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Fostering Climate Change Resilience: A Socio-ecological Forest Systems Approach

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FOSTERING CLIMATE CHANGE RESILIENCE: A SOCIO-ECOLOGICAL FOREST SYSTEMS APPROACH

By Alyssa Soucy

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An Abstract of the Thesis Presented
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As climate change continues to impact socio-ecological systems, those that rely on natural resources are highly sensitive to climatic changes. Maine's forest industry provides for the economic and social well-being of many residents and is especially vulnerable to climate change impacts. Changes in growing season length and timing, forest health threats imposed by insects and pathogens, extreme weather events, shifting forest composition, and changes in natural disturbance severity and frequency have already begun, and are projected to continue, to impact forest systems in the Northeastern U.S. While climate change presents a threat to forest systems, opportunities also arise due to longer growing seasons and warmer temperatures. Socioeconomic pressures and biophysical impacts necessitate the implementation of adaptation strategies among forest managers to maintain and enhance healthy and resilient forest systems in Maine, as well as overcome threats and take advantage of opportunities. Identifying impacts, assessing vulnerabilities, and determining appropriate adaptation strategies are critical first steps in implementing effective adaptive management across the state. The goal of this study was to develop and implement an integrated framework to assess the vulnerability and enhance the resilience, via increased climate change adaptation, of Maine's forest socio-ecological systems to climate change. The thesis uses a sequential mixed-methods approach to combine qualitative and quantitative data, to (1) understand stakeholder perceptions of climate change impacts and adaptation, and (2) to map biophysical and social vulnerability of Maine's forest industry to climate change. Forest stakeholders in Maine generally have high perceptions of risk regarding climate change impacts, and identified and prioritized the following climate change impacts as having the greatest and most likely impact on the forest industry: forest health threats imposed by insects and pathogens, extreme precipitation events, shifts in forest composition, invasive species, and changes in forest productivity. The results of the vulnerability assessment also highlight the unique combinations of exposure, sensitivity, and adaptive capacity to climate change among Maine counties. Management strategies that address prioritized and experienced impacts are widely accepted among stakeholders; however, stakeholders are less willing to formally incorporate climate change into the forest management planning process given barriers and limited access to incentives. Integration of research results indicate the persistence of uncertainty and complexity involved in climate change adaptation and present a challenge to increasing implementation of adaptation strategies among forest stakeholders. However, promoting opportunities for learning and enhancing management flexibility via communications that appeal to stakeholders' perceptions, social norms, experiences, and values can increase the ability of Maine's forest socio-ecological system to respond to change. The framework presented in this thesis can have widespread application elsewhere, given its theoretical and methodological groundings and its novel multi-method approach to study forest industry vulnerability and the potential for adaptation.

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LIST OF ABBREVIATIONS

CCPRM: Climate Change Risk Perceptions Model

GHCN-D: Global Historical Climate Network- Daily

GIS: Geographic Information Systems

IPCC: Intergovernmental Panel on Climate Change

MWO: Maine Woodland Owners

CFRU: Cooperative Forestry Research Unit

NAICS: North American Industry Classification System

NGT: Nominal Group Technique

NIPF: Non-industrial Private Landowners

NLCD: National Land Cover Database

NLDAS: North American Land Assimilation System

PCA: Principal Components Analysis

TBA: Total Basal Area

USDA: United States Department of Agriculture

GLOSSARY OF DEFINITIONS

Term	**Definition**	**Page(s)**
Adaptation	An adjustment of natural/human systems in response to climatic stimuli that is employed, that is employed to better cope with, manage, or adjust to changing conditions (McCarthy et al., 2001; Smit & Wandel, 2006)	47, 76
Adaptive capacity	The ability of a system to adjust, which cab be manifested in adaptations, to climate variability or extremes to moderate damages, take advantages of opportunities, or cope with impacts (IPCC, 2001; Turner et al., 2003)	81
Agency	An individuals' ability to act independently to make their own choices (Berkes & Ross, 2013)	82
Collective action	The ability to self-organize within a group to work towards a common objective, requiring networks and information flows to help in decision-making (Adger, 2003)	82
Exposure	The type and degree to which a system is subject to significant climate variability or impacts (IPCC, 2001)	81
Indicators	Simple measures to understand complex conditions that provide a 'snapshot' of a community in a single place and time (Fischer et al., 2013)	83
Nominal group technique	A structured face-to-face group meeting that generates a list of ranked outcomes (Delbecq et al., 1975)	14
Risk perceptions	A subjective mental construct of one's own personal feelings towards the severity and/or likelihood of a threat or occurrence (Slovic et al., 2004) that are shaped by cognitive, experiential, and socio-cultural factors (van der Linden, 2015; Wolf & Moser, 2011)	5, 51
Self-efficacy	Related to an individual's judgment regarding whether or not they have the skills and/or resources to execute a specific course of action or perform a particular behavior (Bandura, 1997)	53
Sensitivity	The amount to which a system is susceptible, or prone to, either positive or negative impacts from climate-related stimuli, relating to the responsiveness of the system (IPCC, 2001; Preston & Stafford-Smith, 2009)	81

Social learning	Learning that occurs through observations of others via social interactions serve as guides for future action (Bandura, 1986; Reed et al., 2010)	82, 123
Social norms	Expectations regarding how an individual should think or act (Hogg & Reid, 2006; Cialdini et al., 1990),	6, 52
Values	Orienting beliefs that can guide behavior or cognitive processing (Schwartz & Bilsky, 1987; Steg, 2016)	6, 52
Vulnerability	The extent to which a system is unable to cope with threats imposed by climate change, and is a function of exposure, sensitivity, and adaptive capacity (Parry et al., 2007)	7

CHAPTER 1: INTRODUCTION

Climate change poses many complex challenges to today's society with major social, economic, and environmental consequences. The forest industry is highly sensitive to climate change due to a variety of biophysical impacts and the uncertainties involved in managing forest resources on large spatial and temporal scales (Fischer, 2018; Lucash et al., 2017). Specifically, Maine, U.S., with a highly diverse forest system (Butler, 2017), is especially vulnerable to climate variability given the state's social and economic reliance on natural resources. The forest products industry provides for the well-being of residents in many of Maine's communities, supporting more than 33,000 jobs with an economic impact of $8.5 billion (EDAT, 2017). Future climatic changes are expected to impact forests in the Northeastern U.S. in a variety of ways, including: changes in growing season length and timing, changes in seasonal temperatures and precipitation patterns, natural disturbance severity, extent and frequency, and both pest and disease outbreak frequency (Janowiak et al., 2018). Given socioeconomic pressures coupled with projected biophysical changes, forest managers are faced with making difficult management decisions to ensure the future of their businesses as well as the future of resilient and healthy forest systems in Maine. The goal of this study is to develop and implement an integrated framework to assess the vulnerability and enhance the resilience of Maine's forest socio-ecological systems to climate change via an increased understanding of forest industry vulnerability and forest stakeholder perceptions of climate change impacts and adaptation.

1.1 Study area

The study was conducted in the state of Maine (45.2538° N, 69.4455° W), which is located in the Northeastern U.S. (Figure 1.1). Maine is approximately 91,646 km^2, with 7.09 million ha of forested land (89% of the state's area), and has a large diversity of climates resulting in over 50 tree species (Jacobson et al., 2009; Butler, 2017). It has the highest percentage of forested land in the U.S., of which 97% is classified as productive timberland (Correia, 2010). Maine's forest is owned by a variety of stakeholders, including private corporations, individual family owners, and state and federal government agencies (Butler, 2017). Forest industry stakeholders hold positions as land managers, land owners, government officials, forestry consultants, foresters, and environmental non-profit employees. Each stakeholder group also has their own unique set of values, perceptions, and forest management objectives (Lönnstedt, 1997; Kline et al., 2000; Otto-Banaszak et al., 2011), which in combination with climate change and shifting land ownership patterns and socio-economic conditions further complicates sustainably managing Maine's forests (Friedland et al., 2004).

Figure 1.1. Location of study area (State of Maine with its sixteen counties).

Maine's forested areas are dominated by balsam fir (*Abies balsamea* (L.)), maple (*Acer* spp.), spruce (*Picea* spp.), beech (*Fagus grandifolia* (L.)), and birch (*Betula* spp.), in two dominant forest type-groups – maple/beech/birch and spruce fir – accounting for 75% of the forest land (Butler, 2017). Other common species include aspen (*Populus* spp.), northern white cedar (*Thuja occidentalis* (L.)), eastern hemlock (*Tsuga canadensis* (L.) Carrière), and eastern white pine (*Pinus strobus* (L.)) (Butler, 2017). Climate change is already impacting Maine's forests (Fernandez, 2020), and future projections suggest increases in extreme precipitation events (Huang et al., 2017), milder winters (Spittlehouse, 2005), insects and pathogens (Weed et al., 2013), decreases in regeneration due to increased deer browsing (Frelich et al., 2012), and shifts in forest composition (Janowiak et al., 2018) all of which have implications for forestry operations and the commercial value of forest products.

1.2 Mixed-methods approach

A sequential mixed-methods approach (Creswell, 2015) is used to combine qualitative and quantitative social science with biophysical data to evaluate vulnerability of Maine's forest industry to climate change, and understand perceptions of climate change impacts and adaptation (Figure 1.2) that could help enhance system resilience. The study consisted of three phases of data collection and analysis. Using multiple research methods and data types allowed us to address the complexity of the problem (Creswell & Poth, 2018), and begin to discuss effective approaches to communicate adaptation strategies that tackle climate change impacts with Maine's forest stakeholders that could help enhance resilience, or the ability of Maine's forest socio-ecological system to respond to change.

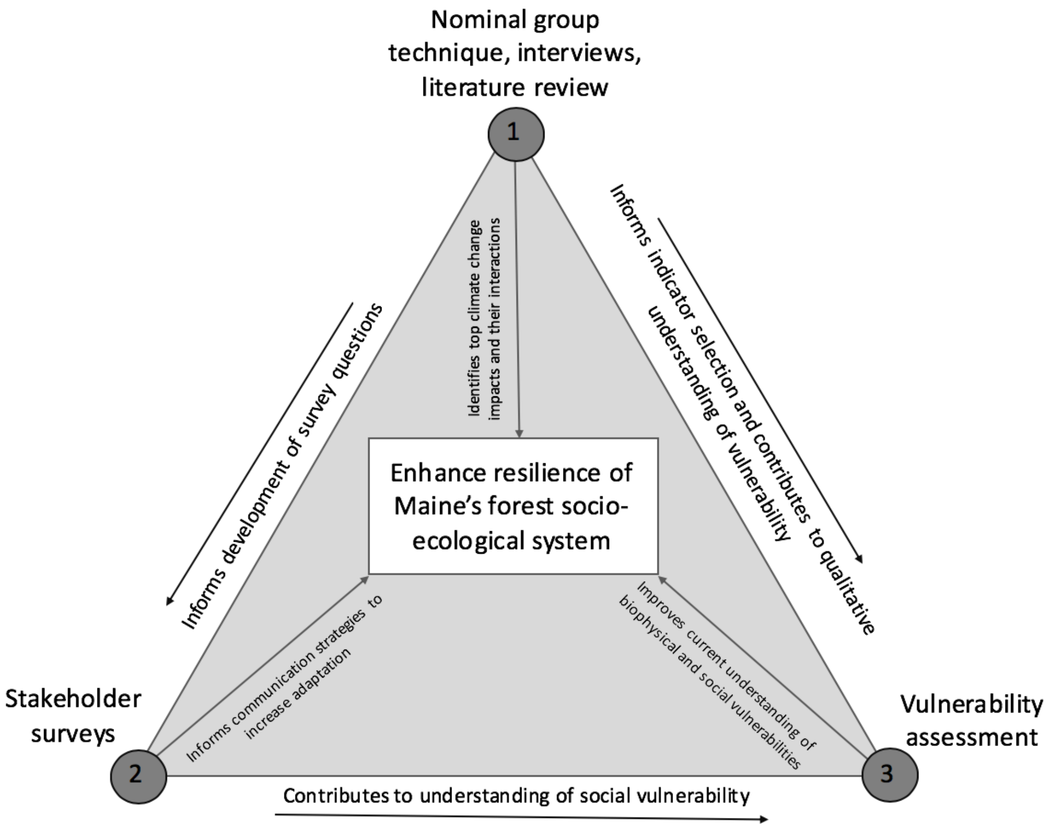

Figure 1.2. Multi-method approach employed to enhance resilience of Maine's forest socio-ecological system to climate change.

