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Recreational Firewood Movement as a Vector of Non-Native Woodborers in Mississippi

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By

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Recreational firewood collected from campers in Mississippi State Parks was investigated for factors associated with insect presence and their diversity. Insects were found in 20% of firewood and evidence of past feeding was found in 64.8%. Representatives of 35 families of insects were reared from collected firewood. These included representatives of Buprestidae, Cerambycidae, Curculionidae, Formicidae, and Rhinotermitidae. The effects of firewood age, moisture content, and source were also examined as effects on insect presence in firewood. At the same time, a survey of campers' beliefs and attitudes about non-native woodborers was conducted. Exposure to public awareness campaigns had the strongest association on reported sources of firewood and support for regulations on firewood movement. However, no association was found between attitudes and beliefs and camper firewood habits. No association was found between camper responses to survey questions and biological factors from firewood collected from them.

DEDICATION

To Sinurd Thorn for relentlessly encouraging my education, teaching me the importance of enjoying life, teaching me how to cook squirrel, and helping to make me the person I am. I couldn’t have had a better grandpa.

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CHAPTER I

LITERATURE REVIEW

Introduction

The introduction and spread of forest pests is correlated with increased international trade throughout the last century (Aukema et al. 2010). As of 2006, it was thought that over 2,000 non-native insects have been introduced to the United States, about 400 of which are damaging to trees and shrubs (Congress 1993, Mattson et al. 1994). The number of nonnative wood-borers detected in the United States from 2000-2010 was three times the number recorded from 1940-1950 (Aukema et al. 2010). During the same time period the use of wood packaging in international trade increased significantly (Aukema et al. 2011). Wood packaging material is often made from low quality materials, such as low-grade wood that may be green (unseasoned) or have bark still attached (Haack and Petrice 2009). The use of low-grade wood in packaging materials poses a problem as the higher moisture content and presence of bark increase the suitability of the wood to oviposition and larval development of wood borers (Haack 1987, Evans 2007, Haack and Petrice 2009). While standards exist for treating wood that is to be used in international shipping (International Standards for Phytosanitary Measures No. 15 or ISPM 15) this wood may become infected after treatment and still contain wood borers (Evans 2007, Haack and Petrice 2009). It is also possible that not all treatments are properly applied (Haack and Petrice 2009). As the amount of international shipping continues to rise, increasing propagule pressure will lead to more frequent establishment of non-native woodborers (Brockerhoff et al. 2014)).

Costs Associated with Non-native Woodborers

There have been many studies focusing on the potential costs of invasive wood borers such as the emerald ash borer (EAB) (*Agrilus planipennis*) and the Asian long-horned beetle (*Anoplophora glabripennis*). The emerald ash borer has the potential to functionally extirpate all North American native ash species, and estimates of the potential economic loss ranges from \$10.7 to 60 billion dollars (Cappaert et al. 2005, Kovacs et al. 2010). The much wider host range of the Asian long-horned beetle suggests potential losses of \$669 billion dollars in damage to urban trees alone and places almost a third of the urban trees in the United States at risk (Nowak et al. 2001). These two beetles are striking examples of how invasive wood-boring insects can cause economic damage, however there are many other species that may become just as costly. Aukema et al. (2011) estimated that all non-native woodborers in the United States cost \$2.2-\$3.9 billion annually in damage to property, including households, residential, and forest ownerships, and government expenditures (Aukema et al. 2011). As new species of non-native woodborers are introduced, this number will continue to increase.

In addition to the economic damage caused by invasive beetles, they have the potential to do a great deal of ecological damage to our native ecosystems (Gandhi and Herms 2010). The damage to the ecosystems where host trees occur is more difficult to quantify, but no less important than their economic damage. Laurel wilt disease, transported by the red bay ambrosia beetle (*Xyleborus glabratus*), is causing greater than 90 percent mortality in red bay (*Persea barbonia*) and has the potential to infect all native trees in the Lauraceae family (Fraedrich et al. 2008). As of 2007 it was estimated that the emerald ash borer had already killed around 53 million ash trees (Kovacs et al. 2010). According to Gandhi and Herms (2010), there are at least forty three native monophagous insect herbivores of North American ash trees, and more than two hundred that use them in some capacity. The loss of native ash species to the emerald ash borer will also impact cultures that utilize ash. Several native American tribes consider ash to be culturally valuable, and black ash (*Fraxinus nigra*) is harvested by native Americans for basket making (Cappaert et al. 2005). Other non-native wood borers with wide host ranges, such as the Asian long-horned beetle (*Acer*, *Aesculus*, *Betula*, *Fraxinus*, *Hibiscus*, *Prunus*, *Pyrus*, *Robinia*, *Salix*, and *Ulmus*) may be capable of causing serious ecosystem disturbances as well (Nowak et al. 2001). In addition to these well-documented examples of invasive woodborers and their impacts to North America, many other non-native woodborers are known to have been introduced as well (Aukema et al. 2011).

Transport of Woodborers in Firewood

Understanding how these insects spread after establishment in the United States is integral to any effort aimed at stopping their spread or eradicating them. Although it is impossible to know the actual mechanism of their dispersal, several economically important non-native wood boring insects are hypothesized to have been transported across state lines in firewood, including the emerald ash borer, the Asian long-horned beetle, the soapberry borer (*Agrilus prionuris*), and the redbay ambrosia beetle (Haack et al. 1997, Haack 2006, Cameron et al. 2008, Herms and McCullough 2014). The rate of emerald ash borer's expansion from the initial introduction location in Michigan is suspected to have been increased by the transport of firewood containing the pest ahead of the main invasion front (Herms and McCullough 2014). The Amityville, New York population of the Asian long-horned beetle is thought to have been seeded through the transport of firewood or horticultural samples moved there from Brooklyn, New York (Haack et al. 1997). The soapberry borer, a pest of western soapberry (*Sapindus drummondii*), is hypothesized to have been transported from its native range in Mexico to Texas in firewood (Haack 2006). In 2004 laurel wilt disease was detected in Stephen C. Foster State Park in Georgia (Cameron et al. 2008). At the time no other infected sites were within 75 miles and it is hypothesized that the redbay ambrosia beetle and laurel wilt were transported to the park through camper firewood. This case shows particularly strong evidence that the recreational movement of firewood has transported non-native wood borers as the initial dieback was noticed in camping areas and the distance from other infected sites makes natural dispersal highly unlikely (Cameron et al. 2008). An even further jump was made in 2009, when Laurel Wilt symptomatic trees and adult redbay ambrosia beetles were found in Mississippi (Riggins et al. 2010). The nearest known infected sites to the detection in Gautier, MS were over 300 miles away in Florida. While the movement of recreational firewood is suspected to have aided in the spread of these species into new areas in North America the actual cause of their rapid advance can only be speculated.

Firewood as a pathway for the dispersal of non-native wood borers is supported by several studies showing that insects are capable of inhabiting firewood (Petrice and Haack 2006, Haack et al. 2010, Jacobi et al. 2012). Petrice and Haack (2006) reported that the emerald ash borer was capable of completing larval growth and emerging from ash (*Fraxinus spp*.) firewood being dried under a variety of outdoor conditions.

Additionally, Haack et al. (2010) dissected and examined firewood surrendered by drivers crossing the Mackinac Bridge in Michigan. Upon dissection, they found that 23% of the firewood collected during their study contained live wood borers, and that 64% had evidence of past infestation. Jacobi et al. (2012) reported that insects emerged from 52% of the commercial firewood bundles purchased for the study. Together these studies show that firewood is a viable host for wood boring insects and that live insects are frequently present in it, regardless of whether it is sourced commercially or not.

Haack et al. (2010) and Jacobi et al. (2012) also provided evidence that a diverse array of insects are capable of surviving in firewood. Haack et al. (2010) found insects from three orders and seven superfamilies or families (Coleoptera: Bostrichoidea, Brentidae, Buprestidae, Cerambycidae, and Curculionidae; Hymenoptera: Sircidae; Lepidoptera: Cossidae) in the firewood collected on the Mackinac Bridge. More than 4,000 insects emerged from the 373 bundles of firewood purchased by Jacobi et al. (2012), including nine insect orders and at least 51 families, although several families were represented by only one specimen. This study found that bark beetles (Curculionidae: Scolytinae) were the most common type of insect to emerge from the firewood collected, and that some borers (Buprestidae) took more than a year to emerge (Jacobi et al. 2012). Although few studies have reared insects from firewood, the evidence supports the hypothesis that many different types of insects are capable of surviving in firewood for a substantial amount of time, and therefore potentially being transported in it.

Wood Characteristics Favoring Wood Borers

Not all firewood is equally likely to transport insects, however, and there are several factors which may influence the survivability of firewood to wood borers. Haack et al (2006) found that the cross-sectional shape (the shape of a piece of firewood when viewed from the end) of firewood pieces influenced the likelihood of it containing live wood borers. They found that greater cross-sectional area and percentage of firewood with live borers were positively correlated (Haack et al. 2010). This correlation may be due to pieces with a greater cross-sectional area having larger volumes on average than those with smaller cross-sectional areas (Haack et al. 2010). Petrice and Haack (2006) found a similar correlation and hypothesized that this was because splitting the firewood caused the moisture and nutritional content of the wood to diminish much more rapidly. As wood dries, the lipid content decreases and soluble carbohydrates and nitrogen accumulate at the outer surface of the wood where it is less accessible to feeding insects (Haack 1987). Haack et al. (2010) also found that firewood aged two years or longer was more likely to contain live insects, but if *Ulmus spp.* (elm) firewood is removed from the analysis, firewood aged less than one year becomes the most frequently infected group (Haack et al. 2010).

Haack et al. (2010) found no association between the presence of bark and live borers. This may be because bark associated with firewood is often in small patches or is unattached or loosened in large areas. The presence of bark, however, is a prerequisite for oviposition of some wood-borers. In heat treated logs and boards, it was found that cerambycids and true bark beetles would only oviposit on wood that still had attached bark, although ambrosia beetles would create galleries in exposed wood (Haack and

Petrice 2009). In the same study it was found that multiple sizes of bark patches were chosen for oviposition, but no insects completed development in bark patches smaller than $25cm^2$. The amount of bark required by woodborers varies depending on the size of the species (Haack and Petrice 2009). Some true bark beetles have small adults (< 1mm in length) and may complete development in small bark patches. By contrast, larger insects or those that create more extensive galleries may require more attached bark. Some cerambycids feed under bark for only part of their lifecycle and then bore into the xylem to complete development, reducing the amount of bark needed for development (Linsley 1961). Some wood borers (e.g. EAB and some cerambycids among others) will feed under the bark, but enter the xylem for pupation (Linsley 1961, Wei et al. 2007). This allows the insects to survive in wood that has been debarked as long as they have already finished feeding.

Petrice and Haack (2006) found that felling trees early during the larval development of the emerald ash borer induced higher larval mortality than trees felled during late development. The early felling dates reduced the quality of the food available to the larvae throughout their development leading to higher larval mortality (Petrice and Haack 2006). Wood has the highest nutritional quality during fall and winter, and the lowest during spring, when resources are being allocated to the growing tissues, and slowly increases through the summer months (Haack 1987). The large variation in the adult size of many wood borers may be due the quality of larval food, and adult size is correlated with numbers of eggs laid as well as flight ability (Haack 1987). This is supported by Petrice and Haack (2006) who found that smaller adult emerald ash borers emerged from wood that was of lower nutritional quality.

In addition, several firewood characteristics mediate the diversity of woodborers they support. Many wood borers are monophagous, thus the species of tree that the firewood originated from has a large impact on the diversity of insects that may be present, although wood borers inhabiting more decayed wood tend to be more polyphagous (Haack 1987). This may be due to the loss of defensive enzymes in decayed wood (Haack 1987). As wood decays, moisture-holding capacity increases and the mineral content of the wood changes; in balsam fir, nitrogen and moisture content increased and calcium, magnesium, and potassium content decreased with degree of decay (Haack 1987). Nutritional quality varies within the bole of a tree, with the cambium being the most nutritious region, followed by the phloem, sapwood, heartwood, and bark (Haack 1987). Borers typically specialize in eating one or two of these sections and, therefore, may only feed in firewood containing their preferred region (Haack 1987). In addition, most wood borers prefer wood with moisture content around the fiber saturation point (~ 26% depending on wood species), but some specialize in wood at higher or lower moisture contents (Haack 1987).

Movement of Firewood by Campers

The enduring popularity of campfires (Reid and Marion 2005) combined with the long distances traveled by campers (Jacobi et al. 2011, Koch et al. 2012) shows the potential for the long range movement of firewood. A study of the relationship between the camper's origin zip code and park reservations on the National Reservation Service found that highest volume links (between origin zip codes and park locations) were all over 250 km in length (Koch et al. 2012). They also found that the median travel distance was 92.6 km, however the mean of the data was 235.9 km, reflecting that some campers traveled significantly longer distances (10% of campers traveled >500km), and some campers traveled up to 5,400 km to their destination (Koch et al. 2012).

Campers do not spread out evenly in search of campgrounds, however. Koch et al. (2012) noted that there appear to be clusters of travel, with campers from certain regions preferring campgrounds in another region (i.e. Eastern Texas campers often travel to campgrounds in Missouri & West Coast campers often travel inland to mountain campgrounds). According to these studies, while most campers travel locally, a significant number of campers are moving long distances. In examining the home state of visitors to Colorado State Parks, Jacobi et al. (2011), observed that most (68%) of campers were from Colorado, however, the second largest group (29%) were from non-neighboring states. They found that the largest group of campers (47%) visiting the National Parks they studied in the Western U.S. were from non-neighboring states, and that 26% of campers were from outside the Western U.S. (Jacobi et al. 2011). This long distance travel, when coupled with the potential of firewood to harbor invasive forest pests, has the risk to greatly accelerate the spread of these pests.

