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The Danger Within: Implications of Firewood Transport in Invasive Forest Insect and Disease Spread

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THE DANGER WITHIN: IMPLICATIONS OF FIREWOOD TRASNPORT IN INVASIVE FOREST INSECT AND DISEASE SPREAD

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ABSTRACT

Invasive forest insects and diseases are a problem affecting North American forests, and their intracontinental spread can be aggravated through the movement of contaminated firewood. We conducted a scoping review to assess trends and gaps in the existing literature, as well as patterns in behavior related to forest pest dispersal through firewood movement in North America. Of the 76 documents identified through our search, 24 met the inclusion criteria and were categorized based on five identified themes: 1) insect incidence in firewood, 2) insect dispersal via firewood, 3) recreational firewood movement, 4) firewood treatments, and 5) behavior and rule compliance. This scoping review found limited research about awareness and behavioral dimensions of firewood movement. To address the public's awareness of forest health issues, and identify an effective mode of information and trusted messenger for conveying information about not moving firewood, we analyzed the data obtained from five surveys conducted between 2005 and 2016 (n=4,840). We selected age, race, gender, education level, and the type of area in which participant's lived as independent variables that could predict awareness, and choice of mode of information and trusted messenger in linear regression models. Our results showed that awareness regarding invasive forest pests was low among participants. A flyer handed out when entering a state or national park, and receiving an email after making a campsite reservation were the modes of information that participants would be most likely to pay attention to. In addition, the State Department of Forestry was selected by participants as the most believable source speaking about forest health issues. Older participants and those with higher education levels were more likely to have greater awareness levels and to pay attention to the modes of information presented in the survey, while females and younger participants were more likely to believe the trusted messengers presented to them. Overall, we conclude that

awareness is key for modifying behavior related to firewood transport; as such, educational campaigns with effective messaging strategies could be a successful approach to improving public outreach efficacy.

DEDICATION

I dedicate this thesis to all those who believed in me, supported me, and helped me grow, especially my unconditionally supportive parents.

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BACKGROUND

Non-native forest insects and diseases have been establishing in the United States since 1635 and since the 1900's this increase has accelerated (Aukema et al. 2010). Non-native forest pests can have detrimental impacts on forest structure and ecosystem services, which, in turn, will affect both wildlife and people (Lovett et al. 2006). Globalization has increased the number of vectors and pathways (e.g., wood-packaging materials, vehicles, live plants, and logs) by which these pests can spread as well as the rate at which these potential vectors move (Meurisse et al. 2019). The issue of forest pest invasions is particularly important in a world that is currently facing climate change, given that non-native forest pests kill live trees and can decrease live tree biomass, which represent an important carbon sink (Fei et al. 2019).

Untreated firewood transport across long distances for recreational purposes, especially by campers, represents an important pathway for non-native forest insect and disease spread (Jacobi et al. 2011; USDA APHIS 2010). Unintentional transport of contaminated firewood can increase the spread of non-native forest insects and diseases, and, as a result, negative impacts for ecosystems, wildlife, and people can be severe. The Nature Conservancy's Don't Move Firewood campaign is one of the few educational programs in North America aiming at educating the general public on the risk of invasive forest pest spread via contaminated firewood (Campbell, 2011).

Our study examined the existing literature on firewood transport as a vector for invasive forest pest spread, identifying trends and gaps, as well as patterns in behavior related to this issue (Chapter 1). Further, we assessed the general public's awareness, attitudes and perceptions of forest health issues, and identified potential modes of information and trusted messengers for conveying information about forest pests and firewood transport to the general public (Chapter

2). In both chapters we suggest future research and educational programs that can help inform management decisions for reducing firewood transport.

CHAPTER ONE

FIREWOOD TRANSPORT AS A VECTOR OF FOREST PEST DISPERSAL IN NORTH AMERICA: A SCOPING REVIEW

Abstract

Native and nonnative insects and diseases can result in detrimental impacts to trees and forests, including the loss of economic resources and ecosystem services. Increases in globalization and changing human behaviors have created new anthropogenic pathways for long distance pest dispersal. In North America, literature suggests that once a forest or tree pest is established, the movement of firewood by the general public for recreational or home heating purposes is one of the primary pathways for its dispersal. Understanding human perceptions and behaviors is essential to inform the most effective strategies for modifying firewood and pest dispersal by humans. This scoping review seeks to assess trends and gaps in the existing literature, as well as patterns in behavior related to forest pest dispersal through firewood movement in North America. We identified 76 documents that addressed this topic to which we applied inclusion and exclusion criteria to select articles for further analysis. Twenty-four articles met the inclusion criteria and were categorized based on five identified themes: 1) insect incidence in firewood, 2) insect dispersal via firewood, 3) recreational firewood movement, 4) firewood treatments, and 5) behavior and rule compliance. The selected articles show trends that suggest that firewood movement presents a risk for forest insect dispersal, but that behavior can be modified, and compliance, monitoring, and treatments should be strengthened. This scoping review found limited research about western United States, Mexico, and Canada, various insect species

and other organisms, regulation and management, awareness, and behavioral dimensions of firewood movement.

Key words: Coleoptera, firewood movement, human behavior, invasive species, regulations

Introduction

Nonnative arthropods and microorganisms are a global issue affecting forest ecosystems (Liebhold et al. 2017, Fei et al. 2019, Linnakoski and Forbes 2019). Both natural and urban forests suffer forest pest invasions which are often capable of causing severe deleterious impacts (Poland and McCullough 2006, Dodds and Orwig 2011, Sweeney et al. 2019). North America appears to be at a higher risk of invasive forest pest introductions compared to other continents (Niemelä and Mattson 1996, Early et al. 2016, Klapwijk et al. 2016), which could be due, in part, to its high rate of imported goods and rich diversity of forest types. Nonnative forest pest introductions can result in devastating ecological impacts to forests, including deterioration of ecosystem services, loss of live biomass, changes to forest structure, and loss or changes to forest resources such as wildlife habitat and timber (Boyd et al. 2013, Freer-Smith and Webber 2017). Economic impacts from nonnative forest pests are estimated to be between $4.2 billion and $14.4 billion per year (Pimentel et al. 2000, Holmes et al. 2009, Moser et al. 2009; Table 1). For example, the emerald ash borer (EAB; *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae)), has killed hundreds of millions of ash trees in North America since its introduction in 2002 (Duan et al. 2018), resulting in costs of over $10.7 billion annually (Kovacs et al. 2010). The projected economic impacts of the Asian longhorned beetle (ALB; *Anoplophora*

glabripennis Motschulsky (Coleoptera: Cerambycidae)) establishing in Canada could be as high as CDN$12 billion annually (Pedlar et al. 2020).

Table 1.1. Major native and nonnative insect species in North America that can spread via firewood, their distribution, and their impact assessed by basal area losses (Krist et al. 2014, Karel and Man 2017, NRCan 2018).

Insect	Scientific Name	Origin	Distribution		Basal Area Losses (m^2 ha^{-2})[1]
			United States	Canada	
Gypsy moth[2]	*Lymantria dispar dispar* L.	Non-native	Northeast	Southeast	338.2
Emerald ash borer	*Agrilus planipennis* Fairmaire	Non-native	Northeast	East	77.7
Redbay ambrosia beetle	*Xyleborus glabratus* Eichhoff	Non-native	Southeast	Not detected	300[3]
Asian longhorned beetle	*Anoplophora glabripennis* Motschulsky	Non-native	East	East (Ontario)	0.12[4]
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins	Native	Midwest & West	Southwest	215.8
Southern pine beetle	*Dendroctonus frontalis* Zimmermann	Native	East	Not detected	197.3
Spruce beetle	*Dendroctonus rufipennis* Kirby	Native	Midwest & Alaska	West (British Columbia)	163.4
Douglas-fir beetle	*Dendroctonus pseudotsugae* Hopkins	Native	West	West (British Columbia)	139.5

It should be noted that while a scenario with no control of ALB populations could be catastrophic, aggressive eradication protocols do exist and are employed for this particular pest, and these activities keep damage relatively low compared to other forest pests.
[1]Measured in millions.
[2]Risk of being moved in firewood only during egg life stage (McManus et al. 1989).
[3]Million trees, not basal area (Hughes et al. 2017).
[4]Does not include losses from the current infestation in South Carolina, USA.

How insects disperse has been the subject of entomological research for decades (Stinner et al. 1983) and has major implications for the broader topic of invasive species movement and insect dispersal via the movement of firewood. Although forest pests can spread naturally, increases in globalization and human-mediated pathways (i.e., transport of pests in infested goods and transport of contaminated conveyances such as shipping

containers and pallets; Gippet et al. 2019, Meurisse et al. 2019) have created new pathways for their rapid dispersal across and between continents (e.g., Short et al. 2020).

This is particularly alarming for wood-inhabiting insects because they can be transported and survive in wood packaging material, logs, wood items, containers, live plants, and vehicles (Liebhold et al. 2012, Meurisse et al. 2019). For example, EAB flight is estimated at only a few kilometers per day (Taylor et al. 2007); however, in 2002, it was found over 9,800 km from its native range. International trade facilitated EAB's accidental introduction to North America, likely through infested wood packaging material (Petrice and Haack 2006, Robertson and Andow 2009, Roy et al. 2014), where it then readily spread via human activities. As such, recent forest pest research has increased attention on forest and tree-inhabiting insects, their rapid spread, and their impacts on natural and managed forests (Table 1; Krist et al. 2014, Karel and Man 2017).

Recreational firewood movement by the general public is considered to be one of the primary means by which wood-inhabiting insects are transported intracontinentally to new areas, serving as an important human-mediated pathway for forest insect dispersal in North America (e.g., Cappaert et al. 2005, Bigsby et al. 2011). After live plants and wood packaging material, firewood logs could be the third most important pathway by which invasive forest insects are transported to other areas (Meurisse et al. 2019). Wood packaging material was likely the pathway by which EAB was introduced to North America, but firewood was been linked to new EAB infestations in the United States (Robertson and Andow 2009). The use of wood as a fuel source dates back thousands of years, but even after industrialization, wood has continued to serve this purpose in North

America (U.S. Energy Information Administration 2020). Approximately 6% of Canada's household energy came from wood in 2011 (Statistics Canada 2012) and approximately 2% of residential energy in the United States comes from wood (U.S. Energy Information Administration 2020). In Mexico, firewood is an energy source for 80% of rural communities (CONAFOR 2013). In addition to residential use of firewood for ambiance or as a heating source, recreational use of firewood (e.g., campfires, outdoor cooking) is prevalent across North America (Bratton et al. 1982, Jacobi et al. 2011). Up to 47% of U.S. residents annually burn firewood outdoors for recreational purposes (Solano et al. 2020).

Firewood movement among and within North America is regulated by federal, state, tribal, and local governments. The Canadian Food Inspection Agency (CFIA), United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS), and the National Forestry Commission of Mexico (CONAFOR) work to prevent forest pest introductions and dispersal through firewood movement; however, regulations are limited. The regulations governing the movement of firewood across international borders are similar across the three North American nations' border authorities and focus on prohibiting untreated firewood from entering a country from a neighboring country (e.g., into United States from Canada; Greenwood 2020). In Canada, the Plant Protection Act applies domestically to prohibit the movement of firewood between regulated and nonregulated areas. There are also Canadian regulations in place and enforced by Parks Canada units and Canadian Provinces such as the Yukon's Forest Resources Act, Alberta's Forests Act, Saskatchewan's Forest Resources Management Act, Manitoba's Forest Health Protection Act, and Ontario's Invasive Species Act (Gagné et al. 2017). Firewood

regulations for commercial and personal firewood movement in the United States vary significantly across authority and jurisdiction, ranging from no applicable state or federal regulations, to regulations held by states, tribes, land owning federal agencies, to USDA APHIS-regulated pest quarantine areas (e.g., around active infestations of federally regulated pests such as ALB) and other entities. CONAFOR prevents untreated firewood from the United States or Canada from entering Mexico (Greenwood 2020).

The effectiveness of quarantines and/or regulations on firewood has been historically limited due to a combination of factors including inconsistent regulations across geographies and authorities, ineffective surveillance, lack of enforcement (Lovett et al. 2016), and both intentional and unintentional noncompliance (Haack et al. 2014). Additionally, firewood related quarantines and requirements in the United States have had their effectiveness limited due to a history of implementation of regulations postintroduction (Roy et al. 2014). For example, the USDA APHIS regulatory structure means a commodity (such as firewood) in interstate commerce cannot be regulated unless it is designated as a regulated item as part of the response to a federally regulated pest, such as ALB or EAB. Therefore, only reactive—not preventative—federal measures can be implemented. There cannot be a federal regulation that applies to firewood without a federally regulated pest that can infest that firewood, and one cannot apply that regulation outside of the given pests' specific regulated area. This structure is why, for instance, hardwood firewood cannot be legally certified as heat-treated to the applicable federal standard (T-314a) if it is not harvested in an area under federal quarantine for EAB.