1.3 Conceptual foundations

Climate change adaptation is one way to respond to environmental change and promote sustainable practices (Jantarasami et al., 2010). In natural resource management, adaptation involves the identification of impacts, assessment of vulnerabilities, evaluation of appropriate adaptation strategies, and their implementation at relevant scales (Swanston et al., 2016). Climate change risk perceptions and vulnerability (both objective and perceived) can impact the extent to which individuals implement adaptation strategies (Guariguata et al., 2012; Chatrchyan et al. 2017), as well as the specific types of adaptation strategies employed (Lenart & Jones, 2014). This study draws on several theories and fields of research, which are useful in understanding risk perceptions of climate change impacts and assessing socio-ecological vulnerability.

1.3.1 Climate change risk perceptions

From a human dimensions standpoint, climate change risk perceptions can impact the extent to which stakeholders implement mitigation and adaptation strategies to cope with climate variability and promote resilient and sustainable socio-ecological systems (Chatrchyan et al. 2017; Habtemariam et al., 2016; Jemison et al., 2014). Risk perceptions are a subjective mental construct of one's own personal feelings towards the severity and/or likelihood of a threat or occurrence (Slovic et al., 2004). In this study, we draw on the climate change risk perception model (CCPRM) to understand the social-psychological determinants of climate change risk perceptions, where cognitive, experiential, socio-cultural, and socio-demographic (e.g. age, gender, political affiliation) factors shape climate change risk perceptions (van der Linden, 2015) (Figure 1.3). *Cognitive factors*, including knowledge about the causes and impacts of climate change, as well as perceived self-efficacy to respond to climate change, have been associated with increased risk perceptions (van der Linden, 2015). Specifically, higher belief in anthropogenic climate change (Blennow & Persson, 2009; Safi et al., 2012), and higher perceived self-efficacy (i.e. individual's judgment regarding whether they can perform an action or behavior (Bandura, 1997)) contribute to higher perceptions of risk (Grothmann & Patt, 2005). *Experiential* factors include experiences with climate change and associated affects, or feelings towards a specific idea/object (Leiserowitz, 2006). Previous experience with risks (Eriksson, 2014) and negative affects towards those experiences (Slovic & Peters, 2006) both increase perceptions of risk. *Socio-cultural* factors include social norms (e.g. descriptive and prescriptive) and values, which both play an important role in determining risk perceptions (Leiserowitz, 2006). Values are orienting beliefs that can guide behavior or cognitive processing (Schwartz & Bilsky, 1987; Steg, 2016). Social norms are expectations regarding how an individual should think or act (Hogg & Reid, 2006; Cialdini et al., 1990), and have been linked with risk perceptions as well as individual adaptation (Vulturius et al., 2020; Hengst-Ehrhart, 2019).

Increased climate change risk perceptions can be important predictors of perceived need to change (Leiserowitz, 2006), and have been linked to readiness for adaptation within forest management (Parkins & MacKendick, 2007). In Maine, where climate change adaptation in managed forests largely relies on individual land manager and owner decision-making, it is critical to understand perceptions of climate change risk to promote and enhance sustainable management practices. Understanding the specific drivers of risk perceptions and behavior can enable policy makers, consultants, and scientists to communicate with stakeholders in ways that connect with audiences to promote resilient forest systems and elicit broader support for action (Roser-Renouf et al., 2012).

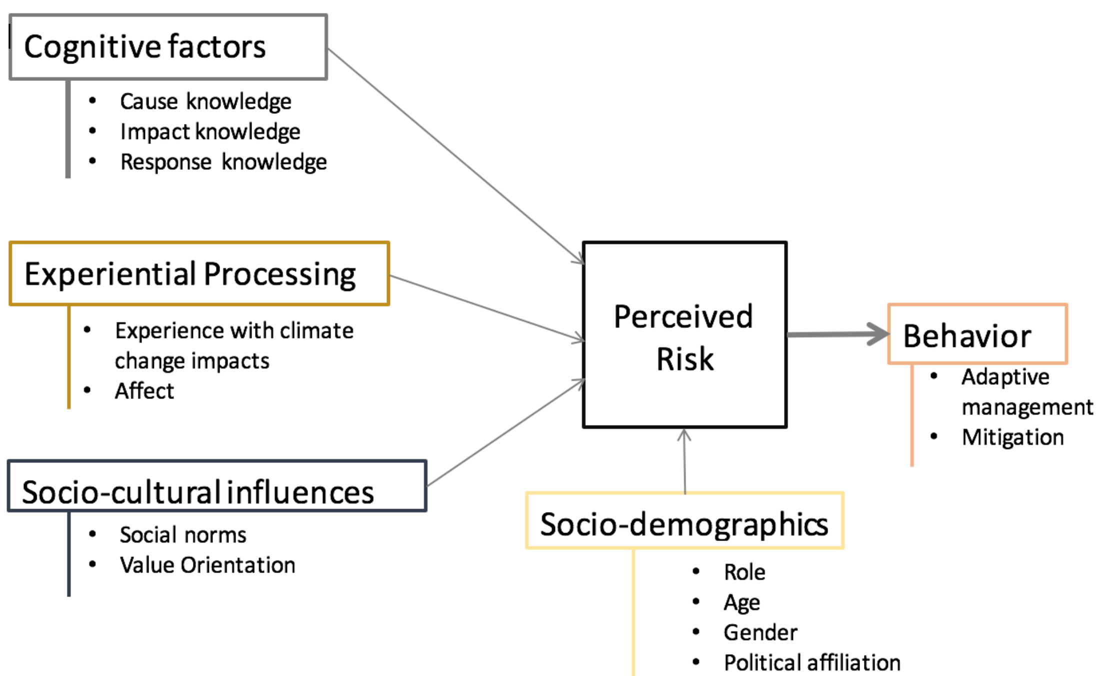

Figure 1.3. Climate change risk perception model adapted from van der Linden (2015).

1.3.2 Vulnerability in socio-ecological systems

Climate change is a highly complex issue involving interactions between humans and the environment; therefore, impact assessments analyzing this coupled human-natural system of products and services are fundamental for forest management (Beier et al., 2008). With the advance in technology of Geographic Information Systems (GIS), it is now possible to integrate human perceptions and behaviors with biophysical trends and changes on the landscape (Herrmann et al., 2014; Kosmowski et al., 2016). This integration enables a holistic understanding of the coupled human-natural climate change system, and can aid in decision-making (Bardsley & Sweeney, 2010). In this study, *vulnerability* is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change… [and] is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Parry et al., 2007, p.6). We rely on literature from community development (Emery & Flora, 2006) and resilience thinking (Adger, 2003; Berkes & Ross, 2013), along with social learning theory (Bandura, 1986; Reed et al., 2010) to conceptualize vulnerability (see Chapter 4 for full discussion).

1.3.3 Risk perceptions and vulnerability

Despite differences in methods and conceptual origins, climate change risk perceptions and vulnerability are largely connected, and this study can benefit from examining their interdependencies. Scientific assessments of vulnerability rely on probability and mathematical reasoning, which differ from public perceptions of risk as these are based on socio-psychological determinants that are cognitive, social, and experiential in nature (Garvin, 2001). However, perceptions of climate change can influence actual and perceived vulnerabilities, and vice versa.

Actual vulnerability can influence perceptions of climate change risk as people may be aware of their physical vulnerabilities and proximity to environmental hazards, and therefore consider the potential impacts of climate change with a higher perception of risk (Brody et al., 2008). Perceived vulnerability can also influence perceptions of climate change risk, as individuals may believe an environmental risk cannot be controlled, and therefore they feel an inability to protect themselves (Breakwell, 2010). In addition, climate change risk perceptions can influence perceived vulnerability by shaping beliefs regarding the likelihood of climate change impacts (Huebner, 2012). Perceptions of climate change impacts are also required to ensure the vulnerability assessment is useful for decision-making (i.e. including relevant sector-specific indicators) (Ludena & Yoon, 2015). Finally, climate change risk perceptions can influence actual vulnerability, as perceptions and individual knowledge of climate change capture the dynamic nature of local adaptive capacity, and therefore vulnerability (Ludena & Yoon, 2015). Evaluating perceptions of climate change risk and adaptation alongside socio-ecological vulnerability provides a more comprehensive picture of the potential for increasing adaptation within the state, more so than each one does alone.

1.4 Research questions

The overall goal of this study is to develop and implement an integrated framework to assess the vulnerability and enhance the resilience of Maine's forest socio-ecological system to climate change. To achieve this goal, there are several research objectives:

i) Assess forest stakeholder awareness and risk perceptions of climate variability and forest socio-ecological system change through quantitative and qualitative social science measures (Chapters two and three).

ii) Determine stakeholders' willingness to implement specific forest adaptation strategies to address climate change along with their perceived barriers and incentives to adaptation (Chapter three).

iii) Evaluate forest stakeholders' social norms, values, and sources of information in regards to climate change adaptation (Chapter three).

iv) Implement an integrated vulnerability assessment to quantify and map potential physical and socio-economic effects of climate change using indicators of biophysical change and stakeholder risk perceptions and management strategies (Chapter four).

1.5 Research justification

While there have been studies on the vulnerability of Maine's forest ecosystems to climate change (Janowiak et al., 2018), and assessments for adaptation needs among forest managers (Janowiak et al., 2020), this study is the first in Maine to present a *spatially explicit* assessment of forest industry vulnerability to climate change using both biophysical *and* social data. Additionally, understanding perceptions of climate change impacts and adaptation can be useful in evaluating willingness to implement adaptation strategies (Parkins & MacKendick, 2007), and designing targeted communication efforts to increase adaptation (Moser, 2014) and resilience. Research activities were continuously shared with stakeholders throughout the process via newsletters, presentations, and one-pagers that helped to ensure relevant and meaningful results to aid in forest management decision-making, while building rapport and trust and enhancing the quality of the research process. This research will lead to an increased understanding of Maine's forest socio-ecological system vulnerability to climate change, as well as enhanced resilience to climate variability via improved understanding of biophysical climate change risk and perceived risk.

Through continued efforts with forest stakeholders, we expect results from this study to enhance the capacity of forest-resource based industries to prepare for and adapt to the impacts of climate change; help in designing targeted communication strategies to stakeholders across the state; leverage institutional resources to aid decision-makers; and evaluate effective adaptation strategies.

The scientific merit of this project stems from its contribution to a systematically applied theoretical framework to understand and predict climate change risk perceptions, climate change vulnerability, and resilience in forest-based systems. The study contributes to our understanding of key variables that drive adaptation implementation and forest vulnerability. The study generates robust data, based on sound theoretical and methodological groundings, to inform climate-change decision-making, and provide a framework for future research in other regions. Through the integration of biophysical and social data, this study also provides a unique multi-method approach that is useful in understanding the complexity involved in climate change adaptation. The lessons we learn in Maine will have widespread application elsewhere given the complexities of the forest socio-ecological system and diversity of stakeholders present.