Support of Invasive Species Management

Several researchers have found that the public's support of and willingness to participate in invasive species management is tied to their knowledge of the species. (Bremner and Park 2007, García-Llorente et al. 2011, Niemiec et al. 2016). Bremner and Park (2007) reported that survey respondents with previous knowledge of invasive pests were more likely to support control or eradication programs. Gordon et al. (2013) found that foresters in Mississippi had increased levels of concern for exotic species that they had experience with or had been educated about. Other studies found that survey respondents were more willing to pay for invasive species management when they had more knowledge of the negative effects caused by the pest and when they felt connected to where the damage occurred (García-Llorente et al. 2011, Niemiec et al. 2016). However, a study conducted on the effectiveness of changing the behaviors of recreational boaters found that increased knowledge does not necessarily lead to changed behaviors, but may be a prerequisite (Cole et al. 2016).

Awareness of management programs also influence willingness to participate in invasive species management. Bremner and Park (2007) also found that respondents that had previously heard of other control programs were more likely to support control or eradication programs. Niemiec et al. (2016) found that respondents who had seen others in their community participating in invasive species management were much more likely to participate as well. Community involvement is crucial is managing invasive species and approaches that engage and inform communities are needed to manage current and future invasive pests. Approaches such as that presented in Van Santen et al. (2004) that utilize “anticipatory dialogue” with communities and discuss management options for future invaders have unique advantages. They have the potential to prepare communities to act quickly once invasive species are detected and allow policy to be enacted more rapidly due to the community already being informed on options and their opinions to already being known.

Several reasons for not participating in invasive species control have also been found. A focus group reported the belief that the general public is not informed or cares about invasive species and the belief that the individual does not know enough to effectively perform invasive species management prevent the individual from participating (Prinbeck et al. 2011). Other reasons that prevent public participation in invasive species management may include the unpleasantness associated with eradication efforts (i.e. killing animals and pesticide use) and the belief that all living animals have a right to exist together (Sharp et al. 2011).

Conclusion

Much research has been focused on the biology and threat posed by invasive forest pests, but comparatively little has been focused on how recreational firewood can serve as a means of their dispersal. The transport of recreational firewood has the potential to hasten the spread of non-native woodborers across North America, bringing them into contact with previously uninfested host populations and making management options more difficult. The research that has been conducted mainly includes two objectives; understanding the spread of a particular pest and understanding the human side of the problem (i.e. how far and often campers transport firewood and public beliefs and attitudes towards invasive species). Little has been done to synthesize the two areas. Combining beliefs and attitudes with firewood data from the campers surveyed could allow correlation between the two areas. This connection opens the potential to better understand the impacts of camper attitudes and beliefs on the spread of non-native woodborers and how to address these issues through outreach programs. Improving the knowledge surrounding the spread of these insects may allow us to better protect and preserve our native ecosystems.

References

Aukema, J. E., D. G. McCullough, B. Von Holle, A. M. Liebhold, K. Britton, and S. J. Frankel. 2010. Historical accumulation of nonindigenous forest pests in the continental United States. BioScience 60: 886-897.

Aukema, J. E., B. Leung, K. Kovacs, C. Chivers, K. O. Britton, J. Englin, S. J. Frankel, R. G. Haight, T. P. Holmes, and A. M. Liebhold. 2011. Economic impacts of non-native forest insects in the continental United States. PLoS One 6: e24587.

Bremner, A., and K. Park. 2007. Public attitudes to the management of invasive non-native species in Scotland. Biological conservation 139: 306-314.

Brockerhoff, E. G., M. Kimberley, A. M. Liebhold, R. A. Haack, and J. F. Cavey. 2014. Predicting how altering propagule pressure changes establishment rates of biological invaders across species pools. Ecology 95: 594-601.

Cameron, R. S., C. Bates, and J. Johnson. 2008. Distribution and spread of laurel wilt disease in Georgia: 2006-08 survey and field observations. Georgia Forestry Commission report: 2006-2008.

Cappaert, D., D. G. McCullough, T. M. Poland, and N. W. Siegert. 2005. Emerald ash borer in North America: a research and regulatory challenge. American Entomologist 51: 152-165.

Cole, E., R. P. Keller, and K. Garbach. 2016. Assessing the success of invasive species prevention efforts at changing the behaviors of recreational boaters. Journal of Environmental Management 184: 210-218.

Evans, H. F. 2007. ISPM15 Treatments and Residual Bark: How Much Bark Matters in Relation to Founder Populations of Bark and Wood Boring Insects. In H. F. Evans and T. Osazko (eds.), Alien Invasive Species and International Trade. Forest Research Institute, Warsaw, Poland

Fraedrich, S., T. Harrington, R. Rabaglia, M. Ulyshen, A. Mayfield Iii, J. Hanula, J. Eickwort, and D. Miller. 2008. A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the southeastern United States. Plant Disease 92: 215-224.

Gandhi, K. J., and D. A. Herms. 2010. North American arthropods at risk due to widespread Fraxinus mortality caused by the alien emerald ash borer. Biological Invasions 12: 1839-1846.

García-Llorente, M., B. Martín-López, P. A. Nunes, J. A. González, P. Alcorlo, and C. Montes. 2011. Analyzing the social factors that influence willingness to pay for invasive alien species management under two different strategies: eradication and prevention. Environmental management 48: 418-435.

Gordon, J. S., J. Henderson, and A. Londo. 2013. Management of Invasive Pests in Mississippi, 55th Annual Southern Forest Insect Work Conference, New Orleans, LA.

Haack, R. A. 2006. Exotic bark-and wood-boring Coleoptera in the United States: recent establishments and interceptions. Canadian Journal of Forest Research 36: 269-288.

Haack, R. A., and T. R. Petrice. 2009. Bark-and wood-borer colonization of logs and lumber after heat treatment to ISPM 15 specifications: the role of residual bark. Journal of Economic Entomology 102: 1075-1084.

Haack, R. A., T. R. Petrice, and A. C. Wiedenhoeft. 2010. Incidence of bark-and wood-boring insects in firewood: a survey at Michigan's Mackinac Bridge. Journal of Economic Entomology 103: 1682-1692.

Haack, R. A., K. R. Law, V. C. Mastro, H. S. Ossenbruggen, and B. J. Raimo. 1997. New York's battle with the Asian long-horned beetle. Journal of Forestry 95: 11-15.

Haack, R. A., Slansky, Frank, . 1987. Nutritional Ecology of Wood-Feeding Coleoptera, Lepidoptera, and Hymenoptera, pp. 449-486. In F. J. Slansky, Rodriguez, J. G. (ed.), Nutritional Ecology of Insects, Mites, Spiders, and Related Invertebrates. Wiley Interscience New York.

Herms, D. A., and D. G. McCullough. 2014. Emerald ash borer invasion of North America: history, biology, ecology, impacts, and management. Annual review of entomology 59: 13-30.

Jacobi, W., B. Goodrich, and C. Cleaver. 2011. Firewood transport by national and state park campers: a risk for native or exotic tree pest movement. Arboriculture and Urban Forestry 37: 126.

Jacobi, W., J. Hardin, B. Goodrich, and C. Cleaver. 2012. Retail firewood can transport live tree pests. Journal of economic entomology 105: 1645-1658.

Koch, F. H., D. Yemshanov, R. D. Magarey, and W. D. Smith. 2012. Dispersal of invasive forest insects via recreational firewood: a quantitative analysis. Journal of Economic Entomology 105: 438-450.

Kovacs, K. F., R. G. Haight, D. G. McCullough, R. J. Mercader, N. W. Siegert, and A. M. Liebhold. 2010. Cost of potential emerald ash borer damage in US communities, 2009–2019. Ecological Economics 69: 569-578.

Linsley, E. G. 1961. The Cerambycidae of North America, vol. 1, University of California Press, Berkeley.

Mattson, W. J., P. Niemelä, I. Millers, and Y. Inguanzo. 1994. Immigrant phytophagous insects on woody plants in the United States and Canada: an annotated list. Immigrant phytophagous insects on woody plants in the United States and Canada: an annotated list.

Niemiec, R. M., N. M. Ardoin, C. B. Wharton, and G. P. Asner. 2016. Motivating residents to combat invasive species on private lands: social norms and community reciprocity. Ecology & Society 21: 398-407.

Nowak, D. J., J. E. Pasek, R. A. Sequeira, D. E. Crane, and V. C. Mastro. 2001. Potential effect of Anoplophora glabripennis (Coleoptera: Cerambycidae) on urban trees in the United States. Journal of Economic Entomology 94: 116-122.

Petrice, T. R., and R. A. Haack. 2006. Effects of cutting date, outdoor storage conditions, and splitting on survival of Agrilus planipennis (Coleoptera: Buprestidae) in firewood logs. Journal of Economic Entomology 99: 790-796.

Prinbeck, G., D. Lach, and S. Chan. 2011. Exploring stakeholders' attitudes and beliefs regarding behaviors that prevent the spread of invasive species. Environmental Education Research 17: 341-352.

Reid, S. E., and J. L. Marion. 2005. A comparison of campfire impacts and policies in seven protected areas. Environmental Management 36: 48-58.

Riggins, J., M. Hughes, J. Smith, A. Mayfield III, B. Layton, C. Balbalian, and R. Campbell. 2010. First occurrence of laurel wilt disease caused by Raffaelea lauricola on redbay trees in Mississippi. Plant Disease 94: 634-634.

Sharp, R. L., L. R. Larson, and G. T. Green. 2011. Factors influencing public preferences for invasive alien species management. Biological Conservation 144: 2097-2104.

U. S. Congress1993. Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. OTA-F-565. US Government Printing Office, Washington, DC.

Van Santen, L., J. Goven, and L. Langer. 2004. The role of community involvement in future incursion responses. NZ J For 49: 38.

Wei, X., Y. Wu, R. Reardon, T. H. SUN, M. Lu, and J. H. SUN. 2007. Biology and damage traits of emerald ash borer (Agrilus planipennis Fairmaire) in China. Insect Science 14: 367-373.

CHAPTER II

INSECT PRESENCE IN RECREATIONAL FIREWOOD IN MISSISSIPPI STATE PARKS

Introduction

About 400 non-native insects that damage trees and shrubs have been introduced into the U. S. (Mattson et al. 1994) . Many of these insects, such as the emerald ash borer (EAB) (Cappaert et al. 2005, Anulewicz et al. 2008, Gandhi and Herms 2010), the Asian long-horned beetle (ALB) (Haack et al. 1997, Nowak et al. 2001), and the redbay ambrosia beetle (RAB) (Cameron et al. 2008, Fraedrich et al. 2008) pose great risks to our native forest ecosystems. The movement of nursery stock, logs, and recreational firewood has been suggested as a vector for the dispersal of these insects (Haack et al. 1997). Recreational firewood, specifically, has been implicated in several long-distances dispersal events of non-native woodborers.

Recreational firewood as a pathway for the spread of non-native woodborers is supported by several studies (Petrice and Haack 2006, Haack et al. 2010, Jacobi et al. 2012) suggesting that insects are capable of being transported and completing development in firewood. Insects developing in firewood coupled with people in the U.S. travelling an average of 93 km to reach campgrounds (Koch et al. 2012) creates the potential for their long-distance dispersal. Even if the spread of non-native woodborers through the movement of firewood is a rare event, each occurrence can potentially create a newly infested area well ahead of the current invasion front.

Firewood is not a homogenous substrate that all wood borers can infest equally well. Each piece of firewood consists of many different factors that alter its suitability as a host. Wood moisture content (MC) is an important limiting factor for some woodborers; and is linked to the nutritional availability of the wood (Haack 1987). The age of the firewood is also a determiner in the ability of wood borers to develop in wood. The nutritional content of wood changes as it is decomposed, and the insect fauna of the wood shifts towards species specializing in more decayed wood (Haack 1987). The tree species of the firewood is also a major factor in determining which insects can feed in the wood. Many woodborers are specialized in one genus or family of trees as hosts and cannot utilize others (Haack 1987). The intersection of these factors becomes the actual niche available to insects inside the wood and determines its suitability as a host.

Moisture content, wood age, and tree species have been examined separately (Petrice and Haack 2006, Haack et al. 2010, Jacobi et al. 2011), but no studies combining these factors have been conducted on firewood in Mississippi or the rest of the southeastern United States. Research in this area is important due to many major ports in the region providing potential entry points for invasive species and a climate conducive to invasions from a wide range of localities. In addition, Haack et al. (2010) and Jacobi et al. (2012) illustrate the differences in tree species used as firewood and the constituent insect diversity in different regions of the U. S. This highlights the importance of investigating insect presence in firewood in the Southeast. The current study seeks to fill these gaps by examining the diversity of recreational firewood species and the insects being transported by campers within Mississippi State Parks and risk factors for insect presence in firewood.

Materials and Methods

Four Mississippi State Parks with campgrounds (Buccaneer, Percy Quin, J. P. Coleman, and Tishomingo) were selected for this study. Two sites were selected in the southern part of the state (Bucaneer and Percy Quin State Parks) and two in the northern part of the state (J. P. Coleman and Tishomingo State Parks). Parks were also selected based on the number of out-of-state visitors they receive to maximize the diversity of campers sampled.

Bucaneer State Park is located on the Gulf Coast near Waveland, MS and receives many campers visiting the beaches. It has the highest number of out-of-state campers per year of any Mississippi State Park. Percy Quin State Park is centered on Lake Tangipahoa and is a popular fishing destination. Its proximity to Louisiana draws out-of-state visitors for fishing. J. P. Coleman State Park is located near the border of Mississippi, Alabama, and Tennessee. Due to its location it is visited by many out-of-state campers from Tennessee and Alabama, states that EAB has been detected in. Tishomingo State Park is located near Bay Springs Lake and close to the Alabama border.

During the fall that this study was conducted, a burn ban was issued that eventually affected all but 7 counties in the state. According to park managers, this resulted in much lower numbers of campers transporting firewood into the parks than is normal for the peak camping season in Mississippi.