There are three generally accepted levels for the international and national heat treatment levels of solid wood products, including firewood. In the United States, the USDA has established heat treatment standards for wood products, including firewood. Heat treatments designated as T314-a, b, and c require solid wood products like firewood to be heated to high temperatures for set periods of time to kill organisms present in or on the wood (USDA APHIS 2010). The International Plant Protection Convention (IPPC) implemented the International Standards for Phytosanitary Measures No. 15 (ISPM- 15) which requires an approved treatment (one of the approved heat treatments is the same temperature and duration as USDA T314-b) to eliminate wood-inhabiting insects from wood packaging material (Haack and Petrice 2009). ISPM-15 provides international regulations for effectively treating solid wood packaging so that it poses minimal risk of moving unwanted pests (Wang et al. 2011, FAO 2017). Kiln drying is a process that seeks to reduce the moisture content within the wood; however, it is not a regulated treatment and, therefore, is not permissible as a legal standard to move firewood (Greenwood 2014).

Current pest and firewood regulations have limitations in terms of their efficacy and reach, and their effectiveness relies on sustained awareness and compliance levels of this issue among the firewood-using public. The movement of firewood and the impacts of this behavior could be dramatically reduced if current rules and regulations were followed (Peterson and Diss-Torrance 2012, 2014; Daigle et al. 2018; Diss-Torrance et al. 2018). However, there are various reasons why people do not adhere to rules and regulations, including perceptions of entitlement and fairness (e.g., entitled people are prone to believing they are more deserving of special treatment; Zitek and Jordan 2019). As such,

understanding human perceptions and behaviors related to firewood use is essential to inform the most effective strategies for modifying human-mediated firewood and pest dispersal. Nongovernment organizations, like The Nature Conservancy (TNC), play a key role in partnerships with federal, state, provincial, and university entities in conducting long-term research and education for the public in this field. Many national, state, or provincial educational campaigns have been implemented to create awareness among the public about the risk of forest pest dispersal through the movement of firewood. TNC's Don't Move Firewood (DMF) campaign (https://www.dontmovefirewood.org/) is one of the longest standing outreach programs in place aiming to understand and educate people, and change their behavior toward the use of recreational firewood (Campbell 2011).

The preventative policies regulating global trade will never completely remove the risk of accidental pest transport. Additionally, given that the movement of firewood for structure heating and recreational use is an established cultural norm despite existing outreach and regulations, the risk of invasive species movement into and within North America remains high (Haack et al. 2010, Jacobi et al. 2011, Meurisse et al. 2019). Since firewood is known to be a major vector for the spread of wood-inhabiting insects, our objective is to assess the trends and gaps in the existing literature on firewood and forest pest movement in North America, including determining patterns in firewood movement behavior. This assessment will help inform recommendations to help guide future research and education efforts for the public.

Methods

Scoping reviews are assessments of available literature on a given topic to identify data within that literature that can be mapped and synthesized to advance the understanding of that topic (Arksey and O'Malley 2005, Pham et al. 2014). Specifically, scoping reviews pinpoint relevant aspects of the literature such as key concepts, study designs, sources, methodologies, and analyses (Arksey and O'Malley 2005). This scoping review will assess trends, patterns, and gaps in the literature and provide key information to researchers, policy makers, the general public, and government and nongovernment organizations to inform future management and policy decisions related to firewood and pest movement. The five-step methodology outlined by Arksey and O'Malley (2005) was used in the development and implementation of, and as a framework for, these results.

Step 1: Identifying the Research Questions

Available literature shows the primary focus of past research on forest pests related to dispersal through firewood movement has been largely limited to the survival, spread (both natural and human-mediated), establishment, treatments, and associated consequences of only a few economically or ecologically important insect species. The focus of this scoping review was firewood because of its importance as a vector for forest pests. The overarching research question that guided this review was: What are the patterns, trends, and gaps associated with the peer-reviewed literature associated with human-mediated dispersal of insects via firewood and its management?

Step 2: Identifying Relevant Articles

The primary method used to find relevant articles was searching electronic databases for literature associated with the topic. The five databases we used were JSTOR,

Web of Science, Google Scholar, Agricola, and BioOne. Search terms were entered in the electronic databases using multiple combinations and Boolean operators. We used a total of 26 search terms (Table 2) from six categories for our search: 1) organism, 2) order, 3) family, 4) dispersal, 5) monitoring, and 6) other. It is important to note that the algorithm for Google Scholar changes periodically, causing search results to vary slightly; as such we accessed the database multiple times between October 2019 and July 2020 to conduct the search. We supplemented our database search with the literature cited sections from selected articles and a short list of relevant research articles and government publications from the DMF webpage (https://www.dontmovefirewood.org/publications-on-firewood-movement-and-human-behavior/).

Table 1.2. Categories and search terms used to find literature on forest pests and their dispersal through firewood movement in electronic databases.

Category	Organism	Order	Family	Dispersal	Monitoring	Other
Search term	Pest* Insect* Human* Fungi Disease*	Coleoptera Hymenoptera Lepidoptera	Siricidae Curculionidae Buprestidae Cerambycidae Scolytinae	Spread Mov* Transport* Vector Incidence Pathway	Regulat* Manag* Compliance Law*	Firewood Forest Heat treatment

Asterisks denote a Boolean operator that will include alternative forms of the given word in the search.

Step 3: Study Selection

The search process generated a total of 76 documents related to forest pests and firewood. Applying inclusion/exclusion criteria (Table 3), we excluded 52 of the 76 documents. Non-peer-reviewed documents were excluded (19), most of which were government agency publications, books, abstracts, university documents, and articles from nonpeer reviewed journals. Articles resulting from research activities that were conducted

outside of North America were also excluded (7). Finally, 26 documents whose focus was not firewood as a vector of insect dispersal were also excluded. These articles focused on topics such as other vectors (i.e., live plant imports, global trade, and wood packaging material), insect biology, global warming implications on invasive species spread, policy, and human health implications. In total, 24 research articles met the inclusion criteria (i.e., peer-reviewed, North American focus, and firewood as a vector of invasive species spread) and were the focus of this scoping review.

Table 1.3. Selection criteria for the articles included in a scoping review related to forest insect pest dispersal through the movement of firewood.

Category	Include if:	Exclude if:
Type of Literature	It is a peer-reviewed research study	It is not a peer-reviewed research study
Location	The study was conducted in North America	The study was conducted at a location different from North America
Vector	The focus of the study was firewood as vector for invasive insect dispersal	The focus of the study did not include firewood as a vector of invasive insect dispersal

Step 4: Charting the Data

We selected 15 key components that allowed for the synthesis and interpretation of relevant information of the selected articles (Table 4). This information is the focus of our study. The selection of these components was guided by previous scoping reviews involving forest pest management as well as consideration of the various components of our selected articles. We developed an Excel sheet with the 15 components of each article to create the themes and categorize the articles into each theme. Organism(s) of study, study keywords, objectives of the study, and important results were the main components guiding this process.

Table 1.4. Key items charted from selected articles for a scoping review related to forest insect pest dispersal through the movement of firewood.

Variables
Article title
Author(s)
Journal
Year(s) the study was conducted
Year the article was published
Study location
Organism(s) of study
Vector
Study keywords
Objectives of the study
Important results
Causing factors for important results
Study methodology
Population of interest
Gaps

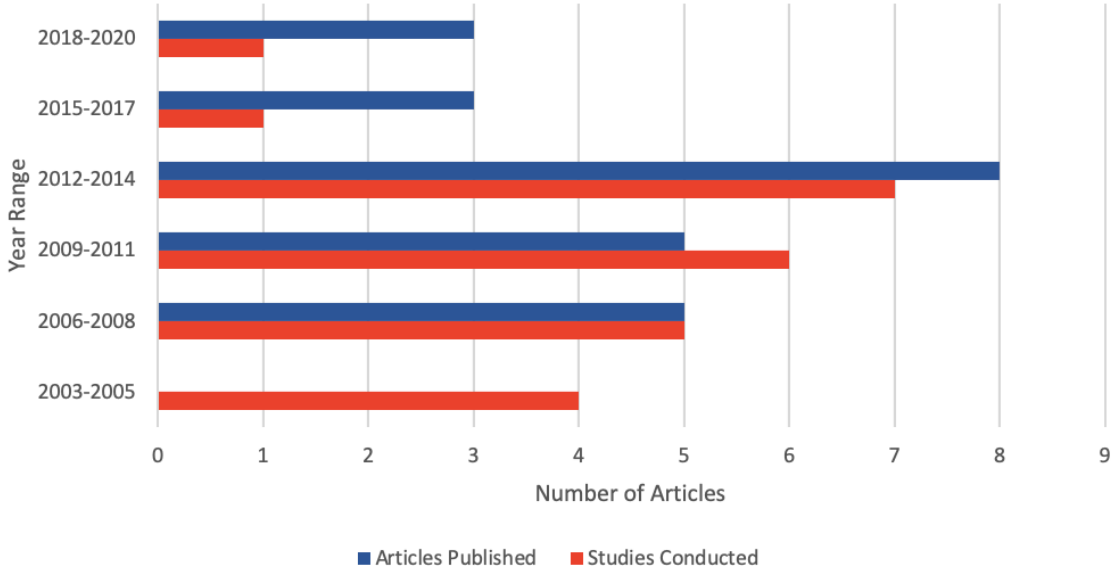
Results

Step 5: Collating, Summarizing, and Reporting the Results

Years of Study and Publication

The 24 articles selected for this scoping review were published between 2006 and August of 2020, half (13) of which were published between 2009 and 2014 (Figure 1.1). Research for most of the articles (18) was conducted between 2003 and 2014. Only a single article began data collection in 2002 (Petrice and Haack 2006), and only two articles began data collection after 2014 (Diss-Torrance et al. 2018, Meurisse et al. 2019).

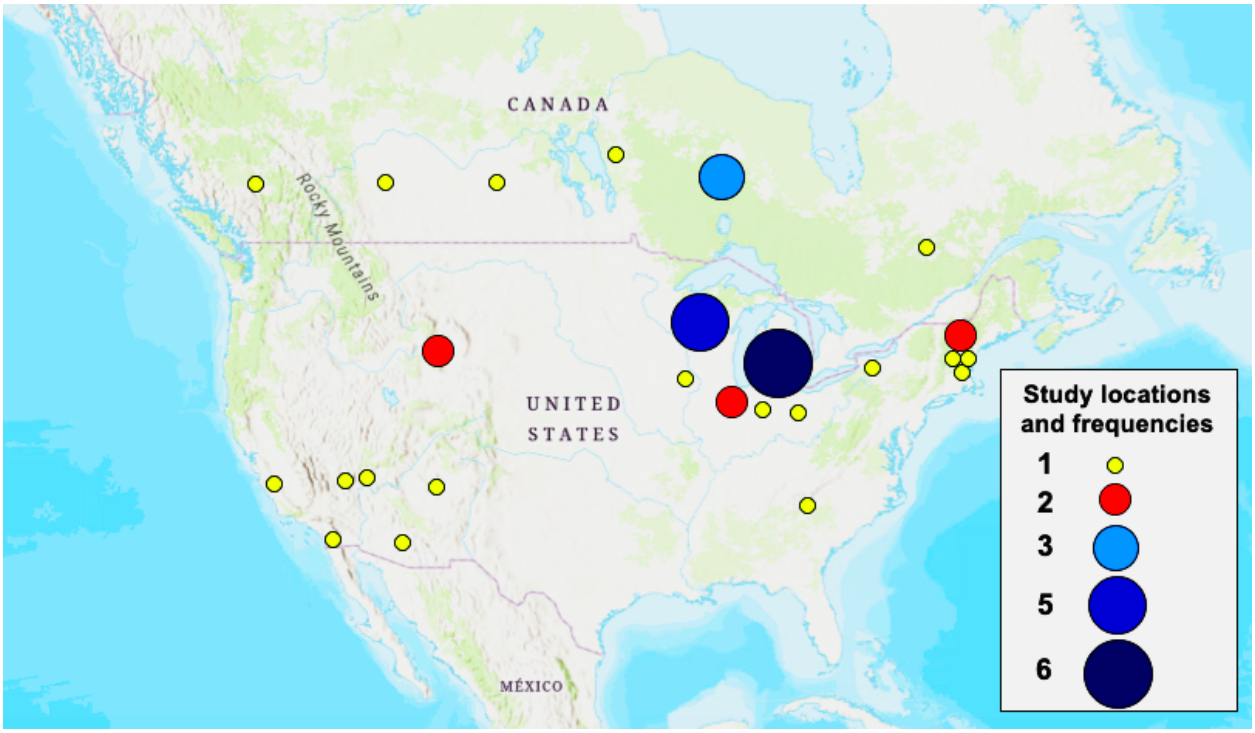
Figure 1.1. Frequency of the 24 selected articles by the year(s) in which the study was conducted and published.



Study Locations

Most of the research activity occurred in the northeastern and midwestern United States (18), with research from five articles being conducted in Michigan (Petrice and Haack 2006, 2007; Poland et al. 2008; Myers et al. 2009; Haack et al. 2010) and research from four articles being conducted in Wisconsin (Tobin et al. 2010; Peterson and Diss-Torrance 2012, 2014; Diss-Torrance et al. 2018). Several research activities were conducted in the western United States, especially the southern Rocky Mountains. Only four were conducted in Canada, two (Barlow et al. 2014, Ali et al. 2015) in Ontario, one (Morrison et al. 2016) in Nova Scotia, and 1 (Koch et al. 2014) in most of southern Canada (Figure 1.2).

