al. (2012) and included stem integrity (intact or broken), presence of dead leaves, twigs, and/or branches, total bark coverage expressed as a rough percentage (0-25%, 26-50%, 51-75%, or 76-100%), wood penetrability based on a four point scale. The wood penetrability ratings were based on how easily and far into the bole a knife blade could penetrate, ranging from one, the blade could not penetrate the bole, to four, there was no hard center and the blade could easily penetrate the bole with little resistance (Angers et al. 2012). This measurement was taken at breast height in the four cardinal directions, and then averaged for analysis. The same knife was used on each occasion and the same observer measured penetrability for each sample. The numbers of nearby snags and live trees (>10.16 cm DBH within a 0.01 ha circular plot) were also noted for each snag.

Insect entrance/emergence holes and galleries present beneath the bark and bark looseness were evaluated at three different heights: 0 m, 1.5 m, and 3 m. Not all snags were > 3 m in height, and in these cases only applicable heights were measured. At each

height, bark was removed from a 0.2 m long band all around the bole (Figure 1). If bark could be removed by hand with minimal effort, this was classified as “loose” and the proportion of loose bark to adhered bark was recorded. Adhered bark often required the use of a metal utensil to remove it from the bole. The number of entrance and emergence holes were counted within each band and galleries were assessed using methods modified from Flower et al. (2013); the research team placed a gridded transparent sheet over the area where bark was removed and recorded the number of 1-cm^2 grid cells containing a gallery. Live trees were sampled in 2016, measuring almost all of the same variables that were measured for the snag treatments, although bark was not removed from the trees.

	Reported cavity heights from ground (m)	Reported cavity entrance diameters (cm)	Reported cavity depths (cm)	Food Source						Relative abundance at SNWR**
				Verte-brates	Insects	Nuts/ Seeds	Fruit/ Berries	Sap	Wood	
Black-backed Woodpecker (*Picoides articus*)	2.7 - 11	3.3 - 4.4	21 - 41		X	X	X		X	Uncommon
Downy Woodpecker (*Picoides pubescens*)	4.7 - 13.5	2.5 - 3.8	15.2 - 30		X	X	X	X	X	Common
Hairy Woodpecker (*Picoides villosus*)	1 - 18.3	3.8 - 5.1	20.3 - 38.1		X	X	X			Common
Northern Flicker (*Colaptes auratus*)	1.3 - 11.4	6.45 - 8.3	14.9		X	X	X			Common
Pileated Woodpecker (*Dryocopus pileatus*)	13.1 - 35.3	8 - 12	47.6 - 60		X	X	X			Common
Red-headed Woodpecker (*Melanerpes erythrocephalus*)	7 - 12.4	5.6 - 5.9	14.3	X	X	X	X		X	Rare
Red-bellied Woodpecker (*Melanerpes carolinus*)	2 - 15	5.1 - 6.4 *	22 - 32	X	X	X	X	X		Rare
Three-toed Woodpecker (*Picoides dorsalis*)	5.2 - 7.7	3.8 - 4.7	24.1 - 30.5		X			X		Rare
Yellow-bellied Sapsucker (*Sphyrapicus varius*)	2 - 9	3.2 - 4.1	27		X	X	X	X	X	Common

Sourced from Birds of North America (2017) unless otherwise noted.
*Jackson (1976)
**Chartier et al. (2011)

Table 1. Woodpecker species (listed alphabetically by common name) known to be present at Seney National Wildlife Refuge, their reported cavity dimensions, and feeding habits. Relative abundance values are derived from a number of data sources, including Breeding Bird Atlas II data (Chartier et al. 2011) and refuge planning documents (USFWS 2009).

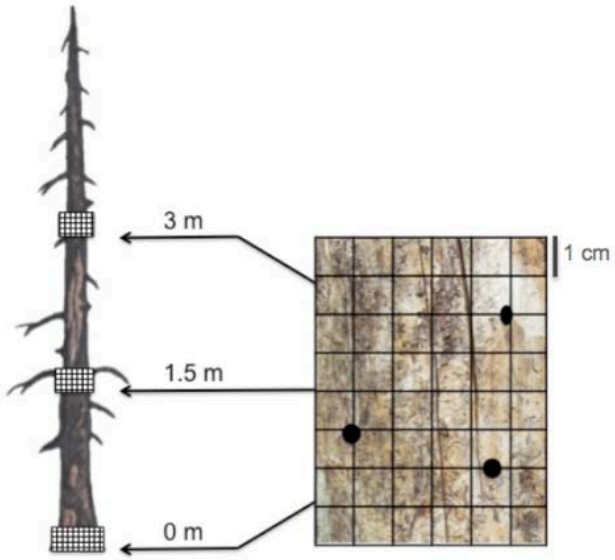

Figure 1. Sampling design for measuring past subcortical insect activity and bark looseness. Sections 20 cm long (vertically) were sampled at three heights on each snag/tree (0 m, 1.5 m, and 3 m). A transparency grid was used to assess gallery cover.

Data Analyses

Principal component analysis (PCA) was used to examine snag and insect variables among the three snag treatments. Eleven variables were included in this analysis, including presence of branches, presence of twigs, proportion of total bark cover, penetrability, number of nearby trees, number of nearby snags, snag diameter at breast height, average number of insect holes, average cover by insect galleries, average proportion of loose bark, and integrity of the snag. Live tree information was not included. The PCA was run using R package “stats” (R Core Team 2013).

While it is understood that decay processes are highly interactive and may be subject to multiple factors, we sought to tease apart some of the relationships between

snag decay across three treatments and their subsequent use by woodpeckers. To examine relationships among woodpecker use, insect use, and snag variables, an information theoretic approach to model selection (Burnham and Anderson 2002) was used to construct and rank candidate models looking at various insect and decay factors as predictors of the presence of cavities or the number of foraging excavations. An information theoretic approach is a model selection technique that commonly uses Akaike's Information Criterion (AIC) to compare candidate models. AIC is based on Kullback-Leibler distance and estimates the relative distance of a fitted model from the true (unknown) underlying mechanism(s) responsible for generating what is observed (Burnham and Anderson 2002). The process of using an information theoretic approach involves specifying hypotheses and constructing a set of hypothesized models based on the known information and relevant literature. The model with the lowest AIC is best supported by the data.

We chose to model foraging excavations and presence of potential cavities separately using two sets of candidate models representing multiple potential combinations of variables thought to influence the use of snags by woodpeckers, consistent with previous findings from the literature. When constructing models with multiple predictors, we did not include variables that were significantly correlated with one another (assessed using Spearman's rank correlation) within the same model. As many of the predictors were (unsurprisingly) inter-correlated, this prevented there from being one global model with all proposed predictors. Snag height was not included in any models for foraging or cavity nesting because height was predetermined by treatment (all topped snags were ~ 3 m in height; Corace et al. 2013). Similarly, time since treatment

was not used as a separate predictor variable because each of the three treatments took place in a different year, meaning that ultimately any treatment effects would be indistinguishable from time effects for a given year.

For modeling foraging excavations, previous research has shown that proximate cause of death can influence decay processes and thus cavity use by woodpeckers (Farris and Zack 2005). Additionally, because all of the woodpecker species present at SNWR may feed on subcortical insects (Table 1), insect activity was included as a predictor. Snag size and stand density are also known to influence colonization by subcortical insects (i.e., woodpecker prey) as well as excavation by woodpeckers (Saint-Germain et al. 2004, Farris and Zack 2005). In line with these findings, we included models representing each of these hypothesized causal variables separately, as well as combined models containing both snag size and insect activity as predictors (Table 2). Based on past studies of woodpecker use in pine-dominated ecosystems (e.g., Farris et al. 2002, Farris and Zack 2005), it was assumed that most insect colonization and bird foraging occurred within the first three years following treatment, when many of the decay variables measured in 2016 (integrity, bark cover, and penetrability) may not have yet developed. For this reason, decay variables were not included in the models of foraging excavations.

A similar method was used in determining the inclusion of predictor variables to model potential cavities. Previous work found that proximate cause of tree death affects the probability of a cavity being excavated in a particular tree/snag, as does wood softness or level of decay, size, and stand density (Petit et al. 1985, Parks et al. 1999, Lehmkuhl et al. 2003, Bagne et al. 2008). Additionally, colonization by insects and

previous foraging by birds is thought to facilitate the snag decay process and creation of suitable nest sites (Harmon et al. 1986, Farris et al. 2004). Considering this previous work, candidate models included variables representing treatment, size, decay, stand density, and previous insect or woodpecker foraging activity.

Foraging excavations were treated as count data and initially modeled using a Poisson distribution, however data were over-dispersed (variance is greater than the mean), and a negative binomial distribution was ultimately used instead. Negative binomial distributions are useful in modeling over-dispersed count data and include a dispersion parameter (Bliss and Fisher 1953). Presence of cavities was modeled using a binomial distribution.

Variable Type	Variable	Abbreviation	Definition	Predictor or Response (P/R)
TREATMENT	Treatment	Trtmt	Method of snag creation (fire, girdled, or topped)	P
SNAG SIZE	Diameter at breast height	DBH	Diameter of the bole of the snag at 1.37 m	P
STEM DENSITY	Nearby snags	NearSnags	The number of snags within 5.5 m	P
	Nearby trees	NearTrees	The number of live trees within 5.5 m	P
DECAY	Integrity	Integrity	Whether a snag was intact in 2016	P
	Total bark cover	BarkCover	Percentage of the bole covered in bark (within 25%)	P
	Penetrability	Penet	Wood density or "softness" measured on a four-point scale (1=least penetrable, 4=most penetrable)	P
INSECT ACTIVITY	Insect entrance/ emergence holes	Holes	Average number of insect entrance and/or exit holes present within the three sections of each snag or tree sampled	P
	Gallery cover	Galleries	Average number of 1-cm^2 cells intersected by an insect gallery	P
WOODPECKER ACTIVITY	Potential cavities	Cavity	Number of potential cavities present on a snag	R
	Foraging excavations	Forage	Number of foraging excavations present on a snag	P, R

Table 2. Response and predictor variables used in creating generalized linear models to predict woodpecker activity on standing dead trees. Foraging excavations was modeled as a response variable and was included as a predictor of potential cavities.

Results

Snag Characteristics

Notable differences in snag characteristics were found among treatments (Table 3). Snags were aggregated more densely in the fire treatment than in the other treatments, and there was a lower number of nearby live trees ($t=-3.01$, $p<0.01$). Snags within the fire treatment were the smallest in diameter on average (27.7 cm dbh ± 8.4). Bark retention within the fire treatment tended to be less, and the bark that was present on these snags was more adhered to the bole ($t=-4.52$, $p<0.01$). Girdled and topped snags had on average a greater number of nearby trees than nearby snags and lower snag density than the fire treatment ($t=6.10$, $p<0.01$). Topped snags were on average shorter than the other treatments ($t=-7.10$, $p<0.01$), but were also larger in diameter ($t=-3.98$, $p<0.01$). Notably, topped snags were on average the most penetrable of the treatments ($t=5.16$, $p<0.01$) while girdled snags were on average the least penetrable, even when compared to live trees ($t=-4.42$, $p<0.01$). Topped snags had an overall greater level of retained bark, and this bark was more loosely adhered to the bole ($t=3.88$, $p<0.01$) so could easily be removed with minimal effort. Total bark cover on girdled snags was in between the values for cover on fire and topped snags. Girdled trees retained very little bark at the middle section of the bole where machine girdling took place.

Differences in insect activity and woodpecker use were found among treatments as well (Table 4). Insect holes in all treatments were concentrated at lower heights on the bole (Figure 3), and foraging excavations were also more numerous at lower heights. The fire treatment had the greatest number of average foraging excavations per snag ($t=2.89$, $p=0.01$) as well as the greatest number of potential cavities (11). The topped treatment

had significantly higher numbers of entrance and exit holes and greater gallery cover than the other treatments ($t=2.22$, $p=0.03$). Foraging depth was also deeper on average for topped snags ($t=3.52$, $p=0.01$). There were three potential cavities found in topped snags. The girdled treatment had overall lower numbers of entrance and exit holes on the sections measured ($t=-4.02$, $p<0.01$) as well as less coverage by galleries ($t=-2.51$, $p=0.01$). Within the girdled treatment, lower numbers for holes and gallery cover were found on the middle section of the bole (1.5 m; Figure 3). The girdled treatment had the fewest foraging excavations ($t=-3.02$, $p<0.01$; not including live trees) and fewest potential cavities. Live trees measured for comparison purposes had very little evidence of past woodpecker or insect activity; no cavities were observed on live trees, only one live tree contained foraging activity, and five of the 35 sample trees contained entrance or exit holes within the sections sampled.

	DBH (cm)	Height (m)	Integrity		% Bark Cover	Penetrability (1-4)*	Trees (per ha)	Snags (per ha)
	Mean *(SD)*	Mean *(SD)*	Intact	Broken	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Girdled	30.2 *(5.6)*	7.4 *(3.9)*	7	28	48 *(24)*	1.7 *(0.4)*	183 *(144)*	31 *(53)*
Topped	33 *(3.6)*	3.4 *(0.3)*	0	35	53 *(27)*	2.2 *(0.5)*	180 *(197)*	26 *(56)*
Fire	27.7 *(8.4)*	5.6 *(3.0)*	7	27	40 *(29)*	1.8 *(0.4)*	82 *(151)*	200 *(160)*
Live	20 *(5.4)*	8.9 *(1.3)*	35	0	99 *(3)*	2.0 *(0.1)*	386 *(260)*	37 *(65)*

*four-point scale with 1 being the least penetrable and 4 being the most penetrable.

Table 3. Snag/tree characteristics 9-13 years post-treatment for three different methods of creating snags (girdling, topping, and fire) and for live trees sampled as a comparison.