1.6 Organization of the thesis

This thesis is composed of five chapters, with three articles intended for publication in scientific journals. The purpose of this introduction has been to provide an overview of the study, including research objectives, background on the study site, study rationale, and theoretical underpinnings. Chapter two presents results from an expert elicitation technique, stakeholder interviews, and a review of the literature to understand perceptions of prioritized climate change impacts (study phase one). This chapter utilizes a multi-method approach to both quantitatively and qualitatively assess potential influences on Maine's forest industry and complements the findings of Chapter three, while guiding the variable selection in Chapter four.

Chapter three draws on results from a survey of two forest stakeholder groups in Maine in an effort to understand potential determinants of adaptation implementation (study phase two). Communication strategies to increase climate change adaptation within each group, as well as across both groups, are discussed. Chapter four presents a spatially explicit vulnerability assessment of Maine's forest industry to climate change (study phase three). Both (1) biophysical data, informed by the results of Chapter two, and (2) social data, largely drawn from Chapter three, are evaluated in the vulnerability assessment. In this thesis, the CCRPM helped to explain perceptions of climate change impacts in Chapter two, influenced the variables analyzed to increase adaptation implementation in Chapter three, and was incorporated as a determinant of adaptive capacity of the vulnerability assessment in Chapter four.

The final chapter (five) concludes with an integration of chapters two through four to discuss how the newly found understanding of perceptions of climate change impacts, drivers of climate change adaptation, and vulnerabilities of Maine's forest industry can be leveraged to create effective communication and outreach materials to increase adaptation implementation and identify management strategies to cope with climate change. Finally, this chapter discusses future research and provides some recommendations for increasing the adaptive capacity of Maine's forest industry.

CHAPTER 2: IDENTIFYING, PRIORITIZING, AND UNDERSTANDING PERCEPTIONS OF POTENTIAL CLIMATE CHANGE INFLUENCES ON MAINE'S FOREST SECTOR

2.1 Introduction

Forest ecosystems, as well as the forest industry, are highly sensitive to climate change due to a variety of biophysical impacts and the uncertainties involved in managing forest resources on large spatial and temporal scales (Fischer, 2018; Lucash et al., 2017). Future climatic changes are expected to impact forests in a variety of ways, including: changes in growing season length and timing, changes in seasonal temperatures and precipitation patterns, natural disturbance severity, extent as well as frequency, and both pest and disease outbreak frequency (Janowiak et al., 2018). As both biophysical and socioeconomic pressures increase, managers must make informed management decisions regarding the future of their businesses in order to overcome threats and take advantage of opportunities. Climate change adaptation is one way to respond to environmental change and promote sustainable practices (Jantarasami et al., 2010). In natural resource management, adaptation involves the identification of impacts, assessment of vulnerabilities, evaluation of appropriate adaptation strategies, and their implementation at relevant scales (Swanston et al., 2016).

While climate change can be personally experienced, the long-term nature of local climatic changes can be difficult to detect (Weber, 2010) and therefore, result in differences in perceptions of impacts and risks due to the diverse ways people may experience change. Climate change risk perceptions are a measure of the degree of personal worry an individual has about a hazard (Leiserowitz, 2009), and is a matter of beliefs concerning risk (Sjoberg, 2000). Risk perceptions are influenced not only by perceived experiences and knowledge, but also by contextual socio-cultural factors, such as societal norms and values (Wolf & Moser, 2011). Adaptation depends upon the perception of risk and whether it is believed it should be acted upon; for this reason, risk perceptions can have a large influence on the implementation of adaptation strategies (Adger et al., 2009) and play an important role in forest risk assessment (Williamson et al., 2005). The uncertainty of management strategies themselves and perceptions of impacts occurring far into the future may also result in a lack of urgency in adaptation (Rodriguez-Franco & Haan, 2015). Therefore, the identification of climate change impacts that lead to implementation of adaptation strategies must take into consideration local contexts as well as stakeholder expertise and perceptions (Lexer & Seidl, 2009) to ensure it is relevant for management (Keskitalo, 2008). Engaging with stakeholders to address their specific needs and reflect on their experiences can increase the adoption of management practices (Vulturius & Swartling, 2015) and help researchers understand whether or not specific climate change impacts are perceived as a threat to the stakeholders' managed lands (Yousefpour & Hanewinkel, 2015).

Participatory processes that integrate science with stakeholder perceptions and preferences are increasingly being used to foster collaboration necessary to inform decision-making (Brandt et al., 2017), especially under high uncertainty situations. Several methods exist to understand and prioritize stakeholder opinions for decision-making, including the Delphi technique, multi-criteria analysis, nominal group technique (NGT), interviews, focus groups, and surveys (Mukherjee et al., 2018). In particular, the Delphi technique and NGT are tools that enhance participation and allow a diversity of voices to be considered in group decision-making processes while seeking to reach consensus (Delbecq et al., 1975). The Delphi technique, which is a series of questionnaires through an iterative feedback process with experts participating remotely (Delbecq et al., 1975), has been used widely within forestry as a means of identifying market shifts (Hurmekoski et al., 2019), research needs (Wolf & Kruger, 2010), and management issues (Filyushkina et al., 2018; Waldron et al., 2016).

The NGT is a structured face-to-face group meeting that generates a list of ranked outcomes (Delbecq et al., 1975). Unlike the Delphi technique, NGT has been underused in ecological applications despite its suitability for identifying stakeholder preferences and attitudes, prioritizing capacity building needs, and exploring novel concepts (Hugé & Mukherjee, 2017). NGT is particularly useful in situations where there are time and cost restraints, as it is a relatively quick and effective process for stakeholder prioritization in cases where experts can easily be brought together for in-person meetings (Mukherjee et al., 2018). Although NGT focuses on building consensus among experts as part of a participatory process, the method allows for views of different individuals to be elicited and maintained (Hutchings, 2013), and the face-to-face meeting is important in establishing collaborative relationships (Harvey & Holmes, 2012). Combining NGT with qualitative interviews is an especially powerful multi-method approach to gain a deeper understanding of stakeholder priorities and perceptions (Hugé & Mukherjee, 2017).

The goal of this project is to identify experts' major concerns in regards to climate change influences, and understand their perceptions of these influences on the forest industry in Maine where forests are especially susceptible to climate variability and experience a variety of climate change impacts. The forest industry is composed of a diversity of stakeholders, with varying roles and functions, management strategies and perceptions on environmental and socioeconomic changes. The industry provides for the well-being of residents in many rural Maine communities, supporting more than 33,000 jobs with an economic impact of $8.5 billion (FOR/Maine, 2018). The combination of climate change, landownership patterns, and changing socio-economic conditions further complicate sustainably managing Maine's forests (Friedland et al., 2004). Therefore, understanding and prioritizing climate change concerns is vital for decision-making in a diverse social-ecological system, and has implications for forest industries in many other natural resource dependent communities. We describe a multi-method approach that gauges the opinions of experts who work within Maine's forest sector in order to begin to understand stakeholder perceptions. Although there is a vast amount of literature on climate change impacts on northeastern, U.S. forests – this is the first time, to our knowledge, a multi-method approach has been used to understand stakeholder perceptions of climate change impacts in Maine. We conclude by discussing the advantages of using a multi-method approach and potential applications for management and research.

2.2 Materials and Methods

2.2.1 Data generation methods

We applied a multi-method approach to understand and prioritize climate change impacts in Maine's forest (Keskitalo, 2008). To achieve this, we (1) conducted a NGT to prioritize impacts while at the same time we; (2) interviewed key forest industry stakeholders to both identify these impacts as well as understand how the impacts may affect their businesses, operations, and ability to make decisions regarding climate change adaptation strategies, and; (3) reviewed existing literature on the effects of climate change on forests and industry in the Northeastern US, and when possible, Maine (Figure 2.1). A multi-method approach allows us to triangulate across different data types in order to obtain a richer understanding of the system and understand both convergent and divergent results (Flick, 2018a, 2018b, 2018c; Jick, 1979).

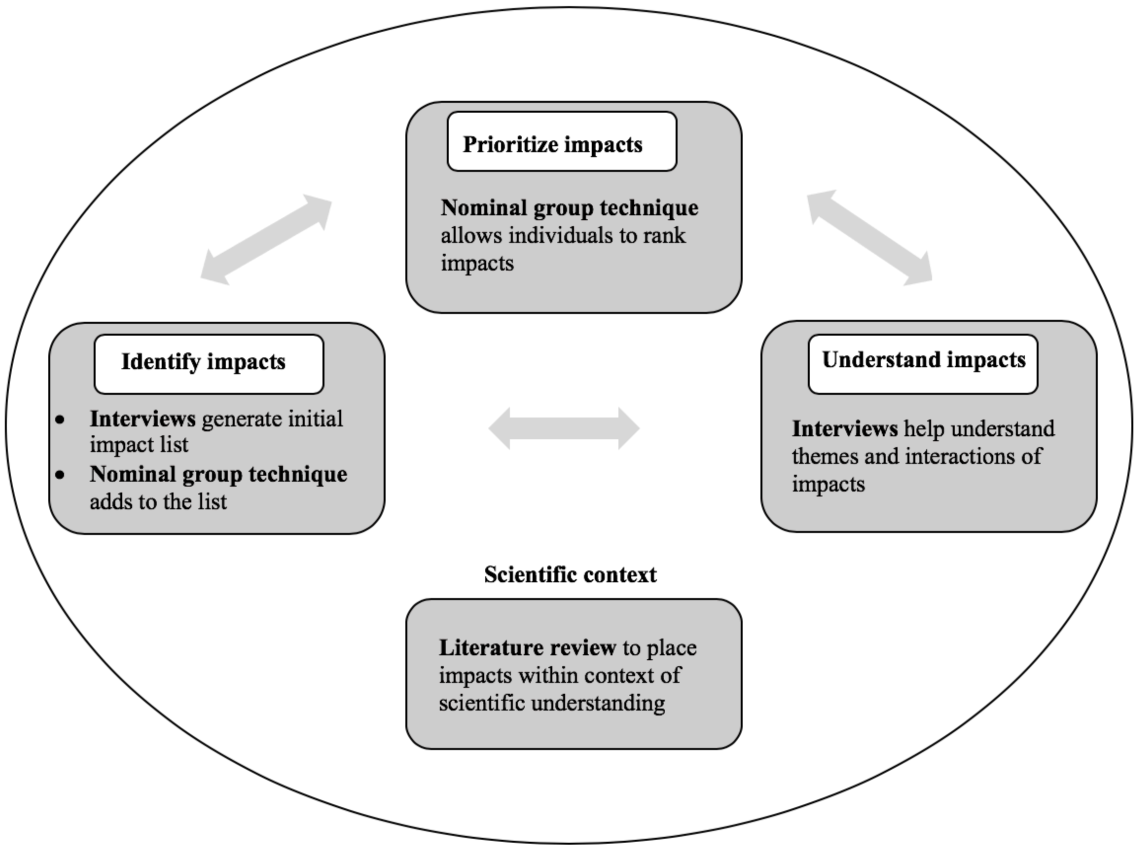

Figure 2.1. Iterative process of identifying impacts, prioritizing impacts, and understanding impacts using Nominal Group Technique (component 1) and interviews (component 2) and existing scientific literature (component 3).