Figure 1.2. Location and frequency of research locations from the 24 articles used in this review. The total research locations (40) is greater than the number of articles because the research from some articles was conducted in multiple locations.



Organisms of Focus

The organisms of focus in the 24 articles selected were either forest insect species or humans, with a major focus on campers. Of the 24 articles, 14 had forest insects as their organism of focus; seven focused on EAB (BenDor and Metcalf 2006; BenDor et al. 2006; Petrice and Haack 2006, 2007; Poland et al. 2008; Myers et al. 2009; Goebel et al. 2010), three (Jones et al. 2013, Mayfield et al. 2014, Morrison et al. 2016) focused on other species (i.e., beech leaf-mining weevil, *Orchestes fagi* L. (Coleoptera: Curculionidae); goldspotted oak borer, *Agrilus auroguttatus* Schaeffer (Coleoptera: Buprestidae); walnut twig beetle, *Pityophthorus juglandis* Blackman (Coleoptera: Curculionidae: Scolytinae), and four (Haack et al. 2010, Tobin et al. 2010, Jacobi et al. 2012, Dodds et al. 2017) were not species-specific. Nine of the 24 articles studied human populations and their firewood

transportation behavior; eight of these focused specifically on campers (Koch et al. 2012, 2014; Peterson and Diss-Torrance 2012, 2014; Barlow et al. 2014; Ali et al. 2015; Daigle et al. 2018; Diss-Torrance et al. 2018), while the ninth addressed humans on a broader scale (Meurisse et al. 2019). Only Jacobi et al. (2011) addressed both forest insects and humans (campers).

Journals

The selected articles were published in 14 different journals (Table 5), with the Journal of Economic Entomology as the most frequent source. Most, but not all, other journals were in the fields of forestry and entomology.

Table 1.5. Journals in which the 24 articles selected for a scoping review related to forest insect pest dispersal through the movement of firewood were published.

Journal	Number of Articles
Journal of Economic Entomology	9
PLOS One	3
Environmental Management	2
The Great Lakes Entomologist	2
Forests	1
Forest Science	1
Arboriculture and Urban Forestry	1
Ecological Modelling	1
System Dynamics Review	1
Journal of Pest Science	1
Agricultural and Forest Entomology	1
The Canadian Entomologist	1
Total	24

Study Methodologies

Based on the methods section of the articles, it was determined that 23 of the 24 articles used quantitative methodologies, while only Meurisse et al. (2019) was a review

article. The quantitative methodologies employed in the selected articles included social science surveys and predictive mathematical models (Table 6).

Table 1.6. Methodology used in the articles selected for a scoping review related to forest insect pest dispersal through the movement of firewood.

Methodology		Number of articles
Quantitative	Biological	13
	Social Science	9
	Combined	1
Review		1

Key Themes Identified in the Literature

Theme 1 is comprised of articles that address the presence of insects in firewood that was collected, confiscated, bought, or treated. Articles in theme 2 focused on insect dispersal via firewood; these articles help explain the role of firewood as a vector for the spread of invasive forest pests. Theme 3 includes articles that address recreational firewood movement, either by examining camper's behavior and decisions or by modeling them to assess the risk of forest pest spread. Articles in theme 4 evaluate the efficacy of firewood treatments (e.g., heat treatments, plastic bags) to prevent insect emergence from firewood. Theme 5 includes articles that examine behavior and rule compliance of firewood users, most of which were campers; these articles identify the factors (i.e., cost, convenience, quality) that influence camper's decisions to comply with firewood regulations, the efficacy of educational campaigns, and possible strategies to modify camper's compliance and decision (e.g., firewood cost).

Seventeen of the 24 articles were categorized into a single theme; however, eight articles (Poland et al. 2008, Goebel et al. 2010, Jacobi et al. 2011, Jones et al. 2013, Barlow et al. 2014, Mayfield et al. 2014, Ali et al. 2015, Daigle et al. 2018) addressed multiple

themes simultaneously. Jacobi et al. (2011) was categorized in themes 1 and 3 as the article addresses both insect incidence in firewood and recreational firewood movement. Four other articles (Poland et al. 2008, Goebel et al. 2010, Jones et al. 2013, Mayfield et al. 2014) were categorized as theme 1 and 4 given that all four articles address insect incidence in firewood and firewood treatments. Three articles (Barlow et al. 2014, Ali et al. 2015, Daigle et al. 2018) were categorized in themes 3 and 5 as they all address recreational firewood movement and behavior and rule compliance.

Results by Theme

Theme 1: Insect Incidence in Firewood

Eleven (Petrice and Haack 2006, 2007; Poland et al. 2008; Goebel et al. 2010; Haack et al. 2010; Jacobi et al. 2011, 2012; Jones et al. 2013; Mayfield et al. 2014; Morrison et al. 2016; Dodds et al. 2017) of the 24 articles comprise theme 1, with a focus on insect incidence in firewood that was confiscated, purchased, or cut. Four (Poland et al. 2008, Goebel et al. 2010, Jones et al. 2013, Mayfield et al. 2014,) of the 11 are also in theme 4 and one (Jacobi et al. 2011) is also in theme 3.

Important findings in this theme include insect incidence in examined firewood and insect emergence in firewood logs years after firewood is cut. Haack et al. (2010) investigated insects in confiscated firewood at Michigan's Mackinac Bridge (a point of entry to an EAB quarantine area) and found 1,045 firewood pieces being transported over a 3-mo period, of which 23% had live borers and 41% had evidence of previous insect infestation. Jacobi et al. (2011) collected firewood from several National Parks in the western United States and found that more than half of the firewood had evidence of

current or previous insect and/or fungal infestation. Jacobi et al. (2012) found that 50% of national retail firewood and 47% of regional retail firewood had evidence of current or previous insect infestation.

Jacobi et al (2012) observed that some species emerged from firewood up to 558 d after the firewood was purchased (Jacobi et al. 2012; it should be noted that this study was conducted in the southwestern United States where certified heat treatment of firewood did not exist at the time of the study). Further, Goebel et al. (2010) found some EAB emerged from firewood even after heat treatment (46 and 56°C for both 30 and 60 min). These studies suggest that the risk of moving invasive insect pests through firewood remains high even years after the firewood is split (Petrice and Haack 2007, Dodds et al. 2017) and after treatment (Goebel et al. 2010).

Theme 2: Insect Dispersal via Firewood

Theme 2 is comprised of only three articles. BenDor et al. (2006) and BenDor and Metcalf (2006) modeled EAB spread and examined different control methods, whereas Meurisse et al. (2019) reviewed the multiple human pathways for insect pest dispersal. BenDor et al. (2006) developed simulation models to compare EAB spread with and without firewood quarantines and found that EAB spread was slower in quarantine models. BenDor and Metcalf (2006) compared three reactive management strategies (i.e., firewood quarantines, ash tree removal, and eradication) using EAB spread simulations and concluded that preventive measures appear to be more successful than reactive measures and that firewood quarantines were a more effective approach. Both articles concluded that

when humans create a dispersal pathway through firewood movement, EAB spreads much faster and has a broader reach.

Meurisse et al. (2019), the only review article selected in this scoping review, indicated that the order Coleoptera, followed by Hymenoptera, Isoptera, and Orthoptera, have the highest frequency of unintentional transport via human-mediated firewood movement. In addition to focusing on firewood, this article also discusses other vectors for invasive insect pest dispersal.

Theme 3: Recreational Firewood Movement

Seven articles were categorized into theme 3, all of which focus on recreational firewood movement, mostly by campers. Jacobi et al. (2011) found that 39% of campers in five western U.S. states brought out-of-state firewood to State or National Parks and some of the firewood in question had evidence of previous or current insect infestations. In addition, only 32% of the firewood assessed in a given National Park had been purchased inside the park (Jacobi et al. 2011). Daigle et al. (2018) also surveyed campers and found that 72% did not transport firewood from home in the case of the specific trip during which the study was conducted. Koch et al. (2012) surveyed campers throughout the United States to find their travel distance to either state or national parks with the goal of showing the potential spread reach if these campers traveled with infested firewood; the median travel distance for campers was close to 100 km and the average was around 236 km, indicating a high potential for pest spread via campers' firewood.

Koch et al. (2014) identified two factors that led to an increased risk of pests in firewood being moved into a new state or province: 1) firewood originating from high-risk

regions adjacent to the target state, and 2) major urban areas or pest 'hotspots' outside the state. In addition, Tobin et al. (2010), Barlow et al. (2014), and Ali et al. (2015) included simulation models that provided useful information for potential management strategies to decrease or slow invasive insect spread. Tobin et al. (2010) conducted simulations to determine the risk of infection for campgrounds based on nonnative insect species distribution and allowable distance for firewood movement, and they recommended adjusting firewood movement regulations (allowable distance) as the distribution of the pest species increases. Barlow et al. (2014) and Ali et al (2015) conducted simulation models of firewood transport with scenarios that included a slight increase in infestation concern among the public, and a small decrease in local firewood cost.

Theme 4: Firewood Treatments

Theme 4 included five articles which focus on different firewood treatments for different forest insect pests. Three articles focus on EAB, two of which used ISPM-15 heat treatments for EAB in firewood, while the other two articles address other treatments for forest pests.

Goebel et al. (2010) found that while the application of the minimum internal temperature of ISPM-15 (56°C) did reduce EAB emergence in the firewood, no treatment in their study was completely effective in eliminating all EAB. Myers et al. (2009) found that a minimum internal temperature of 60°C for at least 60 min or 65°C for at least 30 min was required to eliminate EAB, and Poland et al. (2008) found that when ash firewood logs were double bagged with 4-mm thick plastic bags, the beetles died in the bags.

Jones et al. (2013) evaluated several treatments, including solarization, grinding, and debarking, to eliminate goldspotted oak borer larvae from firewood, and found that grinding and debarking were most effective as possible sanitation measures. Mayfield et al. (2014) evaluated heat treatments and debarking of firewood logs to eliminate the walnut twig beetle; results of this study showed that a temperature of 56°C for at least 40 min was an effective treatment to eliminate this insect from firewood.

Theme 5: Behavior and Rule Compliance

Theme 5 is comprised of six articles that focus on the human dimensions of firewood movement by campers. Two articles address camper behavior and strategies while the other two deal with campers' motivations for rule compliance related to firewood movement. Diss-Torrance et al. (2018) surveyed campers at a state park in Wisconsin over a 10-yr period to assess the efficacy of a firewood educational program and found that camper compliance to firewood movement improved after the implementation of an educational program if the message and information were persistently communicated. Daigle et al. (2018) found that of the 28% of campers who transported firewood from home in the case of the specific trip during which the study was conducted, the most common reason for doing so was cost, convenience, and quality. Further, the campers themselves suggested that showing more of the negative impacts of invasive forest insects in outreach and educational materials could help modify camper behavior (Daigle et al. 2018).

Barlow et al. (2014) found that a slight increase in infestation concern among the public, in addition to a small decrease in local firewood cost, is predicted to be enough to increase the proportion of people who help to reduce insect spread by buying local

firewood. Similarly, based on their simulation models, Ali et al. (2015) suggested that modest increases in tree removal and public concern for insect spread combined with modest decreases in local firewood cost could be a successful strategy.

The other two articles in this theme examine four constructs (i.e., calculated motivation, normative motivation, social motivation, and ability to comply) that influence recreational firewood transport behavior and compliance. Peterson and Diss-Torrance (2012) found that calculated motivations (i.e., price, convenience, quality) have the greatest influence over a camper's decision to comply with firewood regulations. Peterson and Diss-Torrance (2014) also confirmed the strong influence of calculated motivations and found that normative and social motivations have an influence on rule compliance.

Gaps and Limitations

This review has revealed several gaps in the primary literature addressing forest insect dispersal through the movement of firewood and highlights that fact that our understanding of the prevalence, impacts, and management of this pathway is limited. Consistent regulations, monitoring of firewood movement, and firewood treatments are key components for reducing the movement of invasive tree pests. Our review shows that evaluating the success and/or presence of firewood regulations and monitoring of firewood movement is one of the major gaps in our knowledge. No articles directly address the existing regulations on preventing firewood movement. Only one article provides information on insect incidence in firewood collected while entering a quarantined area, as well as rough estimates of how much firewood was being transported at given times of the year past this entry point; however, none of the selected articles address the effectiveness or

enforcement of these quarantines. In addition, only six of the 24 articles selected addressed human behavior and rule compliance. Further, while it is a logical assumption that cost of firewood influences rule compliance, and firewood movement in general, only four of those six article addresses this topic (Peterson and Diss-Torrance 2012, 2014; Barlow et al. 2014; Ali et al. 2015). Likewise, how far campers travel, and where they are traveling from and to may also influence behavior; although thus far there is little information on this in the literature. Having a better understanding of why firewood users behave the way they do, and identifying possible ways to modify their behavior, is key to developing successful management and outreach strategies.