Campgrounds were visited four times during July to December, 2016. During campground visits, campers were asked if they had brought firewood into the campground. If they answered affirmatively, the lead author briefly explained the study to them and they were asked if they were willing to exchange firewood and participate in the study. Campers were offered an LED lantern and a lunchbox containing other incentives to participate in the study (Figure 2.1). If they agreed to exchange firewood, they were traded oak (Quercus spp.) firewood that had been sterilized in a solar kiln and roughly equal in volume to their contribution. Five to six pieces of firewood were collected from each camper. If campers only had very large pieces of firewood, fewer pieces were collected. Each collection of firewood was assigned a collection number. Campers were asked whether they or someone they knew harvested the firewood or whether they bought the wood. If they responded that they had purchased the firewood they were asked whether they purchased it from a commercial source (gas station, grocery store, farm store etc.) or from a non-commercial source (non-business entity). Campers were also asked how long they possessed the firewood. For this information four categories were used, < 6 months, between 6 months and a year, between 1 and 2 years, and greater than 2 years. A locality was ascertained for each sample by asking campers the city or county they procured the firewood in (Appendix A: Questions 1-6). This information was recorded in the iSurvey app, version 2.13.13 (Contact Software Ltd., Lower Hutt, New Zealand, 2017). Campers were given a business card with the collection number assigned to their firewood and told that when results were available the data from their firewood would be posted to the MSU Forest Entomology Lab website under their collection number. The firewood from each collection was labeled with its collection number, placed in a separate trash bag, and zip tied closed until it could be processed, usually within 4 days of collection.

Figure 2.1 Incentives offered to campers for participation

LED lantern, lunchbox, and other incentives offered for participation in exchanging wood to be used in the study.

Once at MSU, the bag containing a sample was opened, a cross-sectional slice approximately 5 cm thick was cut from one end of each piece of firewood with a band saw and stored for later tree genus identification. Roughly half of all pieces of firewood in each sample were randomly assigned to either be immediately dissected and inspected for woodborers, or to be placed in rearing chambers (described below).

Pieces of firewood were identified to genus by inspecting end grain anatomy with a 10X hand lens, following the methods and key published in Panshin and Zeeuw (1980).

Firewood Dissections

Firewood selected for dissection was then split using an electric log splitter until reduced to kindling sized material. Past insect damage was noted and any live insects, larvae or adults, in the firewood were collected and stored in 70% ethanol. Voucher specimens were deposited in the Mississippi Entomological Museum. The moisture content of the firewood was then read using a pin type wood moisture meter (MM70D, General Tools & Instruments, New York, NY) with an accuracy of ± 1%. Readings were taken from as near to the center as was possible on a face newly exposed during splitting. Discovered adults insects were identified to the family level, and wood borers were identified to species. Larvae from woodboring families (Buprestidae, Cerambycidae, and Curculionidae) were identified to family, all others were not identified. Insect identifications were made using Triplehorn and Johnson (2005), Arnett et al. (2002), Wood (1982), Lingafelter (2007), Messenger (2001), and Atkinson (2004).

Rearing

Pieces of firewood selected for rearing were placed into plastic tub measuring 34.3 cm wide by 50.8 cm long by 21.6 cm deep. A 7 cm ventilation hole was cut in each end with a plastic screen hot glued over the holes to prevent insects from escaping (Figure 2.2). If the sample contained large pieces of firewood they were split using an electric log splitter to allow them to fit into the rearing chambers. Every four weeks the rearing chambers were opened, and the surface of the firewood and the box were examined for insects. Due to time constraints, 28 firewood samples were checked monthly for 6 months, and 11 samples were checked monthly for 5 months. All encountered insects were collected and stored in 70% ethanol. Voucher specimens were deposited in the Mississippi Entomological Museum. Insects collected were identified to the family level, and wood borers were identified to species.

Figure 2.2 Rearing Chambers

Firewood pieces collected from campers were placed into 38 liter plastic tubs to collect the insects that emerged. The tubs had a 7 cm ventilation hole cut at each end and covered with plastic mesh.

Analyses

Data was analyzed using JMP®, version 13 (SAS Institute Inc., Cary, NC, 1998-2016). Wilcoxon tests were used to determine if significant differences were present in insect presence in firewood, distance travelled, and firewood moisture content due to the non-parametric nature of the data (α=0.05).

The distance firewood collected in this study was transported by campers was determined using camper reported counties of origin for the firewood. Centroid coordinates were found using ArcMap version 10.4.1 (Environmental Systems Research Institute, Redlands, CA, 2015). Google Earth, version 7.1.5.1557 (Google Inc., Mountain View, CA, 2015), was used to find the distance from the centroid coordinates to the campgrounds. To associate a wood MC with insects reared from firewood samples, the average MC from the dissected firewood of the same sample was used. All values are reported as mean ± SE, unless otherwise noted.

Shannon biodiversity indices were used to compare the evenness of the diversity of the families present in firewood under different conditions. The indices were calculated according to Hill (1973), $-\sum p_i \ln(p_i)$, where p_i is equal to the proportion of the total consisting of family i.

Results

Thirty-nine firewood samples were collected from campers, totaling 226 pieces of firewood. Of which111 pieces were dissected and 115 pieces of firewood were placed in rearing chambers. The firewood collected represented 13 genera and 11 families (Table 2.1). *Quercus* was the predominate genus, constituting 79% of the total firewood, followed by *Celtis*, 4% of total, and *Liquidambar*, 3% of total.

Table 2.1 Wood Identifications by Genus

Genus	Family	Common Name	% of total	n
Acer	Aceraceae	Maple	2.7%	6
Betula	Betulaceae	Birch	1.3%	3
Carya	Juglandaceae	Hickory	2.2%	5
Celtis	Ulmaceae	Hackberry	4.0%	9
Diospyros	Ebenaceae	Persimmon	0.9%	2
Fraxinus	Oleaceae	Ash	2.2%	5
Liquidambar	Hamamelidaceae	Sweetgum	3.1%	7
Picea	Pinaceae	Spruce	0.4%	1
Pinus	Pinaceae	Pine	1.8%	4
Platanus	Platanaceae	Sycamore	0.9%	2
Prunus	Rosaceae	Cherry	0.4%	1
Quercus	Fagaceae	Oak	79.2%	179
Ulmus	Ulmaceae	Elm	0.4%	1

Taxonomy follows that presented in USDA PLANTS Database (USDA, NRCS 2017)

The mean distance campers transported firewood was 89.5±8.9 km. Firewood cut by the camper in possession of the wood traveled 73.9±6.0 km versus firewood purchased by campers which was transported 110.6±19.2 km on average. Mean distances traveled were also calculated for firewood purchased from commercial (72.7±10.3 km) and non-commercial firewood (163.5±41.0 km). No significant difference was found between the average distances firewood was transported by campers who cut their own firewood and those who purchased their firewood. However, it was found that firewood purchased from non-commercial sources was transported significantly farther than firewood purchased from commercial sources.

Firewood Dissections

Sixty four point eight percent of the firewood dissected was found to have evidence of past insect damage (such as feeding galleries or frass), with or without live insects being present, and 20.0% was found to contain live insects. Larvae from Buprestidae, Cerambycidae, and Curculionidae were collected from the firewood. The mean moisture content (MC) of the dissected firewood was 21.7% ± 1.1%. The mean MC of firewood that contained live insects was 27.6%± 3.2%, while the mean MC of firewood that had signs of previous insect infestation, with or without live insects being present was 20.8%± 1.4%, and, finally, the mean MC of firewood with no insects present and no signs of previous insect infestation was 19.5% ±1.3% (Figure 2.3).

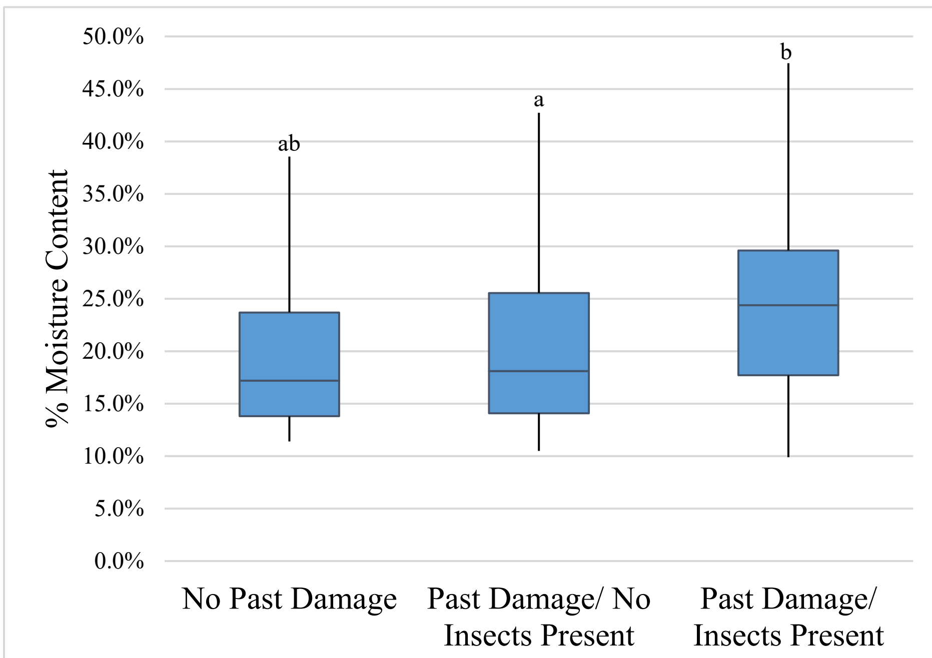

Figure 2.3 Presence of Insects by Wood Moisture Content

The most commonly reported length of time that campers possessed their firewood was between 6 months and a year (43.8%), followed by < 6 months 25.7%, between 1 and 2 years (17.1%), and > 2 years (13.3%). The 6 months to 1 year category continued to be the most common group when the data is divided by whether it was cut or purchased by campers (Figure 2.4). Using We found no significant differences between the median MC of the first 3 age groups, but the median MC of firewood > 2 years old was 7.5% lower than the next nearest age group (p=0.0026, DF 3) (Figure 2.5). Firewood possessed by campers for < 6 months had a 43.1% lower chance than the next nearest age category to have evidence of past insect feeding (p=0.0001, DF 3) (Figure 2.6).

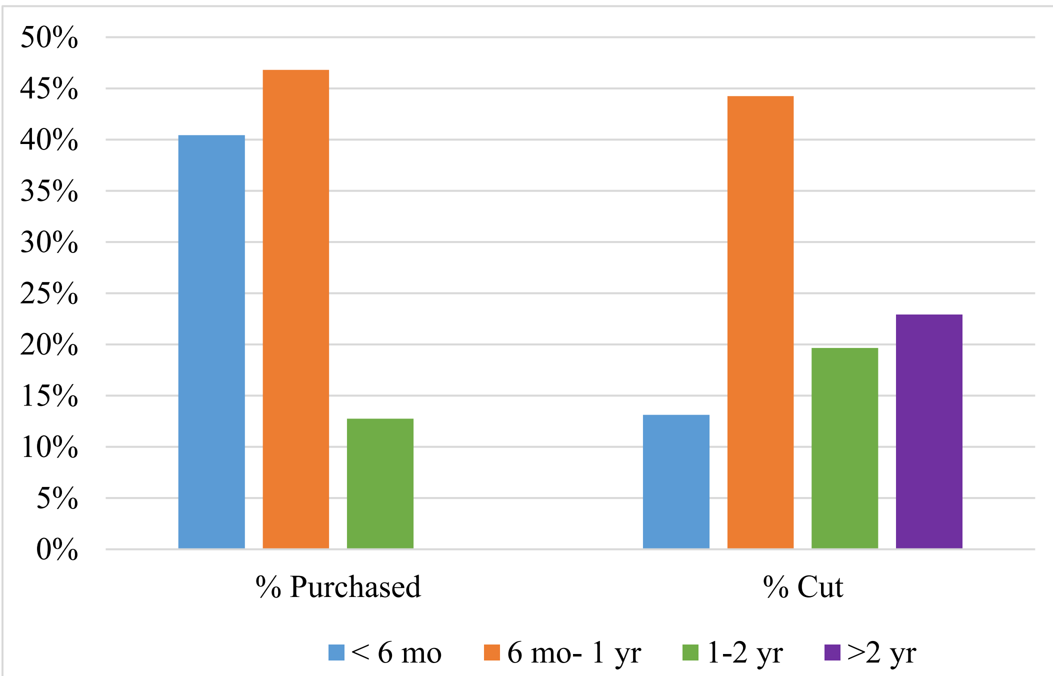

Figure 2.4 Percentage of wood source by age class

Percent of firewood that was purchased and cut by campers belonging to each age category.