2.2.2 Component 1: Nominal Group Technique & questionnaire

We facilitated a NGT with University of Maine's Cooperative Forestry Research Unit (CFRU) members during their January 2018 meeting to identify and prioritize climate change impacts on the forest industry in Maine. The CFRU is a stakeholder-driven research cooperative composed of landowners and land managers from the forest products industry, wood processors, environmental non-profit directors, and researchers. This community of practitioners and research experts meets several times a year to determine priorities for forest management and evaluate research proposals primarily aimed at developing applied information for stakeholders. Following Delbecq et al. (1975), we conducted an NGT in the following process:

(1) We divided the group of 19 members into four randomly assigned groups to create a space for a variety of opinions to be heard, without marginalizing stakeholders who may not feel comfortable sharing their views in a large group (Harvey & Holmes, 2012).

(2) A facilitator at each group presented a list of climate change impacts that had been identified in the literature and mentioned in key stakeholder interviews (see next section).

(3) In a round-robin style, participants suggested additions to the initial list of impacts. During this phase, we encouraged creativity and limited discussion to only suggestions (Hugé & Mukherjee, 2017).

(4) Following brainstorming, we opened up the group to discussion which allowed participants to clarify any items from the list.

(5) We asked the participants to select and rank five impacts. Two of the groups were asked to rank the five *greatest impacts* that climate change poses to the forest industry, while the other two groups were asked to rank the five *most likely impacts* that climate change poses to the forest industry. Here, greatest refers to those having a large magnitude impact (either positive or negative), whereas most likely impacts denote participants' perceptions of likeliness.

(6) Finally, participants indicated if the impact was anticipated to increase or decrease in the near future where applicable.

In addition, we administered a short 10-minute questionnaire following the NGT where we asked participants about their perceptions of important, vulnerable, and resilient tree species as well as socio-demographics. Participants ranked the top three tree species for each category (important, vulnerable, and resilient). In addition, we asked participants to select the forest sub-sector(s) that they represented, their years of experience, and current geographic area of work.

2.2.3 Component 2: Semi-structured interviews with key informants

We conducted two rounds of key informant semi-structured interviews (Seidman, 2013; Kvale, 2007) with forest stakeholders: (1) an exploratory set of 12 interviews conducted from December 2017 to April 2018 that aimed to identify key threats to the forest industry in Maine, and (2) nine interviews conducted from December 2018 to July 2019 to gain an in-depth understanding of forest industry stakeholders' (i.e., forest managers, researchers, and consultants from private industry, government, non-governmental organizations) experiences and views regarding the effects of climate change on the industry and relevant adaptation strategies. Participants were selected via snowball sampling whereby participants recommended other participants until saturation was achieved (Patton, 2015; Emmel, 2013; Gibbs, 2018). The semi-structured interview protocols allowed participants to shape the discussion and the interviewer to pose follow-up questions as emerging interests arose (Kvale, 2007; Brinkmann & Kvale, 2018).

The purpose of the interviews within this project was to (1) help with identifying an initial list of climate change impacts on the forest industry for the NGT, and (2) provide context and a deeper understanding of what these impacts mean to the industry and potential strategies to overcome challenges and take advantage of opportunities posed by climate change. Interviews were between 45 and 90 minutes in length and occurred both in-person and over the phone when face-to-face interviews were not possible. The first round of the interviews largely focused on shocks and global/local changes influencing the success of the forest industry in Maine in terms of opportunities and challenges (see MacDonald et al., 2018 for a full discussion); however, responses related to a changing climate and forest ecosystems fall within the scope of our research question.

The second round of interviews focused solely on the challenges, threats, and opportunities the forest industry is currently facing due to environmental and climatic changes. In particular, participants responded to questions regarding (1) experiences with changing weather and environmental conditions, (2) climate change risk perceptions, and (3) adaptation strategies.

2.2.4 Component 3: Literature review & synthesis

We reviewed existing literature on climate change impacts on forest ecosystems and forest industry to (1) generate an initial list of impacts for the NGT, and (2) examine the current scientific understanding of the top impacts to compare with the NGT and interview results. To generate an initial list of impacts, we used the keywords 'climate change,' 'impact*,' 'forest,' and 'forest industry,' with 'Maine' or 'Northeast*' in a search query within the Web of Science (http://apps.webofknowledge.com) database and Google Scholar (https://scholar.google.com/). We reviewed only peer-reviewed articles that discussed climate change impacts on forests within Maine or the greater US Northeast. We also reviewed the literature for the top five impacts identified from the NGT using individual search queries (e.g. 'extreme precipitation' or 'invasive') in combination with the keywords 'forest*' ('forest industry' or 'operation') 'impact*'. We conducted this search both with and without the keyword 'Maine'. We also reviewed the reference lists of seminal articles and reports to ensure a comprehensive coverage of the existing literature. The results of the literature review are presented in the discussion of the top five impacts.

2.3 Data Analysis

2.3.1 Component 1: Nominal Group Technique

The two groups ranking the greatest impacts were combined, and the two groups ranking the most likely impacts were combined to perform further analyses in Excel. We calculated the sum of the scores for each impact and created an overall ranking based on the calculation. Next, we calculated relative importance (McMillan et al., 2014) using the following equation:

$$\left[\frac{\text{Score achieved for each item}}{(\text{maximum possible score} \times \text{number of participants})}\right] \times 100 \qquad \text{(Equation 2.1)}$$

Given that impacts were similarly ranked using both the scores and the relative importance metrics, the number of votes (Sink, 1983) or frequency was used. For instance, a high score is not indicative of a widely prioritized impact but could be a result of a few people ranking it as high opposed to the majority listing it anywhere in the top five. This same procedure was carried out on the entire dataset. The process of combining individual rankings into overall rankings is useful in order to draw conclusions regarding the consensus of the group (Ssebunya et al., 2017). Unlike other variations of the NGT, whereby a group consensus is determined through facilitated discussion following individual ranking, retention of individual scores helps to reduce the negative consequences of power dynamics which can favor certain voices over others (Maynard & Jacobson, 2017). By treating each individual vote the same, the risks associated with problematic power dynamics are reduced.

The same method was used to determine the top tree species that are important, vulnerable, and resilient. Given the diversity and inconsistency of written responses (i.e. spruce/fir, balsam fir, all spruce, etc.), we combined species as needed to create meaningful categories with an overall rank. Finally, socio-demographics are presented as descriptive.

2.3.2 Component 2: Key informant interviews

Semi-structured interviews were audio-recorded and transcribed verbatim (Gibbs, 2018). Transcripts and reflections from the interviewing processes were entered into an NVivo 12 Plus database (Bazeley & Jackson, 2013) for concurrent qualitative data generation and analysis (Ely et al., 1997; Ely et al., 1991). To analyze the first set of exploratory interviews, we used inductive logic to find patterns in the data through open coding (Bazeley, 2013; Miles et al., 2020), or descriptive codes (Gibbs, 2018) organized based on similar ideas shared by participants. The analysis of the first set of interviews helped inform the development of the protocol and questions for the second set of interviews. Data analysis of climate change focused interviews included two stages of coding used to reflect on emerging ideas, reduce and integrate data into emergent codes and categories, and interpret meanings shared by participants (Miles et al., 2020; Gibbs, 2018; Bazeley, 2013). In stage one, we used open coding to stay close to participants words (Bazeley & Jackson, 2013). Stage two of the cyclical data analysis process included the creation of analytical codes by grouping codes into categories (Miles et al., 2020; Saldaňa, 2013), and interpretation of statements. We focused the in-depth analysis on the top impacts identified through the NGT ranking.

2.4 Results

2.4.1 Component 1: Nominal Group Technique

A total of 19 CFRU members across a broad range of organizations participated in the NGT and completed a questionnaire, of which the majority (75%) had experience either as a land manager and/or landowner. The remaining participants had a diverse range of experiences in research, conservation, pulp/paper mills, and recreation. Participants had up to 50 years of experience in administrative forestry work (mean ± SD = 20 years ± 16), and fieldwork (mean =

22 years ± 15). Participants worked all over the state of Maine, with Penobscot, Aroostook, and Piscataquis as the top three counties with 80%, 75%, and 65% of participants working in these regions respectively (Table 2.1).

Table 2.1. Participant background by data generation method.

Background	**Exploratory interviews**	**Climate change interviews**	**Nominal group technique**
Forest industry subsector*			
Bioenergy	4	0	1
Land management	5	7	13
Land ownership	6	5	8
Logging	4	2	2
Mills	5	1	2
Transportation	3	0	0
Research	0	1	6
Other**	2	3	4
Years of work in a forest resources profession			
Average	30	18	22
Minimum	4	1	2
Maximum	54	50	50
Current geographic area of work*			
Maine	12	9	17
New England	2	7	6
Other US State	2	3	4
Canada	0	3	2
Educational background			
Biology/ecology	0	3	
Business	1	0	
Forestry	7	6	
Engineering	2	0	
Chemistry	1	0	
Policy	1	0	

* Participants selected all applicable options and can therefore represent multiple subsectors or areas of work

** Other includes policy, capital investment, and professional service

In two groups of five, a total of ten participants selected and ranked the greatest climate change impacts affecting the forest industry. During the round-robin phase, one of the groups added the following impacts to the initial list: policy changes and workforce safety. The top five greatest climate change impacts are: forest health threats imposed by insects and pathogens, shifts in forest composition, extreme precipitation events, invasive species, and changes in forest productivity, respectively (Table 2.2). The majority of participants indicated that insects and pathogens (8), extreme precipitation events (6), and invasive species (4) would increase in the future. The group was split in regards to changes in forest productivity with two participants suggesting an increase in forest productivity, one suggesting a decrease, and one suggesting both an increase and a decrease. Following the top five ranked impacts, changes in soil moisture, thaw events in winter, changes in operation length, intense wind events, and drought rounded out the top ten.

In two groups of four and five, a total of nine participants selected and ranked the most likely climate change impacts affecting the forest industry. During the round-robin phase, one of the groups added the following impacts to the initial list: changing of timing in forest operations, increased costs, and increased growth. The top five most likely climate change impacts are: extreme precipitation events, shifts in forest composition, changes in operation length, insects and pathogens, and thaw events in winter, respectively (Table 2.3). The majority of participants suggested an increase in extreme precipitation events (4), insects and pathogens (3), and thaw events in winter (4). Participants, however, were split when it came to changes in operation length, with two participants suggesting a decrease, one suggesting an increase, and another indicating neither. Following the top five ranked impacts, changes in invasive species, intense wind events, unpredictability, changes in forest productivity, and changes in winter snow cover rounded out the top ten. When combining both groups to look at highly prioritized greatest and most likely climate change impacts affecting the forest industry the top five impacts are: insects and pathogens, extreme precipitation events, shifts in forest composition, invasive species, and changes in forest productivity (Figure 2.2).

Participants ranked the top five most vulnerable tree species to climate change as follows: spruce/balsam fir, maple, ash, cedar, and birch. The most important species were: spruce/balsam fir, maple, pine, birch, and ash. Finally, the most resilient species were: maple, oak, pine, eastern hemlock, and aspen.

2.4.2 Component 2: Key informant interviews

We conducted 12 interviews during the first round of exploratory interviews with stakeholders representing the following subsectors: land ownership (6), land management (5), bioenergy (4), pulp and paper mill (4), sawmill (4), logging (4), transportation (3), policy (2), and capital investment (1). On average, participants had 30 years of experience in the forest industry and worked across the US, with the majority working in central Maine (11). We conducted nine interviews during the second round of climate change focused interviews with stakeholders representing the following subsectors: land management (7), land ownership (5), logging (2), professional services (2), pulp and paper mill (1), sawmill (1), policy (1), research (1) and capital investment (1). In both sets of interviews, many of the participants worked across subsectors (i.e. through roles in land ownership and management) and had an educational background in forestry (Table 3.1). During both the exploratory and climate change interviews participants discussed impacts that were identified during the NGT. We present key findings from both sets of interviews with a focus on themes that emerged from the top five impacts.