Currently, no primary literature addresses the public's awareness of invasive species spread via firewood. This is a key, unexplored, aspect in the literature, given that rule compliance will remain low and behavior will likely not change if the public is not aware that there is an issue. National and regional surveys conducted by The Nature Conservancy revealed that up to 81% of respondents were unaware of laws and regulations preventing firewood movement. Further, 61% had not seen any information urging the public not to move firewood (Solano et al. 2020). As such, research addressing awareness is key for further research in behavior, rule compliance, policy, and management.

While forest pests are a serious concern to North American forests, dispersal of many such species through firewood is understudied. The species that has received the most focus is EAB given that its rapid spread and extensive tree mortality in urban and natural forests is one of the main reasons for the awareness and rise in research on the issue of forest pest dispersal via firewood. However, other insect species—both nonnative and

native—that cause damage and/or are continuing to spread (e.g., gypsy moth, *Lymantria dispar dispar* L., Lepidoptera: Erebidae; spotted lanternfly, *Lycorma delicatula* White, Hemiptera: Fulgoridae; redbay ambrosia beetle, *Xyleborus glabratus* Eichhoff, Coleoptera: Curculionidae: Scolytinae; ALB, and goldspotted oak borer) have not been given nearly as much attention in the peer-reviewed literature, either because they are already very common or because discovery of their invasiveness has been too recent for significant amounts of research to have yet occurred. We also do not know how the potential protection firewood provides insects that may be transported inside might impact pest movement, particularly in light of our changing climate. Wood can act as a temperature buffer to insects, keeping internal wood temperatures up to 4°C warmer than external (Vermunt et al. 2012). Some forest pests have a high thermal plasticity, allowing them to survive a range of temperatures (Sobek et al. 2011), which might further increase their ability to tolerate suboptimal conditions. How might climate change interact with insect physiology, phenology, and development (including emergence) is unknown, likely depends on both the insect and host species, and further underscores the importance of the fire- wood pathway. Further, since there has been a focus on insects in the literature, other macro (e.g., mites) and microorganisms (e.g., pathogens) have largely been unaddressed, thus their exclusion in our re- view. Organisms that also cause damage to forest trees like mites and pathogens can also be transported via firewood (Jacobi et al. 2011, 2012), so future research could address this gap.

Most of the research (80%) featured in this review was conducted in the United States and the majority of that (70%) was conducted in the northeastern region of North

America, likely because this region has experienced the highest rate of invasion of forest insects (e.g., EAB, ALB, gypsy moth; Liebhold et al. 2013) and high use of firewood for home heating and recreation (U.S. Energy Information Administration 2014). Thus, we lack critical knowledge with regards to forest pests and firewood from several regions of North America (Figure 1.2) even though invasive insects are established in these areas. Specifically, the southeastern and northwestern United States, western Canada, and Mexico have a dearth of research attention. As a result, we know little about interactions between native and invasive forest pests and firewood in these regions even though many significant forest pests are prevalent. For example, Ips bark beetles, southern pine beetle (*Dendroctonus frontalis* Zimmermann (Coleoptera: Curculionidae: Scolytinae)), and redbay ambrosia beetle can all be moved in firewood in the southeastern United States, yet we know very little about these species' spread via firewood. In summer 2020, ALB was found infesting trees in South Carolina, the first time the species has successfully established in southeastern forests (Coyle et al. 2021). While it is unlikely the pathway for ALB into South Carolina will ever be definitively determined, it is certainly plausible that firewood may have played a role, or at least was an important factor in spread of the insect. The recent discovery of this federally regulated invasive forest pest in a new region further underscores the importance of knowing how forest pests, human behavior, and firewood interact, and our lack of this knowledge represents a significant gap in the literature.

Over half of the selected articles were conducted between 2009 and 2014 (Figure 1.1). Since 2014, a decreasing trend has emerged regarding the number of articles published, which could lead funding agencies, the scientific community, and general public

to believe that the dispersal of forest insect pests through firewood is no longer an issue, or is not an important issue, neither of which is accurate (Seebens et al. 2017). While we have identified relevant information from the available literature, there is still much to be learned about insects, firewood, and potential pest movement.

Finally, only Jacobi et al. (2012) examined retail firewood, demonstrating that this significant source for acquiring firewood is understudied (the other articles examined firewood split or collected for the study, firewood that was confiscated, or firewood brought by campers). Much firewood is produced and sold by smaller businesses, and tracking where it was sourced, sold, and used is difficult and time consuming. Providing free or lower-cost firewood at camp- grounds may be an alternative for reducing firewood transport by the public, although more research is needed on the economic costs and benefits of this alternative.

Conclusions

The literature identified in this scoping review examines insect incidence in firewood (showing that firewood serves as a vector for forest insect dispersal), assesses the effectiveness of heat treatments for firewood, and addresses human behavior and decision-making related to recreational firewood transport to analyze the rationale behind this behavior. These articles provide useful information to gain a better understanding of this issue and serve as a baseline for future research. Future research should explore the gaps identified in this scoping review to identify and obtain new information that will guide effective management. These gaps include: 1) policy and management assessment, 2) behavior and rule compliance assessment, 3) public awareness, 4) study of species less

present in the literature, and 5) study of midwestern and western regions of the U.S, western Canada, and Mexico. Although research in the fourth and fifth gaps would give us more information on aspects we do not know, the most impactful research would fill the first through third gap. This research could potentially answer key questions such as why do people move firewood? Are messages being communicated effectively? What are the inconsistencies among regulations? Tangible benefits from new management strategies could include reduced impacts on forest health and ecosystem services, as well as a decrease in economic costs (e.g., management) associated with forest pest eradication or management and prevention of economic losses (e.g., timber industry).

The articles in theme 1, which addressed insect incidence in fire- wood, suggest that insects can emerge many years after trees are dead and a substantial amount of transported firewood has evidence of insect infestation. This supports the need for effective and consistent treatments and regulations, educational campaigns, and monitoring of firewood movement. Also, Jacobi et al. (2011; theme 3) found that only a third of the firewood assessed in a given National Park had been purchased inside the park, demonstrating the need to support efforts to increase local firewood sales, as firewood that is harvested and burned locally is not considered a threat for pest movement.

Invasive forest insects are a persistent problem worldwide and they have been introduced and spreading in North America since 1653 (Aukema 2010) and the acceleration of their spread across the continent through human-mediated pathways has been understood for over 100 yr (McManus and Csóka 2007). Further analysis of the human dimensions of forest insect pest dispersal through firewood movement is key for future invasive species

management or, where feasible, eradication. Although the existing literature on this topic is limited, the articles addressing behavior and rule compliance (theme 5) suggest that firewood-related behaviors may be changed using informed approaches. Therefore, it is important to expand research that seeks to understand awareness and behaviors by the public in regard to firewood issues, and how professionals can better convey messages about the risks of moving firewood and the importance of obtaining firewood locally. Collaborating or co-managing with the public as a stakeholder by incentivizing education, accountability towards the resources (i.e., forests), and participation may make people more likely to change their firewood use behaviors (Decker and Chase 1997).

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CHAPTER TWO

NON-NATIVE INSECT AND DISEASE DISPERSAL VIA FIREWOOD

Introduction

There is a long history of non-native forest pests being introduced to North America, with most arriving through wood packaging material, live plant imports, and other means associated with international trade (Meurisse et al. 2019). The first record of the establishment of non-native forest pest was the codling moth (*Cydia pomonella*) in 1635 (Aukema et al. 2010). Since then, the introduction of non-native forest pests has increased exponentially. Among the worst early introduced invasive insects is the gypsy moth (*Lymantria dispar dispar*), which was introduced to the United States in 1869 (Elkinton and Liebhold 1990) and has caused severe biological impacts and economic losses (Liebhold et al. 1992). The gypsy moth has become one of the first pests widely known to spread by human movement of firewood for recreational and commercial purposes (Haack et al. 2010, Jacobi et al. 2011, Koch et al. 2012). However, only a fraction of these non-native introduced species become invasive and are capable of widespread economic and ecological damage. Species like the gypsy moth, redbay ambrosia beetle (*Xyleborus glabratus*), and emerald ash borer (*Agrilus planipennis*) were introduced from Asia and Europe and have caused severe damage to millions of trees in North America (Elkinton and Liebhold 1990, Poland and McCullough 2006, Kendra et al. 2013, Hughes et al. 2017). Some native species, such as the mountain pine beetle (*Dendroctonus ponderosae*), can also cause widespread damage and be spread to other regions of North America (Safranyik et al. 2010, Cooke and Carroll 2017). The results of invasive forest pests and their spread throughout North America include detrimental biological impacts on

natural and urban forests, their species composition, and ecosystem services, and the annual cost of these impacts can reach into the billions of dollars (Pimentel et al. 2000, Pimentel et al. 2005, Poland and McCullough 2006, Dodds and Orwig 2011, Boyd et al. 2013).

Recreational firewood movement plays a big part in the spread of and risk of invasion for non-native insects and diseases (Solano et al. 2021). For instance, Haack et al. (2010) found that more than half of the firewood confiscated over a three-month period in Michigan had evidence of current or previous forest insect infestation. Jacobi et al. (2011) surveyed national and state campers of which 39% transported firewood to the park from another state. More recent studies have shown that firewood transport by campers is still an issue, thus, the need to increase awareness and change the way prevention messaging is transmitted to the public (Diss-torrance et al. 2018, Daigle et al. 2019).

Currently, some federal regulations on forest pests (most of which are species-specific) are monitored and enforced by the federal government through the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) and United States Customs and Border Protection (in partnership with international agencies to protect against their spread across international borders). There are also state regulations, usually through a state's Department of Agriculture or Regulatory Department, to prevent the intra- or interstate movement of invasive forest pests through the transport of firewood. Through these various mechanisms, both internal and external quarantines are in place across the country, representing a patchwork of preventative strategies (Greenwood 2020). However, despite these regulations, the persistent spread of invasive insects and

diseases across North America has increased the need for educational campaigns for citizens which are aimed at reducing the spread of invasive species.

Insight on the likely psychological barriers related to preventing the spread of non-native insects and disease spread via firewood can be found in a model designed to address climate change-related behavior (Swim et al. 2009). The model specifies four barriers that can prevent people from acting against climate change by addressing: 1) lack of awareness, 2) mistrust and reactance, 3) habit, and 4) social comparison, norms, conformity, and perceived equality. Through the application of the model to the firewood vector issue, we can hypothesize that people are more likely to change their behavior if they are aware of the risk of spreading insects and diseases when they move firewood from place to place. In order to prevent reactance (i.e. feeling that one's behavioral freedom is threatened and the need to restore it; Steindl et al. 2015), people must trust whoever is providing them the information. Many people are in the habit of cutting their own firewood and transporting it with them; as such, habit must be overcome to modify people's behavior. Finally, because people are more likely to do what others do in order to fit the norm, the peer norm must be changed from transporting firewood to purchasing it locally. If local firewood is more expensive and/or most people cut their own firewood, people will also be less likely to purchase local firewood because it will be perceived as unfair.

The Nature Conservancy (TNC) implemented the Don't Move Firewood Campaign (DMF) in 2008 with the purpose of creating a consistent continent-wide campaign aimed at educating the general public on the spread of invasive forest insects and diseases through the movement of contaminated firewood. The goal of the DMF campaign was to effectively

and efficiently prevent movement of firewood and associated pests by the public through research-informed outreach and coordination (Campbell 2011). Over an 11-year period, TNC conducted regional and national surveys in preparation for, and later part of, their educational program to gain a better understanding of the public's knowledge, perceptions of, and attitudes towards various environmental issues, including forest health and invasive species, as well as their behavior related to buying, transporting, and using firewood. With this study, our objectives are to 1) measure the public's awareness of firewood issues (awareness), 2) identify the most effective mode for conveying information to the public (mode of information), 3) identify the most trusted messenger for conveying information to the public about firewood and the spread of invasive forest insects and diseases (choice of trusted messenger), and 4) determine what sociodemographic variables predict awareness mode of information, and trusted messenger.

Methods

Survey Administrations

Between 2005 and 2016, TNC coordinated and conducted multiple studies addressing the use and movement of firewood relative to the spread of invasive forest insects and diseases. TNC hired a research firm (Fairbank, Maslin, Maullin, Metz & Associates, Oakland, CA, U.S.) to develop the questionnaires and their respective sample frames for each survey administration and to implement data collection for each survey. The firm accessed state registered voter databases to develop the sample frames and the surveys were administered via phone. We used data from five questionnaires that were administered over the course of 11 years (Table 2.1).

Table 2.1 List of surveys administered in the U.S. including survey number, administration date and location, the sample frame (or total number of people who were contacted, N), and the number of participants that responded to each survey (n).