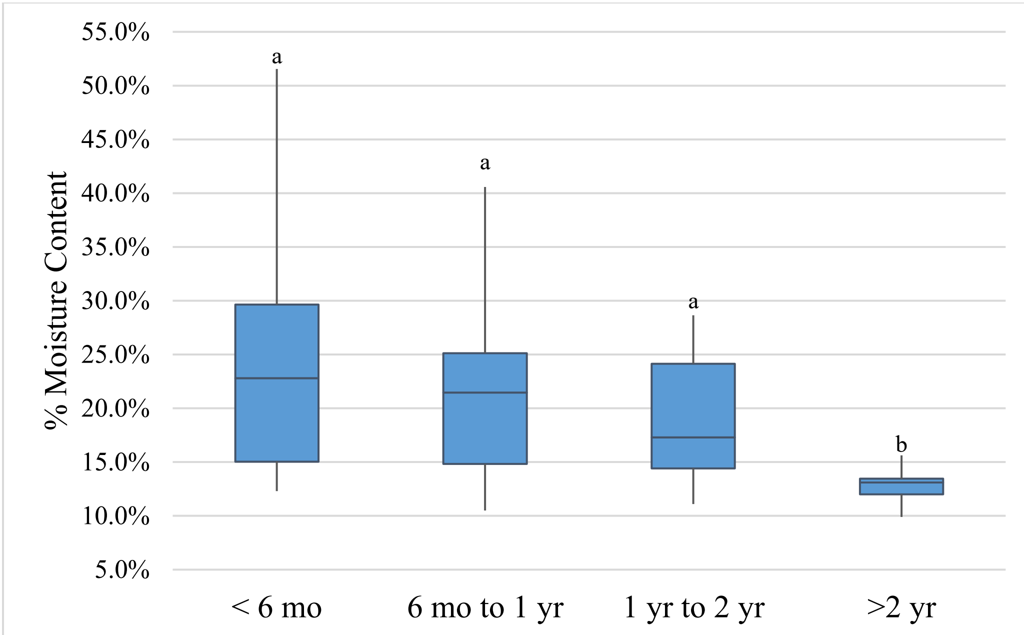

Figure 2.5 Wood Moisture Content by Age Class

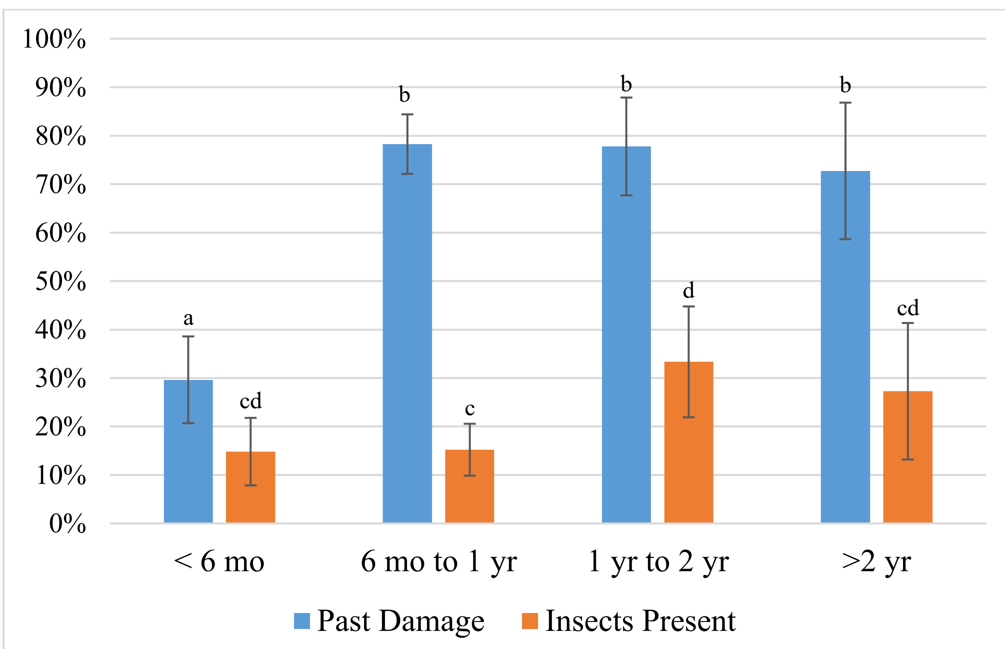

Figure 2.6 Insect Presence by Wood Age Class

Past damage indicates that evidence of previous feeding by insects was present in the firewood.
Insects present indicates that either larval or adult insects were present in the firewood.

59.3% of the firewood collected for dissection was reported to have been cut by the campers themselves and 40.7% was purchased. Fifty percent of the purchased firewood was purchased from commercial sources, and 50.0% was from non-commercial sources. Firewood cut by campers had a median MC of 22.7%, while firewood purchased from commercial and non-commercial sources had significantly lower median MC's (15.5% and 15.7%, respectively) (Figure 2.7).

Firewood cut by campers and firewood purchased from non-commercial sources had very similar chances of having insects present and past damage from insects, but no live insects were found in firewood from commercial sources and it had a significantly lower level of pieces with past damage (Figure 2.8).

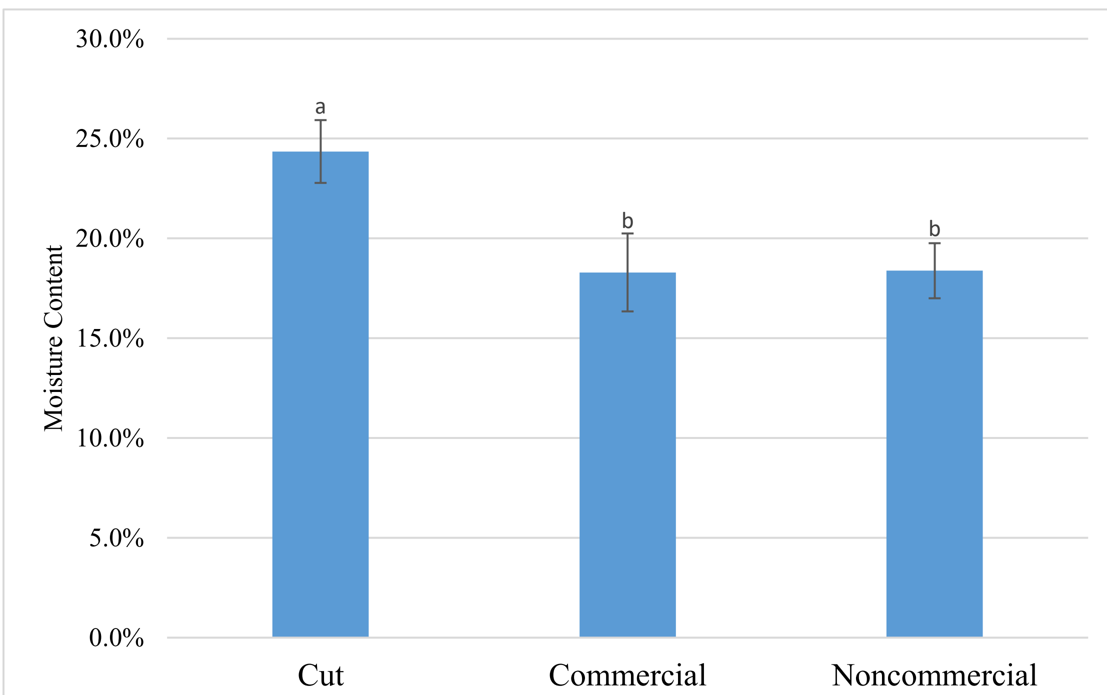

Figure 2.7 Wood Moisture Content by Firewood Source

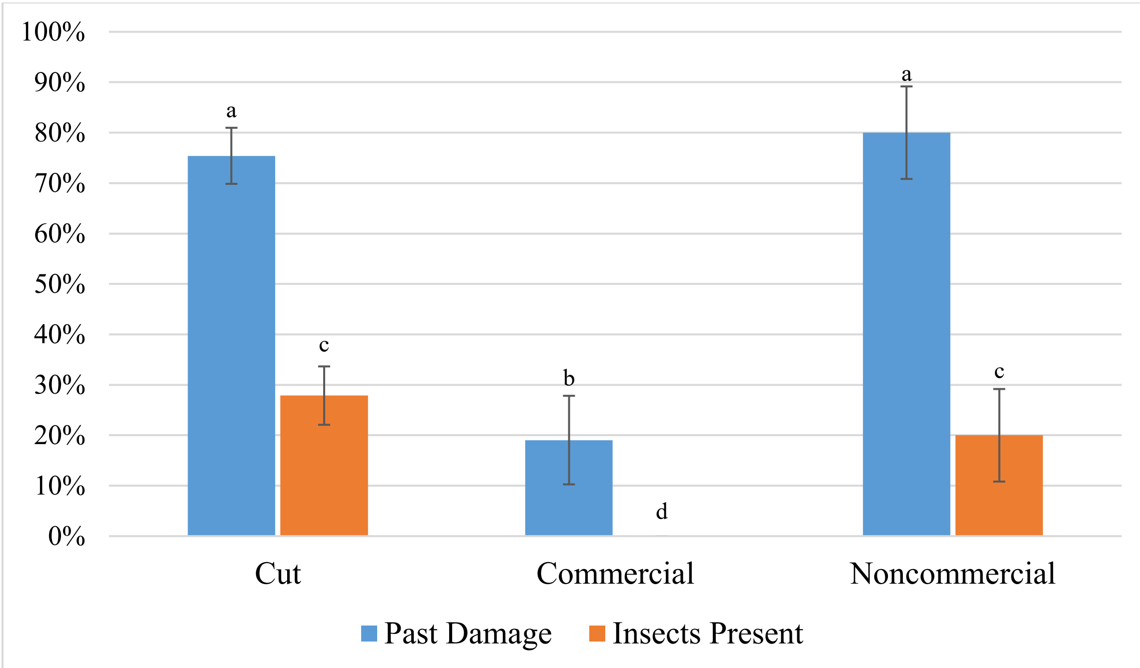

Figure 2.8 Percentages of Firewood with Evidence of Past Infestation and Insects Present by Source

Past damage indicates that evidence of previous feeding by insects was present in the firewood.
Insects present indicates that either larval or adult insects were present in the firewood.

Rearing

Thirty five families of insects, representing 14 orders, were collected during the course of rearing insects from the firewood (Table 2.2). The most commonly collected orders were Coleoptera (73), Psocoptera (35), and Hymenoptera (25). The most common families collected (>10 times) were Liposcelididae (33), Formicidae (17), Tenebrionidae (13), Ciidae (13), Zopheridae (12), and Cerambycidae (10).

Table 2.2 All Families Collected

Family	Number of Collections[1]	Mean Age[2]	S.E. Age	Mean Months[3]	S.E. Months[3]	Mean MC	S.E. MC
"Parasitica"	1	3.0		1.0		28.5%	
Anobiidae	1	3.0		4.0		28.5%	
Aradidae	5	2.8	0.5	1.2	0.2	17.8%	2.2%
Braconidae	2	3.0	1.0	3.0	0.0	18.5%	6.7%
Buprestidae	1	2.0		4.0		19.2%	
Cerambycidae	10	2.1	0.3	3.9	0.5	26.7%	4.2%
Cerylonidae	1	1.0		4.0		35.3%	
Chironomidae	3	1.3	0.3	1.7	0.3	47.5%	1.3%
Chrysomelidae	1	3.0		3.0		17.0%	
Ciidae	13	2.4	0.2	2.7	0.4	33.7%	4.1%
Cleridae	4	3.0	0.6	4.3	0.6	19.8%	5.8%
Cosmopterigidae	1	2.0		2.0		50.1%	
Curculionidae	5	1.4	0.2	2.4	0.8	33.5%	5.8%
Elateridae	1	2.0		2.0		20.4%	
Entomobryidae	1	2.0		1.0		37.4%	
Formicidae	17	1.7	0.2	2.5	0.4	37.8%	2.1%
Labiidae	4	1.3	0.3	1.7	0.1	43.1%	5.2%
Laemophloeidae	4	2.5	0.3	1.8	0.5	19.9%	3.5%
Lepismatidae	2	3.0	1.0	2.0	0.0	11.6%	0.1%
Liposcelididae	33	1.9	0.1	2.8	0.3	31.1%	2.0%
Mycetophagidae	1	1.0		1.0		35.3%	
Myrmecophilidae	1	1.0		3.0		46.3%	
Passalidae	1	2.0		2.0		37.4%	
Phlaeothripidae	4	2.5	0.3	2.5	0.3	25.3%	3.7%
Platygastridae	1	2.0		5.0		19.2%	
Reduviidae	2	3.0	1.0	1.5	0.5	18.2%	6.4%
Rhinotermitidae	1	2.0		2.0		37.4%	
Scelionidae	2	2.5	1.5	4.5	0.5	22.3%	10.6%
Silvanidae	2	2.0	1.0	2.5	0.5	27.8%	7.5%
Staphylinidae	3	2.0	0.0	2.0	0.0	33.9%	3.5%
Tenebrionidae	13	2.2	0.2	2.5	0.5	39.6%	3.8%
Tineidae	1	2.0		2.0		50.1%	
Tiphiidae	1	3.0		2.0		28.5%	
Vespidae	1	4.0		4.0		11.8%	
Zopheridae	12	2.0	0.3	2.7	0.4	34.1%	3.0%

[1] Number of times a family was identified from samples.
[2] Mean and S.E. of age Mean age was calculated by assigning numerical values to the age categories reported by campers using <6 months=1, 6 months to 1 year=2, 1 to 2 years=3, and > 2 years=4.
[3] Mean and S.E. months refer to months since rearing was initiated.

The mean moisture content of the wood from which the most commonly collected families were reared ranged from 26.7±4.2% (Cerambycidae) to 39.6±3.8% (Tenebrionidae) (Figure 2.9). The mean firewood age class for the most commonly collected families ranges from 1.7±0.20 (Formicidae) to 2.4±0.18 (Ciidae), with the mean firewood age class for all insects collected being 2.1±0.069 (Figure 2.10). The mean number of months the firewood was reared before the most common families emerged ranged from 2.5±0.46 (Tenebrionidae) to 3.9±0.48 (Cerambycidae), while the mean for all insects collected was 2.7±0.11 (Figure 2.11).