Table 2.2. Prioritized and ranked greatest climate change impacts from the NGT.

Impacts	**Priorities (scores from individual participants)**										**Sum of scores**	**Ranked priority (via scores)**	**Relative importance (%)**	**Ranked priority (via %)**	**Frequency (# votes for each impact)**	**Ranked priority (via scores & frequency)**
	1	2	3	4	5	6	7	8	9	10						
Insects and pathogens	5	4	4	4	5	3	1	4		2	32	#1	21.3	#1	9	#1
Shifts in forest composition	3	1	5	5		5	2				21	#2	14.0	#2	6	#2
Extreme precipitation events	2		2		3	1		1	5	5	19	**#3**	**12.7**	**#3**	**7**	**#3**
Invasive species		3	3	3			5	5			19	**#3**	**12.7**	**#3**	**5**	**#4**
Change in forest productivity	4		1			4	4			1	14	#5	9.3	#5	5	#5
Changes in soil moisture		5		1				2	4		12		8.0		4	
Thaw events in winter						2		3	3		8		5.3		3	
Changes in operation length		2								4	6		4.0		2	
Intense wind events					2					3	5		3.3		2	
Drought					4						4		2.7		1	
Changes in wildlife populations							3				3		2.0		1	
Changes in road condition									2		2		1.3		1	
Changes in market*				2							2		1.3		1	
Changes in seasonal temperatures									1		1		0.7		1	
Policy changes*	1										1		0.7		1	
Workforce safety*					1						1		0.7		1	

*Indicates a suggested impact during round-robin phases

Table 2.3. Prioritized and ranked most likely climate change impacts from the NGT.

Impacts	**Priorities (scores from individual participants)**									**Sum of scores**	**Ranked priority (via scores)**	**Relative importance (%)**	**Ranked priority (via %)**	**Frequency (# votes for each impact)**	**Ranked priority (via scores & frequency)**
	11	12	13	14	15	16	17	18	19						
Extreme precipitation events	3		5		2	3	5			18	#1	13.3	#1	5	#1
Shifts in forest composition	5			2			3	1	3	**14**	**#2**	**10.4**	**#2**	**5**	**#2**
Changes in operation length						5	4	3	2	**14**	**#2**	**10.4**	**#2**	**4**	**#3**
Insects and pathogens		2	4	1	5					12	#4	8.9	#4	4	#4
Thaw events in winter	4	5			1	1				11	#5	8.1	#5	4	#5
Invasive species					3	2		5		10		7.4		3	
Intense wind events		4				4		2		10		7.4		3	
Unpredictability*	1	1	3	3			1			9		6.7		5	
Change in forest productivity	2			5						7		5.2		2	
Changes in winter snow cover									5	5		3.7		1	
Changes in growing season length				4						4		3.0		1	
Changes in seasonal temperatures								4		4		3.0		1	
Changes in soil moisture									4	4		3.0		1	
Changing of timing of forest operations*					4					4		3.0		1	

Table 2.3 continued

Drought	3				3	2.2	1
Changes in road condition			2	1	3	2.2	2
Inventory costs*		2			2	1.5	1
Increased growth*		1			1	0.7	1
Changes in wildlife populations					0	0.0	0
Wildfire					0	0.0	0

*Indicates a suggested impact during round-robin phase

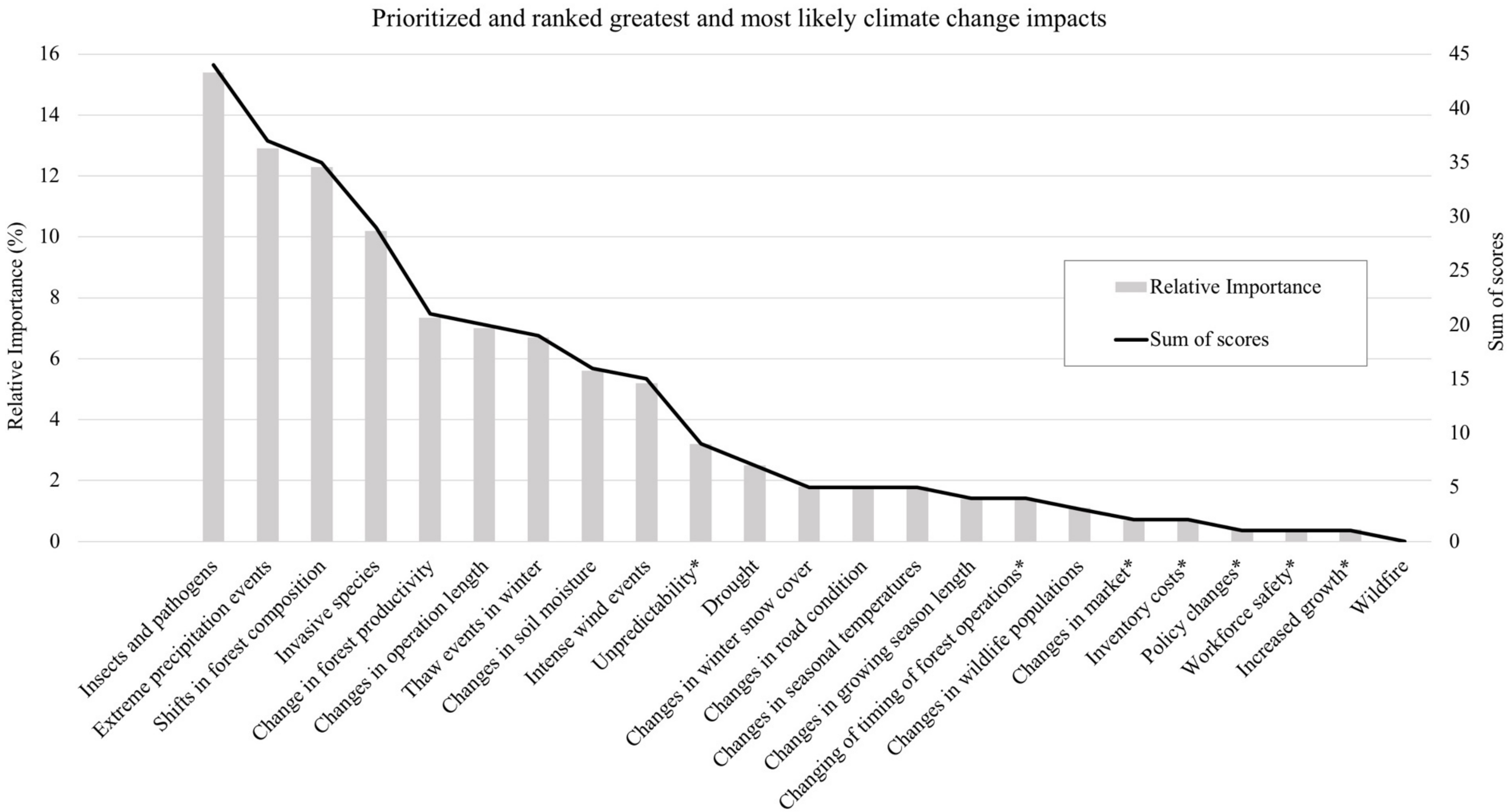

Figure 2.2 Combined NGT results for both greatest and most likely impacts groups.

Note: Represented by relative importance (grey bar chart) and sum of scores (black line).

* indicates an item was added by participants during the brainstorming phases.

2.4.2.1 Exploratory interviews

During the exploratory interviews, stakeholders identified three of the top five impacts that were also reported during the NGT, including: including insects and pathogens, extreme precipitation, and shifts in forest composition. Other impacts identified during the exploratory phase included changing seasons, increased thaw events, drought, and the need to develop adaptation strategies. The majority of interviewees (8) discussed *changing seasons* primarily in terms of changes during winter and spring. Multiple interviewees (5) expressed concern over *increased thaw events* and increased temperatures during winter and spring that have major implications on operations and investment in new forms of infrastructure. There was also a concern over the effects that changing seasons could have on contractors' ability to conduct operations safely, and unemployment that may rise with increased thaws during longer periods of time that disrupt forestry operations. A few interviewees also mentioned the effects that changes during summer (i.e., drought) could have on operations, with two participants referencing a potential increase in fire risk in Maine, which has not been a major concern in decades. One participant discussed the potential for harvesting more during summer with increased droughts,

> "we've kinda looked at the summer as an opportunity now with […] the drier conditions, we have actually harvested in land we never would have dreamt of harvesting ten years ago in the summer and have reduced the amount we might harvest in the winter." (Interview conducted on 1/30/2018 with a forester from the pulp and paper mill subsector, with 41 years of experience in the forest industry in Maine)

This speaks to both the challenge of altering the timing of forest operations (i.e. harvesting) given the impact of changing seasons, but also the new opportunities climate change may present.

Several participants talked about the need to develop *adaptation strategies* to (1) overcome negative impacts of changing seasons on the forest industry, especially to reduce the impacts of increased thaw events (e.g., building small bridges that might be more effective than culverts); (2) take advantage of opportunities that might result from changing conditions like increased comparative advantages of the Maine forest industry if other regions are affected more heavily from climate change; and (3) diversify the forest products portfolio if the forest composition changes as a result of new species migrating to the state.

2.4.2.2 Climate change interviews

Participants shared their perspectives on the changing conditions of the forest as a result of climate change, the impacts that the forest industry is experiencing or likely to experience given changing conditions, and management strategies that can be utilized to respond to the impacts of climate change. During the interviews, participants discussed all of the top five impacts identified during the NGT: insects and pathogens, extreme precipitation events, shifts in forest composition, invasive species, and changes in forest productivity.

In addition, participants mentioned *changing winters* (i.e., decreased number of days with frozen soil conditions and shorter winters), and changes in precipitation patterns with not only increased rainfall, but also increased drought. As expressed by participants, changes both pose challenges and present opportunities to the forest industry in Maine. Increased thaw events pose a real challenge to the forest industry as they impact the ability of foresters to harvest and transport wood for processing given the concern with the negative effects on soils and roads if logging occurs when soils are not frozen. While prolonged droughts may negatively affect species regeneration, they may also allow harvesting to occur in late spring and hence provide a longer harvesting season (a potential opportunity as a result of climate change). We present a synthesis of key perspectives shared by participants during interviews as related to the five top ranked impacts from the NGT as they depict both challenges and opportunities for the forest sector.

When asked about the impacts of climate change on the forest industry in Maine, the majority of participants (7) were concerned with the increased presence of *insects and pathogens* resulting from changing weather patterns. Some participants noted that not all insects and pathogens are solely driven by climate change, but can interact with other climate change driven factors (i.e., fire and drought) resulting in outbreaks. Insect and pathogen outbreaks can have major perceived implications on harvesting and even lead to a reduction in prices of wood products.

> "Compounding disturbances of having drought and pests or even wind events…I think that's where we are going to see the big shifts happening […]That's going to definitely negatively influence forestry and forestry practices and the value of timber that's coming out of the forest. You know if there's a pest coming through, but then it becomes a lot in the market. And all of a sudden there's a lot of timber flooding the market. And then it's not worth anything because supply is such higher than demand." (Interview conducted on February 7, 2019 with a land manager with 15 years of experience in the forest industry).