	Foraging Excavations		**Average Foraging Depth (cm)**	**Potential Cavities**	**Entrance and Exit Holes (per cm^2)**	**Entrance and Exit Holes (per cm^2) by Size**			**Gallery Cover (per cm^2)**
	Total	Mean *(SD)*	Mean *(SD)*	Total	Mean *(SD)*	# Small <0.2mm Mean *(SD)*	# Medium 0.2-0.5mm Mean *(SD)*	# Large >0.5mm Mean *(SD)*	Mean *(SD)*
Girdled	152	4.3 *(8.0)*	2.27 *(1.22)*	2	0.02 *(0.03)*	0.01 *(0.01)*	0.01 *(0.01)*	<0.01 *(<0.01)*	0.05 *(0.04)*
Topped	252	7.2 *(11.1)*	3.86 *(1.67)*	3	0.08 *(0.06)*	0.05 *(0.03)*	0.02 *(0.01)*	0.01 *(<0.00)*	0.09 *(0.05)*
Fire	546	16.1 *(19.7)*	2.46 *(1.01)*	11*	0.03 *(0.02)*	0.01 *(0.01)*	0.01 *(0.01)*	<0.01 *(<0.01)*	0.07 *(0.08)*
Live	23	0.7 *(3.9)*	0.71 *(1 tree)*	0	<0.01 *(<0.01)*	<0.01 *(<0.01)*	<0.01 *(<0.01)*	<0.01 *(<0.01)*	0 (0)

*Cavities were found in 5 snags, two of which were red pines.

Table 4. Evidence of past activity left on snags/trees by woodpeckers and subcortical insects 9-13 years post-treatment for three different methods of creating snags (girdling, topping, and fire) and for live trees sampled as a comparison.

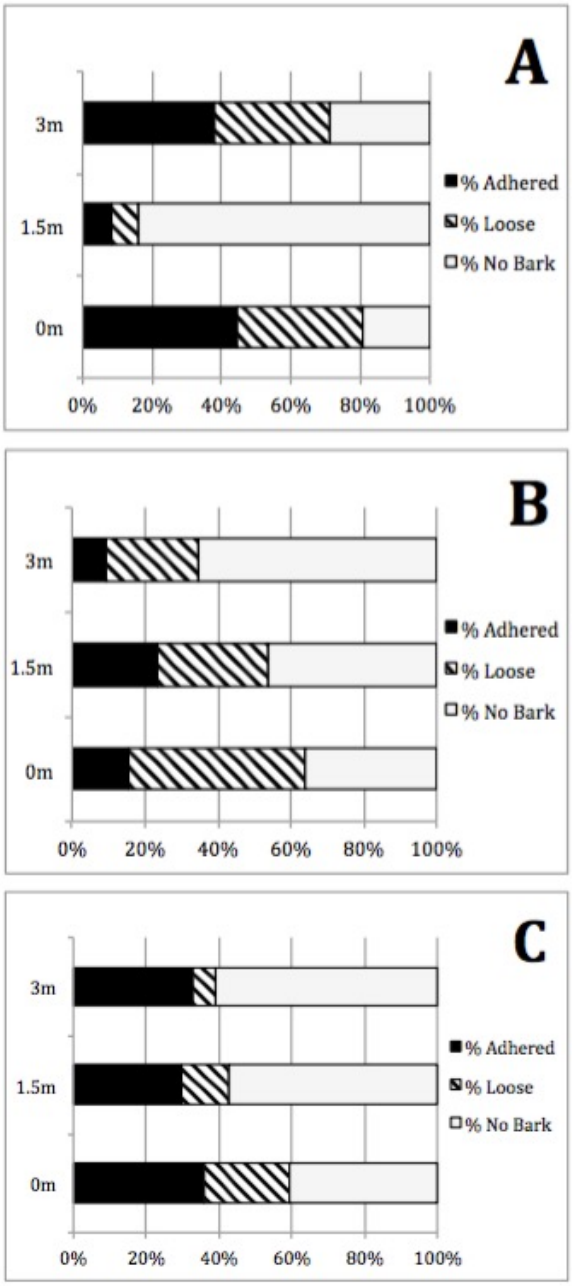

Figure 2. Percentage of adhered bark, loose bark, and no bark on sections sampled at three heights (0m, 1.5m, 3m) on standing dead trees that were created by girdling (A), topping (B), or burning (C).

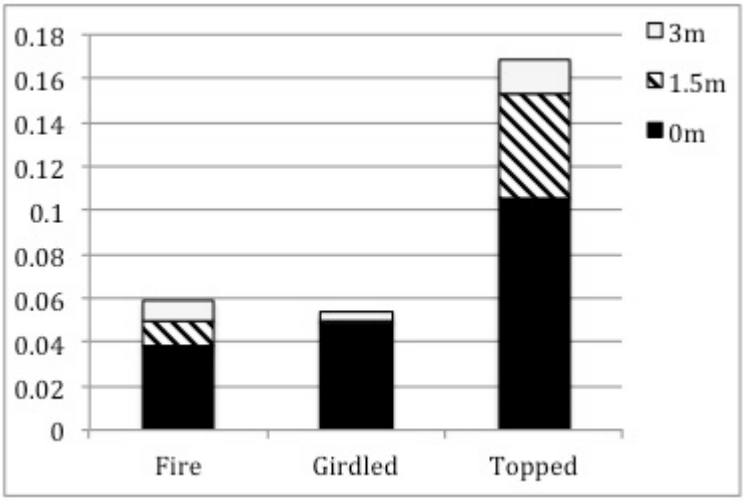

Figure 3. Average subcortical insect entrance and exit holes per cm^2 on sections sampled at three heights (0m, 1.5m, 3m) on standing dead trees that were created by fire, girdling, or topping.

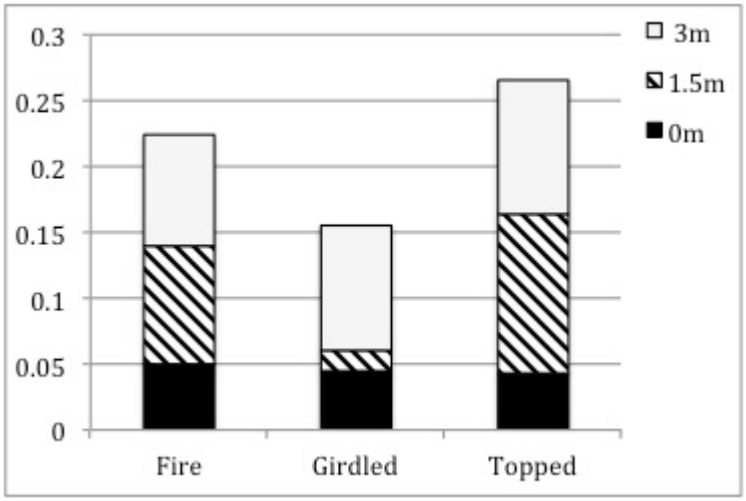

Figure 4. Average subcortical insect gallery cover per cm^2 on snags among three treatments on sections sampled at three heights (0m, 1.5m, 3m) on standing dead trees that were created by fire, girdling, or topping.

Principal Components Analysis

The first three principal components (PCs) cumulatively described 49% of the variance within the data. The first two PCs described 35% of the total variance within the data, with both the second and the third PCs describing near equal amounts of the variance; approximately 14%. For this reason, the third PC was investigated in addition to the first two PCs. In doing this analysis, we hoped to describe any existing gradients in the characteristics measured and to see where each particular snag creation treatment fell along these gradients.

Based on factor loadings, the first PC was most represented by a mix of decay and insect use variables, including: presence of fine twigs on as snag, by the number of insect holes present, and to a lesser degree penetrability, percentage of loose bark, and cover by insect galleries (Table 5). Along this axis, there is also clear separation between the topped treatment and the fire and girdled treatments (Figures 5 and 6). Vectors for penetrability, loose bark, and insect use all appear to be more associated with topped snags, while vectors for presence of fine twigs, branches, and integrity are more associated with the fire and girdled snags, which show a high degree of overlap. Overall, this indicates that topped snags were softer and had been more heavily used by insects.

The second PC was most represented by presence of branches and total bark cover (Table 5), however, there appears to be less clear separation in multivariate space between treatments (Figures 5 and 7). The third component is represented primarily by snag DBH and the number of nearby snags (Table 5), variables that are specific to individual characteristics and spatial arrangement of snags. Along this axis, there appears to be some separation of the fire treatment from the other two treatments (Figures 6 and

7). Vectors for snag density and snag DBH were oppositely oriented along this axis, indicating that the denser the aggregation of snags, the smaller in diameter snags tended to be (Figure 6). Along this axis, vectors for insect gallery cover and snag density also appear to be closely aligned with one another (Figure 7), and fire snags tended to be more densely aggregated and more covered by galleries within the sections sampled.

In summary, treatments differentiated the most along the first and third components, with the topped treatment separating based on presence (or absence) of twigs, insect holes, and penetrability and the fire treatment separating based on snag DBH and snag density. There appears to be a high degree of overlap between the girdled treatment and fire treatment along the first axis, overlap among all treatments along the second, and overlap between the girdled and the topped treatment along the third. Overall, this means the girdled treatment seems to more closely resemble the fire treatment in terms of decay variables, such as penetrability, and insect use. In terms of the spatial arrangement with other snags and diameter, however, girdled snags more closely resemble the topped snags.

Component Loadings			
	1	**2**	**3**
Branches	0.28	-0.51	
Twig	0.42	-0.37	
Penet	-0.34	-0.38	
Integrity	0.29		0.30
DBH			0.61
Loose Bark	-0.33	-0.31	
Bark Cover	-0.21	-0.48	-0.34
Nearby Snags	0.22	0.26	-0.48
Nearby Trees	-0.18		-0.16
Holes	-0.45		0.20
Galleries	-0.32	0.21	-0.32

Table 5. First three component loadings for each variable from a principal components analysis of characteristics and subcortical insect use of standing dead trees created using one of three methods: girdling, topping, or fire**.**

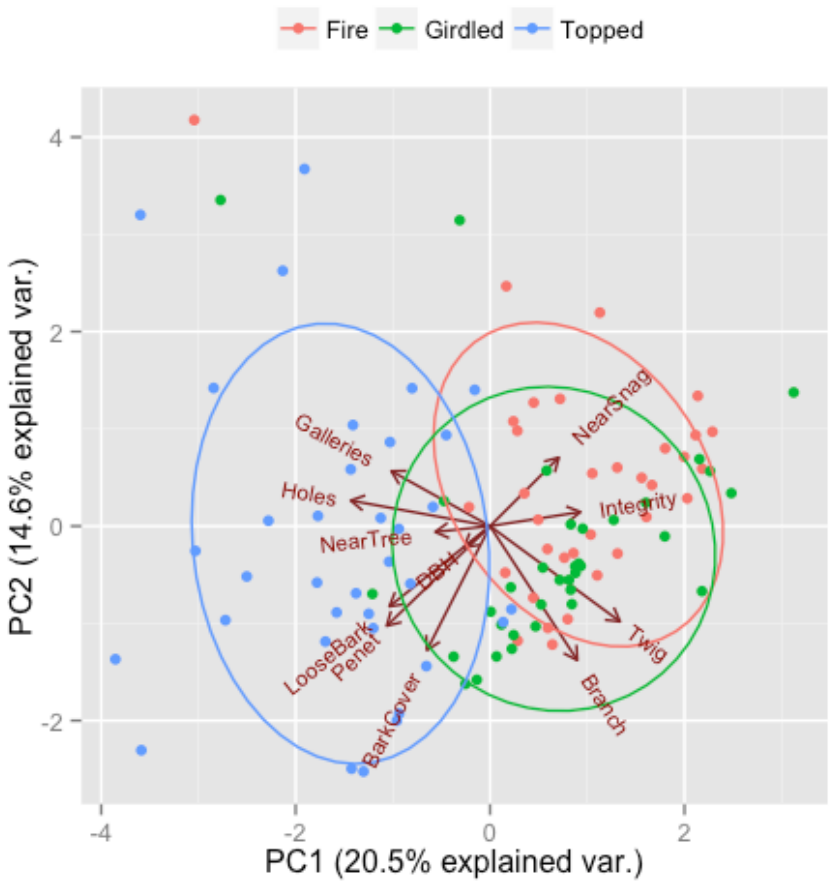

Figure 5. The first two principal components resulting from an ordination of the characteristics and subcortical insect use variables collected from standing dead trees (snags) created using one of three methods: girdling, topping, or fire. Vectors indicate the degree to which snag characteristics and subcortical insect use variables are associated with the data. Normal probability ellipses correspond to each treatment.

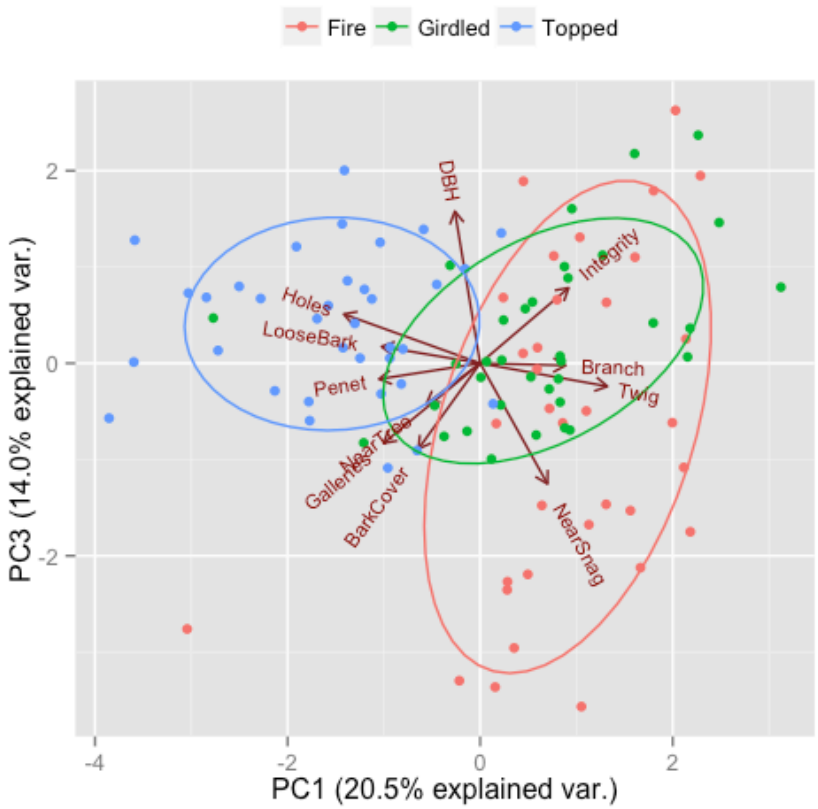

Figure 6. The first and third principal components resulting from an ordination of the characteristics and subcortical insect use variables collected from standing dead trees (snags) created using one of three methods: girdling, topping, or fire. Vectors indicate the degree to which snag characteristics and subcortical insect use variables are associated with the data. Normal probability ellipses correspond to each treatment.