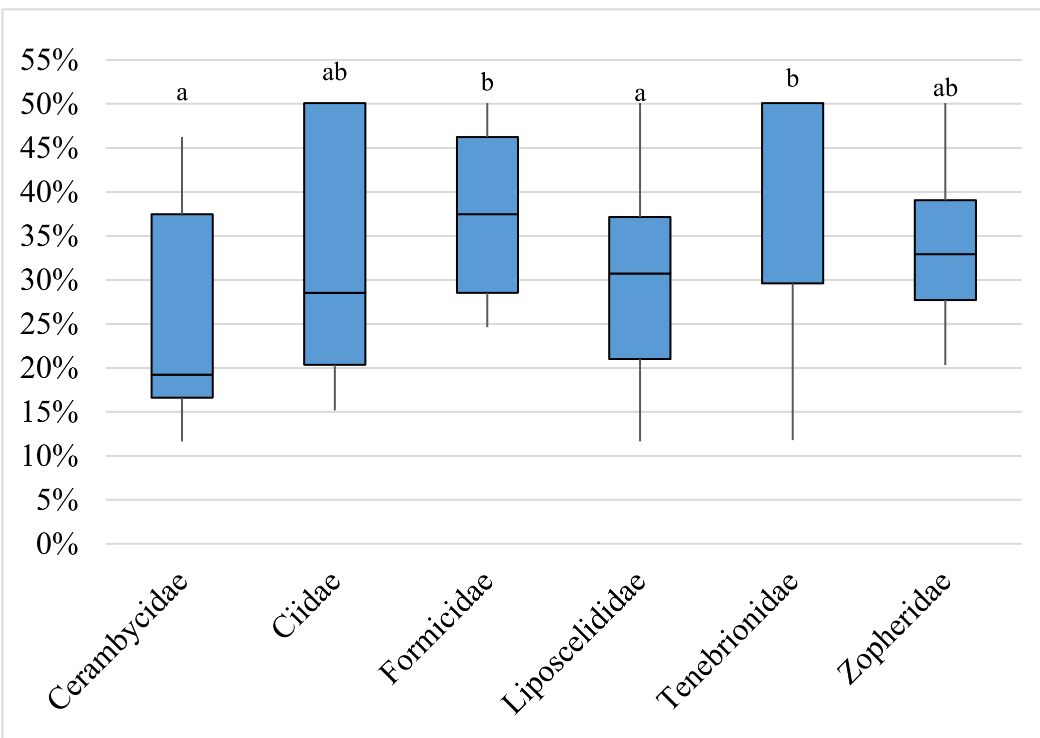

Figure 2.9 Moisture Content at which Common Families were Collected

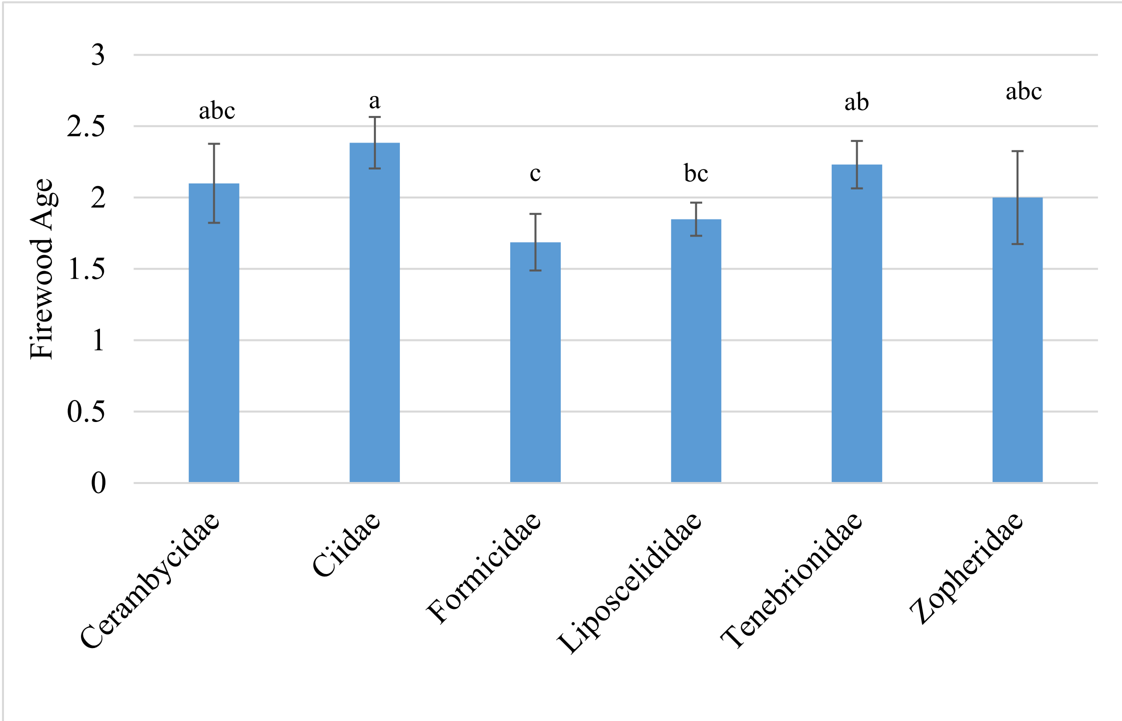

Figure 2.10 Common Families by Mean Firewood age

Mean age was calculated by assigning numerical values to the age categories reported by campers using <6 months=1, 6 months to 1 year=2, 1 to 2 years=3, and > 2 years=4.

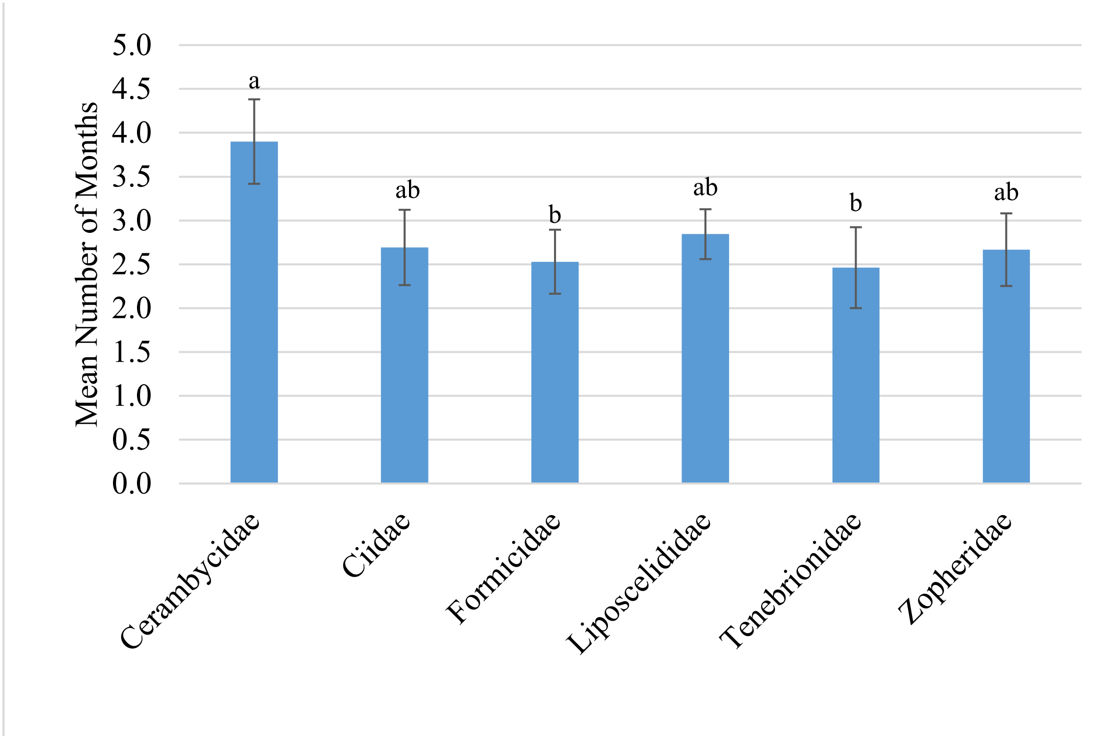

Figure 2.11 Common Families by Mean Number of Months before Emergence

Mean number of months refer to the average number of months since rearing was initiated until the insects were collected.

The Shannon biodiversity index (Hill 1973) was calculated on count of family level data (Figure 2.12). The second month after rearing initiation had the greatest evenness. Subsequent collections became increasingly dominated by fewer families. The Shannon index calculated on count of family collections by MC groups shows no clear trend, but varies from 2.4 (10-15% and 35-40% MC groups) to 1.5 (45-50% MC group) (Figure 2.13). Similarly to the collection number indices, the Shannon indices calculated with count of family collections by firewood age class rise from firewood < 6 months old to firewood between 6 months and year old and then falls with older firewood (Figure 2.14).

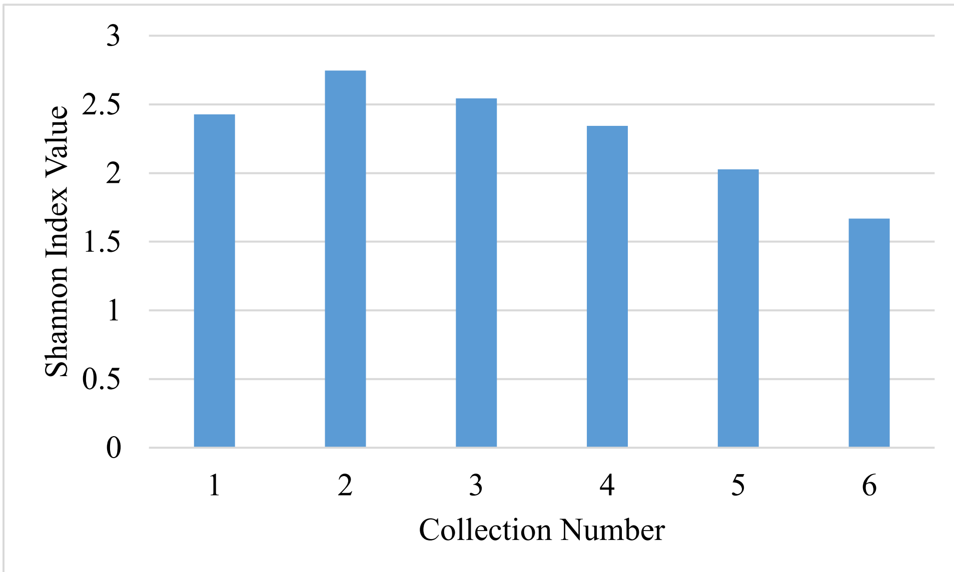

Figure 2.12 Shannon Index Values by Collection Number

Shannon Index values calculated by number of times a family was identified from samples during each monthly collection.

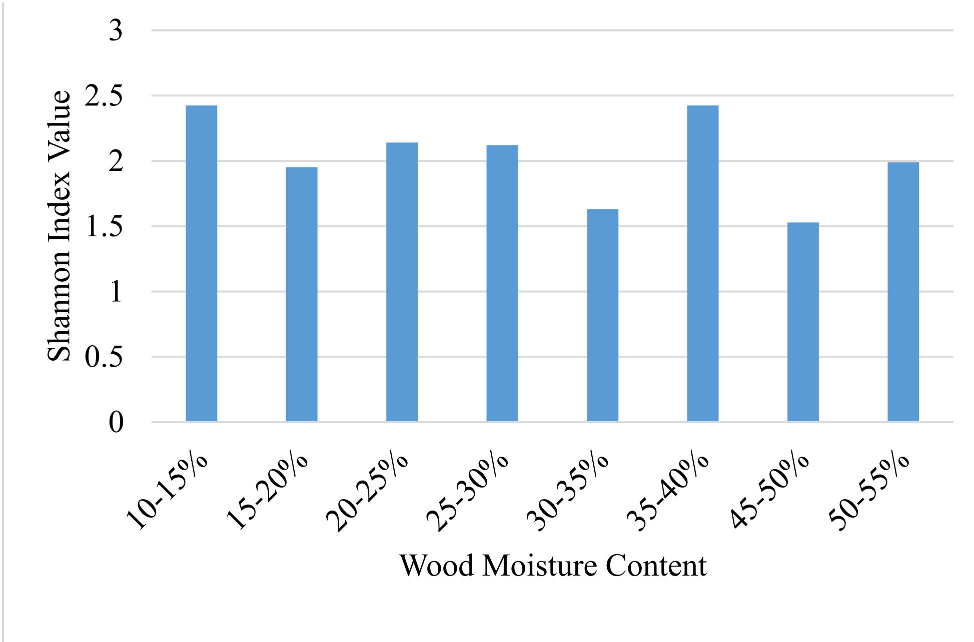

Figure 2.13 Shannon Index Values by Wood Moisture Content

Shannon Index values calculated by number of times a family was identified from firewood belonging to each MC category.

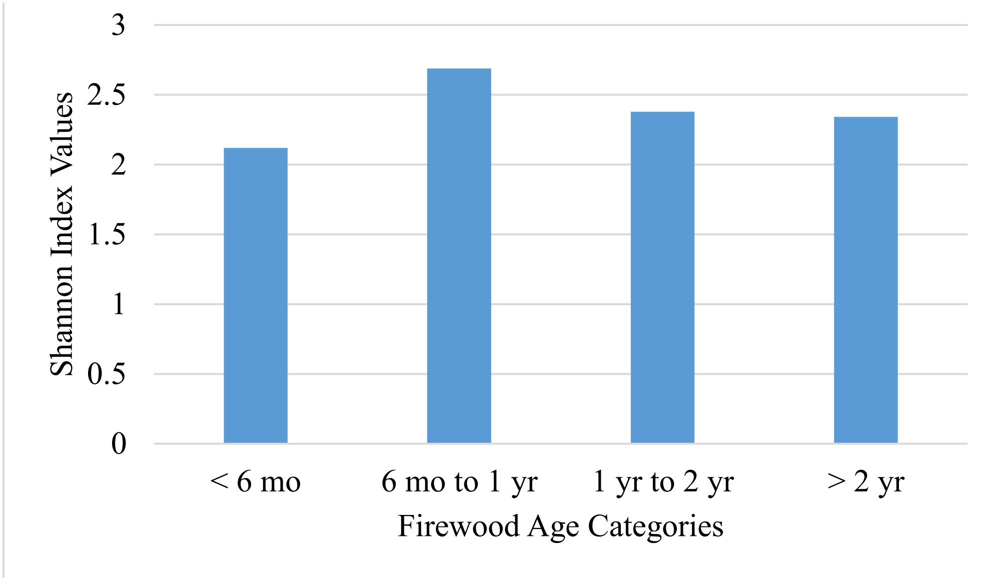

Figure 2.14 Shannon Index Values by Firewood Age Categories

Shannon Index values calculated using number of times a family was identified from firewood from each firewood category.

Discussion

During the fall that this study was conducted, a burn ban was issued that eventually affected all but 7 counties in the state. According to park managers, this resulted in much lower numbers of campers transporting firewood into the parks than was normal for the peak camping season in Mississippi. This abnormality may have had an effect on the firewood that was collected, but we cannot be sure of how or if this affected the results of the study.

The firewood dissections revealed similar results to the firewood dissections performed by Haack et al. during their study on firewood surrendered at the Mackinac Bridge (Haack et al. 2010). In that study evidence of past insect infestation was found in

64% of firewood pieces dissected and live insects were found in 23% of pieces. We found insects in 64.8% of firewood pieces, and live insects in 20.0%. The similarity of the findings between studies conducted in the northern and southern regions of the eastern United States suggests that a fairly uniform rate of insect presence in firewood may exist in the eastern part of the United States. This is reinforced by the fact that even though the firewood had distinctly different compositions of tree genera the rate of insect presence in the wood was similar. This also suggests that while the tree genera that make up the firewood may affect the species of the insects present it does not drive the presence of insects in the firewood.