Survey Number	Admin Date	Location	Sample Frame (N)	Sample size (n) (Response rate)
320-262 (S262)	Dec 2005	National	• 36,000 from the continental U.S.	817 (2.3%)
320-300 (S300)	Mar 2007	Midwest	• 18,000 from IL • 18,000 from WI	800 (2.2%)
320-338 (S338)	Dec 2007	Regional (Northeast, Upper Midwest)	• 5,625 from ME, VT, NH, MA, CT, RI • 4,500 from NY • 2,250 from NJ • 5,625 from PA • 18,000 from WI, IL, IN, MI, OH, WV	600 (1.7%)
320-452 (S452)	Sept 2010	National (California, Northeast, South)	• 9,000 from the continental U.S • 9,000 from CA • 9,000 from the northeastern region (CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT) • 9,000 from the southern region (AL, AR, FL, GA, KY, MS, NC, SC, TN, VA, WV)	1,400 (3.9%)
320-705 (S705)	Jul 2016	National	• 5,000 from the continental U.S.	1,223 (12.2%)
		North Carolina	• 4,000 from NC	100 (2.5%)
		Massachusetts	• 1,000 from MA	605 (60.5%)

Questionnaires

Question type varied between multiple choice, Likert scale, open-ended, select all that apply, and binary (i.e., yes, no). Some questions (i.e., multiple choice and Likert scale)

included a "split sample" methodology, wherein different terms for a similar item (e.g., "forest" and "wooded area") or more or less information is given (e.g., "creating an official, but voluntary, state certification for firewood encouraging people to only purchase such certified firewood" and "creating an official, but voluntary, state certification for firewood encouraging people to only purchase such certified firewood, even though it might cost slightly more") to determine if there is a significant difference in response from random sub-sets of the sample frame depending on question wording. Open-ended question responses were coded (based on similarity of the responses) by the research firm at the time of the initial analysis. Although some of the questionnaires share common questions (e.g., birth, race, and education level), none of the five questionnaires are identical.

The questionnaires can be divided into three main question themes related to the dispersal of forest insects and diseases through firewood movement: 1) awareness of the issue, 2) attitudes towards the issue, and 3) behaviors related to the issue. Within these three themes, we selected questions that addressed our four objectives (i.e., awareness, mode of information, choice of trusted messenger, and predicting participant's responses).

Three questions addressed participant's awareness about issues related to firewood movement. The only consistent question across the five surveys addressed whether participants had heard anything about non-native insects and diseases infesting or killing a large number of trees (S262, S300, S338, S452, S705, 4-pt Likert scale). Three of the five surveys asked participants if they had ever seen, heard, or read any information urging the public to not move firewood from place to place (S338, S452, S705; multiple choice). In all but one survey participants were asked to indicate whether they had heard anything about

trees being infested or killed by a given insect or disease (i.e., four insects and three diseases; S338, 4-pt Likert scale).

Four questions were related to modes of conveying information about firewood to the public. Participants were presented with various sources of information about not moving firewood to the public (S338, S705); they scored each source on a 3-pt Likert scale depending on whether they would be more or least likely to pay attention to them. Participants were also given a series of terms referring to invasive forest insect pests and diseases and were asked to indicate whether they perceived the term to be positive or negative (e.g., foreign insect and introduced insect; split sample question, S262, 7-pt Likert scale). Similarly, another question in this subtheme presented phrases that might be used to describe a program; participants were then asked if they perceived the phrase to be positive or negative (S300; split sample question, 7-pt Likert scale). In S705, participants were given two different phrases related to firewood movement and asked to indicate which they thought would serve best as a slogan for an educational poster or billboard (split sample question, multiple choice).

A single question assessed who participants would consider as a trusted messenger. Participants were given a list of sources of information related to forest health and asked if they consider the source to be believable (S300, S452, S705; 4-pt Likert scale).

In addition to the questions addressing the four objectives, some questions geared towards understanding participant perceptions and attitudes related to firewood movement (these variables were included in the descriptive analysis, but not in the inferential analysis). In three of the surveys, participants were twice asked to indicate how concerned

they were about insects and diseases that are killing large numbers of trees across the U.S.; the first time as a baseline early in the survey and the second time near the end of the survey to address if responses changed (S262, S300, S452; 4-pt Likert scale). Participants were given some brief information on the issue of insect and disease dispersal through firewood movement and were subsequently asked how willing they would be to only use local firewood instead of moving it from place to place (S338, S705; 4-pt Likert scale). In S262, participants were asked if they would support a proposal to the U.S. Congress to increase funding for efforts to eradicate and stop the spread of non-native insects and diseases (4-pt Likert scale). This survey also asked participants to indicate which one of the statements presented about insects and diseases that are killing large numbers of trees across the U.S. caused the most concern (S262; multiple choice). Similarly, in another survey, participants were presented with three statements and asked to indicate which one offers the best reason to support efforts to fight tree-killing non-native insects and diseases (S300; multiple choice),

The questionnaires also included various sociodemographic questions such as age, race, gender, education and income level, political affiliation, number of children in the household, the type of area in which participants lived (e.g., a big city, a suburban area, a rural area), and household's economic dependence on forest resources. It is worth noting that only five of these sociodemographic questions were consistent among the five surveys (i.e., age, race, gender, education level, and type of area in which participants lived).

Data Entry and Analysis

Data from each survey were provided to us by TNC in separate Excel spreadsheets, which we subsequently organized into a single Excel spreadsheet for the purpose of

creating and analyzing aggregate data. Most questions in the 5 questionnaires included a "don't know" answer option; we excluded all "don't know" answers for our analyses in order to represent the proportions of the definitive answer options. In addition, some Likert scales were reversed in order to properly represent the direction of the scale (e.g., 4-pt Likert scale where 1=heard a lot and 4=not heard was reversed to 1=not heard and 4=heard a lot).

Descriptive statistics were used to address the first three objectives of this study (i.e., awareness, mode of information, and choice of trusted messenger), as well as for the additional questions related to perceptions and attitudes related to firewood movement not included in the inferential analysis. Objective 4 (i.e., predicting participant's responses) was addressed using linear regression analysis. We selected nine dependent variables related to awareness to help provide insight on whether participants had heard of non-native insects and diseases infesting or killing a large number of trees and specific species of which they had heard. Twelve dependent variables were selected as modes for conveying information to the public about not moving firewood, and 15 dependent variables provided possible trusted messengers speaking about forest health issues. We used five independent variables as predictors of all 36 dependent variables across awareness, mode of information, and trusted messenger. (Table 2.2). The independent variables were selected because they were asked consistently across the five surveys, and because these characteristics could be more easily considered when making management decisions. We used the Statistical Package for Social Sciences (SPSS; 26.0.0, Chicago, Illinois) to calculate all descriptive and inferential statistics.

Table 2.2 Independent variables used in linear regressions to predict awareness of firewood issues, ways of conveying information about nor moving firewood, and a trusted messenger to convey the information.

Variable	Variable Type	Description	Mean/%	SD
AGE	Categorical	11-point Likert scale; 1=18-24, 2=25-29, 3=30-34, 4=35-39, 5=40-44, 6=45-49, 7=50-54, 8=55-59, 9=60-64, 10=65-74, 11=75+	50-54	2.85
RACE	Binary	0=white, 1=other	85% white	-
EDUCATION	Ordinal	Highest level of education completed; 6-point Likert scale; 1-2=less than high school, 3=high school, 4=some college, 5=college, 6=post-graduate wok	3.97	1.29
LIVE AREA	Categorical	Area where participant lives; 5-point Likert scale; 1=big city, 2=medium/small city, 3=suburban area, 4=small town, 5=rural area	3.29	1.32
GENDER	Binary	0=male, 1=female	48% male	-

Results

In total, there were 4,840 participants from all five surveys, with the largest portion of the total sample (1,400) from S452 (September 2010; Table 2.1), while the smallest portion of the total sample (600) came from S338 (hereafter, surveys that included a given question will be listed in parenthetical). The total aggregate response rate for all five surveys was 4.5%, however individual survey response rates ranged from 12.2% (S705; 10,000 sample frame) to 1.7% (S338 36,000 sample frame).

The aggregate mean age range of participants at the time of their respective response was 50 to 54 years old (Table 2.3). Most self-identified as White/Caucasian (85%)

and the most common educational level among participants was some college (27%), followed by high school (26%). The majority of participants lived in suburban areas (28%) and small towns (28%). Seventy percent of participants that were asked if they had children under 19 living at home indicated that there were only adults in the home (S300, S338, and S452). Most identified their political affiliation as Democrat (44%), followed by Republicans (29%), and Independents (25%; S262 and S300). The average income level was $60,001-$90,000 (5 categories; SD=1.18; S338), and most owned their home (90%; S338). Most indicated they were not were not dependent economically on the condition of forests in their area (72%), while an additional 20% indicated they were somewhat dependent, and 8% indicating they were very dependent on the forests (S300). Most (69%) had never volunteered time or donated money to an environmental organization (S338).

Table 2.3 Demographic characteristics of participants from five surveys (S262, S300, S338, S452, S705) regarding forest health issues at a national and regional level.

Variable	% of participants	Variable	% of participants
Age		Race	
18-24	3.2	White/Caucasian	84.9
25-29	4.1	Black/African American	7.6
30-34	4.6	Hispanic/Latino	3.2
35-39	8.7	Native American	1.9
40-44	10.4	Asian/Pacific Islander	1.3
45-49	10.6	Other	1.0
50-54	10.0		
55-59	10.7		
60-64	10.3		
65-74	14.1		
75 +	13.2		
Educational level		Live area	
Less than high school	12.0	A rural area	8.9
High school	25.5	A small town	28.2
Some college	27.2	A suburban area	28.4

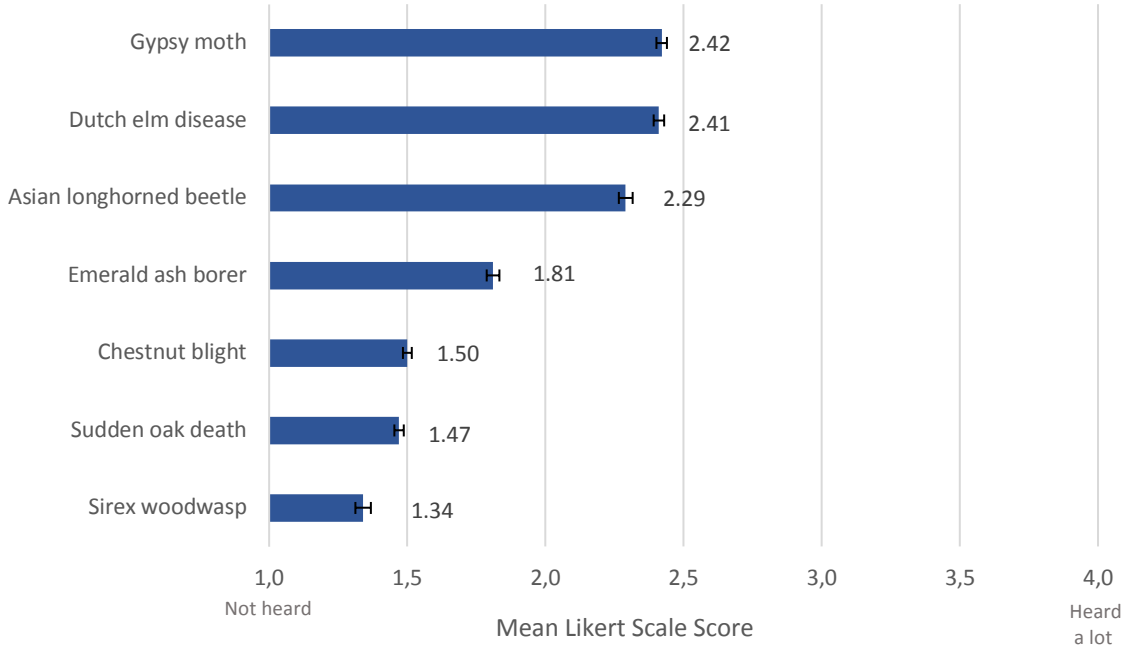
College	21.4	A medium/small city	20.9
Post-graduate work	13.9	A big city	13.6

Awareness

Over half of participants (61%) indicated they had not seen, heard, nor read any information urging the public to not move firewood from place to place (S338, S452, 705). Most indicated that what they had heard about this issue was that it was "not a good idea to transport firewood from one place to another" (20%; S338), while in a later survey most had heard that moving firewood "spreads around insects" (45%; S705). In addition, 81% of participants indicated they were not aware of any state laws or regulations in their area limiting the public's ability to move firewood from one location to another (S338, S452, and S705).

Participants indicated they had heard most about the gypsy moth and Dutch elm disease (*Ophiostoma ulmi;* Figure 2.1). Most participants had not heard of the emerald ash borer (59%), chestnut blight (*Cryphonectria parasitica*; 71%), sudden oak death (*Phytophthora ramorum*; 72%), or Sirex woodwasp (*Sirex noctilio*; 78%).

Figure 2.1. Mean response to whether participants had heard anything about trees being infested or killed by that insect or disease on a 4-point Likert scale, where 1= not heard and 4= heard a lot.