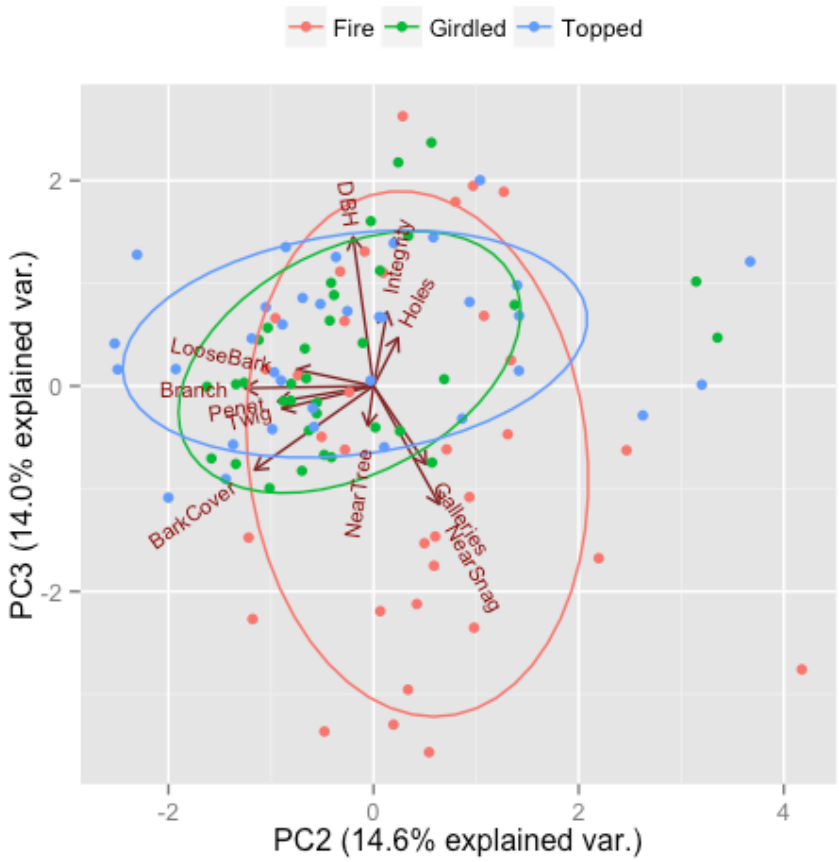

Figure 7. The second and third principal components resulting from an ordination of the characteristics and subcortical insect use variables collected from standing dead trees (snags) created using one of three methods: girdling, topping, or fire. Vectors indicate the degree to which snag characteristics and subcortical insect use variables are associated with the data. Normal probability ellipses correspond to each treatment.

Generalized Linear Models

A comparison of candidate models indicated that for foraging activity, indicator variables for treatment had the greatest support as a predictor, with Akaike weights indicating that the model only including treatment variables was 25.46 times more likely than the next highest ranked model (NearSnags, Table 6). The estimated response of foraging activity from the fire treatment was nearly twice that of the response from the

girdled treatment (Table 8); the topped treatment foraging response was higher than that of the girdled treatment, but not at a significant level (p=0.13).

In comparing candidate models for potential cavities, a combination of foraging activity and DBH as predictors had the greatest support (Table 7). Both had significant effects on the potential presence of a cavity on a snag across treatments (Table 9). For example, if foraging activity was to increase on a snag by one excavation, the odds of there being a potential cavity on that snag would increase by about 8% with size held constant. Considering size, for every centimeter increase in DBH, the odds of a potential cavity would increase by about 75% (with foraging activity held constant).

Predictor Type	Predictors	K	AIC_C	Δ AIC_C	w.AIC_C
TREATMENT	Trtmt	4	645.56	0.00	0.92
INSECT ACTIVITY	Holes	3	654.95	9.39	0.01
	Galleries	3	657.37	11.82	0.00
SNAG SIZE	DBH	3	654.89	9.33	0.01
STEM DENSITY	NearSnags	3	652.01	6.45	0.04
	NearTrees	3	657.91	12.36	0.00
	NearSnags + NearTrees	4	654.25	8.69	0.01
COMBINATIONS	DBH + Holes	4	654.73	9.17	0.01
	DBH + Galleries	4	656.31	10.75	0.00

Table 6. Comparison of candidate generalized linear models predicting the number of foraging excavations in snags among three snag creation treatments: girdling, topping, and fire. Data were modeled with a negative binomial distribution. Model predictors, number of parameters (K), Akaike's Information Criterion (corrected for smaller sample sizes), AIC_C rescaled from the lowest score (Δ AIC_C), and Akaike weights (w.AIC_C) are listed for each model.

Predictor Type	Predictors	K	AIC_C	Δ AIC_C	w.AIC_C
TREATMENT	Trtmt	3	70.73	15.79	0.00
SNAG SIZE	DBH	2	65.21	10.27	0.01
STEM DENSITY	NearSnags	2	67.36	12.42	0.00
	NearTrees	2	70.05	15.12	0.00
	NearSnags + NearTrees	3	69.59	14.65	0.00
DECAY	Integrity	2	67.97	13.03	0.00
	Penet	2	70.08	15.14	0.00
	Bark Cover	2	70.09	15.16	0.00
INSECT ACTIVITY	Holes	2	69.54	14.60	0.00
	Galleries	2	69.59	14.65	0.00
FORAGING ACTIVITY	Forage	2	63.38	8.44	0.01
COMBINATIONS	Forage + DBH	3	54.94	0.00	0.93
	Forage + Bark Cover	3	65.64	10.70	0.00
	Forage + Integrity	3	63.93	8.99	0.01
	Forage + Galleries	3	65.14	10.20	0.01
	Forage + Holes	3	65.53	10.60	0.01
	DBH + Holes	3	66.77	11.84	0.00
	DBH + Galleries	3	67.10	12.16	0.00
	DBH + Bark Cover	3	67.20	12.27	0.00
	DBH + Penet	3	67.46	12.53	0.00
	DBH + Integrity	3	64.12	9.18	0.01
	NearSnags + Integrity	3	67.54	12.61	0.00
	NearSnags + Penet	3	69.53	14.60	0.00
	NearTrees + Integrity	3	70.12	15.18	0.00
	NearTrees + Penet	3	72.30	17.36	0.00
	NearSnags + NearTrees + Integrity	4	69.75	14.81	0.00
	NearSnags + NearTrees + Penet	4	71.86	16.92	0.00
	BarkCover + Holes	3	71.80	16.87	0.00
	BarkCover + Galleries	3	71.81	16.87	0.00

Table 7. Comparison of candidate models predicting potential cavities using logistic regression in snags among three snag creation treatments: girdling, topping, and fire. Predictors, parameters (K), Akaike's Information Criterion (AIC_C , corrected for smaller sample sizes), AIC_C rescaled from the lowest score (Δ AIC_C), and Akaike weights (w.AIC_C) are listed for each model.

	Estimate	SE	z-value	p-value
Intercept	1.47	0.24	6.11	<0.01
Fire	1.31	0.34	3.90	<0.01
Topped	0.51	0.34	1.51	0.13
Null deviance: 133.55 on 103 degrees of freedom				
Residual deviance: 117.67 on 101 degrees of freedom				

Table 8. The effect of snag creation treatment type on predicting the number of foraging excavations on snags modeled using a negative binomial distribution.

	Estimate	Odds Ratio	SE	z-value	p-value
Intercept	-10.64		3.09	-3.45	<0.01
Forage	0.08	1.08	0.02	3.33	0.01
DBH	0.56	1.75	0.20	2.77	0.01
Null deviance: 65.842 on 103 degrees of freedom					
Residual deviance: 48.415 on 101 degrees of freedom					

Table 9. The effect of woodpecker foraging excavations and snag diameter on predicting the presence of potential cavities on snags using logistic regression.

Discussion

The goal of this study was to identify unique characteristics in the decay patterns among three snag creation treatments as well as describe their use by wildlife, specifically, woodpeckers. In the following sections, we discuss decay characteristics that were specific to each treatment, the factors found to be important to predicting woodpecker foraging and cavity creation, and the limitations of this study.

Decay Characteristics

Different snag treatments produced unique combinations of decay characteristics. Particularly distinct were snags from the topped treatment as they differed significantly in

terms of colonization by insects and their level of penetrability compared with the other two treatments. These results further substantiate studies from conifer forests of the western U.S. that observed differences in decay development for trees killed by topping. These studies have found that topped snags experience an accelerated rate of decay and die more quickly, particularly when topped below the crown (Bull and Partridge 1986, Hallett et al. 2001, Filip et al. 2004). Topping creates a flat exposed surface on the stem that can more readily collect moisture, creating a suitable environment for microbes and fungi to penetrate the tree and accelerate decay (Harmon et al. 1986). Additionally, topped snags were found to be more heavily used by insects and this may have facilitated the breakdown of woody tissues within the stem and allowed further access to the interior of the tree by other microbes and organisms (Harmon et al. 1986).

Decay of girdled snags also progressed differently than those from the other treatments. These snags were in general harder and less penetrable (than even live trees) and were less heavily used by insects and woodpeckers. While girdled snags had three to four less years to develop than topped or prescribed fire snags, girdled snags showed observable treatment effects from the girdling process. Girdling was done midway up each bole during treatment and these middle sections had very little remaining bark and very little past insect activity or woodpecker foraging activity. Thus, scraping the bark in this way may have resulted in higher rates of drying within this section on the bole. As wood dries, cells shrink, and as moisture is lost, there is generally a decrease in plasticity of the wood (Panshin and de Zeeuw 1980). Adjacent cells drying at different rates can create points of tension, and it is possible that this contributed to the increased rate of snapping of girdled snags at Seney NWR that was observed by Corace et al. (2013).

Further supporting this idea, Hallett et al. (2001) also found that girdled snags broke at faster rates compared to topped snags.

The prescribed fire treatment was unique in that it resulted in a higher density of snags than was seen in the mechanical treatments, in which snags were less concentrated. The prescribed fire itself was of mixed severity; there was high (>70%) mortality of jack pine trees, with many (70%) red pine trees remaining alive post-fire (Weiss/Corace pers. obs.). Snags within this treatment had levels of penetrability between those for the topped and girdled snags. These snags also had less total bark cover overall, but that remaining bark was more adhered to the tree. Fire severity has been shown to affect snag use by insects and woodpeckers in past studies, with snags produced by high severity fires often experiencing lower levels of use by insects and woodpeckers due to the drying that occurs when the bark falls off (Nappi et al. 2010). While bark cover was still lower for this treatment than for the others, the wood remained relatively penetrable, with an average penetrability rating only slightly lower than what was observed in live jack pine trees. Burned snags also experienced greater insect use than that observed in the girdled treatment. Some species of subcortical insects (e.g., *Monochamus scutellatus*) almost exclusively colonize recently killed trees, and are thought to detect chemicals released from injured or dying trees (e.g. monoterpenes, ethanol; Chénier and Philogène 1987). The density of the burned snags within the treatment area may have especially drawn these species in soon after the fire to take advantage of the abundant food resource.

Woodpecker Use

Snag creation treatment was an important predictor of foraging activity, with the model containing the treatment variable ranked higher than models containing insect

variables. This is contrary to what one might expect if woodpeckers were specifically targeting foraging trees based on subcortical insect abundance. Despite topped trees having the highest levels of insect use, this did not coincide with the highest rate of foraging, indicating that woodpeckers were selecting foraging location based on additional environmental cues. This would be consistent for a species such as the black-backed woodpecker, a known post-fire specialist that shows a strong preference for recently burned forest stands (Nappi et al. 2010). When fires occur, it is posited that the influx of subcortical insects into burned areas largely drives this preference (Nappi et al. 2003, Nappi et al. 2010). Though black-backed woodpeckers are cited as an uncommon species at SNWR (Table 1), past work by Youngman and Gayk (2011) have noted their irruptive nature and high population density following high severity fire in pine-dominated ecosystems of eastern Upper Michigan.

When examining the presence of potential cavities on snags, tree size (DBH) was an important predictor, and this was consistent with other studies that have found larger snags to be preferred by cavity nesters (Parks et al. 1999, Lehmkuhl et al. 2003, Farris and Zack 2005). Past foraging activity was also a significant predictor of cavity presence in the top ranked model, though the reasons for this pattern are not clear. It could be that birds returned to previous foraging sites when seeking a nest tree to excavate, though there is no way to know if the same birds responsible for foraging on trees also excavated cavities on those same trees. This trend could also have been driven by the high number of cavities within the fire treatment, which also had the greatest level of foraging activity. Woodpeckers may have targeted characteristics present at the fire site or specific to fire-created snags. Black-backed woodpeckers are known to nest in recently burned areas of

eastern Upper Michigan (Youngman and Gayk 2011), so it is possible that birds responsible for the high level of foraging within the prescribed fire treatment were also responsible for the potential cavities observed. Past studies found that cavity nesters more frequently used snags created by topping than other artificial means of creating snags, such as girdling (Bull and Partridge 1986). Three potential cavities were found in the topped treatment for this study, though it is possible that some species may have been deterred from excavating cavities in the topped treatment based on snag height being limited to 3 m (Table 1).