Wood Genera

A wide variety of tree genera were found to be utilized as firewood during the study, but *Quercus*, predominated (followed by *Celtis*, *Liquidambar*, and *Acer*). Other studies that examined the genera of wood being sold as or used for firewood found very different compositions of genera. In the study that Haack et al. (2010) conducted in Michigan the most common tree genera were *Acer, Betula,* and *Carya*, with *Acer* making up 30.3% of the total. In the study by Jacobi et al. (2012) in Colorado the two most common genera were *Pinus* (60% of total) and *Quercus* (20% of total). The differences in genera found may be due to cultural preference for specific woods, or the makeup of the different forest types in which the studies occurred.

Distance Travelled

The mean distance travelled by firewood in this study (89.5 km) is similar to the mean distance travelled by campers (92.6 km) in Koch et al. (2012). The distances travelled by firewood of all source types indicates that much of the firewood is being procured by campers near where they live. This distance is well beyond what nearly all insects would disperse under their own power, and could move invasive insects well beyond the current invasion front.

Moisture Content

The MC of firewood that contained live insects was significantly higher than that of firewood that only had evidence of past insect infestation. No significant difference was found in the MC of firewood with no past damage or insects present and firewood with insects present (p-value=0.054). If a larger sample size of firewood was collected a difference may have been found, but this study was not able to. The mean MC of the firewood that contained insects (27.6%) was near the fiber saturation point (FSP) of most wood species. This fits well with the information presented in Haack (1987). Insects feeding in firewood have no access to moisture except that contained in the wood they ingest, and this becomes a limiting factor for insect development as the wood becomes drier. Some species are adapted for survival in drier wood (Haack 1987) and escape this restriction and dry firewood cannot be deemed as always being free from insects.

Firewood Age

Most (57%) campers who cut their own firewood reported that they had cut it less than one year ago, this combined with the average moisture content of those age categories (28.7±2.6%) indicates that campers are transporting firewood that is still near the FSP, and susceptible to insect infestation.

Firewood greater than 2 years old was found to have a significantly lower MC than the other age categories, but not a significantly lower percentage with insects present. Based solely on the mean MC of this age group (12.9%) one would predict a lower percentage of the firewood to contain insects. Perhaps the insect community inside the older firewood has shifted towards insects that are more adapted to the drier conditions. If so, this community shift may exclude insects that are adapted to attack live trees and inhabit wood with a higher MC.

Firewood Source

More than half the firewood collected (59.3%) was reported to have been cut by campers, and the firewood that was purchased was equally split between commercial and non-commercial sources. Other studies suggest that the preference for cutting one's own firewood may be due to the convenience of not having to find sources of firewood near the campground and avoiding the expense of purchasing it (Peterson and Nelson 2009, Peterson and Diss-Torrance 2012).

Firewood that was cut by campers had a significantly higher MC than firewood that was purchased from either source type. This may be due to campers who cut their own wood not properly seasoning it. This is supported by the relatively short time period between cutting and transport and the high moisture content of self-cut firewood.

The lower MC of firewood that was purchased from non-commercial sources did not, however, lower the percent found with live insects. There was no significant difference in the percentages found to have past damage or live insects between firewood cut by campers and purchased from non-commercial sources.

No live insects were dissected from firewood purchased from commercial sources, and a significantly lower percentage contained evidence of past insect feeding. While collecting firewood from campers, it was noted that the packaging of much of the commercially purchased firewood indicated that it had been heat treated. These results corroborate the current consensus that commercially purchased firewood is the safest option. Even though firewood from non-commercial sources has a greater risk of insect presence, the danger of moving exotic woodborers can be negated by purchasing it near the camping destination.

Insect Fauna of Firewood

During the course of rearing insects from the collected firewood 35 families of insects, representing 14 orders, were collected. Jacobi et al. (2012) identified 51 families of insects from those emerging from firewood procured in the Southwestern United States. This may be due to the larger scope of the study conducted by Jacobi et al. or differences in the insect fauna of the regions. Of the families in this study that were found 10 or more times, only one was a family of woodborers (Cerambycidae). The second most commonly collected family (Formicidae), however, is also a family of concern as it also contains economically and ecologically threatening invasive species. Of the commonly collected families the remaining four families (Liposcelididae, Tenebrionidae, Ciidae, and Zopheridae) feed on fungi and detritus (Imms 1960, Arnett et al. 2002). Fungivores, detritivores, predators, parasites, and woodborers were collected from the firewood. The variety of insects collected illustrates the diverse niches available in firewood and the insect community that fills them.

Shannon Indices

As count of individuals was not able to be used to calculate Shannon index values count of times a family was identified from a category was used instead. Inability to collect all individuals of families with small insects (ex. Liposcelididae and collembolans) and the high number of destroyed specimens found during collections, from predation inside the rearing chamber or feeding by detritivores, removed the needed accuracy to use count of individuals. Count of family identifications is substituted as it acts as a population of families and still illustrates the commonness of the taxa in firewood. Shannon indices allow the evenness of the diversity in a system to be evaluated (Hill 1973) and using count of family identifications preserves this goal and allows similar conclusions to be reached. Other modifications of the Shannon Index have been used previously, including substituting percent cover of plant species for counts of individuals (Tilman et al. 1997). We believe this modification to be a valid use of the index and still provides insight into the diversity and evenness of the insect families present in the firewood sampled.

The Shannon Indices calculated based on the MC of the firewood does not show a clear pattern. This may indicate that the evenness and diversity of the insect fauna is not driven by the MC of the firewood, but by other factors. The Shannon Indices calculated using the collection during which families were found, however, appears to have a clear upward and then downward trend with increasing collection number. This may be due to the maximal diversity of insects emerging during the second month of rearing or due to the lowering moisture content of the firewood as it dries only allowing a smaller group of families to successfully complete development. If the latter is true this effect could represent an artifact of laboratory rearing of the samples, or be representative of the effect of drying firewood for seasoning on the insect community. The Shannon Indices calculated using the reported age of the firewood exhibited a similar trend to those based on the collection number, but the effect is much less marked. The age of the firewood may play a role in driving insect diversity, but conclusions drawn from this analysis may be suspect.

Conclusions

Going in to this study it was hypothesized that MC of the firewood would play a major role in determining the presence and diversity of insects, but the results suggest that it is a more complicated situation. While MC may affect whether particular species of insects are present, firewood source and age also interact with MC to determine the likelihood and range of insects present. Insects have adapted to utilize wood in all conditions and this is represented by their presence in a variety of wood conditions.

While insects were present in many wood conditions, it was found that wood with a higher MC was associated with increased levels of past damage, and older firewood with increased levels of both past damage and live insects. Commercially purchased firewood was associated with lower levels of both past damage and live insects. According to these results firewood with the lowest insect risk would be commercial firewood that is dry and recently purchased. This adds support to the current consensus on safe firewood practices.

Unfortunately, this is not the firewood campers are commonly transporting. Half of campers are transporting firewood that was cut by themselves and the average MC is above that of properly seasoned firewood. This movement of high risk firewood in

Mississippi opens the possibility for the spread of invasive woodborers into and throughout the state. The presence of EAB in nearby states and RAB in the state (Riggins et al. 2010, Anonymous 2017) makes the issue of woodborer spread through recreational firewood crucial to assess and control.

References

Anonymous. 2017. Emerald Ash Borer. https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/emerald-ash-borer

Anulewicz, A. C., D. G. Mccullough, D. L. Cappaert, and T. M. Poland. 2008. Host range of the emerald ash borer (Agrilus planipennis Fairmaire)(Coleoptera: Buprestidae) in North America: results of multiple-choice field experiments. Environmental Entomology 37: 230-241.

Arnett, R. H., M. C. Thomas, P. E. Skelley, and J. H. Frank. 2002. American Beetles, Volume II: Polyphaga: Scarabaeoidea through Curculionoidea, vol. 2, CRC press.

Atkinson, T. 2004. Ambrosia beetles, Platypus spp.(Insecta: Coleoptera: Platypodidae). EENY1 74 Univ Florida: 1-7.

Cameron, R. S., C. Bates, and J. Johnson. 2008. Distribution and spread of laurel wilt disease in Georgia: 2006-08 survey and field observations. Georgia Forestry Commission report: 2006-2008.

Cappaert, D., D. G. McCullough, T. M. Poland, and N. W. Siegert. 2005. Emerald ash borer in North America: a research and regulatory challenge. American Entomologist 51: 152-165.

Fraedrich, S., T. Harrington, R. Rabaglia, M. Ulyshen, A. Mayfield Iii, J. Hanula, J. Eickwort, and D. Miller. 2008. A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the southeastern United States. Plant Disease 92: 215-224.

Gandhi, K. J., and D. A. Herms. 2010. North American arthropods at risk due to widespread Fraxinus mortality caused by the alien emerald ash borer. Biological Invasions 12: 1839-1846.

Haack, R. A., T. R. Petrice, and A. C. Wiedenhoeft. 2010. Incidence of bark-and wood-boring insects in firewood: a survey at Michigan's Mackinac Bridge. Journal of Economic Entomology 103: 1682-1692.

Haack, R. A., K. R. Law, V. C. Mastro, H. S. Ossenbruggen, and B. J. Raimo. 1997. New York's battle with the Asian long-horned beetle. Journal of Forestry 95: 11-15.

Haack, R. A., Slansky, Frank, . 1987. Nutritional Ecology of Wood-Feeding Coleoptera, Lepidoptera, and Hymenoptera, pp. 449-486. In F. J. Slansky, Rodriguez, J. G. (ed.), Nutritional Ecology of Insects, Mites, Spiders, and Related Invertebrates. Wiley Interscience New York.

Hill, M. O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology 54: 427-432.

Imms, A. D. 1960. A General Textbook of Entomology: Including the Anatomy, Physiology, Development, and Classification of Insects, 9th ed. Metheun & Co. Ltd., London.

Jacobi, W., B. Goodrich, and C. Cleaver. 2011. Firewood transport by national and state park campers: a risk for native or exotic tree pest movement. Arboriculture and Urban Forestry 37: 126.

Jacobi, W., J. Hardin, B. Goodrich, and C. Cleaver. 2012. Retail firewood can transport live tree pests. Journal of economic entomology 105: 1645-1658.

Koch, F. H., D. Yemshanov, R. D. Magarey, and W. D. Smith. 2012. Dispersal of invasive forest insects via recreational firewood: a quantitative analysis. Journal of Economic Entomology 105: 438-450.

Lingafelter, S. 2007. Illustrated key to the longhorned woodboring beetles of the eastern United States. Coleopt. Soc. Spec. Pub 3: 206.

Mattson, W. J., P. Niemelä, I. Millers, and Y. Inguanzo. 1994. Immigrant phytophagous insects on woody plants in the United States and Canada: an annotated list. Immigrant phytophagous insects on woody plants in the United States and Canada: an annotated list.

Messenger, M. T. 2001. The termite species of Louisiana: an identification guide, New Orleans Mosquito & Termite Control Board.

Nowak, D. J., J. E. Pasek, R. A. Sequeira, D. E. Crane, and V. C. Mastro. 2001. Potential effect of Anoplophora glabripennis (Coleoptera: Cerambycidae) on urban trees in the United States. Journal of Economic Entomology 94: 116-122.

Panshin, A. J., and C. d. Zeeuw. 1980. Textbook of wood technology, McGraw-Hill Book Co.

Peterson, K., and E. B. Nelson. 2009. Firewood Use in Wisconsin State Parks and Forests, 2006 and 2008. Research/ Management Findings.

Peterson, K., and A. Diss-Torrance. 2012. Motivation for compliance with environmental regulations related to forest health. Journal of environmental management 112: 104-119.

Petrice, T. R., and R. A. Haack. 2006. Effects of cutting date, outdoor storage conditions, and splitting on survival of Agrilus planipennis (Coleoptera: Buprestidae) in firewood logs. Journal of Economic Entomology 99: 790-796.

Riggins, J., M. Hughes, J. Smith, A. Mayfield III, B. Layton, C. Balbalian, and R. Campbell. 2010. First occurrence of laurel wilt disease caused by Raffaelea lauricola on redbay trees in Mississippi. Plant Disease 94: 634-634.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. Science 277: 1300-1302.

Triplehorn, C. A., and N. F. Johnson. 2005. Borror and Delong's introduction to the study of insects, 7th ed. Thomson Brooks/Cole, Belmont, CA.

(USDA, NRCS) U.S. Department of Agriculture, Natural Resources Conservation Service. 2017. USDA PLANTS Database. https://plants.usda.gov/java/

Wood, S. L. 1982. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae), a taxonomic monograph. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae), a taxonomic monograph.

CHAPTER III

ATTITUDES, BELIEFS, AND ACTIONS OF CAMPERS IN MISSISIPPI STATE PARKS REGARDING NON-NATIVE WOODBORER TRANSPORT IN RECREATIONAL FIREWOOD

Introduction

Informing the public about the dangers of invasive species is the first step to creating changed behaviors that promote invasive species management (Cole et al. 2016). Associations have been found that link awareness of invasive species to willingness to participate in invasive species management (Bremner and Park 2007, García-Llorente et al. 2011, Niemiec et al. 2016), however, additional factors play a role in creating changed behaviors (Peterson and Diss-Torrance 2012).

García-Llorente et al. (2011) found survey respondents were more willing to contribute to invasive species control programs if they had knowledge of the invasive species, had awareness of the negative impact of the invasive species, and had an interest in nature. The authors also found that respondent's willingness to participate increased with knowledge of how invasive species threatened native species and feelings of connection to the place where damage was occurring. Niemiec et al. (2016) similarly found that knowledge of invasive species threats on biodiverity and public property increased willingness to partipate in mangement activities.

Beyond invasive species awareness, respondents' views of actions or mores that are considered socially acceptable, surrounding invasive species management impact their willingness to participate in management activities (Peterson and Diss-Torrance 2012, Niemiec et al. 2016). Awareness of invasive species management can be created by seeing others in one's community engage in management activities or discuccions about them (Niemiec et al. 2016). This awareness must be turned into a personal norm before it is acted on, however (Peterson and Diss-Torrance 2012).

Factors discouraging involvement in invasive species management include beliefs that the general public does not care or is not informed about invasive species and that the individual does not know enough to effectively perform preventative or control measures (Prinbeck et al. 2011). In order for individuals to be willing to participate in invasive species management, they need to feel their efforts are making a difference. Factors that specifically discourage public involvement in management activities in relation to firewood movement are firewood price and convenience (Peterson and Diss-Torrance 2012).