All demographic characteristics had significant predictive power on awareness, however, EDUCATION and RACE were the strongest predictors of participants' likelihood of having heard about non-native insects being a problem and the most consistent predictor among all the insects asked about (Table 2.4). EDUCATION had a strong positive relationship to all dependent variables except *sirex woodwasp*, meaning, all other variables held constant, participants with higher education levels had heard more about the non-native insects we asked about being problematic than those participants with lower education level. RACE had a strong negative relationship with all dependent variables but *sudden oak death* and *sirex woodwasp*, thus, white participants were much more likely to have heard of *Asian longhorned beetle*, *chestnut blight*, *emerald ash borer*, *gypsy moth*, and *Dutch elm disease*. AGE had a strong positive correlation (i.e., older participants) with

having heard of *chestnut blight*, *emerald ash borer*, *gypsy moth*, *Dutch elm disease*, and *heard of insects & diseases,* while it had a negative correlation with *Asian longhorned beetle*. LIVE AREA (i.e., participants who live in larger areas) had a strong positive relationship with having heard about *chestnut blight*, positively predicted *emerald ash borer* and *gypsy moth*, and had a weak positive relationship with *heard of insects & diseases*, and *sudden oak death*. GENDER predicted all but one variable (i.e., *sudden oak death*), yet it only had a strong negative relationship with *heard of insects & diseases*, *chestnut blight* and *gypsy moth*; meaning males were much more likely to have heard about these pests. GENDER was also a negatively related to *emerald ash borer* and resulted in a weak negative relationship with *Asian longhorned beetle*, *Dutch elm disease*, and *sirex woodwasp*.

Table 2.4 Standardized coefficients, standard error, and unstandardized coefficients of linear regression models predicting who or what participants are more likely to have heard anything about trees being infested or killed by insects or diseases.

Coefficient (Standard error) [Unstandardized coefficients]						**R^2**	**n**
Variable	**GENDER**	**AGE**	**LIVE AREA**	**RACE**	**EDUCATION**		
Heard of insects & diseases	-.061*** (.033) [-.134]	.082*** (.006) [.032]	.028* (.013) [.023]	-.130*** (.047) [-.401]	.093*** (.013) [.080]	.041	4,432
Asian longhorned beetle	-.039* (.050) [-.094]	-.050** (.009) [-.021]	-.027 (.020) [-.025]	-.083*** (.074) [-.284]	.069*** (.019) [.062]	.016	2,270
Chestnut blight	-.089*** (.032) [-.160]	.109*** (.006) [.033]	.051*** (.012) [.035]	-.053*** (.044) [-.127]	.055*** (.012) [.037]	.029	3,062
Emerald ash borer	-.041** (0.46) [-.092]	.060*** (.008) [.023]	.051** (.018) [.045]	-.108*** (.066) [-.341]	.144*** (.017) [.119]	.044	2,338
Gypsy moth	054*** (.037) [.127]	.115*** (.007) [.047]	.032** (.014) [.029]	-.205*** (.051) [-.652]	.047*** (.014) [.042]	.071	3,840

Table 2.4 CONTINUED Standardized coefficients, standard error, and unstandardized coefficients of linear regression models predicting who or what participants are more likely to have heard anything about trees being infested or killed by insects or diseases.

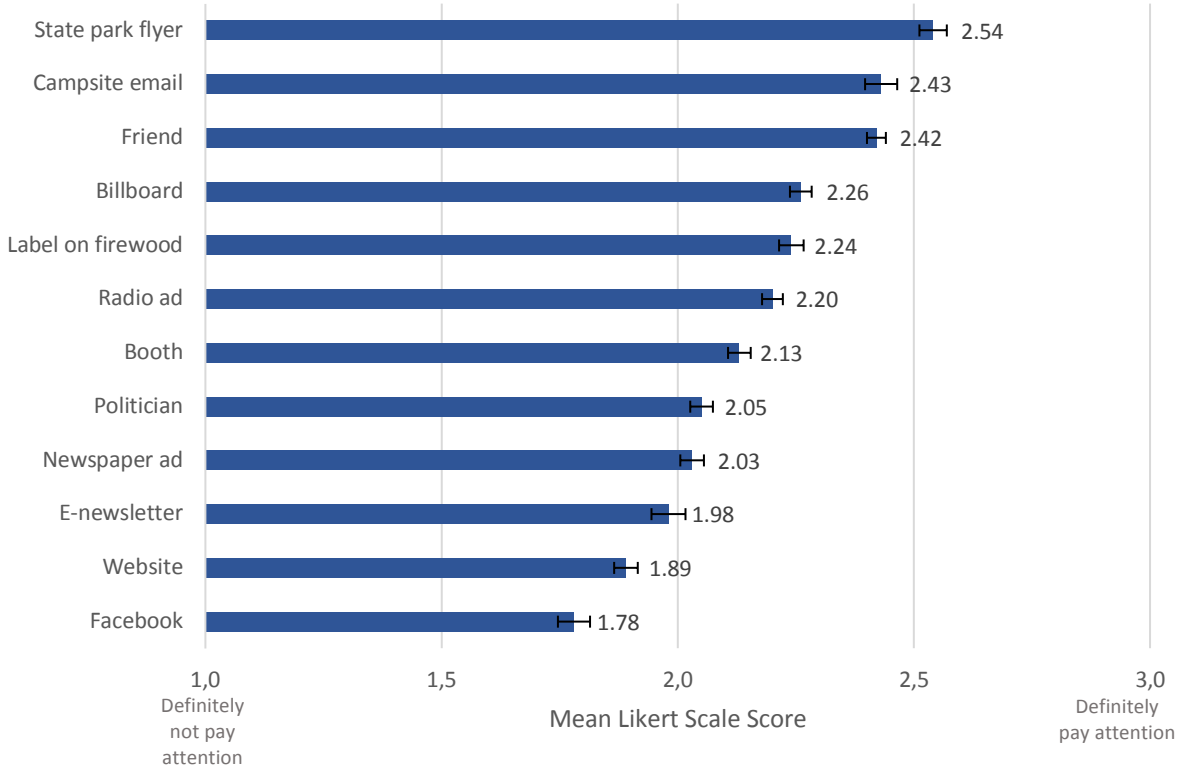
Coefficient (Standard error) [Unstandardized error]						R^2	n
Variable	**GENDER**	**AGE**	**LIVE AREA**	**RACE**	**EDUCATION**		
Gypsy moth	054***	.115***	.032**	-.205***	.047***	.071	3,840
	(.037)	(.007)	(.014)	(.051)	(.014)		
	[.127]	[.047]	[.029]	[-.652]	[.042]		
Dutch elm disease	-.027*	.226***	.006	-.214***	.138***	.128	3,858
	(.037)	(.006)	(.014)	(.051)	(.014)		
	[-.065]	[.094]	[.006]	[-.701]	[.128]		
Sudden oak death	-.013	.004	.033	.005	.097***	.010	2,571
	(.034)	(.006)	(.013)	(.048)	(.013)		
	[-.022]	[.001]	[.022]	[.012]	[.063]		
Sirex woodwasp	-.080*	.022	-.003	.040	.002	.008	718
	(.055)	(.010)	(0.22)	(.083)	(.026)		
	[-.118]	[.006]	[-.001]	[.085]	[.001]		

*Significance at 0.10, **Significance at 0.05, ***significance at 0.01

Mode of Information

Our results suggest that participants would be most likely pay attention to a flyer distributed when entering a state park and information from a camp site reservation email (Figure 2.2). Participants indicated they would be least likely to pay attention to a Facebook post.

Figure 2.2 Mean response on ways to present information to the public about not moving firewood that they would pay most attention to, using a 3-point Likert scale, where 1=definitely not pay attention and 3=definitely pay attention.



GENDER, AGE, RACE, and EDUCATION were positively associated with respondent's likelihood to pay attention to different forms of communication, meaning females, older, and non-white participants, and those with higher education levels were more likely to pay attention to the forms of communication presented in the survey. All dependent variables for mode of information were predicted by at least one independent variable. Paying attention to a *newspaper ad* that presents information about not moving firewood was positively associated with all independent variables although it had the strongest relationship with AGE and EDUCATION and the weakest relationship with RACE. As such, females, older and non-white participants, and participants with higher

education levels living in larger areas are more likely to pay attention to this mode of information (Table 2.5). Paying attention to an *elected politician* had a strong positive relationship with GENDER (i.e., females), AGE (i.e., older participants), and RACE (i.e., non-white participants), and a negative relationship to LIVE AREA (i.e., people who live in larger areas). The likelihood of paying attention to a *booth* at fair or local farmer's market was strongly predicted by AGE and RACE, with older and non-white participants being more likely to pay attention. Paying attention to a *Facebook post* and *a label on firewood* had a correlation with GENDER; the former also had a strong positive correlation with AGE and a weak positive correlation with RACE, while the latter had a strong negative correlation with LIVE AREA and a weak positive correlation with RACE. Paying attention to a *friend* and a *flyer* given when entering a state park had a strong positive relationship to EDUCATION; it also had a relationship to *e-newsletter*. A *friend* and an *e-newsletter* were also positively predicted by RACE and strongly predicted by AGE, respectively. An *email* sent when making a campsite reservation has a strong positive association with EDUCATION and strong negative association with LIVE AREA. A *radio ad* and a *website* that presents information about not moving firewood had a strong relationship to RACE, and a weak negative relationship to AGE and weak positive relationship to GENDER, respectively. A *billboard on the highway* had a strong positive correlation to AGE only. GENDER had a weak positive relationship with *email*, and e-newsletter; RACE also had a weak positive relationship with *label*, *Facebook*, *newspaper ad*, and *e-newsletter.*

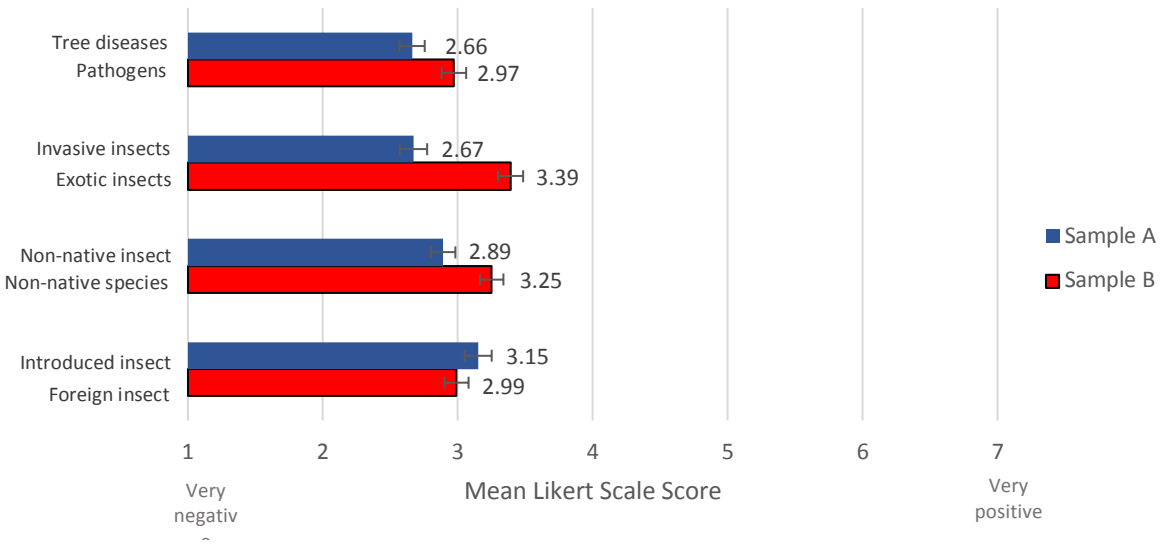
Table 2.5 Standardized coefficients, standard error, and unstandardized coefficients of linear regression models predicting who or what participants are more likely to pay attention to these ways to present information to the public about not moving firewood.

Coefficient (Standard error) [Unstandardized coefficients]						R^2	n
Variable	**GENDER**	**AGE**	**LIVE AREA**	**RACE**	**EDUCATION**		
Radio	.014 (.044) [.020]	-.053* (.008) [-.014]	-.019 (.017) [-.011]	.089*** (.075) [.217]	.004 (.016) [.002]	.013	1,102
Booth	.028 (.046) [.043]	.089*** (.008) [.024]	.020 (.018) [.012]	.107*** (.080) [.279]	.034 (.017) [.019]	.017	1,104
Website	.051* (.049) [.083]	-.047 (.009) [-.014]	-.020 (.020) [-.013]	.116*** (.087) [.326]	.039 (.018) [.023]	.022	1,089
Billboard	.124*** (.045) [.187]	-.004 (.008) [-.001]	-.041 (.018) [-.024]	.046 (.078) [.118]	.015 (0.17) [.008]	.020	1,105
Label	.066** (.050) [.111]	-.018 (.009) [-.005]	-.110*** (.020) [-.072]	.055* (.087) [.155]	.023 (.019) [.014]	.023	1,090
Newspaper ad	.066** (.049) [.108]	.116*** (.009) [.034]	.061** (.019) [.039]	.054* (.084) [.147]	.126*** (.018) [.076]	.037	1,089
Facebook	.098** (.067) [.152]	.164*** (.012) [.043]	-.041 (.026) [-.025]	.075* (.100) [.169]	-.027 (.025) [-.016]	.048	529
Politician	.097*** (.047) [.152]	.129*** (.008) [.036]	-.075** (.018) [-.046]	.115*** (.080) [.304]	.010 (.017) [.006]	.047	1,093
Friend	.045 (.039) [.058]	-.039 (.007) [-.009]	-.048 (.015) [-.024]	.068** (.067) [.147]	.085*** (.014) [.040]	.018	1,099
E-mail	.080* (0.68) [.125]	-.049 (.011) [-.013]	- .118*** (.027) [-.072]	-.021 (.100) [-.047]	.145*** (.025) [.085]	.047	518
E-newsletter	.077* (.071) [.126]	.124*** (.012) [.033]	-.028 (.028) [-.018]	.081* (.103) [.194]	.085** (.026) [.052]	.038	541
Flyer	-.016 (.058) [-.023]	-.038 (.012) [-.011]	.056 (.024) [.032]	.066 (.124) [.190]	.131*** (.027) [.083]	.026	562

*Significance at 0.10, **Significance at 0.05, ***significance at 0.01

With respect to a series of terms referring to invasive forest insect pests and diseases, all terms scored below the neutral point of 4 (Figure 2.3), however, the term "tree diseases" had, on average, the lowest score (i.e., most negative perceived connotation), followed by "invasive insects". Three of the four pairs of terms showed significant differences between samples. "Invasive insects" and "exotic insects" had the most significant difference (t=5.287, p<0.001), followed by "non-native insect" and "non-native species" (t=2.868, p<0.05=0.004), and "tree diseases" and "pathogens" (t=-2.435, p<0.05=0.015). The terms "introduced insect" and "foreign insect" had no significant difference between samples.