Snag Utility Across Wildlife Taxa

Although the focus of this study was to evaluate observable evidence of past use by woodpeckers and subcortical insects, observations of decay characteristics across treatments may also be useful in evaluating the utility of such treatments to other wildlife (Table 10). For example, species that shelter beneath bark or in crevices of trees, such as bats or even anurans (Foster and Kurta 1999, Bull 2002), would likely find treatments where bark is more likely to be retained following death (topping) most beneficial. Species that rely on dead material on the forest floor as cover, such as small mammals (Maser et al. 1979), would likely benefit more from a treatment that resulted in stem breakage soon after tree death and downed woody material that is more sound and resistant to decay (girdling). Summarized in Table 10 are some of the potential benefits of each treatment for different vertebrate taxa.

Treatment	Major Snag Characteristic(s)	Implications for Birds	Implications for Mammals	Implications for Herptofauna
Girdled	➢ Low bark retention at site where girdling occurred ➢ Low penetrability ➢ Prone to breaking ➢ Lowest level of colonization by subcortical insects	Of all three treatments, this may be the one with the lowest snag value for cavity-nesting birds. Low penetrability and insect use may preclude much use by woodpeckers. Nonetheless, for perching species (e.g., raptors) the soundness of wood may be useful.	As a snag, they are unlikely to have high value for mammals relative to other treatments. Due to the soundness of the material, however, this treatment may yield long-lasting coarse wood material benefiting small mammals as cover over time.	As a snag, they are unlikely to have much value relative to other treatments. Due to the soundness of the material, however, this treatment may yield long-lasting coarse wood material benefiting herptofauna as cover over time.
Topped	➢ High bark retention ➢ Greater proportions of loose bark ➢ High penetrability ➢ Most heavily colonized by subcortical insects	Use by insects and woodpeckers is relatively high. Decay and wood softness resulting from this treatment may benefit secondary cavity-nesters.	Possibly high value for bats (Chioptera) due to high bark retention. Combined with high degree of insect use and penetrability, may provide feeding sites and cover for rodents as well.	Possibly high use by herptofauna due to high bark retention. Two green snakes (*Opheodrys vernalis*) and one tree frog (*Hyla* spp.) were observed beneath the bark of topped snags during the course of this study.
Prescribed Fire	➢ Low bark retention ➢ Greater adherence of remaining bark ➢ Penetrability similar to that of live trees ➢ 2nd most colonized by subcortical insects	As other studies show and this study further supports, this treatment is likely preferred (or necessary) for some species of woodpeckers.	In terms of amount of bark present, possibly lower use by bats and mammals in short-term. However, over time the remaining bark may become less adhered and provide microclimatic conditions and cover for bats and small mammals.	In terms of amount of bark present, possibly lower use by herptofauna in short-term. However, over time the remaining bark may become less adhered and provide microclimatic conditions and cover.

Table 10. Potential implications for multiple wildlife taxa of the Great Lakes region of creating standing dead trees (snags) using one of three methods (girdling, topping, or fire) based on the major snag characteristics that were associated with each treatment type at Seney National Wildlife Refuge, MI.

Limitations

There are several limitations to consider when interpreting the results presented here. First, due to the nature of the study being opportunistic, each treatment was confined to a specific area of the SNWR, and we did not have the opportunity to replicate these treatments at multiple locations. Site effects may have contributed to the observed treatment effects, although site characteristics were relatively uniform across treatments; soil type, topography, and site history were all consistent. Second, each treatment took place in a different year, so we were not able to account for time since treatment as a variable in our models. There was a difference of three to four years between the girdled treatment and the other treatments. However, since we assume that most of the foraging and insect activity would have likely occurred within three years of tree death (Farris et al. 2002, Farris and Zack 2005), we do not anticipate that this would have affected the results of our model for foraging. There were also observable effects of the treatments that could be traced back to the manner in which the treatment took place, in particular girdling (e.g., the lack of woodpecker or insect activity on the middle section of the tree) that likely affected the decay process, regardless of time since treatment. Lastly, this study focused primarily on jack pine snags. Snags in mixed-pine ecosystems of the Great Lakes region have been found to exhibit species-specific decay rates (Corace et al. 2013), so our results may not hold true for other species, particularly deciduous species. However, given that jack pine was a target species for harvest in the restoration treatments that prompted this study, insights on snags of this species will be useful to land managers faced with similar situations in the region.

Conclusions

This study contributes region-specific knowledge on wildlife use of snags, providing an important step towards understanding decay processes, wildlife-snag interactions, and potential snag management options within Great Lakes jack pine forests. Biological legacies, such as snags, play an important role in ecosystem restoration. Great Lakes forest mangers seeking to restore altered ecosystems and manage for the benefit of multiple taxa and species may desire to incorporate these features in their restoration treatments. One potential application of this knowledge is in northern Michigan jack pine managed for the Kirtland's warbler. Current management practices to promote Kirtland's warbler breeding habitat commonly consist of harvesting and replanting jack pine in an opposing wave pattern, meant to emulate the historic stand-replacing fires that were once historically typical to the region (MDNR et al. 2014). This intensive mechanical management, however, has been shown to simplify habitat structure, with resulting plantations differing from those originating following fire in overall regenerating stem density, and patchiness (Kashian et al. 2017), and the amount, spatial configuration, and longevity of biological legacies (Spaulding and Rothstein 2009, Corace et al. 2010, Kashian et al. 2012). Therefore, there may be opportunities for managers to consider incorporating snag treatments into their jack pine plantation management.

It is important to consider that different methods of creating structures, such as snags, result in differing subsequent decay processes, so use by target species will likely vary depending on the treatment chosen. It appears that girdling jack pine snags did not result in snag characteristics that were as favorable to subcortical insects and woodpeckers for feeding and nesting. In previous work at SNWR, these girdled snags

were also shown to be more prone to breaking within four years following treatment (Corace et al. 2013). It is important to consider that some specialist species may have other ways of identifying quality foraging and breeding habitat beyond the presence of dead trees alone. The topping treatment appears to provide some of the preferred characteristics by subcortical insects and woodpeckers; future study is needed to see if taller topped snags might result in a higher rate of cavity excavation by woodpeckers. Beyond use by insects and woodpeckers, snags are also known to provide important habitat features for mammals and herpetofauna (Table 10). Knowledge of the decay characteristics that result from snag creation treatments and how they may affect various taxa can be useful for managers when considering snag treatment options that align with their management objectives.

Chapter 3: Aligning Endangered Species Management with Ecosystem Restoration: Manager Perspectives on Red-cockaded Woodpecker Conservation

Introduction

The US Congress passed the *Endangered Species Act* (hereafter, ESA) in 1973 with the goal of providing the means to conserve threatened and endangered species (16 U.S.C. Sec. 2(b)). Achieving this goal has at times proven to be difficult and the ESA has come under criticism for a variety of reasons. Some have criticized the ESA for encouraging a single-species approach to conservation, with emphasis on conserving parts of ecosystems, namely individual species, rather than those systems as a whole (Barnes 1993, Corace et al. 2010, Benson 2012). This critique points to the substantial resources that are often dedicated to efforts focused on providing for the specialized needs of a single species that results in proportionally fewer resources available to meet other objectives.

Others have recommended the development of recovery plans that consider the needs of multiple species rather than the more typical approach of single-species conservation in endangered species management (Culbert and Blair 1989, Barnes 1993). The question of how to effectively incorporate multi-species objectives into endangered species conservation has subsequently sparked discussion of targeting conservation

efforts at species that are thought to be more representative of their environments and other species rather than addressing the specific needs of individual, protected species (Simberloff 1998). Some examples of this approach include using indicator species (species whose fluctuations are thought to reflect the fluctuations of other species in the community), umbrella species (species with large habitat requirements that are thought to encompass the habitats of many other species), or keystone species (species having far-reaching impacts on other species beyond what might be expected respective to their biomass in the system) as foci for management (Simberloff 1998). However, these concepts are also fraught with ambiguity; in particular, definitions lack consistency (Mills et al. 1993) and there is debate over the criteria by which such species should be identified and selected for prioritization (Simberloff 1998).

The still broader approach of "ecosystem management," has also been proposed as a possible way to meet the needs of endangered species while also considering the needs of other species and related management objectives (Barnes 1993, Franklin 1993). Such an approach focuses on working across boundaries requiring interagency cooperation, implementation of research, monitoring and adaptive management, as well as emphasizing that humans play a part in these processes (Grumbine 1994). Ecosystem management often emphasizes the restoration of natural processes and management for ecological integrity (Barnes 1993, Swanson et al. 1994, Grumbine 1997). The goal of such efforts shifts from an emphasis on one individual species, to instead focusing efforts on maintaining ecosystem patterns and processes (Barnes 1993), with the idea that if the ecosystem is healthy, threats to individual species will likely be mitigated.

Thinking more broadly can be useful when threats to a species are in part attributed to the disruption of natural processes. The history of fire suppression in the U.S. has altered the vegetation structure within some fire-adapted ecosystems, which has in turn, negatively impacted species that rely on the vegetation patterns that were historically created or maintained by fire (Van Lear et al. 2005). Thus, restoration of fire regimes can prove beneficial to these species and their habitats. For example, the endangered RCW in the Southeast U.S. depends on relatively open, old growth southern pine ecosystems maintained by frequent surface fires. In these systems, fire suppression results in hardwood encroachment and degradation of RCW habitat, so management recommendations often include the use of prescribed fire (USFWS 2003b). However, applying restoration treatments (which may consist of mechanical thinning or fire) to lands where species at risk are found can be complicated. The ESA emphasizes extinction risk, including that posed by management actions, which can result in restrictions on the range of management options considered by management personnel. Management interventions, even those designed to benefit the species, run the risk of resulting in negative impacts to the species as well as available habitat. Moreover, the impacts and outcomes of treatments may differ over time. Restoration treatments that are more aggressive may reduce the available habitat in the near-term while interventions that are too conservative may provide limited value for the protected species over the long-term. Thus, endangered species management can require decisions that balance risks and benefits in both the short and long-term. Some decisions about potential restoration efforts may increase risk to the species in the near-term, but may ultimately benefit the species through improved habitat in the long-term (O'Laughlin 2005).

To further examine the balance between endangered species management and management of whole ecosystems, this research examines the RCW as a case study. The RCW was among the first species listed under the ESA and conservation efforts for the species include both broad efforts to restore longleaf pine (*Pinus palustris*), as well as more intensive, species-specific strategies, such as installing artificial cavities in trees (USFWS 2003b). Considering the tension in endangered species management identified elsewhere, we designed this research to learn from managers regarding the challenges and potential conflicts they may face when balancing endangered species management with their other objectives.

RCW and Longleaf Pine Ecosystems

RCWs exclusively excavate and nest in live pine trees, making them unique among woodpecker species in that they only use live (not dead) trees. RCWs breed within a variety of pine ecosystem types across the southeastern U.S., but show a preference for longleaf pine ecosystems (Jackson 1994). They live in small cooperative family groups that consist of a breeding pair and helpers. These helpers are often male offspring from the previous breeding seasons that assist in raising young (Jackson 1994). Family groups excavate and maintain a number of cavities within their territory, each cavity taking multiple years to construct. The series of cavities maintained by a family group, termed “cluster,” often serves as the unit of measurement for agencies involved with habitat management for RCW (USFWS 2003b). Excavating live pine trees appears energetically costly upfront because of the extensive amounts of pitch produced by pine trees. Pitch dripping down the tree and surrounding the nesting cavity also prevents predators (e.g. snakes) from accessing nests (Jackson 1994). In fact, birds will continue to

maintain “resin wells” around the cavity by chipping holes even after their cavities are established causing trees with occupied cavities to have a recognizable candle-like appearance (USFWS 2003b).

RCWs prefer large, older (>60 year) pine trees as nesting habitat (DeLotelle and Epting 1988, Hooper 1988, Rudolph and Conner 1991, USFWS 2003b). Older trees are more susceptible to redheart fungus (*Phellinis* [*Fomes*] *pini*), a disease that causes the heartwood to soften, making it easier for RCWs to excavate cavities (Mitchell et al. 2009). RCW occupancy of a site also depends on the availability of quality foraging habitat, influenced by the size, age, and density of over-story trees, as well as groundcover composition (USFWS 2003b). Generally, old-growth longleaf pine ecosystems in the southern U.S. are characterized by an average of 99 trees ha^{-1}, an accumulation of woody debris (both standing and on the forest floor), and patchiness in the distribution of tree age classes throughout the landscape (Landers and Boyer 1999, Mitchell et al. 2009). Based on these characteristics, the *RCW Recovery Plan* outlines a specific recovery standard of quality foraging habitat that federal agencies are compelled to follow and state agencies are strongly encouraged to manage for in order to grow populations (USFWS 2003b, p. 187). This recovery standard provides guidance on the amount of habitat to provide for each group of woodpeckers (49 ha when site index is > 60, 80 ha when site index is < 60), on stems ha^{-1} (45 + pines per ha > 60 years old and > 35 cm in diameter, and < 50 trees per ha for pines < 25.4 cm), and basal area of each tree size class (< 2.3 m^2 per ha for pines < 25.4 cm; at least 9.2 m^2 ha^{-1} for pines > 25.4 cm). It also recommends there be little to no hardwood mid-story or canopy present, and

groundcover should consist of native bunchgrass or other native fire-dependent herbs (USFWS 2003b).