Over half of the interviewees (6) talked about changes in precipitation patterns in Maine, particularly the *extreme precipitation events* that they have experienced in recent years that impact logging activities and affect regeneration. Participants experienced shifting precipitation patterns associated with extreme storm events.

> "I know that we're getting more deluges of rain. The rain that we are getting is more often in heavy rains followed by dry periods. Or receded by dry periods rather than distributed." (Interview conducted on February 2, 2019 with a land owner and land manager with 50 years of experience in the forest industry).

There was great concern with the negative effects that extreme storms have on road networks and trail systems that support forest operations and transportation of forest products to processing sites, as well as the negative environmental impacts on streams. Investment in infrastructure and alternative management of culverts was one of the important issues mentioned.

> "I think the kind of the most direct climate impact that I have noticed is those the extreme storms like the really heavy precipitation storms… that's been a huge impact kind of on you know road networks, trail systems, streams, sedation in streams, you know culverts blowing out, those sorts of things" (Interview conducted on July 18, 2018 with a government official and researcher with 11 years of experience in the forest industry).

Participants (5) also believed climate change will have an impact on the species composition of Maine forests. Half of the participants mentioned the impact that multiple climate related factors (i.e. changes in snowpack, temperature, precipitation, insect and pathogens, and invasive species) have on regeneration of species of interest to the industry, and the likely effects on future *species composition*. When asked about the greatest risks climate change poses to the forest industry an interviewee responded,

> "...species composition change. Um I read something recently about the importance of snowpack on sugar maple. That's definitely one of the most important species here for whether it is sugaring but it also the timber product so market changes and fluxes because of the cover type and then just you know um bio ecosystem concerns you know and the ecosystem services." (Interview conducted on March 12, 2019 with a logger and land manager with 9 years of experience in the forest industry).

Almost half of interview participants (5) mentioned that one of the most noticeable changes are the pressures that *invasive species* pose to the health of Maine forests. While participants shared that colder temperatures prevented the migration and expansion of multiple invasive plants and insects of concern to the industry, they believed that given changing conditions there still needs to be greater emphasis on invasive species management, policies and regulations on the use of pesticides and herbicides, and awareness among land managers of ways to prevent invasive pests.

> "In terms of our management, we are looking a lot more at invasive species... I think in some places we're at a tipping point. That if we don't react pretty quickly, we're gonna lose productive stands to invasives and I don't know how we're gonna get them back." (Interview conducted on December 12, 2018 with a land manager with 18 years of experience in the forest industry).

Insects and pathogens, extreme precipitation events, shifts in forest composition, and invasive species were all viewed as challenges to the forest industry. Each of the interviewee quotations demonstrates the difficulties in managing for negative impacts that can affect forest operations, harvesting, wood prices, and forest health in Maine as a result of a changing climate.

Despite the perceived negative effects of several climate change impacts, the majority of participants believed that changing climate conditions will have a positive effect on the *productivity of the forests* in Maine. Multiple participants believed that wetter conditions might have a positive impact on the industry by providing a longer growing season and increasing productivity rates.

> "There are some studies that indicate that obviously longer growing seasons combined with more nitrogen falling from the sky, will increase growth rates for forests. So that could conceivably be a good thing if forest productivity increases... We can see more […] climate refugees from other areas. Population wise some might say that's a good thing in terms of our economy because you know obviously a tradeoff there...So it's going to benefit our biodiversity, it's gonna benefit our forest productivity in terms of growing more wood and it's going to give us money." (Interview conducted on February 14, 2019 with a land manager with 15 years of experience in the forest industry).

The quotation speaks to the perceptions of potentially cascading positive impacts of increases in forest productivity: more wood, increased human population, and larger financial gains.

2.5 Discussion

We integrate the findings of the interviews and the literature review with the prioritization obtained during the NGT to help us explain the reasoning behind the prioritization and place our findings within the current scientific literature. In doing so we are able to gain a deep understanding of stakeholder perceptions of current top climate change impacts, including uncertainties and the degree of perceived threat. Additionally, analyzing perceptions with current scientific understanding highlights potential research areas. Three out of five of the top impacts prioritized during the NGT were discussed during the exploratory interviews, while all five were mentioned during the climate change interviews. We now integrate NGT, interview, and literature findings below to explain the top five impacts.

2.5.1 Prioritized climate change impacts

2.5.1.1 Insects and pathogens

Insects and pathogens were ranked as the top greatest impact and fourth most likely climate change impact among participants with 11 out of 13 suggesting an increase in the near future. The majority of participants recognized the potential threat of insects and pathogens during both rounds of interviews as well, primarily concerned with their impact on forest health and wood products in combination with other climate driven factors.

Both the spread and survival of insects and pathogens and the susceptibility of forest ecosystems to them are influenced by climate (Dale et al., 2001). Current research indicates that direct and indirect effects from warmer temperatures may allow some species to become a greater threat in forest ecosystems as pests and pathogens interact with other disturbance agents resulting in cascading effects on forest ecosystems and substantial socioeconomic losses (Weed et al., 2013). However, relatively few species have been researched, especially those impacting Northeastern US forests (Janowiak et al., 2018), and there is great uncertainty involved in making predictions about their effects on forest composition and structure as the feedbacks involved in these socio-ecological processes are complex (Dukes et al., 2009; Régnière et al., 2010). Spruce budworm (*Choristoneura fumiferana* Clem.), however, has been widely researched in the state of Maine, in the U.S., and New Brunswick province in Canada given its ability to cause widespread outbreaks that result in socio-economic losses of productive spruce-fir forests (Rauchfuss & Ziegler, 2011). The focus of spruce budworm research has been on impacts to forest ecosystems, as well as economic impacts on forest industry (Chang et al., 2012; Wagner et al., 2015), and potential early intervention management (Johns et al., 2019).

The current state of scientific knowledge on insect and pathogen outbreaks coincide with stakeholder perceptions that they pose a great risk to the forest industry in Maine. The complexity and unpredictability of this intricate agent acknowledged in the literature can explain why stakeholders may be more uncertain of its likelihood, ranking it as less likely than extreme weather events or shifts in forest composition. Given the difficulty involved in effectively monitoring and predicting insects and pathogens and the high prioritization of this impact from stakeholders' point of view, it is increasingly important to develop scientifically-informed management strategies to anticipate changes in the distribution and frequency of outbreaks. It is equally important to focus on proactive communications and outreach with stakeholders and collaboration across agencies to ensure information is shared (Johns et al., 2019) and collaboration is supported to jointly implement strategies to reduce risk.

2.5.1.2 Extreme precipitation events

Extreme precipitation was ranked as the third top impact and second most likely impact to the forest industry in Maine, with the majority suggesting an increase in events. The majority of participants also recognized the negative impact of extreme precipitation on roads and forest operations during interviews as well, with a large concern over infrastructure and culvert design. Total annual precipitation and heavy precipitation events have increased in the northeast since the early 1900s (Huang et al., 2017) with the greatest increases occurring over the past 40 years (Hoerling et al., 2016; Huang et al., 2017; Kunkel, 2013). The increases in extreme precipitation events (characterized by precipitation falling on the top 1% of wet days) are largely evident in late summer and fall (Agel et al., 2015). Extreme climatic events are projected to continue to increase, creating major concerns for terrestrial, freshwater, and marine environments (Horton & McKenzie, 2009).

Despite the large social and economic consequences of extreme rainfall on forest operations via road and culvert damage and soil erosion (Bradley & Forrester, 2018), there remains very little work on assessing the magnitude or perceptions of impacts (with some exceptions, such as McKenney-Easterling et al., 2000). In terms of forest operations, extreme precipitation events are often examined in light of how forestry practices influence stormflow and peak discharge, rather than how these impact forest operations (Eisenbies et al., 2007; Ford et al., 2011; Horton & McKenzie, 2009). Given the concern over increases in extreme precipitation and their associated costs with forest operations, it is important to study not only how forestry practices may influence the impacts of heavy precipitation, but on how heavy precipitation may have a socio-economic impact on the forest sector and communities reliant on forest-based economics.

2.5.1.3 Shifts in forest composition

Shifts in forest composition were ranked as the second greatest and second most likely climate change impact on the forest industry in Maine, with participants mostly noting this as a positive change. During interviews, participants also mentioned the importance of shifting forest composition as well, though they were largely perceived as a challenge to the forest industry as economically viable species may decrease as a result of climate change. Current scientific understanding of the dynamics of shifting forest compositions can help explain several of these perceptions. Boreal and northern species (i.e. spruce and northern white cedar) at the southern range of their limits are projected to face increasing climate stress as they are pushed beyond their temperature thresholds, while temperate species (i.e. oaks, hickories) could tolerate a moderate warming, but may suffer losses under more severe levels of climate change (Janowiak et al., 2018). This is evident in participants' rankings of spruce and balsam fir forests as the most highly vulnerable species, which is consistent with past research on these species (Andrews, 2016). Similarly, participants ranking of oak, eastern hemlock, pine, and aspen also align with projections that suggest these species may be more resilient to climate change based on their increases in suitable habitats due to their physiological traits (Brecka et al., 2018; Dunckel et al., 2017). Studies suggest a shift towards early successional species (i.e. aspen, pine, birch) at the expense of late-successional conifers (Brecka et al., 2018), which has both benefits and disadvantages as participants identified both spruce and balsam fir, as well as pine and birch as important to their business.

The largely contextual nature and differences among species described in the literature may explain the varied perceptions of shifts in forest composition as either having a positive impact (NGT) or negative impact (interviews) on the forest industry depending on species of interest. Additionally, it is important to note that participants ranked maple as both a vulnerable and resilient tree species in regards to climate change. Given the inconsistency in tree species names (i.e. some writing sugar or red maple, others writing just maple), we grouped at the genus level. However, for those participants that did indicate a species, sugar maple was identified as a vulnerable species, while red maple was more commonly identified as a resilient species, which is consistent with the current scientific understanding of sugar maple declines (Oswald et al., 2018) and high increasing abundance of red maple (Fei & Steiner, 2007) given a changing climate. This highlights the high within-genus variability of individual species responses to climate change and the challenges faced by forest managers on identifying effective local management strategies for a given species.

As species respond individually to climate change, novel community types may emerge; however, major shifts in forest composition may take 100 years or more to develop (Janowiak et al., 2018). At the same time, there will be differential effects according to stand development stage, with mortality being higher in younger stands (Chen & Luo, 2015). Given the environmental and economic implications of shifting species, assisted migration and simulated climate planning are often presented as a solution for active management to keep pace with threshold shifts (Dunckel et al., 2017; Duveneck & Scheller, 2015). The NGT results suggest the high priority of this impact as both great and most likely; therefore, land managers may consider implementing a management strategy that takes into account future climate. There is however a large degree of uncertainty involved in planting species or promoting desirable regeneration for the future so more small-scale experiments may be required to establish assisted migration as a management strategy in Maine. Similarly, it is important to consider the socio-economic impacts of shifting species compositions on the forest sector and potential for decreased regeneration of economically valuable species in the long-term.

2.5.1.4 Invasive species

Increases in invasive species were ranked as the fourth greatest and sixth most likely climate change impact on the forest industry in Maine. During interviews, participants also discussed the potential of increasing invasive species management in light of changing climate conditions. Invasive species compete for resources, limit regeneration of native tree species, and alter forest dynamics by changing species competition, biogeochemical cycling, water use, and disturbance regimes (Vose et al., 2012). It is suggested that invasive species could disproportionately benefit from climate change in Northeastern US forests (Dukes et al., 2009). As climate affects invasive distributions and ecological dynamics, they may be able to tolerate new climates better than average species or rapidly colonize in newly suitable climates (Dukes et al., 2009). Invasive forest species can negatively impact operations as management costs increase once invasive species become established (Moser et al., 2009). Within Maine, there is a variety of non-native invasive plant (e.g. dandelion (*Taraxacum officinale* L.), honeysuckle (*Lonicera caprifolium* L.), glossy buckthorn (*Rhamnus frangula* L.), etc.) and pests (e.g. Emerald ash borer (*Agrilus planipennis* F.) and hemlock woolly adelgid (*Adelges tsugae* A.)), which pose a concern for altering forested ecosystems (McCaskill et al., 2011).