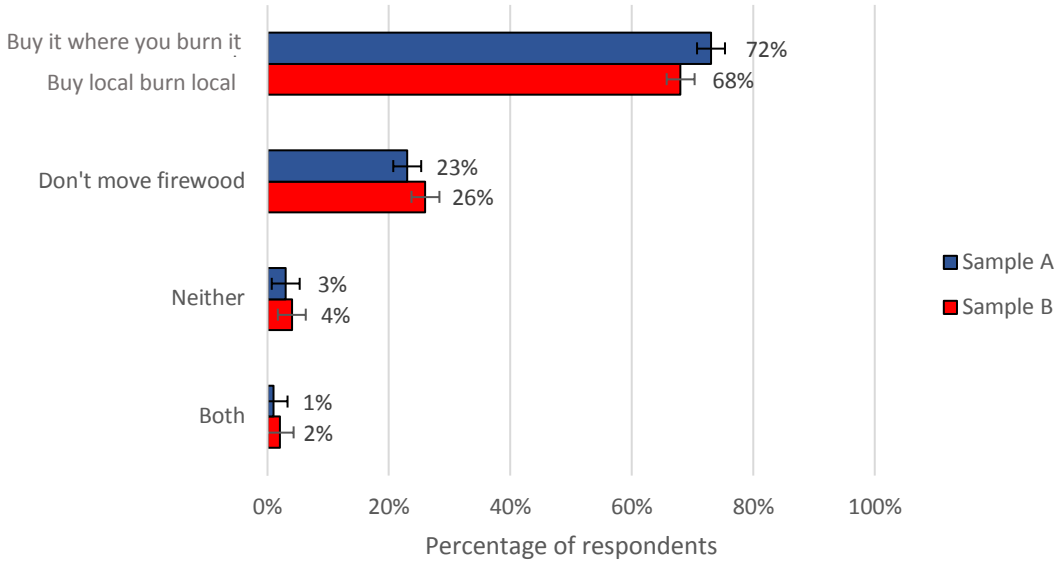
Figure 2.3 Comparison of mean responses of split sample question about the connotation of terms referring to invasive forest insect pests and diseases using a 7-point Likert scale, where 1=very negative, 4=neither, and 7=very positive. Blue bars represent sample A and red bars represent sample B.



On average, participants indicated the phrases "buy it where you burn it" and "buy local burn local" would serve best as a slogan for an educational poster or billboard (S705; Figure 2.4). Most participants in sample A chose "buy it where you burn it" (72%) over

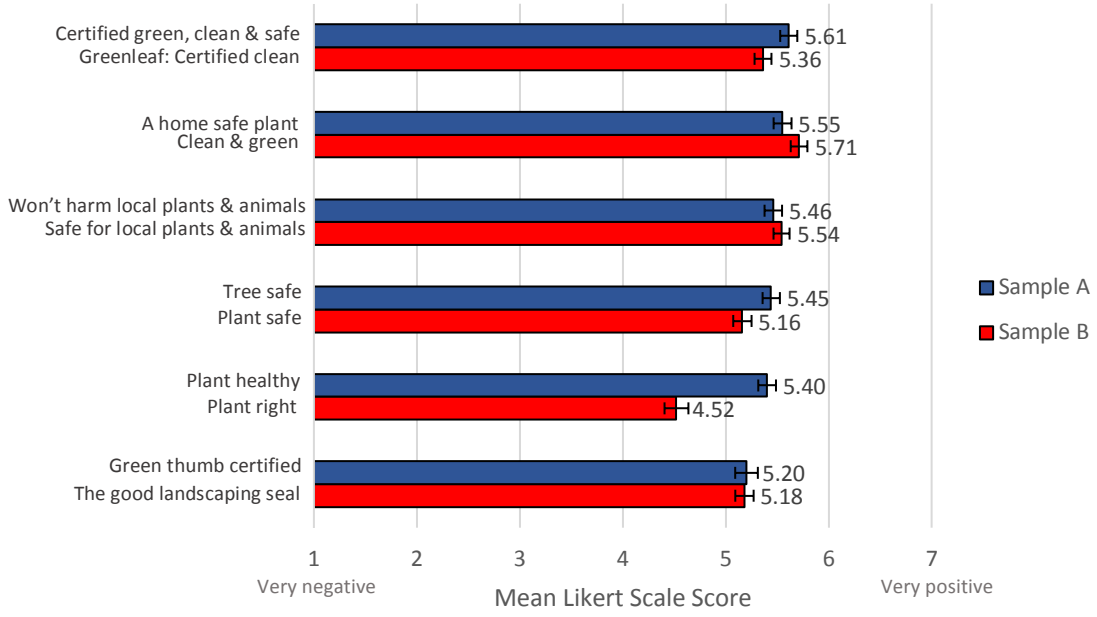
"don't move firewood" (23%), while most participants in sample B preferred "buy local, burn local" (68%) over "don't move firewood" (26%). The difference in preference between "buy it where you burn it" and "buy local, burn local" was not statistically significant.

Figure 2.4. Comparison of respondent's choice of phrase to use as a slogan for an educational poster or billboard. This was a split sample question; blue bars represent sample A and red bars represent sample B.



The phrase rated as having the most positive connotation to describe a program was "Clean & Green: Certified free of Invasive Species", while the phrase that had the least positive connotation was "Plant Right" (Figure 2.5). Of the six pairs of phrases presented to participants, three pairs showed significant difference in preferences between samples. The phrases "Plant healthy" and "Plant right" had the greatest significant difference (t=-6.227, p<0.001), followed by "Tree safe" and "Plant safe" (t=-2.301, p<0.05=0.002), and "Certified green, clean, & safe" and "Greenleaf: Certified clean" (t=-2.156, p<0.05=0.03). It is important to note that all phrases scored, on average, above the neutral score.

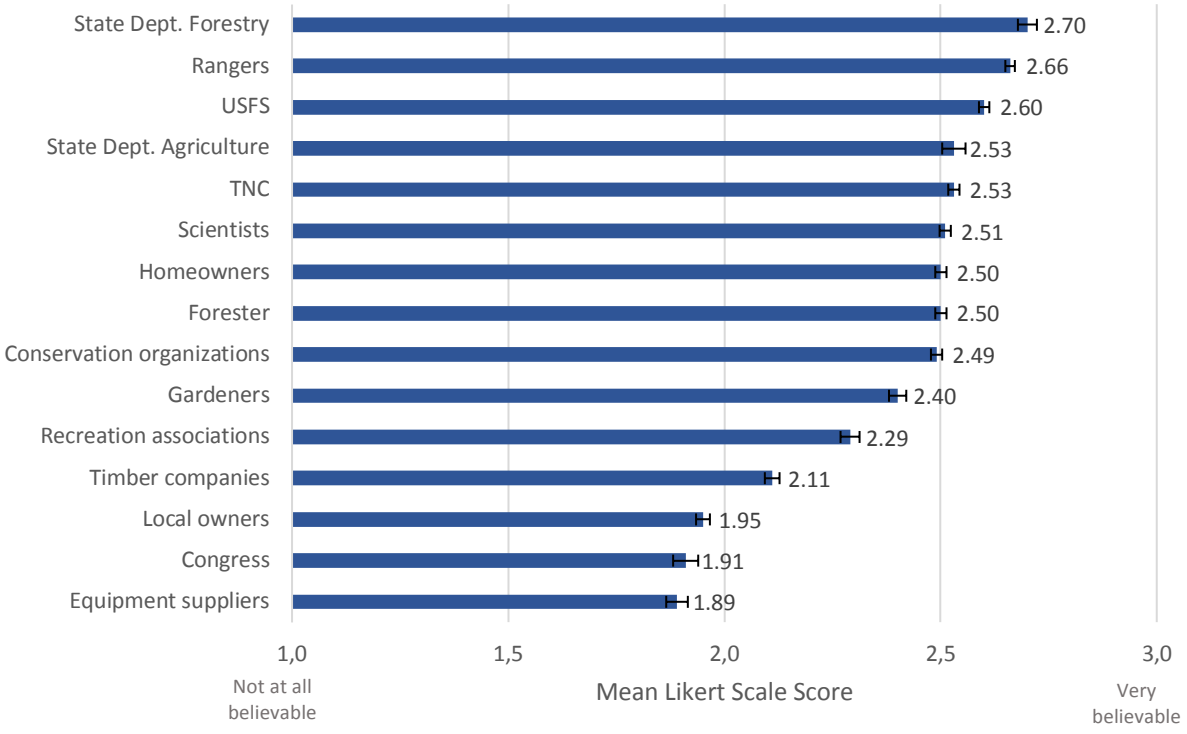
Figure 2.5. Comparison of mean responses to split question about the connotation of phrases used to describe a program using a 7-point Likert scale, where 1=very negative, 4=neither, and 7=very positive. Blue columns represent sample A and red columns represent sample B.



Choice of trusted messenger

According to our results, the most believable sources of information regarding forest health issues are state-level forestry departments (Figure 2.6), followed by park rangers. The least believable sources of information were equipment suppliers and congress.

Figure 2.6. Mean response to how believable are these sources of information speaking about issues relating to forest health on a 4-point Likert scale, where 1= not at all believable and 4= very believable.



GENDER and AGE were the most common predictors of whether a forest health information source was considered believable. GENDER significantly predicted 10 of the 15 dependent variables, while AGE was significant in 7 of 15. GENDER had a strong positive correlation with a *homeowne*r who lost their home to a forest fire, the *United States Forest Service*, *conservation organizations*, and *The Nature Conservancy*, (Table 2.6); this means that females, more than males, were much more likely to consider these messengers as believable sources of information about forest issues. On the other hand, GENDER had a strong negative correlation with *equipment suppliers* such that males were more likely to believe this source. GENDER also positively predicted *scientists*, *gardeners*, *congress*, and the *state's Department of Forestry*, and had a weak positive correlation with *rangers*. AGE

had a strong negative relationship with *local business owners*, *recreation associations*, and the *state's Department of Forestry*, meaning that younger participants were much more likely to believe these trusted messengers. *Scientists* and the *state's Department of Agriculture* as trusted messengers were also negatively predicted by AGE, while a *local homeowner* was positively predicted by AGE. AGE also had a weak negative relationship with *congress* as a believable source of information. RACE had a strong positive relationship (i.e., non-white) with *equipment suppliers* and a strong negative relationship with *local business owners* and *rangers*; it also negatively predicted the *United States Forest Service* and the *state's Department of Forestry*. LIVE AREA had a strong positive association (i.e., those living in larger areas) with *timber companies* and *local business owners*, and a weak negative association with *equipment suppliers*. Scientists was also negatively predicted by LIVE AREA. EDUCATION had the lowest predictive power as it only had a weak positive correlation with *timber companies*, *rangers*, and *The Nature Conservancy*, and positively predicted *scientists* as a trusted messenger, thus, those with higher education levels were more likely to believe these sources as trusted messengers.

Table 2.6 Standardized coefficients, standard error, and unstandardized coefficients of linear regression models predicting who or what participants are more likely to believe these sources speaking about issues relating to forest health.

Coefficient (Standard error) [Unstandardized coefficients]					
Variable	**GENDER**	**AGE**	**LIVE AREA**	**RACE**	**EDUCATION**
Timber Companies	.011 (.042) [.023]	.035 (.008) [.012]	.095*** (.017) [.074]	-.025 (.060) [-.069]	.038* (0.17) [.031]
Homeowners	.081*** (.031) [.118]	.055** (.006) [.014]	.024 (.012) [.014]	-.017 (.043) [-.033]	.018 (.012) [.011]
USFS	.078*** (.027) [.104]	.018 (.005) [.004]	-.010 (.011) [-.005]	-.046** (.038) [-.083]	-.013 (.011) [-.007]

Table 2.6 CONTINUED Standardized coefficients, standard error, and unstandardized coefficients of linear regression models predicting who or what participants are more likely to believe these sources speaking about issues relating to forest health.