When first listed, recovery efforts for the RCW sparked controversy, primarily due to the association of the species with old-growth pine ecosystems that would otherwise be targeted for timber harvest. Longleaf pine ecosystems, located within the Southeast Coastal Plain region, are important to RCWs and are considered one of the most species-rich ecosystems in North America (Jose 2007). The Coastal Plain region spans nine states, running along the Atlantic coast from Virginia to Florida and along the Gulf coast from Florida to eastern Texas. One third of the flora in North America are native to the Coastal Plain, and longleaf pine communities in particular have remarkably high levels of endemism and are host to many rare plant species (Christensen 2000, Noss 2013). Longleaf pine ecosystems once dominated the southeastern Coastal Plain at an estimated 38 million ha, however, today these ecosystems occupy < 5% of their original extent (Brockway et al. 2005; Jose et al. 2007). Several factors have contributed to this decline, including harvesting for naval stores (e.g., tar, pitch, and turpentine), intensive logging practices, fragmentation from development and agriculture, and fire suppression (Frost 1993).

Longleaf pine is a shade-intolerant species; when fire is removed from the system, hardwood species move in and shade out longleaf pine regeneration. Maintaining an open condition in these systems requires surface fires every one to five years. Historically, these fires were produced by lightning strikes from spring and summer thunderstorms characteristic of the South (Landers and Boyer 1999). Such fires were typically low in severity, resulting in limited impact to mature and fire-tolerant longleaf pines, but burned

frequently enough to prevent hardwood species from becoming established in the understory. Fire is widely recognized as an essential disturbance of multiple ecosystem types in the Southeast and it is viewed as an essential component to RCW management (USFWS 2003b), though its use in management may be restricted by other factors including budgetary constraints or smoke regulations.

Policy Context

A variety of policies influence public forest management. These existing legal statutes often have specific procedural and bureaucratic elements that may affect the ability of agencies to adopt new management approaches (Meidinger 1997). Statutes and ownership boundaries of natural resource management agencies tend to classify management into single resource categories (e.g., endangered species) and divide ecosystems according to arbitrary boundaries, which present problems when attempting to apply a more holistic approach (Cortner et al. 1998). For example, endangered species are managed under federal law; however, the habitats on which they depend may cross jurisdictional boundaries including federal, state, and private lands. This creates a complex institutional context for decision making (Meidinger 1997) and so taking a broader approach will require a high level of coordination and communication among the agencies involved as well as in cooperation with private landowners (Cortner et al. 1998). Overall, natural resource management institutions have been criticized as being too hierarchical and rigid to achieve the level of adaptability likely needed to successfully apply broader ecosystem-focused approaches (Meidinger 1997, Cortner et al. 1998). Holling and Meffe (1996) criticized the rigidity of natural resource institutions and their tendency to approach problems as though they are clearly defined and have set

boundaries, allowing for direct solutions. Ultimately, while such an approach may help simplify decision making, ecological processes are usually too complex to fit nicely into this model. To begin addressing some of these institutional problems, Cortner et al. (1998) recommend that management be viewed as more of an "improvisory art" rather than trying to design "recipes" for management.

Study Objectives

Conserving endangered species within ecosystems that have been altered by past human action prompts the question of how restoration management objectives may overlap or come into conflict with species recovery efforts. If species threats are related to the disruption of natural processes, it follows that any treatments to restore these processes may also benefit protected species in the long-term. However, endangered species often require addressing multiple threats in their recovery that may not always align with ecosystem management objectives. Through semi-structured interviews with managers, I address the following questions regarding RCW management:

1. How has RCW management developed to where it is today? How have strategies changed over time?; and
2. How do manager goals and objectives for RCW management align or conflict with other natural resource management priorities?

In examining these questions for this particular case, our intention is to identify lessons that can be learned from RCW management that may help inform management of other endangered species.

Research Methods

Data Collection

This study used qualitative methods to explore the factors influencing decision-making for RCW management. Data were collected primarily conducted through one-on-one semi-structured interviews. We took a qualitative approach to data collection and analysis to allow for an in-depth, detailed exploration of the management environment with participants. The complexity of making management decisions given multiple influencing factors as well as potential sensitivity given the high stakes resulting from legal requirements and extinction risks are not well suited for exploration through standardized, quantitative methods (e.g., surveys). Qualitative methods, such as conducting interviews, are particularly well suited for gaining detailed data regarding specific cases or phenomena (Corbin and Strauss 2014).

Interviews were conducted until a saturation of ideas was reached, with subsequent interviews failing to provide new information (Creswell 2007). In total, 32 individuals involved in a various aspects of RCW planning and management were interviewed. RCWs occur across 11 states in the Southeastern U.S. (Figure 8). There are a total of 13 physiographic recovery units identified in the RCW Recovery Plan (USFWS 2003); our study was primarily limited to RCW management areas within the coastal plain recovery units (as defined by USFWS 2003; Figure 8), with the exception of one property located in the Upper East Gulf Coastal Plain. Ecosystems within the Coastal Plain recovery units contain sufficient diversity among variables relevant to our questions of interest and included a range of resource management agencies operating within

multiple states. We sought to speak with a broad range of individuals who had first-hand knowledge and experience of working with RCWs.

As an initial step in identifying interview participants, the RCW Recovery Coordinator from the USFWS was consulted and provided a list of potential interviewees (including biologists, foresters, and property managers). The initial participant list focused on public properties with large RCW populations, though properties with smaller populations were included over time based on suggestions from participants and as further knowledge of RCW management was acquired. Within the *RCW Recovery Plan*, the USFS is responsible for managing the greatest number of properties for RCW in the Coastal Plain. Consequently, USFS employees represented almost half of the interviewees (Table 11). The focus of this study was primarily on public land managers for RCWs, however, one private landowner was interviewed to gain additional information about the factors that influence decisions regarding RCW management on private lands. Management of RCWs on private lands has had a complex history, and this study was not designed to encapsulate the scope of those efforts. Care should be taken not to extend the findings presented here to private lands management as the factors of influence will likely differ from those on public lands.

Interviews were done between January and July 2016. Nine interviews were completed in person and the remaining 23 interviews took place over the phone. Where possible, in-person interviews were combined with field visits in an effort to gain first-hand experience with examples of RCW management. Interviews lasted between 30 minutes and two hours. Each interview was audio taped with the consent of the participant and began with a brief description of the project before proceeding with a set

of questions included in our interview guide (Appendix 1). Questions addressed longleaf pine ecosystem restoration, history of RCW management, resource management goals, communication among managers and scientists, management strategies for RCWs, and views on the RCW conservation status. The semi-structured nature of the interviews allowed flexibility to deviate from these topics if warranted based on the information provided by participants.

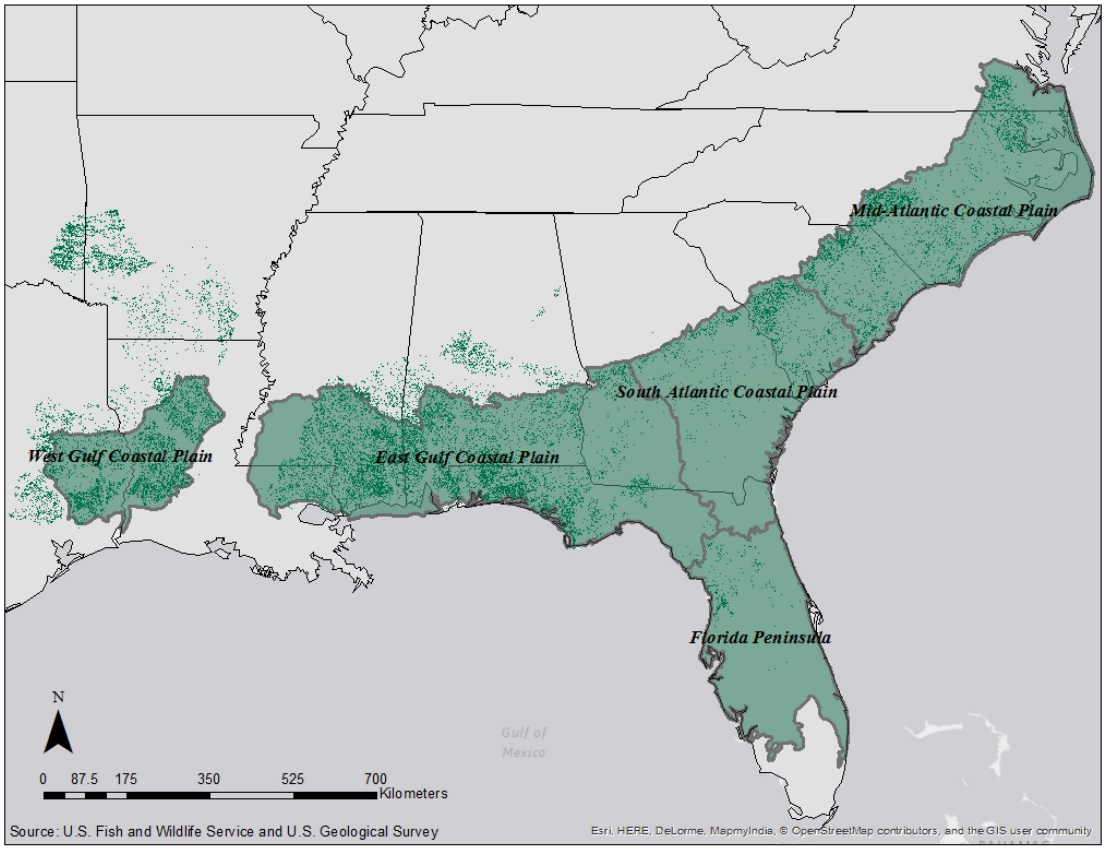

Figure 8. Red-cockaded woodpecker coastal plain recovery units defined by U.S. Fish and Wildlife Service overlaid with the species distribution model of red-cockaded woodpecker based on habitat association data from the U.S. Geological Survey GAP Analysis Program (USGS).

		RCW Professionals
Landownerships represented	U.S. Forest Service	14
	U.S. Fish and Wildlife Service	2
	U.S. Department of Defense	6
	State agency	8
	Private/Other	2
Coastal Plain States Represented	Alabama	3
	Florida	11
	Georgia	3
	Louisiana	3
	North Carolina	1
	South Carolina	9
	Texas	2

Table 10. Numbers of natural resource professionals interviewed who are involved in red-cockaded woodpecker conservation listed by management agency and state.

Data Analysis

Interviews were transcribed verbatim and responses coded thematically using a systematic process. In developing our approach to coding, we began with a coding scheme developed by Myer (2012) for a related case study on a different endangered species of fire-dependent forest ecosystems (the Kirtland's Warbler) and then expanded it according to new themes and ideas that emerged during our analysis. Following methods suggested by Campbell et al. (2013), inter-coder reliability was assessed by comparing assigned codes between the primary researcher and another person trained in qualitative methods who was not directly involved in the project. This evaluation occurred during

the development of the coding scheme. First, the primary researcher coded an interview (sampled at random) and developed an initial code scheme made up of parent codes and subsequent levels of codes nested within these broader concepts. A separate researcher then independently coded the same interview based on this initial coding scheme. Transcripts were compared and discrepancies discussed to better refine the initial coding scheme. Comparison between researchers focused on agreement of the first two broad levels of codes.

Following this first round of comparison, additional transcripts were sampled to provide a diversity of participant types (different agencies and states), coded separately, and compared again using the developing coding scheme until a satisfactory level of agreement was reached (>80%) for the first two levels of codes (Campbell et al. 2013). This occurred after six interviews were compared. The primary researcher then used the same approach to code the remaining interviews. The final scheme consisted of the following parent codes: 1) behavioral decision making, 2) external influences on decision-making, 3) communication/social influence, 4) recovery effects and consequences, 5) management approach, 6) management priorities, 7) benefits of fire, 8) conservation reliance, and 9) desired future management.

Results

The following sections include a summary of qualitative analyses of interviews conducted with RCW natural resource professionals. Sections are organized according to the major topics and themes that emerged from interviews. These topics include: current approaches and strategies used in management for RCWs and how these have shifted

over time, RCWs as an impetus for ecological restoration efforts, the compatibility of RCW goals and objectives with other management objectives, balancing short-term and long-term management goals, perspectives on recovery of RCWs, and the potential effects of a delisting decision for the species. Results are presented in the form of counts of responses and with direct quotes from interviewees, which are noted in italics.

RCW Management

There was a high level of agreement among managers regarding the strategies commonly used in RCW management today. As one manager stated, *"it's one nice thing about working with red-cockaded woodpeckers: everybody knows what to do."* These strategies included a mix of those that were more specifically geared towards increasing the number of RCW groups for a given population, and those that have broader impacts to the structure of the forest (Table 12).

First and foremost, all managers indicated that fire was used in RCW management (Table 12). Fire was often referred to as an integral and important part of land management, not only for RCWs, but also for the pine ecosystem as a whole.

> *…burning is really what keeps the mid-story out because if we weren't burning we would get a lot of mid-story encroachment in the pine stands. And, you know, burning here in the Southeast is ecologically important because of all these stands evolved with fire and they're dependent on fire to stay in the sort of natural habitat that encourages red-cockaded woodpeckers. So we see it as critical for red-cockaded management and it's also important for us…to manage the timber for timber harvesting, to keep them open for outdoor recreation and aesthetics, and keep the fuel loads down to try to minimize the impact of any wildfires we might have here.*

Managers talked primarily about the use of prescribed fire, but in some cases, they also mentioned taking advantage of natural ignitions. It seems that particularly on Department of Defense (DoD) lands, there is generally more flexibility to let natural ignitions, or even

ignitions caused by military training activities, burn for ecological benefits. When asked about this, one manager replied, *"We have less oversight…the managers [here] have a lot more say so and a lot more control over individual decisions than say the Forest Service or something like that."*

Next, maintenance or installation of artificial cavities was mentioned by 84% (Table 12; 27) of managers. The development of artificial cavities was considered revolutionary and was cited as an important milestone in the history of RCW conservation. Artificial cavities, sometimes referred to as inserts, allow RCWs to occupy trees that would otherwise be too young for them to excavate (birds usually target trees that have a certain level of internal decay to expedite the excavation process). Many (53%, 17) managers talked about the age of their forests as posing a challenge to providing RCW habitat as there were limited trees the birds were able to excavate on their own. Artificial cavities have provided a solution for this:

> *…it takes a long time for a single longleaf pine to age and get old enough for woodpeckers to be able to use that habitat. So it's a long process…the only tool that managers had for years and years was to try to restore longleaf, but of course that can take a century in order to get woodpeckers back. After Hurricane Hugo, some Forest Service folks up in the Francis Marion National Forest developed a technique- the first technique- for drilling cavities into second-growth pine in order to stabilize the population after Hurricane Hugo. Subsequent [to] that, somebody else developed an artificial cavity insert technique, which was more applicable across the range because you didn't necessarily have to have trees with a large heartwood to sapwood ratio, which is what you had to have for the drilled cavities. It can be a relatively young tree with very little heartwood, and you can just slap that insert in there and you're good to go. So that has been the basis of the rapid growth that we've experienced...*

Forest thinning and reduction of the hardwood mid-story were also both mentioned by the majority of managers (Table 12). These were cited as contributing to

the restoration of the historic vegetation structure that would have been present pre-European settlement.