The current study seeks to apply these factors to camper movement of recreational firewood in Mississippi. Recreational firewood as a pathway for the dispersal of non-native woodborers is supported by several studies (Petrice and Haack 2006, Haack et al. 2010, Jacobi et al. 2012). Slowing and stopping the anthropogenic spread of non-native woodborers necessitates understanding the beliefs and attitudes of campers who move firewood and how these relate to their actions. Without understanding how these insects disperse, resources cannot be efficiently allocated to control efforts. Most current research on social aspects of invasive species management explores survey data from users of recreational areas or areas affected by invasive species, leaving a gap in the knowledge where camper attitudes and beliefs meet actions. I seek to fill this gap by combining camper survey data on attitudes and beliefs with data from firewood collections from respondents.

Materials and Methods

An intercept survey with questions directed at camper attitudes and beliefs surrounding non-native wood borers in firewood and their impacts was designed using principles from Dillman (1978). The survey was focused on State and Federal forests in the Mississippi as well as camper habits associated with the acquisition and transport of recreational firewood (Appendix A). The survey was 21 questions long and took less than five minutes to administer. The survey consisted of questions regarding camper knowledge of non-native woodborers, camper attitudes and beliefs surrounding their impacts, camper firewood habits, and camper exposure to public awareness campaigns.

Data were gathered during visits to four state park campgrounds in Mississippi, Buccaneer State Park, Percy Quin State Park, J. P. Coleman State Park, and Tishomingo State Park. Two sites were selected in the southern part of the state (Bucaneer and Percy Quin State Parks) and two in the northern part of the state (J. P. Coleman and Tishomingo State Parks). Parks were also selected based on the number of out-of-state visitors they receive to maximize the diversity of campers sampled.

Bucaneer State Park is located on the Gulf Coast near Waveland, MS and receives many campers visiting the beaches. It has the highest number of out-of-state campers per year of any Mississippi State Park. Percy Quin State Park is centered on Lake Tangipahoa and is a popular fishing destination. Its proximity to Louisiana draws out-of-state visitors for fishing. J. P. Coleman State Park is located near the border of Mississippi, Alabama, and Tennessee. Due to its location it is visited by many out-of-state campers from Tennessee and Alabama, states that EAB has been detected in. Tishomingo State Park is located near Bay Springs Lake and close to the Alabama border.

During the fall that this study was conducted, a burn ban was issued that eventually affected all but seven counties in the state. According to park managers, this resulted in much lower numbers of campers transporting firewood into the parks than is normal for the peak camping season in Mississippi.

Campgrounds were visited four times during July to December, 2016. During campground visits, campers were approached at campsites and asked if they were willing to participate in the study. Campers were offered an LED lantern and a lunchbox containing other incentives to participate in the study (Figure 3.1). If campers agreed, they were given the investigator's contact information and informed that they could refrain from answering any questions in the survey. The survey was delivered verbally, with answers inputted by the interviewer in iSurvey, a smartphone application (app version 2.13.13 Contact Software Ltd., Lower Hutt, New Zealand, 2017).

Figure 3.1 Incentives offered to campers for participation

LED lantern, lunchbox, and other incentives offered for participation in the survey.

Statistical analyses were performed using JMP®, version 13 (SAS Institute Inc., Cary, NC, 1998-2016) using alpha levels of 0.05. Chi-square tests were used to determine if campers' responses to a question were independent of how they answered other questions. Data from firewood collected from campers in chapter 2 were used to compare attributes of firewood brought to campgrounds with camper responses to survey questions. Wilcoxon analyses were used to compare wood moisture content, number of insect families reared from the firewood, and distance firewood was transported to the survey responses due to the nonparametric nature of the data. Presence of past damage during dissection, presence of insects during dissections, presence of woodborers during dissection, and firewood source were compared to survey responses using Pearson chi-square analyses.

Results

During visits to state parks, 168 campers were surveyed. The mean age of surveyed campers was 50.1 years. Of the surveyed campers, 161 identified as white, one identified as American Indian, one identified as Hispanic, and five campers preferred not to say. The most common response to what is your highest level of education was “high school” (n=50). The next most common was “completed college (Bachelor’s degree)” (n=45), followed by “some college” (n=42), “post-graduate degree” (n=21), “none of the above” (n=5), and “technical school or GED” (n=4). Sixty five point five percent of surveyed campers were male, and 34.5% were female.

Camper reported sources of firewood

When asked where they were most likely to obtain firewood, 68.5% of campers responded that they most likely obtain it close to home and 31.5% responded that they most likely obtain it close to the campground (Figure 3.2).

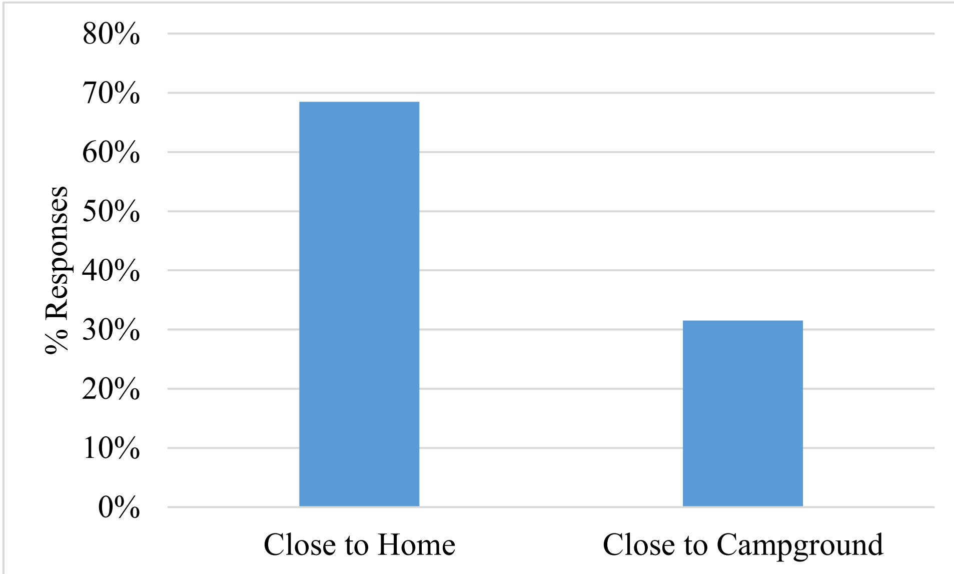

Figure 3.2 Camper responses to “where are you most likely to obtain firewood?”

Age, race, highest level of education, and gender were independent of responses to this question. Responses were compared with responses to five other questions; “are you aware invasive species can be transported in firewood?”;“do you think non-native woodborers pose a threat to forests in the U.S.?”; “how important is it to you to stop the spread of invasive woodboring insects?”; “are you aware that several states have placed bans on the movement of firewood across stateliness?”; and “have you seen public awareness campaigns aimed at the dangers of moving firewood?” to test for independence of the responses. Of these questions “have you seen public awareness campaigns aimed at the dangers of moving firewood?” had the largest effect on their responses, followed by “how important is it to you to stop the spread of invasive woodboring insects?” and “are you aware that invasive species can be transported in firewood?” (Table 3.1). Camper responses to “do you think that non-native woodboring insects are a threat to forests in the U.S?" and "are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?" were found to be independent from their responses to "where are you most likely to obtain firewood?".

Table 3.1 Effects of other questions on responses to "Where are you most likely to obtain firewood?"

Where are you most likely to obtain firewood?					
	Close to home		Close to campground		p-value[1,2]
	n	%[3]	n	%[3]	
Are you aware that invasive species can be transported in firewood?					0.0188
Yes	49	59.8%	33	40.2%	
No	63	76.8%	19	23.2%	
Do you think non-native woodboring insects are a threat to forests in the U.S.?[4]					0.343
How important is it to you to stop the spread of invasive woodboring insects?					0.0137
Very important	63	60.6%	41	39.4%	
Moderately important	35	79.6%	9	20.5%	
Not important	15	88.2%	2	11.8%	
Are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?[4]					0.192
Have you seen public awareness campaigns aimed at the dangers of moving firewood?					0.0011
Yes	16	45.7%	19	54.3%	
No	97	74.6%	33	25.4%	

[1]P-values represent the Pearson chi-square p-value for the interaction between questions.
[2]$\alpha=0.05$
[3]Percentages are represented as row percentages from a Chi-square table.
[4]The responses for questions with non-significant p-values are excluded.

Camper support for government regulations

When asked "would you support government regulations restricting the movement of firewood?" Sixty four point three percent of campers responded yes, 14.3% responded maybe, and 21.4% responded no (Figure 3.3).

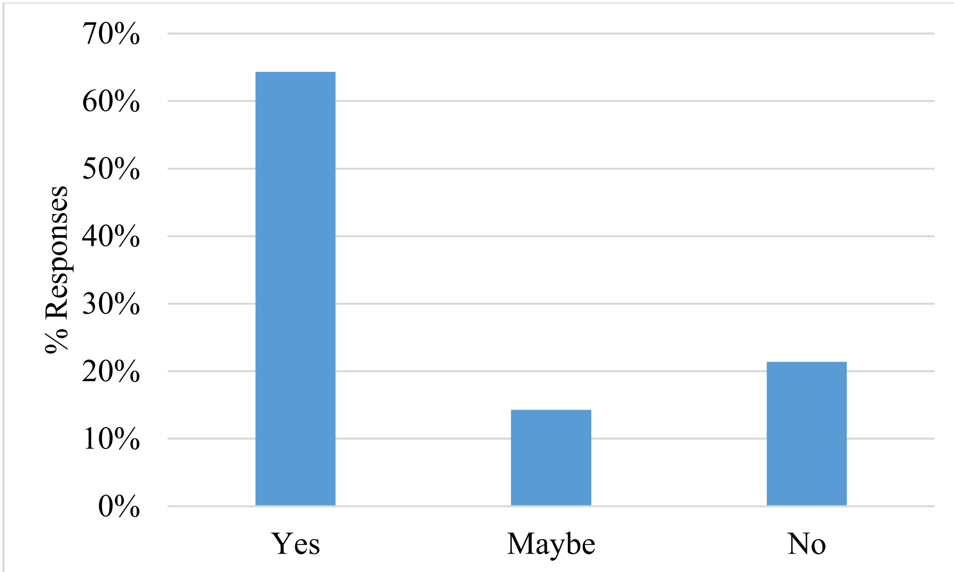

Figure 3.3 Camper responses to "would you support government regulations restricting the movement of firewood?"

Age, race, highest level of education, and gender were independent of responses to this question. Camper responses to this question were compared to responses to the same five questions as “where are you most likely to obtain firewood?” to test for independence. Responses to “have you seen public awareness campaigns aimed at the dangers of moving firewood?” had the largest impact on responses to “would you support government regulations restricting the movement of firewood?” (Table 3.2). This was followed by “do you think non-native woodboring insects are a threat to forests in the U.S.?”, “how important is it to you to stop the spread of invasive woodboring insects?”, and “are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?”. Campers’ responses to “are you aware that invasive species can be transported in firewood?” were independent to their responses of “would you support government regulations restricting the movement of firewood?”.

Table 3.2 Effects of other questions on “Would you support government regulations restricting the movement of firewood?”

Would you support government regulations restricting the movement of firewood?							
	Yes		No		Maybe		p-value[1,2]
	n	%[3]	n	%[2]	n	%[3]	
Are you aware that invasive species can be transported in firewood?[4]							0.671
Do you think non-native woodboring insects are a threat to forests in the U.S.?							0.0406
Major threat	39	75.0%	7	13.5%	6	11.5%	
Moderate threat	39	73.6%	9	17.0%	5	9.4%	
Minor threat	10	55.6%	5	27.8%	3	16.7%	
Don’t know	20	44.4%	15	33.3%	10	22.2%	
How important is it to you to stop the spread of invasive woodboring insects?							0.0059
Very important	74	71.2%	17	16.4%	13	12.5%	
Moderately important	27	60.0%	9	20.0%	9	20.0%	
Not important	7	36.8%	10	52.6%	2	10.5%	
Are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?							0.0458
Yes	43	76.8%	9	16.1%	4	7.2%	
No	65	58.0%	20	17.9%	27	24.1%	
Have you seen public awareness campaigns aimed at the dangers of moving firewood?							0.0082
Yes	30	83.3%	6	16.7%	0	0.0%	
No	78	59.1%	30	22.7%	24	18.2%	

[1]P-values represent the Pearson chi-square p-value for the interaction between questions.
[2]α=0.05
[3]Percentages are represented as row percentages from a Chi-square table.
[4]The responses for questions with non-significant p-values are excluded.

Sources of firewood collected in state parks

When asked about the source of their firewood 41.0% responded that they had purchased the firewood, and 59.0% responded that they or someone they knew had cut the firewood (Figure 3.4).

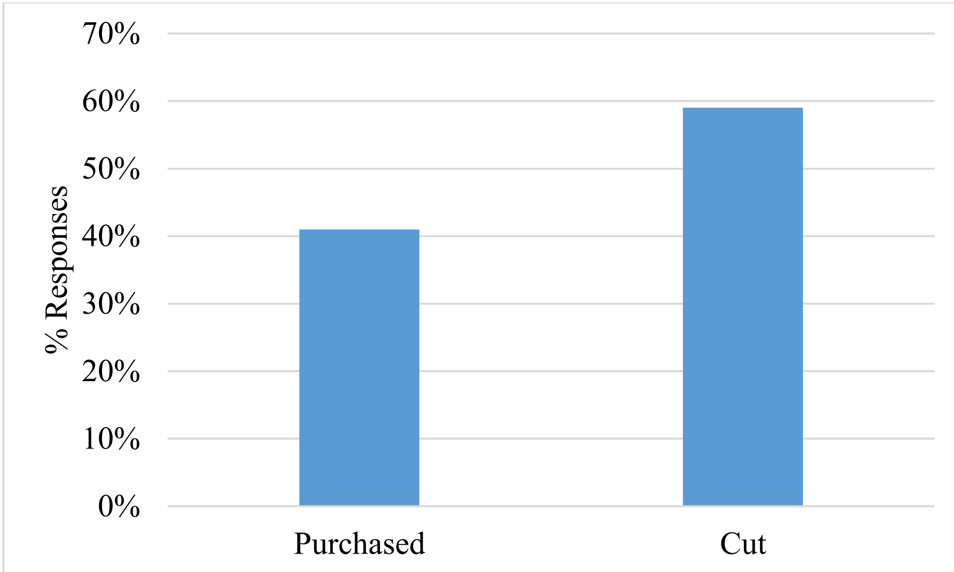

Figure 3.4 Camper responses to "did you purchase this firewood or did you or someone you know cut it?"