Invasive species can interact with other disturbances such as fire, insects, drought, or longer dry seasons; therefore, as these other disturbances increase, invasive species will likely become more widespread (Vose et al., 2012). Invasion of nonnative plant species depends on the environment, disturbance, timing, and resource availability, which all may be influenced by climate change and be spatially and temporally variable (Vose et al., 2012). The variety of factors influencing nonnative plant species results in large uncertainties in predicting how climate change will affect invasive species as complex interactions exist among stressors and disturbances and invasive species outbreaks can result in complex cascades that affect the entire ecosystem (Dukes et al., 2009). Therefore, more research is required to understand how specific invasive species may behave under climate change and which new species may appear (Hellmann, Byers, Bierwagen, & Dukes, 2008). This is especially necessary given the identified need among interviewees for a greater emphasis on invasive species management given species ability to potentially benefit from warming temperatures.

2.5.1.5 Changes in forest productivity

Changes in forest productivity was ranked as the fifth greatest and ninth most likely climate change impact on the forest industry in Maine, with over half of the participants indicating a positive effect on the forest industry. Interviewees discussed increases in tree productivity as largely an opportunity for higher profits in Maine.

Forest productivity describes the net growth rate of forests (or the total amount of biomass after subtracting losses from respiration), and is influenced by growing season length, temperature, ozone damage, and carbon dioxide (Janowiak et al., 2018; McMahon et al., 2010). In the northeast, biomass is projected to increase under climate change by 82% in the year 2110 (Duveneck et al., 2017). Despite several models suggesting an increase in biomass (Duveneck et al., 2017; Wang et al., 2017), there is also evidence that while longer growing seasons and increased temperatures may increase tree growth, when taking into account tree mortality due to other climate change impacts (i.e. pests, invasives, drought), biomass may actually decrease (Gonzalez et al., 2010). This suggests a decrease in timber volume as climate change-induced mortality offsets growth gains (Brecka et al., 2018).

The presence of many models describing an increase in productivity may explain the perceptions among participants as an opportunity; however, the disagreement in the literature regarding the actual effects on biomass was evidenced in the NGT as two participants noted a decrease in productivity. The uncertainty involved in predicting forest productivity in a changing climate may explain participants relatively low ranking of forest productivity as most likely (#9) as well as participants' mixed perceptions regarding whether or not productivity will increase or decrease. While forest productivity was ranked as a top climate change impact, both the perceptions and literature tell a story of high uncertainty.

The top five impacts identified by stakeholders during the NGT have also been identified through similar expert elicitation methods in the existing literature. For example, in Eastern United States forest ecosystems, stakeholders frequently identified soil moisture, pest and disease outbreaks, and invasive species as contributing to the vulnerability of forest ecosystems (Brandt et al., 2017). Additionally, experts in Austria identified biodiversity and productivity as top indicators of forest vulnerability to climate change (Lexer & Seidl, 2009). Given our focus on impacts to the *forest industry*, in comparison to forest ecosystems, it is possible that the identification of extreme precipitation events as a top impact is unique to those in the forest industry due to resulting road and culvert damage and therefore may explain why forest stakeholders in other regions did not mention extreme precipitation events as a major concern.

2.5.2 NGT and interviews as a participatory process

Integration of stakeholder knowledge and perceptions are critical for developing relevant management strategies that take into consideration local context and stakeholder needs (Brandt et al., 2017; Keskitalo, 2008). We demonstrate a multi-method approach that uses NGT, interviews, and existing scientific literature to identify, prioritize, and understand climate change impacts on the forest industry in Maine. In doing so, we can inform decision-making to jointly identify adaptation efforts with local stakeholders that address Maine forest industry needs, concerns, and perceived threats and opportunities. The decision-making process involved in developing management strategies is complex and can sometimes require that decisions be made in the absence of complete scientific information (Mukherjee et al., 2018).

Group-based decisions, like those that are a result of a group consensus processes such as an NGT, can harness the collective power of minds in a group to reduce bias (Mukherjee et al., 2018), and provide useful insights for decision and policy-making (Granger Morgan et al., 2001). Local stakeholder knowledge can also provide a more comprehensive understanding of the socio-ecological system, and can even enhance the quality of environmental decisions by addressing a diversity of perceptions and capturing an array of experiences (Reed, 2008).

The multi-method approach that combines NGT and interviews can be viewed as part of a participatory process that begins to incorporate stakeholder needs, in-depth knowledge, experiences, and priorities into decision-making. NGT is a particularly useful tool that requires limited time and money, but provides a quality participatory process with clear and usable outputs (Hugé & Mukherjee, 2017) resulting from expert consensus. In addition, semi-structured interviews can be used to gain an in-depth understanding of people's perspectives and attitudes, and help incorporate human experiences into decision-making (Sutherland et al., 2018). When combined, NGT and interviews begin to create a dialogue between researchers and stakeholders in a process of knowledge co-production that opens up opportunities for two-way communication (Klenk & Wyatt, 2015), prioritizes threats and data needs, and reaches a consensus that supports decision-making. The ability of the NGT and interviews to initiate iterative processes of knowledge generation to develop solutions to stakeholder identified problems suggests their applicability in research that demands local knowledge and expertise.

The quality of the decisions made through stakeholder participation, however, is highly dependent on the nature and levels of engagement, and therefore, require us to view participation as a process (Reed, 2008). This requires taking into consideration equity, empowerment, and trust as knowledge is incorporated from various voices at multiple stages in the decision-making process (Reed, 2008; Sutherland et al., 2017). Despite an effort to encourage participation and creativity from all participants, the NGT can be susceptible to biases such as group thinking and production blocking (Mukerjee et al., 2018), and can also favor dominant interests (Hugé & Mukherjee, 2017). While there are strengths in maintaining individual ranking to develop a consensus, we did not provide an opportunity for experts to discuss their rankings and re-evaluate them as a group. This would have allowed for further discussion that may have enhanced collaboration, and the group consensus process as participants may come to similar conclusions. Despite this limitation, there was a large degree of agreement among individual votes so that relative importance often aligned with score frequency, indicating that a high level of consensus was achieved. In addition, it is important to consider the diversity of stakeholders that we engaged with during interviews. We were able to reach saturation, in that we heard similar ideas shared again and again among participants; however, hearing from additional stakeholders from capital investment, transportation, and policy may have helped to further diversify the voices of stakeholders.

2.6 Conclusions

While the NGT allowed us to build a consensus on climate change priorities in Maine, semi-structured interviews and existing literature provide a deep understanding of the issue and can help us explain the reasoning behind prioritization. Experts identified and prioritized the greatest and most likely climate change impacts on the forest industry as: insects and pathogens, extreme precipitation events, shifts in forest composition, invasive species, and changes in forest productivity. During the interview phase, participants often described that climate change has negative implications to the industry in Maine with potential disruption of forest operations and transportation (i.e., increased presence of insect pests and invasive species that can affect forest productivity and composition, extreme events that can greatly affect operations and transportation infrastructure). Interviewees also perceived positive effects resulting from climate change with increased productivity due to longer growing season.

Future research may further develop our understanding of how climate change impacts the forest industry. Currently, the focus has been on examining how climate change impacts forest ecosystems and how forest management influences these impacts; however, there are relatively fewer studies on how climate change impacts forest operations and industry as evidenced by the limited literature on extreme precipitation events and shifts in forest composition. Given stakeholder concerns and the associated costs of impacts such as extreme climatic events, it will be important to study how the impacts may influence forest operations, transportation, and the socio-economic facets of the forest industry.

Complexity and uncertainty cut across all of the ranked impacts in terms of participants' perceptions in both interviews and as evidenced in varying perceptions of impacts as positive or negative in the NGT. There was an acknowledgment of the uncertainties involved in adapting to climate change impacts, such as with planning for changing species compositions, anticipating insect and pathogen outbreaks, or knowing whether productivity will increase or decrease. A degree of uncertainty and complexity is also acknowledged in the literature in terms of developing predictive models for various climate change impacts.

For these reasons, it is critical to consider which management strategies may lack widespread adoption given stakeholders' opinions of uncertainty of impacts and potential communication and outreach strategies that may be useful to increase adaptation. As an example, promoting management strategies that reduce the risks of insects and pathogens or lessen the effects of extreme precipitation events may have success given stakeholders concerns regarding socio-economic losses and infrastructure damage. While promoting management strategies that plan for the future, such as assisted migration, have a high degree of uncertainty, focusing on species of socio-economic importance (i.e. spruce, fir, maple, pine, ash) may have greater success as they specifically address stakeholder needs and perceptions.

Finally, while stakeholders identified and prioritized climate change impacts - not all were perceived as risks and negative impacts on the forest industry in Maine (i.e. forest productivity, and shifts in species composition), and therefore can also be considered when identifying management options. Our work highlights the importance of identifying stakeholder priorities through a consensus building process and gaining a deep understanding of perceptions to incorporate stakeholder opinions into decision-making.

CHAPTER 3: UNDERSTANDING CHARACTERISTICS OF FOREST LAND MANAGERS AND SMALL WOODLOT OWNERS' FOR EFFECTIVE COMMUNICATION OF CLIMATE CHANGE ADAPTATION STRATEGIES

3.1 Introduction

Climate change is impacting both natural and human systems globally, as climate extremes are increasing, and changing temperature and precipitation patterns are altering plant and animal species distributions (IPCC, 2014). In particular, forests are impacted by climate change due forest health threats imposed by insects and pathogens, extreme weather events, and shifting forest compositions (Kirilenko & Sedjo, 2007), all of which threaten both forest ecosystems and the people that rely on them (Bernier & Schoene, 2009). Forest management plays a key role in maintaining ecosystem services by decreasing vulnerabilities to climate change that may negatively impact the ability of the forest to maintain its essential functions (Locatelli et al., 2011). Specifically, adaptation strategies are employed to better cope with, manage, or adjust to changing conditions (Smit & Wandel, 2006) and may involve reducing impacts of climate-related events or increasing the capacity of the forest system to recover from shocks (Keenan, 2015).

Despite the growing interests in specific adaptation strategies among policy makers and scientists, there is differential adoption by forest stakeholders (Sousa-Silva et al., 2016). Within forestry, and natural resource management more generally, there is growing concern that simply increasing knowledge about climate change will not always necessarily translate to adopting management strategies (Gootee et al., 2010). Instead, the focus has shifted to communication frameworks that appeal to cognitive, experiential, and social-normative dimensions of human behavior that address specific barriers to action (Sousa-Silva et al., 2016; van der Linden, 2014b;

Moser, 2014). Communication aims to improve the relationship between science and society by fostering dialogue, meaningful engagement, and attending to difference and diversity among audiences (Nerlich et al., 2010; Suldovsky, 2016; Pearce et al., 2015). Through two-way inclusive dialogue, communication can deepen understanding among all parties, foster empathy, and change behaviors (Moser, 2016). Communicating adaptation, and climate change more broadly, is a challenge given the variety of factors that influence how the message is perceived and understood (e.g. personal capacities, social influences, and contextual factors), which in turn influences how people respond and make decisions (Moser, 2014). Connecting with audiences in terms of what they care about, through an understanding of their values, beliefs, and norms, is critical to engage in conversations that make climate change adaptation meaningful and elicit broader support for action (Nerlich et al., 2010; Moser, 2014).