Fifty percent of managers mentioned conversion of offsite pine species to longleaf pine as a strategy they use in RCW management (Table 12). At many locations, stands of longleaf pine had previously been cutover and planted to faster growing, shorter-lived species, such as loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm). Referred to as "offsite species," managers are currently seeking to convert these stands back to longleaf pine on many public lands and are doing so a couple of different ways. The most direct method is to clear-cut a stand composed of offsite species and replant with longleaf pine, however, there are also those who advocate for a more gradual method of progressively thinning out the undesirable species, and even going in and planting longleaf pine in the understory during the process (referred to as under-planting).

> *I think if you're talking about strategies for thinning forests, some people still maintain that doing small clear-cuts is a good way to go. I think over time that most people have seen the benefit of selective thinning because you can maintain the forest while you're transitioning from you know say an old slash plantation to a longleaf pine forest. It depends on each situation. Sometimes you do need to [clear-cut]. If it's a bunch of cankered loblolly, the best bet is probably just to clear-cut it and replant longleaf and wiregrass and get going as soon as you can. If it's a mature slash pine forest and it's in good shape, you know, if it's an old plantation, probably better off to do a selective thinning and under-plant longleaf as you go to take a slower approach to converting the forest.*

Finally, translocation of individual RCWs is another intensive strategy that was mentioned by half of the managers interviewed. Translocation consists of moving young birds from a location with a high population to augment the population at another location. It takes a lot of coordination among managers, as well as substantial monitoring:

> *…you have to know and report on the success of your translocations. So when you have a bird with a band on, you have to follow that bird throughout the time it's*

> *[here]. [We] have to follow it throughout time to make sure it stayed on the [property], became a breeding bird or whatever the outcome was. [I] have to report on that over the years in the annual report.*

Though it requires additional effort and monitoring, translocation has overall been very successful at promoting the growth of many populations that may have otherwise been lost.

Many managers indicated that RCW management began with a singular focus on species recovery, resulting in adoption of intensive actions (e.g. translocation and artificial cavities) targeted specifically at growing RCW populations throughout the range. Then in the early 1990s, managers described how they began to take a broader perspective and approach. This was in part driven by policy changes; it was at this time that the USFS shifted its focus from being more resource-based management to having a broader vision of ecosystem management for managing National Forests and Grasslands (USFS 1992). Approximately one-third (11) mentioned ecosystem management being integrated with RCW management, and many talked about this shift being influential in how they manage RCWs. One manager talked about embracing ecosystem management as a "light coming on:"

> *So that was kind of a light coming on is that if we would shift to longleaf, it would be more sustainable. It would embrace ecosystem concepts and I think it was the very beginning. The light wasn't…didn't have a lot of voltage or a lot of wattage. It was a little glimmer, but it was the beginning. And so that to me was where we started looking at how to fit species composition and structure to the land, as opposed to fighting all these perceived restrictions and to get a perceived quantity of timber out.*

Though use of both artificial cavities and translocation are still quite common in RCW management today, 31% (10) of managers said they were shifting away from intensive practices like these towards a more broadly focused approach that emphasizes longleaf

pine restoration. *"…well it used to be a lot more about inserts and a lot more about translocation. And now it's much more about ecosystem restoration… I feel like we used to treat the symptoms and now we're actually treating the disease."*

Management strategies	**# of Participants**			**Overall %**
	Federal	*State*	*Private*	
1. Fire	23	8	1	100%
2. Maintain/install artificial cavities	20	6	1	84%
3. Timber thinning	19	6	1	81%
4. Reduce midstory/hardwoods	17	7	0	75%
a. Mechanical	12	5	0	53%
b. Herbicide	7	4	0	34%
5. Convert offsite pine species to longleaf pine	12	3	1	50%
6. Translocation	13	3	0	50%
7. Plant wiregrass	3	1	0	13%
N=32	**23**	**8**	**1**	

Table 11. Red-cockaded woodpecker management strategies most frequently listed by natural resource managers involved in red-cockaded woodpecker conservation.

The RCW as an Impetus for Ecological Restoration

Federal agencies have a greater obligation to manage for the benefit of endangered species and this can be a strong driver on federal lands. Many managers (14, 44%) mentioned that having RCWs present on their land provided justification for the use of fire or mechanical restoration treatments. Moreover, 39% (9) of federal managers talked about the presence of the RCW as being an impetus of engaging in habitat restoration projects. One USFS biologist stated:

> *The pressure from the RCW pushed the agency to take care of this ecosystem better and more aggressively than if it were just managing for commodity. If we were just cutting pines to make houses, we wouldn't have been taking care of the ground cover. We wouldn't have been worrying about the oaks…as much. We still need to reduce oaks to grow pines. I mean, you [have to] reduce the competition. So, even if you were just managing as a commodity, you'd want to have some level of oak control. But not like we've done. The RCW was the fire to get all these things looked at.*

On state lands, managers also felt that the RCW provides a strong justification for being able to implement restoration management activities, such as prescribed fire (63%, 5). State agencies are able to apply for funds to do endangered species habitat conservation actions under Section 6 of the ESA (16 U.S.C. Sec. 6 (d)). Whether it is through this program or in pursuing other grants, managers at the state level indicated the RCW provided justification for treatments and supported grant applications and indicated the resulting treatments not only benefit RCWs, but also many other species within southern pine ecosystems. "*It's almost always mentioned when we're applying for grants, that we're recovering red-cockaded woodpecker, and so that has helped us I believe in getting funding for our fire program.*"

Compatibility of RCW Management with Other Agency Objectives

Agency-specific guidelines can sometimes hinder the ability of managers to pursue specific strategies. Throughout interviews, managers noted that agency policies, mandates, and goals were found to impact the flexibility that RCW managers could exercise. At the state level, agencies vary in the priority they give to RCW management. These priorities seemed to be influenced by the structure of the agency as well as agency sources of funding. In particular, state agencies that have timber quotas or derive a substantial percentage of their funding from timber sales must balance RCW

management with the financial incentives to harvest timber. Some managers indicated that this could lead to conflicts with RCW management due to the basal area recommendations and restrictions on timber harvest in the *RCW Recovery Plan* (USFWS 2003b; Table 13).

Apart from their mandate to manage for endangered species, federal agencies have additional internal regulations that impact the types of strategies they may pursue. Of the 14 USFS employees interviewed, five indicated the USFS was subject to strict regulations on burning and managing with fire. While some employees view this as positive and that this represents a commitment to doing things the "right way", others expressed frustration with the extensive processes within the organization that results in less flexibility in decision making than what is typical among other agencies. One USFS employee expressed it in this way:

> *[The] Department of Defense has better success in growing woodpeckers than [the] Forest Service does, because once again, they're not constrained by all the [regulations] that we are, they just go out there and do what needs to be done. For years we used to hear people say, 'Well we don't know what they need.' We know what they need, it's just getting it done [in the] Forest Service. You know we strangle ourselves with our own regulations all the time. There's no other agency that has limited themselves like we do. So that's why things are really slow. And then of course it takes time for trees to grow, but we've gotten around some of those problems with artificial cavities and things like that. But you know you've got the forestry slowness of it, and then the bureaucracy slowness*.

As alluded to by this participant, the DoD, which is a major landholder of RCW habitat, appears to have greater flexibility in executing their natural resource management goals. However, managers within this agency are balancing a different set of objectives. All but one (83%) of the DoD participants mentioned that their agency-wide goal to ensure mission flexibility would sometimes interfere or affect the prioritization of

conservation activities, including managing for RCWs. Within the DoD, managing for RCWs is primarily driven by the desire to free the agency from restrictions associated with the ESA and to mitigate any potential losses. As one employee stated, *"our goal is to do the best we can for the species, so there's less impact to the military if we do need to do something."*

While military activity was prioritized, DoD participants viewed this as being relatively compatible with RCW management. One manager joked, "*fortunately the woodpecker and the army prefer the same type of habitat (laughs). The army likes it open."* The DoD is able to operate with greater flexibility and has more latitude to allow unplanned ignitions to burn as well, even when fires are ignited by military training activities (i.e., munitions). One manager speculated: *"That's one reason why the military has some of the best woodpecker habitat... I think one of the reasons is past military wildfires, where they were burning before prescribed fire became popular. You know, routine."*

Across landownerships, over one-third of managers said there were no conflicts with RCW management and other objectives (Table 13; 37%, 11). Managers also generally described RCW management as being compatible with longleaf pine restoration objectives and beneficial to other species.

> *Our objective is to restore native longleaf ecosystems and when we do that we're going to have RCW. And so I tend to think that our goal is to fit the management to the ecosystem. And then the endangered species will take care of itself. Now that's not…sometimes you have to do the things like inserts and those types of things to help out. But if it was a perfect world, we would manage the ecosystem and the woodpecker would take care of itself. It's not a perfect world so the things that drive some of our management probably is RCW right at the top of our list.*

Words such as “keystone species,” “umbrella species,” and “indictor species” were used by 41% (13) managers to describe RCWs to convey the extended benefits of managing for them. One biologist from the DoD said, *“most of the management that we’re doing for the RCW is also beneficial to other species that are in the longleaf pine wiregrass ecosystem. So it kind of has an umbrella effect on a lot of other species at risk.”* Overall, 69% (22) managers said they saw managing for RCWs as having beneficial impacts to things beyond RCWs, such as other species or in meeting restoration objectives.

> *[I was] here in the early days when people thought woodpeckers were the enemy, and now I never get a single complaint about anything I’ve ever done for woodpecker management, because we do so little, and everything we do for woodpeckers is actually showing some benefit on the ground. People are happy to see us, you know, improving it. Because everywhere that we don’t manage for woodpeckers is just a wall of…privet and stuff like that is just growing crazily. So some of our impetus to get things going is just woodpecker management. But we all know that we do it for multiple reasons. It’s just the best way to manage the forest.*

Balancing Short and Long-term Objectives

Although RCW management was described as generally compatible with other objectives, 32% (10) of RCW managers mentioned encountering problems with balancing short and long-term goals with regards to one specific issue: foraging requirements from the *RCW Recovery Plan*. The *RCW Recovery Plan* recommends state and federal lands provide 120 acres (48.6 ha) of good quality foraging habitat per woodpecker group on medium to high quality sites and 200-300 acres on lower productivity sites (USFWS 2003b). However, problems arise at locations where RCWs are doing really well and have “packed themselves in” to an area. When many RCW groups are present within a given area, it makes it difficult for managers to provide the designated amount of foraging habitat specified in the *RCW Recovery Plan* to each

cluster. Managers at sites where this was occurring talked about how site productivity and arthropod abundance allowed for more groups to occupy an area than is normally considered possible.

> *…we've got [an] incredibly high density of RCWs, which is indicative of the quality of habitat. So in a lot of areas you'll see RCWs have a territory of anywhere from 150-500 acres, because they need that foraging habitat to go out. Here we've got woodpeckers that are- we've got areas of the forest you can stand in one spot and see 4 clusters. So essentially, they're packed in very tightly. So we're almost getting to the point in some areas where we're reaching carrying capacity. And that's just because of the quality of the habitat has been improving. …they didn't anticipate us having this many birds. So essentially, we have difficulty because we have so much overlap in the foraging partitions for our birds because they're just packed in so tightly. It becomes difficult to manage timber sometimes.*

In some instances, the recommended provisions for foraging habitat have also prevented managers from implementing restoration treatments for longleaf pine. Stands composed of offsite species (e.g. slash pine), though usually not used for nesting, can provide foraging habitat for RCWs, and managers wishing to convert these aging stands to longleaf pine as a part of their restoration objectives are faced with a dilemma. One manager articulated the problem this way:

> *So that's a challenge, it really is. And it depends on who you talk to what you think how to do that. Some people probably lean more heavy into managing more aggressive for longleaf restoration while biologists probably say, "No we need to do more to preserve what we have and manage for the red-cockaded woodpecker we currently have. And the habitat we currently have". Because if you clear-cut it, you're going to have to clear-cut to restore longleaf, you clear-cut it and plant it back with a little pine sapling longleaf. Well that's not, that's going to be basically unsuitable for foraging for at least 30 years and unsuitable for nesting for at least 60. So you just took it out for at least 30 years for even being utilized by RCW. So, there's a challenge in dealing with that. You're taking good habitat and have to basically start over with it.*

This need to provide suitable habitat now appears to create a situation where managers may disproportionally favor the short-term benefits of providing foraging habitat over the long-term benefits of restoring longleaf pine.

Sources of conflict	**# of Participants**			**Overall %**
	Federal	*State*	*Private*	
1. No conflicts	10	1	0	37%
2. Timber harvest	3	5	1	30%
a. Foraging habitat requirements	5	0	1	20%
3. Mission conflicts	5	0	0	17%
4. Activity during the nesting season	2	1	0	10%
N=30[a]	**21**	**8**	**1**	

[a]Two interview participants were not asked this question.

Table 12. Most frequent responses by natural resource managers involved in red-cockaded woodpecker conservation when asked about sources of conflict between red-cockaded woodpecker and other management objectives.