Coefficient (Standard error) [Unstandardized coefficients]						R^2	n
Variable	**GENDER**	**AGE**	**LIVE AREA**	**RACE**	**EDUCATION**		
Cons. Org	.097*** (.032) [.148]	-.026 (.006) [-.007]	.009 (.012) [.005]	-.014 (.045) [-.029]	-.006 (.013) [-.004]	.009	2,361
Scientist	.042** (.029) [.060]	-.042** (.005) [-.011]	-.047** (.011) [-.026]	.001 (.041) [.002]	.044** (.012) [.025]	.008	2,432
Forester	.018 (.032) [.027]	-.030 (.006) [-.008]	.054 (.012) [.031]	-.025 (.044) [-.050]	.028 (.013) [.017]	.005	2,215
Local Owner	-.005 (.040) [-.010]	-.060*** (.007) [-.020]	.068*** (0.15) [.049]	-.090*** (.057) [-.235]	.022 (.016) [.017]	.017	2,227
Ranger	.039* (.025) [.047]	.029 (.004) [.006]	.000 (.010) [-1.086e-5]	-.081*** (.035) [-.135]	.036* (.010) [.017]	.009	2,636
Rec. Ass.	.022 (.054) [.037]	-.100*** (.010) [-.031]	-.005 (0.21) [-.003]	-.019 (.070) [-.043]	-.009 (.024) [-.007]	.009	1,105
Gardeners	.073** (.045) [.111]	-0.19 (.008) [-.005]	.027 (.017) [.016]	-.020 (.059) [-.039]	-.039 (.020) [-.027]	.008	1,230
Congress	.073** (.064) [.156]	-.068* (.012) [-.026]	-.018 (.025) [-.015]	.023 (.084) [.062]	.001 (.029) [.001]	.009	1,156
Equip. Suppl.	-.105*** (0.58) [-.199]	.035 (.011) [.012]	.055* (.022) [.041]	.096*** (.076) [.239]	-.027 (.026) [-.023]	.022	1,125
TNC	.096*** (.034) [.144]	.001 (.006) [.000]	-.023 (.013) [-.013]	-.027 (.048) [-.056]	.042* (.014) [.026]	.012	1,935
State D.A.	.050 (.065) [.070]	-.108** (.011) [-.025]	.026 (.025) [.014]	-.052 (.097) [-.109]	-.001 (.024) [-.001]	.015	480
State D.F.	.098** (.053)	-.132*** (.009)	.008 (.021)	-.095** (.084)	.016 (.021)	.028	466

[.113]	[-.026]	[.004]	[-.166]	[.007]

*Significance at 0.10, **Significance at 0.05, ***significance at 0.01

Perceptions and attitudes related to firewood movement

Approximately 90% of participants who were asked to indicate how concerned they were about insects and diseases that are killing large numbers of trees across the U.S. expressed some level of concern (Table 2.7). There was a significant increase in those who were *extremely concerned* (from 17% to 22%) and *very concerned* from (32% to 40%) between the first and second time the question was asked throughout the survey. Likewise, there was a significant decrease in those who were *not concerned* from 10% to 5%.

Table 2.7 Answer choices for participants who were asked how concerned they were about invasive insects and diseases killing a large number of trees across the United States and percentage of participants who selected each answer.

Answer choices	% of participants (Baseline)	% of participants (Follow-up)
Extremely concerned	17%	22%
Very concerned	32%	40%
Somewhat concerned	41%	33%
Not concerned	10%	5%

Over three-quarters of our sample responded with support for a proposal to congress to increase funding to stop the spread of non-native insects and diseases (Table 2.8). However, although there was a slight change in responses between the first and second time the question was asked, none of the changes showed significant differences.

Table 2.8 Answer choices for participants who were asked if they would support a proposal in congress to increase funding for efforts to eradicate and stop the spread of three specific non-native insects and diseases that are killing millions of trees across the United States and percentage of participants who selected each answer.

Answer choices	% of participants (Baseline)	% of participants (Follow-up)
Strongly support	44%	47%
Somewhat support	34%	34%
Somewhat oppose	12%	8%
Strongly oppose	10%	12%

Eighty percent of participants indicated they were *very willing* to use only local firewood and not move it from place to place (S338, S705); another 11% were *somewhat willing*. Some participants were asked the same question a second time at the end of the questionnaire (S338); the follow up resulted in a shift in numbers but there were no significant differences. The most common reason participants would not use firewood from local areas was "I live in the woods and use my own firewood/ I have lots of trees around" (34%). Another 22% of participants cited reasons related to price and convenience (i.e., "easier and safer", "cost factor", "out of my way", "don't like all the cutting and lugging"), and 17% indicated "I don't know".

Table 2.9 Answer choices for participants who were asked how willing they would be to use only firewood gathered or purchased by them in the local area and percentage of participants who selected each answer.

Answer choices	% of participants (Baseline)	% of participants (Follow-up)
Very willing	80%	77%
Somewhat willing	11%	17%
Not too willing	2%	4%
Not at all willing	7%	2%

Thirty-eight percent of participants indicated the *most concerning* statement about insects and diseases that are killing large numbers of trees across the U.S. was their threat to "… our clean air, clean water, and public health". Also, the statement "forests are critical to our public health, providing natural filters that keep our air and drinking water clean" stood out (39%) among participants as the best reason for *supporting* additional efforts to fight tree-killing non-native insects and diseases.

Discussion

It appears that overall across 5 surveys spanning 11 years, awareness surrounding forest health, forest insect and disease dispersal, and the movement of firewood is relatively low among our sample. This could suggest that the messaging strategies implemented between 2005 and 2016 were not reaching the target audience. Although awareness levels were low among our sample, there is indication that when awareness increases, there is concern and willingness to take or support measures related to improving forest health and stopping forest pest dispersal through firewood movement. Therefore, these results suggest that if relevant information can be more effectively transmitted, firewood movement might

be reduced. Support for preventing forest pests from entering the USA may be garnered with the information that prevention is less expensive than mitigation and damage control. Presenting the information about forest health, forest insect and disease dispersal, and the movement of firewood in collaboration with a state Department of Forestry may increase the credibility of such messaging as it was the most trusted messenger.

The positive relationship between EDUCATION and *having heard of an invasive insect* highlights the need for educational and outreach programs that target those with lower education levels since, in a given year, about 60% of campers have lower education levels (The Coleman Company Inc. and The Outdoor Foundation 2014, 2015, 2016, 2017). The finding that older respondents were more likely to have heard about non-native insects, in general, and which species they had about is likely a result of how long ago these pests established in the U.S. Most likely, older participants have heard about or seen tress the effects of gypsy moth, Dutch elm disease, and chestnut blight firsthand. Although older campers represent up to 31% of campers in a given year (Kampgrounds of America 2019), between 2015 and 2018, the percentage of millennials and Gen X campers has been increasing from 34% to 41% and from 28% to 36%, respectively (Kampgrounds of America 2019), meaning there is also a need to increase awareness levels about invasive forest insects and diseases among younger audiences.

In addition to awareness, our results highlight the importance of effective messaging. We focused on two important aspects of effective messaging: 1) the mode, and 2) the messenger. Participants preferred slogans and phrases whose framing was more positive (e.g., “buy it where you burn it” and “buy local burn local” over “don’t move

firewood"). This is supported by research from Lee, Liu, and Cheng (2018), who found that positive message framing is more effective, especially when the message has a "promotion" focus (i.e., "buy it where you burn it" and "buy local burn local") rather than a "prevention" focus (i.e., "don't move firewood"). Likewise, avoiding fatalistic framing (e.g., "moving firewood transports tree-killing insects and diseases"), and having the message focus on the positive impacts of public support is more likely to be effective when communicating about invasive species (Clarke et al. 2020). As such, future messaging would benefit from building on the momentum of positively framed messaging such as "buy it where your burn it: protect our forests, air, and water".

Participants may have been less likely to prefer Facebook, a website, and an e-newsletter as modes of information for conveying information about not moving firewood given that most surveys being conducted before 2011. Research on social media use has found that in 2005, social media use among adults was around 5%, increased to 50% in 2011, and is currently at 72% (Pew Research Center 2019). This could indicate that social media and other forms of electronic communication might still be a viable platform for communicating about invasive forest pests. Handing out flyers at state parks and sending an email when making a campsite reservation are likely to be a more successful means for conveying information for the portion of the population that does not rely on social media. Overall, efforts towards increasing the public's awareness about forest health, forest insect and disease dispersal, and the movement of firewood through more effective channels of communication and message framing may help reduce firewood movement.

Our finding that females were more likely to believe the trusted messengers presented in the survey suggests the need for a trusted messenger for the majority of our target audience, given that males represent up to 55% of campers in a given year (The Coleman Company Inc. and The Outdoor Foundation 2017). On the other hand, the negative relationship between AGE and choice of trusted messenger provides valuable information for future management decisions since younger people represent up to 77% of campers in a given year (Kampgrounds of America 2019).

The results to this study echo previous literature related to firewood movement by campers where convenience and cost were the strongest motivations for participants who move firewood or do not buy local firewood (Peterson and Diss-Torrance 2012, 2014, Daigle et al. 2018). Since most participants cut their own firewood because they live close to wooded areas, or buy firewood and transport it because they believe it is easier and cheaper, one strategy that could have a substantial effect in changing firewood movement behavior could be selling firewood at a lower cost in national and state parks. Providing information about the availability of this low-cost firewood in parks, and why locally sold firewood is a better choice than moving firewood, could increase the impact since most participants (up to 80%) were very willing to only use local firewood after they were given some brief information on the issue of insect and disease dispersal through firewood movement.

Three of the four psychological barriers discussed by Swim et al. (1. lack of awareness, 2. mistrust and reactance, 3. habit, and 4. social comparison, norms, conformity, and perceived equality; 2009) appear to be prevalent among the public regarding forest

health and firewood movement issues. Ignorance might be the main psychological barrier considering 61% of participants had not seen, heard or read any information urging the public to not move firewood from place to place, and 81% were not aware of any state laws or regulations in their area limiting the public's ability to move firewood from one location to another. Our results suggest that if the lack of awareness can be overcome, there is promise for behavioral change; given that when participants are aware, there is concern and willingness to take or support measures related to improving forest health and stopping forest pest dispersal through firewood movement.

Habit is also an important barrier to the prevalence of firewood movement; the finding that participants "cut their own" firewood or "do not know" why they do not buy local firewood suggests their behavior is likely a result of habit. However, since nearly all participants in our study indicated willingness to change this type of habitual behavior, these results suggest that if relevant information can be more effectively transmitted, there is promise for reducing firewood movement. Reactance is relevant to our results related to slogan preference where participants preferred the slogans without the negative framing. The phrase, "don't move firewood" may convey limited behavioral freedom by forbidding a behavior, making it more likely to increase reactance, while the framing of the other two slogans provide more behavioral freedom. This result indicates that reactance might be decreased if messaging is framed positively.

Unintentional human-mediated transport of invasive species is a prevalent issue beyond firewood and forest pests. In addition to invasive insects and diseases, plants, fish, aquatic invertebrates, and even terrestrial organisms are unintentionally transported by

humans or become invasive due to pathways created by humans (Hulme 2009). Firewood is just one of the vectors facilitating invasive species spread; others include fruits and vegetables, ships, airplanes, and cars (Carlton and Ruiz 2005). Our results suggest that lack of awareness is one of the major problems behind forest insect and diseases dispersal via firewood. It is likely that this issue occurs in other scenarios of invasive species spread. Our findings suggest that participants are more likely to support additional efforts to prevent the movement of nonnative insects and diseases via firewood transport when they are told that this issue threatens clean air, clean water, public health, and overall quality of life. As such, managers, agencies, and other organizations dealing with invasive species spread can improve messaging through the mode, messenger, and effective message framing.

Overall, willingness to prevent the spread of forest pests appears to be highest when it does not require major effort on the part of the participants. When the suggested alternatives create a discomfort, such as increase in taxes, volunteering, or donating, there may be less compliance and/or support.

Management Implications

A significant limitation to this study and its results is the low response rate from the data we were provided, as well as the lack of non-response sampling. While the low response rate and lacking non-response sampling from each individual study means that the sample is not statistically representative of the respective populations of interest, the size of each sample was large enough to allow us to glean a considerable amount of information on the topic and cautiously use this valuable information to inform management and education efforts.

We recommend that future research focus on filling the gaps highlighted by our results, such as finding a trusted messenger for males and older people, an effective mode of information for younger audiences and those with lower education levels. Assessing awareness before and after implementing new educational strategies that use effective messaging would also provide valuable information for behavior and rule compliance. In addition, based on the methodology implemented for conducting the surveys in this study, we suggest that future studies have consistent questions among surveys, consistent sample frames, and use non-response sampling.

In the midst of climate change, forests play a key role in counteracting the negative impacts caused by human behavior. Preventing firewood movement is one of the many pro-environmental behaviors that need to be encouraged among the general public in order to protect these ecosystems. The issue of forest pest dispersal via firewood provides a glimpse on the importance of environmental education and pro-environmental behavior; further, it shows that modifying a simple behavior can have an impact on protecting an ecosystem, its wildlife, and its ecosystem services.

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