Age, race, highest level of education, and gender were independent of responses to this question. Camper responses to this question were compared to responses to the same five questions as above. Camper responses to each of the questions were independent to their response to “Did you purchase this firewood or did you or someone you know cut it?” (Table 3.3).

Table 3.3 Effect of other questions on “Did you purchase or cut this firewood?”

Did you purchase this firewood or did you or someone you know cut it?					
	Purchased		Cut		p-value[1,2]
	n	%[3]	n	%[3]	
Are you aware that invasive species can be transported in firewood?[4]					0.272
Do you think non-native woodboring insects are a threat to forests in the U.S.?[4]					0.604
How important is it to you to stop the spread of invasive woodboring insects?[4]					0.646
Are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?[4]					0.103
Have you seen public awareness campaigns aimed at the dangers of moving firewood?[4]					0.416

[1]P-values represent the Pearson chi-square p-value for the interaction between questions.
[2]α=0.05
[3]Percentages are represented as row percentages from a Chi-square table.
[4]The responses for questions with non-significant p-values are excluded.

Camper actions and firewood data interactions with beliefs and attitudes

No significant interactions were found between data from firewood collected from campers in chapter 2 (Table 3.5) and campers’ self-reported actions based on questions focusing on attitudes, beliefs, and actions (Table 3.5). This indicates that there was no association between how campers responded to survey questions and the attributes of their firewood or actions in relation to safe firewood practices. If a change in camper actions occurred due to their attitudes and beliefs regarding non-native woodborers that would result in a change in data from their firewood.

Table 3.4 Camper firewood data versus attitudes and beliefs

Wood MC[1]	Past Damage[2]	Insects Present[3]	Woodborers Present[4]	Number of families reared[5]
Where are you most likely to obtain firewood?				
0.8998	0.8294	0.8294	0.2365	0.0602
Are you aware invasive species can be transported in firewood?				
0.8360	0.2301	0.9402	0.0736	0.2256
Do you think non-native woodboring beetles are a threat to forests in the U.S.?				
0.3932	0.7782	0.1100	Assumptions not met[6]	0.1002
How important is it to you to stop the spread of invasive wood boring insects?				
0.6874	0.9759	0.8904	0.4561	0.2213
Are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?				
0.8940	0.6056	0.4386	0.0888	0.2789
Have you seen public awareness campaigns aimed at the dangers of moving firewood?				
0.8998	0.2812	0.4506	0.9730	1.0000

Values represent P-values for Wilcoxon (wood MC and number of families reared) and Pearson chi-square (past damage, insects present, and woodborers present) analyses between responses to survey questions and data from camper firewood.

$\alpha=0.05$

[1] Average moisture content of the firewood pieces in a sample.

[2] Presence or absence of past insect feeding during firewood dissections.

[3] Presence or absence of live insects during firewood dissections.

[4] Presence or absence of woodborers during firewood dissections.

[5] Number of insect families identified from insects reared from firewood samples.

[6] Mean cell count was <5, chi-square invalid.

Table 3.5 Camper actions versus attitudes and beliefs

Where are you most likely to obtain firewood?	
Firewood source[1]	Distance transported[2]
0.0744	0.5779
Are you aware invasive species can be transported in firewood?	
Firewood source[1]	Distance transported[2]
0.2723	0.6802
Do you think non-native woodboring beetles are a threat to forests in the U.S.?	
Firewood source[1]	Distance transported[2]
Assumptions not met[3]	0.9915
How important is it to you to stop the spread of invasive wood boring insects?	
Firewood source[1]	Distance transported[2]
0.6461	0.5788
Are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?	
Firewood source[1]	Distance transported[2]
0.1030	0.8315
Have you seen public awareness campaigns aimed at the dangers of moving firewood?	
Firewood source[1]	Distance transported[2]
0.6592	Assumptions not met[3]

Values represent P-values for Pearson chi-square (firewood source) and Wilcoxon (distance transported) analyses between responses to survey questions and data from camper firewood.
α=0.05
[1] Source of firewood (cut or purchased by campers).
[2] Distance firewood was transported to campground based on camper reported origin localities.
[3] Insufficient data to meet assumptions of test.

Discussion

Camper sources of firewood

Camper responses to “Where are you most likely to obtain firewood?” were most influenced by their having seen public awareness campaigns; however, the amount of importance they ascribed to stopping the spread of invasive wood borers and their awareness of the problem were also important. This suggests that campers who are aware of invasive species being transported in firewood are more likely to report having safe firewood practices. In addition to campers being aware of the problem, campers who placed importance on the problem were more likely to report having safe firewood habits. This fits with Cole et al. (2016), who found that knowledge of the problem is required for a change in behavior, but may only be a prerequisite to it. Other drivers of change to behavior include the attitude that the problem is worth making a change for and caring about the issue.

Awareness of public awareness campaigns had a larger effect on camper responses to where they are most likely to obtain firewood than awareness of invasive species in firewood. Also, a greater proportion of campers responded that they were aware of invasive species than responded that they had seen a public awareness campaign. This suggests that the way information is presented to campers affects how likely they are to practice safe firewood habits. It may also suggest that seeing a public awareness campaign is more likely to change camper behavior than other methods of learning about invasive species in firewood.

Camper support for government regulations

Support for government restrictions on the movement of firewood was motivated by a different set of attitudes and beliefs than where campers obtain firewood. Awareness of invasive species in firewood was not a significant influence on their support for government restrictions, however, believing that invasive species pose a threat to forests in the U.S. and having heard of other states' measures to restrict firewood movement had an impact on how likely campers were to support similar government restrictions. This supports the finding by Bremner and Park (2007) that awareness of other invasive species management programs increases willingness to support other management programs. The finding that the belief that invasive species pose a threat to U.S. forests increases support for government regulations is in agreement with the findings of García-Llorente et al. (2011) and Niemiec et al. (2016), who found that greater awareness of the damage caused by invasive species increased support for invasive species management.

Camper exposure to public awareness campaigns was the best predictor for camper responses to “where are you most likely to obtain firewood” and “would you support government regulations restricting the movement of firewood”. This indicates that public awareness campaigns are succeeding in educating campers, and this knowledge affected how they responded on the survey. Actual behavioral changes are different from changes to how campers respond on a survey, however.

Camper firewood habits

During the firewood collections for chapter 2, campers were asked whether their firewood was purchased or cut by themselves. Responses to this question were independent from responses to any of the questions with which it was analyzed. The factors of campers being exposed to public awareness campaigns or awareness of invasive species had no effect on how they procure their firewood. This again supports the findings of Cole et al. (2016) that campers have not made behavioral changes to safer firewood practices even though they have knowledge of non-native woodborers in firewood and know it is important to stop their spread.

The survey responses were analyzed in a further effort to correlate camper behavior to attitudes, their awareness of invasive species transported in firewood, the distance campers transported firewood, the average moisture content of their firewood, and the presence of live insects in their wood. If camper attitudes and beliefs regarding non-native woodborers changed their actions with respect to safe firewood practices it would be visible in the data from their firewood. Not finding an association suggests that no significant change in camper actions has occurred, and if a change has occurred it is not lowering their risk of spreading invasive species.

Wood moisture content and the distance firewood had been transported were used as a proxy for safe firewood practices regarding storage and procurement of firewood. A high wood moisture content indicates that the wood was recently cut or had been stored in a way that was not protected from water and allowed to dry, both of which are not considered safe firewood practices (NFTF 2010).

Conclusions

Many campers have gained awareness of the danger of moving firewood, as indicated by their responses to survey questions, but the behaviors of some campers relative to use and transportation of firewood have not changed. Many campers are aware that procuring firewood locally is the best option for preventing the spread of non-native woodborers, but they are not following what they know to be safe firewood practices. Awareness of invasive species and knowledge of their effects are the first step in changing camper behaviors, but more must be done to change behaviors.

Creating a community setting where invasive species management is the norm is important to affecting change in habits (Van Santen et al. 2004, Niemiec et al. 2016). People are more likely to practice invasive species management when they see others do so (Niemiec et al. 2016). Educating campers on the dangers of non-native woodborers and safe firewood practices is the easy part, creating conditions that promote campers to participate in invasive species management is more difficult, but is more effective at changing behaviors.

Further work is needed in order to further understand the associations between camper attitudes and beliefs and their firewood habits. A larger study focused on more specific aspects; such as firewood source, firewood storage, or firewood species utilized; could provide useful information.

References

Bremner, A., and K. Park. 2007. Public attitudes to the management of invasive non-native species in Scotland. Biological conservation 139: 306-314.

Cole, E., R. P. Keller, and K. Garbach. 2016. Assessing the success of invasive species prevention efforts at changing the behaviors of recreational boaters. Journal of Environmental Management 184: 210-218.

Dillman, D. A. 1978. Mail and telephone surveys: The total design method, vol. 19, Wiley New York.

García-Llorente, M., B. Martín-López, P. A. Nunes, J. A. González, P. Alcorlo, and C. Montes. 2011. Analyzing the social factors that influence willingness to pay for invasive alien species management under two different strategies: eradication and prevention. Environmental management 48: 418-435.

Haack, R. A., T. R. Petrice, and A. C. Wiedenhoeft. 2010. Incidence of bark-and wood-boring insects in firewood: a survey at Michigan's Mackinac Bridge. Journal of Economic Entomology 103: 1682-1692.

Jacobi, W., J. Hardin, B. Goodrich, and C. Cleaver. 2012. Retail firewood can transport live tree pests. Journal of economic entomology 105: 1645-1658.

(NFTF) National Firewood Task Force. 2010. NFTF Recommendations. U.S.D.A APHIS, Riverdale, MD.

Niemiec, R. M., N. M. Ardoin, C. B. Wharton, and G. P. Asner. 2016. Motivating residents to combat invasive species on private lands: social norms and community reciprocity. Ecology & Society 21: 398-407.

Peterson, K., and A. Diss-Torrance. 2012. Motivation for compliance with environmental regulations related to forest health. Journal of environmental management 112: 104-119.

Petrice, T. R., and R. A. Haack. 2006. Effects of cutting date, outdoor storage conditions, and splitting on survival of Agrilus planipennis (Coleoptera: Buprestidae) in firewood logs. Journal of Economic Entomology 99: 790-796.

Prinbeck, G., D. Lach, and S. Chan. 2011. Exploring stakeholders' attitudes and beliefs regarding behaviors that prevent the spread of invasive species. Environmental Education Research 17: 341-352.

Van Santen, L., J. Goven, and L. Langer. 2004. The role of community involvement in future incursion responses. NZ J For 49: 38.

APPENDIX A

CAMPER SURVEY

Q1 Where did your firewood come from (city, state)?

Q2 Did you purchase this firewood or did you or someone you know cut it?

- ☐ I purchased it
- ☐ Someone else cut it
- ☐ I cut it

Q3 Where was the firewood purchased?

- ☐ Commercial store (e.g., gas station, grocery store, coop)
- ☐ Noncommercial source (e.g., neighbor, Boy Scouts)

Q4 When did you purchase the firewood?

- ☐ Less than 6 months ago
- ☐ 6 months to a year ago
- ☐ Between one and two years ago
- ☐ More than two years ago

Q5 Please estimate how long ago you or someone you know cut the wood if it was not purchased?

- ☐ Less than 6 months
- ☐ 6 months to a year
- ☐ Between one and two years ago
- ☐ More than two years

Q6 Do you think the tree where this firewood came from was a healthy tree or did it appear to be a dead or dying tree?

- ☐ Definitely healthy
- ☐ Maybe healthy
- ☐ Definitely not healthy
- ☐ I don't know enough to answer

Q7 Where are you most likely to obtain firewood?

- ☐ Close to home
- ☐ Close to campground
- ☐ Somewhere else (specify) ____________________

Q8 How often do you transport firewood to campgrounds?

- ☐ Less than once a year
- ☐ About one time per year
- ☐ Two to three times a year
- ☐ More than three times per year

Q9 Are you aware invasive species can be transported in firewood?

- ☐ Yes
- ☐ No

Q10 Have you heard of any of the following wood-boring insects?

- ☐ Emerald ash borer
- ☐ Asian long-horned beetle
- ☐ Redbay ambrosia beetle

Q11 Do you think non-native wood boring insects are a threat to forests in the United States?

- ☐ A major threat
- ☐ A moderate threat
- ☐ Minor threat
- ☐ Don't know

Q12 How important is it to you to stop the spread of invasive wood boring insects?

- ☐ Very important
- ☐ Moderately important
- ☐ Not important

Q13 How important do you think stopping the spread of invasive species should be to the government (federal or state)?

- ☐ Very important
- ☐ Moderately important
- ☐ Not important

Q14 Are you aware that several states have placed bans on the movement of firewood from out of state sources into the state?

- Yes
- No

Q15 Would you support government regulations restricting the movement of firewood?

- Yes
- Maybe
- No

Q16Have you seen public awareness campaigns aimed at the dangers of moving firewood?

- Yes
- No

Q17 Have these public awareness campaigns had any impact on your opinion regarding moving firewood?

- I am much less likely to move firewood
- I am somewhat less likely to move firewood
- No effect

Q18 Now I just have a few background questions so I can compare data from all the people we're asking. Again, all your responses are confidential and anonymous

- ☐ White
- ☐ Black or African American
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Native Hawaiian or Pacific Islander
- ☐ Other (specify) ____________________
- ☐ Prefer not to say

Q19 What year were you born?

____

Q20 What is your highest level of education

- ☐ None of the below
- ☐ High school
- ☐ Some college
- ☐ Technical school or GED
- ☐ Completed college (Bachelor's degree)
- ☐ Post-graduate degree

Q21 Gender (do not ask)

- ☐ Male
- ☐ Female