Desired Future Management

When asked which strategies for managing RCWs they would like to pursue to a greater extent than they are currently able, one quarter (8) of RCW managers expressed a desire to do more timber management and 41% (13) of managers wanted to be able to burn more, some specifically mentioning growing season fire (Table 14). One state forest biologist spoke about their wish to use more growing season fire because of the benefits that it provides to the ecosystem:

> *Growing season [fire] is probably my great unattained goal for RCW sites. I mean we have growing season fire in other forests and in other systems… You know, it's not like there's not growing season fire in my agency, but we just haven't it applied to these RCW sites. And you know that and until I can make that a standard procedure at least some of the time in some colonies, I don't really think we're doing the birds a service, because it's just such a radical difference in the arthropod dynamics in terms of species composition and biomass and timing and the quality of the arthropod browse, to have those growing season fires. And it's reflected so quickly in the number of viable fledges that get produced, you know.*

By those who mentioned it, prescribed burning during the growing season was thought to be more difficult to accomplish and only recently becoming more accepted at some sites. Burning during the growing season was thought by some to have more potential to result in more extreme, less-predictable fire behavior, and potentially impact ground-nesting game birds. When asked about the specific barriers to using growing season fire, the same individual replied:

> *The combination of getting adequate dormant season fire frequency and also just some agency resistance. You know, people don't see, you know… people don't perceive summer as the time to burn flatwoods. They got a way that they burn flatwoods that they know works and that's what they want to keep going with. And they see wildfire as a cause of large-scale mortality and so they assume that summer prescribed fire is going to be the same thing because of …the fire extent, the effects. You're going to blow the needles off any kind of a longleaf with any kind of growing season fire, but doesn't correlate to mortality, and you know that's just a hard… you've got to have a couple successful ones to get people comfortable doing that.*

Other strategies named by managers as things they wished to pursue more included herbicide treatments, ground cover restoration, and under-planting. Under-planting is when managers convert a stand to a desirable species, such as longleaf pine, over time by planting the target species below the undesirable one and thinning progressively. The primary barriers cited by managers to pursuing

these strategies were logistical, including funding, time, weather, capacity, proximity to human development, and smoke emission guidelines.

Desired Strategy	# of Participants			Overall %
	Federal	*State*	*Private*	
1. More prescribed fire	8	5	0	41%
a. Growing season fire	1	2	0	9%
2. More timber thinning/harvest	7	1	0	25%
3. Accelerate conversion to longleaf pine	5	1	1	22%
4. More mid-story reduction	3	2	0	16%
a. Mastication	1	0	0	3%
b. Herbicide	2	0	0	6%
5. Status quo	3	0	0	9%
6. Improve connectivity	2	1	0	9%
7. More ground cover restoration	1	1	0	6%
8. Under-planting	1	1	0	6%
N=	**23**	**8**	**1**	**32**

Table 14. Most frequent responses by natural resource managers involved in red-cockaded woodpecker conservation when asked about management strategies they wished to pursue to a greater extent.

Recovery

In RCW management, recovery goals are set for specific properties outlined in the plan, which are designated as primary core populations, secondary core populations, or essential support populations. When asked about recovery, however, nearly one-fifth of managers (19%, 6) believed they would have trouble meeting the goals for their property that were set in the 2003 *RCW Recovery Plan.*

> *I know the recovery plan has a population objective in there, but I don't think it's realistic. We just don't have enough landmass to support that population objective.*

The way they came up with those objectives I don't think were really scientifically based that much…It really isn't a real hard look evaluation of like ecological modeling or population monitoring dynamics or things like that to determine, what is a real true viable, true realistic population goal- population for this area, these forests. Even with the best scenario managing the habitat we have, it's going to be very, very difficult to [reach our goal].

Forty percent of managers (14) mentioned having issues with recovery goals or some aspect of the recovery guidelines; the main critique being that the guidelines and goals are not appropriate across all contexts. Anecdotally, some managers mentioned that they knew RCWs to utilize habitat not recognized in the plan as appropriate:

So the Recovery Plan was written [in] 2003 and that did not cover…. I don't think they covered any loblolly populations at all… Since then, we've found out that woodpeckers can do pretty well in loblolly… And there's also some special populations that exist in habitat that the Recovery Plan would say is not woodpecker habitat. But the birds are there, so possibly as the woodpeckers increase in their population that some of some of those most of those things would be taken into consideration, like including other species besides longleaf.

As detailed earlier, foraging requirements were often talked about as being inappropriate for some contexts. One member of the team who was a part of the process of determining recovery goals for the most recent *RCW Recovery Plan* described this controversy over designating foraging habitat:

Where you begin to get disagreements and conflicts minor or major is with foraging habitat and territory size. I mean those are things that a lot of these people at the team… They've all published papers; their own papers on their own research in their own habitats... You know they all had their own opinions about- based on their own science and their own research- about what quality foraging habitat was. So that was probably the most controversial thing we had to deal with.

The other criticism of the *RCW Recovery Plan* mentioned by RCW managers was over how recovery goals were initially determined. Many conveyed skepticism over whether original numbers were scientifically based. Most thought that these numbers were based on simply dividing the acreage on a property considered available habitat by

200 (corresponding with the perceived amount of acreage needed for each group), and that this should provide an estimate of how many potential breeding groups could be contained within that property. One manager speculated:

> *I think they use like a number of acres divided by 200 because they think birds need 200 acres you know taken out, although [it's] a hundred and twenty acres of good quality foraging habitat per group. So let's just make it 200 cause you're going to have some areas out there [that are] going to be you know bottoms or riparian areas, so let's take out 80 acres of that kind of stuff and so if you just divide by 200 you know you should be able to get a rough idea...*

Despite these issues, most managers who indicated having these problems also felt that there would be room for them to negotiate and consult with USFWS regarding any difficulty in reaching population goals. The *RCW Recovery Plan* has been through two revisions at this point, and several managers indicated that they felt there would likely be additional adjustments in the future, or at least the opportunity to seek exceptions for their specific case. One manager of a recovered population talked about being able to negotiate these guidelines with USFWS:

> *…in order to provide the recovery plan basal areas for each cluster, we would have to have way too many trees…because it's not compatible with what this forest should look like in terms of the historic landscape. It should be more open canopy, more herbaceous ground cover, those sorts of things. So we've been working with Fish and Wildlife Service to- and they know all this. They know that the birds are so close together that we just can't manage timber the way the recovery plan wants us to…They're going to give us some rope to manage, but they don't want to give us too much rope...*

When asked to define a recovered population, 22% (7) of RCW managers mentioned that a recovered population would need to have a certain level of self-sustainability. However, 44% of managers (14) indicated that the species would require some form of continuing management action to persist over time; most commonly cited was the need to continue maintaining habitat through thinning and burning.

> *You're always going to be managing, you know we're always going to be doing management techniques, because you can't get fire on the ground any other way, but maybe not so heavy handed. I've been trained to know the recovery guidelines, but I guess once all those primary [core] populations hit their goals, then I would look at it as such…When I attend the translocation meeting, there are more and more populations that are taking them off of that cooperative because they've hit their recovery goals. So really, I'm one of those if you build it they will come. If you if you create some good habitat where there's longleaf and [loblolly], shortleaf and you start managing with fire and continue those activities, then I'm looking at recovered being a success. And hopefully weaning off of having to do artificial cavities so heavily and replacements because that is very time consuming.*

Effects of Delisting

There seemed to be general agreement among managers that habitat management activities would be continued regardless of the RCW listing status to benefit the ecosystem and other species (Table 14; 81%, 26). More intensive and time-consuming RCW management strategies such as installing artificial cavities or translocating birds were thought by some to not be needed in the long term because these activities are needed primarily due to the relatively young age of many of the designated habitat areas, and as forests age, more trees would develop the heart rot which allows easier excavation of cavities. Nearly half (47%, 15) of managers believed it would be possible to scale back their more intensive management efforts (artificial cavities and translocation) over time as the species continued to make progress.

> *[Upon meeting our goal], what we would probably do is spend a little bit less time in the field as far as with the cavity management and things like that…We'd still have to determine the number of suitable cavities and make sure that we had all of the resources that were available each year, but we may not have to do things like spending all the time catching birds and color banding and things like that…The main reason we do that is for translocation purposes. You're required to do that, because you have to know and report on the success of your translocations…As far as our management of habitat, it wouldn't affect it at all. The only thing it would affect, maybe, is some of the cavity management. We may step back a little bit from that and not have to do as much.*

Further, restrictions on the allowable level of management activity (e.g. operating equipment within a defined radius of a cluster) during the breeding season would no longer have to be as strictly adhered to following recovery, giving managers greater flexibility with timber harvest and other treatments to reduce the mid-story.

Forty-four percent (14) of managers also predicted there would be changes in their monitoring of RCWs, likely scaling back efforts to band nestlings as population numbers increased. It was also thought that funding would change (38%; 12), and so they would consider shifting focus and resources on other priorities or species.

> *So when I hit recovery, it means that my funds can go to other species and other needs that need the same attention…It'll allow me to divert the focus, because now management is cheaper…So it will probably allow us to spread the wealth better, where it's needed. So that would actually be beneficial for us to get to that point. Where you just start saying, I don't have as much to do anymore.*

Predicted management following recovery/delisting	**# of Participants**			**Overall %**
	Federal	*State*	*Private*	
1. Maintain current habitat management	20	5	1	81%
2. Less intensive management	12	3	0	47%
3. Change in monitoring	9	5	0	44%
4. Focus on other priorities/species	9	4	0	41%
5. Change in funding	11	1	0	38%
6. Greater flexibility with timber harvest	4	2	0	19%
N=	**23**	**8**	**1**	

Table 13. Most frequent responses by natural resource managers involved in red-cockaded woodpecker conservation when asked how they predict management would change following the recovery of the red-cockaded woodpecker.

Discussion

Federally listed since 1973, RCWs have been protected under the ESA for over four decades. The objective of studying this case was to describe how RCW management has developed and changed over this period and to assess how current manager goals and objectives for RCWs align with other natural resource management priorities. RCW managers by and large agree that management has evolved and shifted over time. Currently, strategies for RCW conservation include both those that are more intensive and single-species focused as well as those that are seen as more compatible with other species and ecosystem restoration goals and objectives. In the following paragraphs we further explore those instances in RCW management where fitting species-specific needs into a broader ecosystem management approach has succeeded, instances where there has been conflict, and finally potential measures to address future challenges when priorities conflict. These findings contribute to a growing body of literature on how greater integration of ecosystem-based approaches to endangered species conservation might be achieved.

Managers largely felt that habitat management (i.e., thinning an burning) for RCWs was compatible with their broader ecosystem management objectives. They often even described using RCW as a justification or impetus for longleaf pine restoration efforts. One potential reason why these goals appear to be so compatible could be because one of the primary threats to RCW populations is linked to their reliance on natural disturbance processes. Since RCWs rely on an open park-like stand structure, their decline has been in part attributed to the removal of fire from southern pine ecosystems (USFWS 2003b). Fielder et al. (1993) specifically discuss the southeastern

Coastal Plain and the high level of rare and endangered species present within it, many of which are associated with fire. Given this, they argue that a single-species management approach in this system would not be an appropriate conservation strategy, whereas managing the ecosystem process of fire would better conserve diversity at multiple spatial scales. Numerous researchers have suggested a more systems-based or ecological approach to endangered species management, largely because more effectively and more pragmatically address the inherent complexity of managing biodiversity loss (LaRoe 1993, Corace et al. 2010, Benson 2012). Particularly in cases where threats to species are directly linked to ecosystem processes, it may be advantageous to integrate species conservation actions into a broader ecosystem restoration approach.

Linking conservation efforts to broad scale restoration will also likely be important to sustained success of RCW conservation. There was general agreement that habitat management would continue for RCW into the future regardless of conservation status because it was well aligned with ecosystem restoration. The ESA is primarily geared towards providing critical habitat for endangered species, though this does not explicitly address the potential need for ecosystem restoration on lands that contain critical habitat. In an analysis of 311 recovery plans, Foin et al. (1998) found that over half of the plans they reviewed recommended restoration of habitat or some form of active management in addition to simply setting land aside for species. Ultimately, this suggests that, in many cases, ongoing active interventions will be required to maintain recovered populations. Goble et al. (2012) define this type of condition as “conservation reliance,” and describe this as when species threats “cannot be eliminated, but only managed.” Managers and authorities may not feel comfortable moving forward with

pursuing delisting of a species that has exceeded the specified recovery goal if they cannot ensure that threats to the ongoing persistence of the species will not be sufficiently addressed in perpetuity. Some have gone as far as to say the underlying assumption (that once species are considered recovered, continued efforts to manage for them will not be necessary) of the ESA is flawed and that the vast majority of endangered species will require some continued investment in management (Scott et al. 2010). In the case of RCWs, managers across agencies readily acknowledged that RCWs will require habitat management into the future. However, they generally expected that resources would continue to be allocated to maintain high quality habitat because management was compatible with broader ecosystem management and longleaf pine restoration goals.

One of the only instances where managers cited conflict between RCW management and ecosystem management goals was when the need to provide foraging habitat for RCWs was viewed as limiting longleaf pine restoration efforts. In order to provide the recommended acreage of foraging habitat for RCWs, guidelines have in some cases prevented managers from undertaking more aggressive conversion of stands from offsite (and shorter-lived) pine species to longleaf pine. RCWs ultimately stand to benefit from longleaf pine restoration treatments in the long term and it was noted that delaying these treatments would likely cause future problems and complications in RCW management as stands of shorter-lived offsite species age and deteriorate. However, managers felt constrained to manage for near-term benefits because these stands are currently being used by RCWs. Discounting the future benefits of a particular action may occur when managing endangered species because conservation efforts are largely reactive and there is a focus on mitigating more near-term, acute risks to species (Kohm

1990, Wilson et al. 2011). It can be difficult to accurately analyze the risks and benefits of performing a treatment that is felt as risky in the short-term (immediate loss of foraging habitat) without the promise of seeing potential benefits until much later (long-lasting high quality habitat; Camerer 1989).

Ultimately, these findings point to a potential tension that may develop between broader policy goals that may complicate management of protected species. Specifically, there may be times where tradeoffs develop between goals embedded in the ESA to prevent the extinction of protected species and encourage their long-term recovery. In this case, some management interventions pose near-term risks to the species (such as the conversion of offsite species that could result in a near-term loss of foraging habitat), but, if implemented successfully, could lead to long-term benefits (availability of more longleaf pine forests to serve as foraging and nesting habitat). Similar to other protected species, the *RCW Recovery Plan* contains prescriptive guidelines intended to prevent the extinction of the species (USFWS 2003b). While the success of the species suggests such guidelines have been successful at encouraging recovery, questions are now being raised about their continued utility in cases where they do not match conditions on the ground or where they may limit the transition to other approaches that are expected to provide long-term benefits for RCWs and achieve broader restoration objectives.

Overcoming conflicts between species-specific management (focused on reduction of extinction risk) and ecosystem management (address broader objectives and contribute to long-term maintenance of recovered species) will likely be challenging both due to psychological processes as well as institutional constraints that may limit perceived flexibility in management. When making decisions where outcomes are

uncertain, humans often rely on heuristics, or mental shortcuts, that can lead to systematic biases and miscalculation of probabilities for the potential outcome (Tversky and Kahneman 1974). For example, use of the “precautionary principle” can result in an unwillingness to make a choice that carries some risk because the outcome of inaction is seen as more certain and safe (Maguire and Alright 2005). Also referred to as “certainty bias” (Kahneman and Tversky 1979), this may result in a failure to recognize the risks that are carried by inaction over a long time frame (e.g., deterioration of stands composed of offsite pine species). There has also been evidence of natural resource managers relying on psychological variables, such as their personal values regarding wildlife as well as expert norms, when considering the listing status for endangered species, despite the assertion that these decisions should be based solely on the best available science (Heeren et al. 2016). Decisions surrounding endangered species may be viewed as especially high stakes, and so the pressures exerted on managers by their peers may influence their decisions and limit their willingness to take an action that is perceived as risky.

Additionally, public land managers may tend towards making decisions that are more risk-averse because there are rarely rewards for experimentation or for adapting established methods. Further, any negative consequences incurred from taking a risk usually reflects poorly on the individual rather than resulting in an analysis of the decision itself. Maguire and Albright et al. (2005) observed this with federal fire managers and suggested that institutions make efforts to change perverse incentives that effectively promote risk-aversion and fail to reward efforts to manage adaptively. Similar to making calls regarding wildfire, managing endangered species requires managing risk,

specifically risk of extinction. Making a decision or implementing a management strategy that may have negative impacts to listed species may reflect poorly on the individual(s) involved, potentially discouraging innovation or acceptance of new practices. In the case of RCWs, the desire for managers to pursue some strategies, such as doing prescribed fire in the growing season or more rapidly converting offsite pine stands to longleaf pine, seem to be at least in part impeded by some internal resistance to taking action that may be detrimental to RCWs in the short-term.

Holling and Meffe (1996) recommend that natural resource institutions be facilitators of natural processes and retain ranges of variation within ecosystems rather than seeking to control them. They caution against oversimplification of natural systems in policy and that a lack of appreciation for the range of natural variation would likely lead to a loss in ecosystem resiliency (Holling and Meffe 1996). Managing endangered species can entail managing uncertainty and making decisions without complete knowledge, so it is all the more important for guidelines and policies to be adaptable, with particular potential to do so in the implementation of recovery actions that are recurrent and have more potential for experimentation (Runge 2011).

Overcoming institutional constraints to embracing a new approach may also be dependent on the perceived flexibility to adapt established guidelines to specific contexts or new knowledge that develops through ongoing management or science. In this case, RCW managers seemed to believe such adaptability was possible; most who indicated a problem with current foraging requirements felt that the problematic guidelines could be negotiated with the USFWS and some had already engaged in such discussions. The ability of the managing agency to maintain an open line of communication with their

regulatory body may help managers to more adaptively respond to challenges or perceived conflicts between their objectives. Success of this communication depends upon how open the regulatory body is to reconsider their guidelines as new information and on-the-ground experiences emerge. Meretsky et al. (2000) provide an example of a case where protections for endangered species came into conflict with restoration of natural processes (flooding in the Grand Canyon). In this case, they found frequent communication between natural resource managers, researchers, and other stakeholders allowed for a more responsive where new problems could be addressed as they arose.

As RCWs occupy habitat across a range of southern pine ecosystems, it is not surprising that their foraging habitat needs might differ across contexts. Evaluating threats to species according to specific circumstances and allowing flexibility across in approaches across locations would acknowledge these differences and may contribute to more effective integration of recovery efforts in natural resource management at the local level.

Limitations

This study is limited in scope in several ways. First, in examining manager perspectives on a single species, any insights and inferences must be looked at in light of these species-specific contexts. Additionally, the qualitative nature of the data also prevents most formal statistical analyses beyond descriptive statistics for this particular group of managers. The percentages reported reflect concepts or ideas that arose from conversations with managers, and not all questions were asked of all managers in the same manner. Although this approach does not allow broader inferences to other

populations to be made, it allowed for a greater depth of information to be collected from participants.

Conclusions

When considering what lessons might be taken from RCW management and applied to the conservation of other endangered species, it is important to note that not all endangered species may be so well positioned as the RCW for aligning species management with other objectives. Restoring fire to southern pine ecosystems is well supported on public lands and has been broadly implemented (Fowler and Konopik 2007). RCWs are also unique in that many of the more intensive aspects of their management are not likely to be required once forests have aged to the point where red heart fungus allows cavities to be excavated without the assistance of an artificial box. As populations continue to grow, the demand for translocation will also likely decrease.

When managing other at-risk species that are reliant on active management to maintain or restore processes, there may be context-specific factors that preclude some activities. For example, using fire to create or restore fire-dependent habitats may not be as accepted in other geographic regions outside of the Southern U.S. where fire regimes and the public acceptance of prescribed fire use may differ. In northern Michigan, for example, the Kirtland's Warbler is reliant on the vegetation patterns (dense regeneration of jack pine) that would have historically been created by fire, though today their habitat is managed almost entirely through mechanical means. This has in part been attributed to risk-aversion and resistance on the part of managers to using prescribed fire in jack pine ecosystems (Myer 2012).

However, RCW management does provide a useful example of integration of habitat management consistent with the restoration of natural processes that supports other resource management objectives. It is evident that the ability for managers to align RCW management with their other objectives, such as longleaf pine restoration, has been beneficial and will likely be important to continue conservation efforts beyond initial species recovery. Ensuring that specific habitat management strategies emulate or restore natural processes allows for extended benefits to other species and the ecosystem as a whole. Engaging in a broader approach may also help to justify management in the long term for other species that rely on continued maintenance of their habitat.

Chapter 4: Conclusion

Restoring altered landscapes and ecosystems is complex. Not only is our ecological knowledge be lacking in some cases due to the challenge of addressing novel problems, managers are also operating within increasingly complex decision making contexts with uncertain budgets and other constraints. The two case studies presented here provide insight into some of the challenges faced in managers' efforts to restore natural processes to ecosystems.

The first case study aimed to evaluate the creation and retention of snags and the implications of these features for wildlife in jack pine forests of the Great Lakes region. Though there have been previous studies on wildlife use of snags in other geographic regions, largely in the western U.S., there is no guarantee that such treatments and processes of decay or wildlife use will progress similarly in other regions. In pine ecosystems of the Great Lakes region, it is recognized that snags and dead woody material provide important habitat for numerous taxa. However, in some cases, current forest management on public lands may not sufficiently retain levels of dead material within the natural range of variation, particularly when creating young jack pine plantations as breeding habitat for the endangered Kirtland's warbler through traditional plantation management (Spaulding and Rothstein 2009). The 2014 *Kirtland's Warbler Breeding Range Conservation Plan* recognizes this need and gives recommendations to

use techniques that may imitate the structural diversity resulting from wildfire (the natural disturbance that would have perpetuated the vegetation patterns in jack pine forests historically; MDNR et al. 2014). The findings here may provide a useful reference to any future efforts to create or retain snags for this purpose.

In examining the decision environment of land managers charged with managing ecosystems, we see that objectives may not always align and there are numerous factors that must be balanced. The stakes are very high when endangered species are present and their specific needs must be accounted for. In the case of RCWs, one of the principle threats that led to listing the species was the disruption to the natural disturbance of fire within southern pine ecosystems. In this regard, ecological restoration objectives are conceptually well aligned with those for RCW management. However, in implementation, tensions may still arise between the need to minimize immediate risks to species by protecting all acres in use and the need for restoration treatments where the benefits may not be appreciated until later on. Remaining flexible in setting guidelines for endangered species management and allowing for adaptability and for new knowledge to shape future strategies may help ameliorate such issues. However, we recognize that such actions may be viewed as risky themselves as they may be perceived as providing less stringent protections for listed species. Navigating this tension will likely be quite complex; findings here suggest the importance of considering both risks and benefits in both the near and long-term in considering how to balance prescriptive guidelines with potential flexibility.

Ecological restoration targets can be challenging to define and achieve in many cases. Indeed, in some cases it likely is not realistic to expect that landscapes can be

effectively returned to a specific previous state. Additionally, early definitions of ecological restoration implied that a restored site should have the ability to sustain itself after damages are repaired and stressors are removed, requiring no further energy or input by managers (Jackson et al. 1995), however, this may not be possible in all circumstances. Faced with continual and rapid changes to environments worldwide, restoration ecologists are exploring novel ways of preserving ecological function and promoting resiliency within ecosystems (Hilderbrand 2005). Returning natural disturbance processes, such as fire, to ecosystems may become increasingly complex and difficult in the future; using fire itself may not always be a possible course of action in some contexts, particularly in places where human communities may be impacted. In these cases, managers are tasked with developing alterative strategies to restore or maintain vegetation patterns and structure through continued active management.

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Appendix: Red-cockaded Woodpecker Interview Guide

Thank you for participating in this project. This project is designed to explore what shapes management decisions in fire-dependent forested ecosystems that are also critical habitat for wildlife species of high conservation concern, such as the red-cockaded woodpecker. Questions examine your specific management goals and objectives for red-cockaded woodpecker habitat, the strategies you use to achieve them, and potential risks and benefits of these approaches. There are no right or wrong answers; I am simply interested in your ideas.

This is meant to be informal, but I do have a list of questions that I need to ask each participant. Your responses will be kept anonymous. If you feel that I am asking something you have already addressed, please do not hesitate to tell me to move on or to say that you have nothing additional to contribute. You may refuse to answer any question you do not feel comfortable answering and you may also end the interview at any point in time. Do you have any questions?

Is it okay if I audiorecord this interview for my notes? If yes, please indicate consent by answering "yes."

If you agree to participate further, please indicate that you understand the purpose of this research and that you are a willing participate by answering "yes".

Background Info and Characterization of the Land

1. Can you describe your job for me?

2. Can you describe your background and how you began working here?

    a. How long have you been with this agency?

    b. How long have you been working with RCW?

3. How would you describe the current condition of the lands you manage?

    a. How are conditions similar or different from pre-European settlement?

    b. What has contributed to these similarities or differences?

4. How do you think the landscape today would be different if it hadn't been

managed to provide red-cockaded woodpecker habitat?

5. Besides the red-cockaded woodpecker, how much experience do you have managing for other endangered species?
    a. How is managing habitat for RCW similar or different from managing habitat for other endangered species?

Current Management Goals and Strategies for RCW

Goals

6. Can you describe some of the history of RCW management for me? How has management arrived at where it is today?
7. How are recovery goals determined for RCW?
    a. To what degree are other government agencies involved in recovery goal setting? How do these groups work together?
8. Do non-governmental organizations or the public have a role in making management decisions?
9. What opportunities are there for managers and scientists to communicate regarding RCW habitat management?
    a. Who is normally included (e.g., agencies, NGO's, general public)?
    b. Is anyone not involved you feel should be?
    c. If someone disagrees with a proposed technique or strategy, what actions can they take (if any)?
10. How is input from science and management balanced in setting goals and objectives for RCW?

Strategies

11. How do you take the recovery goals for RCW and translate those into management actions on the ground?
12. Is there a difference in your short-term vs. long-term objectives for managing habitat?
13. Could you walk me through the process of making a specific management decision for RCW habitat here?
    a. What strategies do you utilize for managing RCW habitat currently?
    b. What factors influence your selection of a specific strategy? (effectiveness, associated risk, budgets, time, other agengies, NGOs, location/size of habitat area)
14. Does fire play a role in restoring ecosystem processes and function? If so, how?
    a. How often is wildfire utilized to achieve these objectives? What influences the frequency of its use?
    b. How often is prescribed fire utilized to achieve these objectives? What influences the frequency of its use?
15. Where does management of RCW rank in relation to your other management objectives?
    a. Which objectives carry the most weight?
    b. Are there any conflicts between RCW recovery goals and your other resource management objectives?
16. In your experience, how have RCW management practices changed throughout your career?

Desired Management Strategies

17. Are there any management strategies you would like to pursue to a greater extent than you currently are able?
    a. What are the barriers that prevent you from using these approaches as much as you'd like?
    b. What incentives do you have to explore alternative management strategies?

Recovery

18. What policies/regulations play a role in the decisions regarding objectives and management strategies?
19. Given the goal of the Endangered Species Act is to achieve recovery of listed species, how would you personally define a recovered RCW population?
    a. How is your definition similar or different from what is defined in the Recovery Plan?
20. If recovery were achieved for the RCW population at (insert location), how would that influence your future management approaches?
21. If RCW were delisted from the ESA, how would that influence your future management approaches?

Wrap-up

22. Is there anything else you feel is important that we haven't discussed?
23. Is there anyone else you feel would be a good person for me to interview?