The forest industry comprises a variety of stakeholders with different values, needs, and perceptions. For example, non-industrial private landowners (NIPF) differ from industry land managers, as NIPFs have multiple objectives in terms of forest management that are not always aligned with the timber market (i.e. preserving family land or conserving wildlife habitat) (Lönnstedt, 1997; Kline et al., 2000). Different stakeholder groups also have diverse perceptions of adaptation actions as well as differences in personal capabilities and social and cultural norms (Otto-Banaszak et al., 2011). Given the differences among forest stakeholder groups, understanding key audiences to identify different distinct message frames is an important first step to addressing the specific needs and engaging with diverse stakeholders (Lahtinen et al., 2017; Moser & Dilling, 2012). Specifically, message frames that connect and resonate with audience values and beliefs can (1) engage broader support in eliciting behavioral change (Nisbet & Mooney, 2007); (2) serve as a starting point for stakeholders to make sense of and discuss an issue (Bubela et al., 2009); and (3) open up discussions that focus on salient solutions people care most about (Moser & Dilling, 2012). Different framings impact mobilization for adaptation and public engagement (Moser, 2014); therefore, switching the frame to different audiences to make climate change adaptation more personally relevant is critical to connecting with audiences to increase support for adaptation actions (Nisbet & Mooney, 2007).

In areas with highly diverse forest ownership, successful adaptation requires the participation of a wide range of stakeholders, including private landowners, industrial land managers, decision-makers, and government officials (Laatsch & Ma, 2015). Perceptions of climate change adaptation among forestry professionals have been widely studied (Boby et al., 2016; Guariguata et al., 2012; Lenart & Jones, 2014), particularly among non-industrial private landowners (Boag et al., 2018; Quartuch & Beckley, 2014). While multiple studies have compared perceptions of adaptation among forestry professionals and the general public (Hajjar et al., 2014; Eriksson, 2018), there is a current lack in research that examines the similarities and differences between private landowners and industrial land managers, especially as it relates to targeted communication strategies.

In this study we surveyed two groups of forest stakeholders in Maine, U.S, specifically industry land managers and small woodlot owners. Maine has a highly diverse system of forest ownership, including private landowners, industrial land managers, decision-makers, and government officials; therefore, assessing group characteristics is critical. Fifty-nine percent of Maine's forest is privately owned by corporations, where the majority of harvesting occurs (65%), and 32% is private family-owned land (Butler, 2017). The extensive privately-owned forests of Maine have experienced ownership changes over the past century (Irland, 2000), with more investment-focused timberland management since the 1990s (Jin & Sader, 2006). The significant changes in forestland ownership has resulted in concern over the future sustainability of Maine's forests and timber availability (Jin & Sader, 2006). At the same time, climate change is already impacting Maine's forests (Fernandez, 2020) and future projections suggest increasing extreme precipitation events (Huang et al., 2017), milder winters (Spittlehouse, 2005), insects and pathogens (Weed et al., 2013), and shifts in forest composition (Dunckel et al., 2017). The future of Maine's forests will in part be determined by the ongoing human influences on the landscape via forest management practices (Kittredge et al., 2003). Therefore, given the diversity of land owners in the state with varied management objectives, it is important to understand their needs and perceptions regarding factors that may influence adaptation implementation. We compared stakeholder perceptions in order to determine relevant message frames to connect with both stakeholder groups to increase support for adaptation. Specifically we sought to answer the following questions:

(1) How do climate change risk perceptions, socio-cultural influences, perceptions of self-efficacy, barriers and incentives to adaptation, sources of information, and management actions compare among commercial land managers and small woodlot owners?

(2) How can communication messages be framed to connect with different and diverse stakeholder groups?

3.2 Conceptual foundations

A number of factors can influence whether or not specific adaptation strategies are implemented by forest managers and land owners, including risk awareness, management options in light of individual capacities, values and attitudes, and education and finances (Vulturius & Swartling, 2015; André et al., 2017; Moser, 2014). In this study we draw on cognitive hierarchy theory (Fulton et al., 1996), the theory of reasoned action (Fishbein & Ajzen, 2010), and risk perception frameworks (van der Linden, 2015; Leiserowitz, 2006) to identify the key factors that may influence willingness to implement forest adaptation strategies. Cognitive hierarchy theory contends that underlying values shape attitudes, beliefs, and norms which in turn influence behavioral intentions (Fulton et al., 1996), while the theory of reasoned action identifies the importance of attitudes, norms, perceptions of self-efficacy, and environmental constraints as influencing behavioral intentions (Fishbein & Ajzen, 2010). Both theories have been applied in studies that seek to understand and promote climate change adaptation among forest stakeholders (Eriksson & Klapwijk, 2019; Eriksson, 2018; Hengst-Ehrhart, 2019). Additionally, climate change risk perception frameworks that emphasize the importance of social-psychological determinants can be extremely useful in understanding why individuals engage in pro-environmental behaviors that may have high levels of uncertainty (van der Linden, 2014a; Bradley, 2020; Weber, 2010). Given the importance of values, norms, risk perceptions, perceptions of self-efficacy, and environmental constraints in influencing behavioral intentions, we consider their possible influences on adaptation implementation (Figure 3.1).

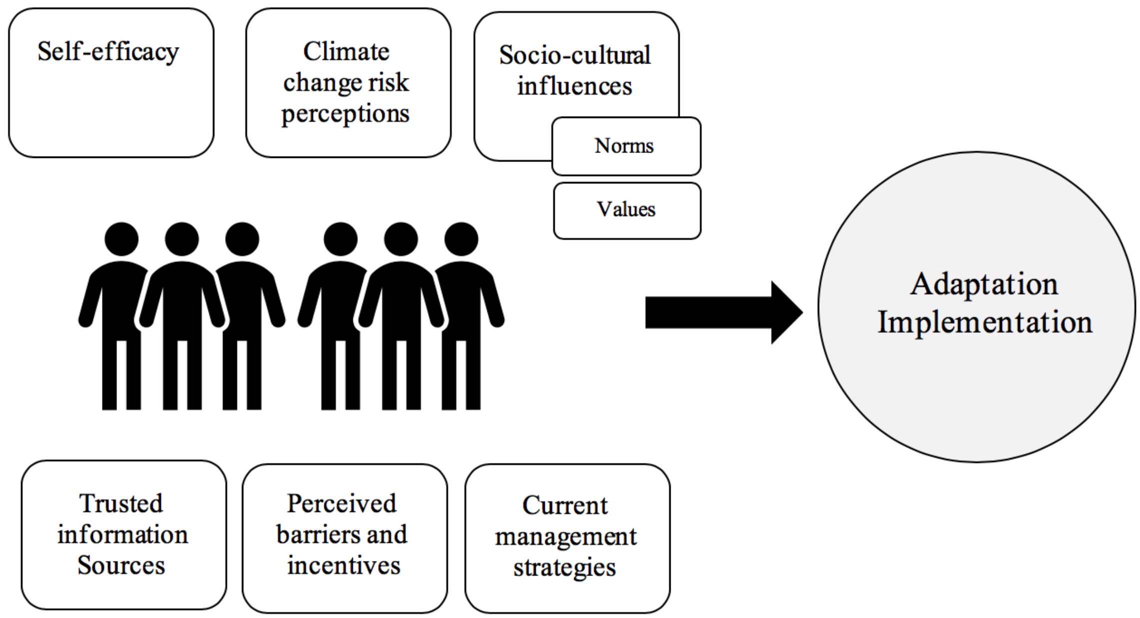

Figure 3.1. Important factors to consider when communicating to forest stakeholders about adaptation implementation.

3.2.1 Climate change risk perceptions

Climate change risk perceptions are a subjective mental construct of one's own personal feelings towards the severity and/or likelihood of a threat or occurrence (Slovic et al., 2004). Climate change risk perceptions are shaped by cognitive, experiential, and socio-cultural factors (van der Linden, 2015; Wolf & Moser, 2011). Specifically, previous experience with risks, forest dependency, and perceived control over risks are associated with climate change risk perceptions among forest owners (Eriksson, 2014). Increased climate change risk perceptions can be important predictors of perceived need to change (Leiserowitz, 2006) and have been shown to influence behavior indirectly via response efficacy (i.e. belief that one's actions will be effective) (Bradley et al., 2020). Within forest management, increased risk perceptions have been linked to willingness to implement adaptation strategies (Blennow et al., 2012).

3.2.2 Socio-cultural influences

Value orientations and social norms can play an important role in determining risk perceptions (Leiserowitz, 2006) as well as climate change adaptation (Kahan et al., 2012). Values are orienting concepts or beliefs that can guide behavior or evaluation of events (Schwartz & Bilsky, 1987). Stern et al. (1993) identify three broad value orientations that are relevant for influencing behavior: egoistic (i.e. maximizing individual benefits), altruistic (i.e. helping others), and biospheric values (i.e. caring for nature). Values affect how people evaluate different consequences of choices, and therefore their actions (Steg, 2016). High biospheric values in natural resource management have been found to increase the adoption of sustainable land management practices (Leviston et al., 2011; Krantz & Monroe, 2016). However, while values can have a minor direct effect on behavior, their effect on behavior is largely mediated by other factors including climate change risks perceptions, norms (van der Linden, 2014a), and general attitudes and beliefs (Fulton et al., 1996).

Social norms are expectations concerning how people are supposed to believe or act within specific social groups (Hogg & Reid, 2006). Two types of norms act together to influence action – *descriptive norms* refer to what people in a group think or do, and *injunctive,* or *prescriptive, norms* refer to what others approve or disapprove of (Cialdini, 1990). Social norms have been found to influence perceptions of climate change risk, as the more climate change is perceived as a risk to important social contacts, the more it increases one’s own risk perceptions (van der Linden, 2015). Norms can also influence behavior as they may encourage or limit adaptation depending on the perception of what is socially acceptable (Adger et al., 2009) and have been shown to directly influence behavioral intention for adaptation among forest land owners (Hengst-Ehrhart, 2019).

3.2.3 Self-efficacy

Self-efficacy is related to an individual's judgment regarding whether or not they have the skills and/or resources to execute a specific course of action or perform a particular behavior (Bandura, 1997). Both knowledge and concern influence perceptions of self-efficacy, as knowing more about climate change increases overall concern about risks, which in turn lead to greater perceived efficacy and responsibility to act (Milfont, 2012). Perceptions of self-efficacy can directly and indirectly (via climate change risk perceptions) impact behavior (van der Linden, 2014a; Grothmann & Patt, 2005). Communication efforts that understand perceived self-efficacy and attempt to increase efficacy can lead to increased adaptation implementation (Krantz & Monroe, 2016).

3.2.4 Barriers and incentives to adaptation

A variety of adaptation barriers exist, including knowledge, technological, financial, biophysical, and human resource constraints (IPCC, 2014). Sousa-Silva et al. (2016) found that understanding the barriers limiting forest adaptation to climate change must be considered to understand differences in adoption, as constraints may severely limit engagement in specific behaviors (Steg & Vlek, 2009). Barriers can directly influence behavior by foreclosing on the possibility of even engaging in that specific behavior, or may indirectly influence behavior via attitudes, norms, socio-cultural factors, or perceived self-efficacy (e.g. a removal of a specific constraint may result in more positive attitudes or higher perceived efficacy towards a behavior) (Moghimehfar et al., 2018; Yoon et al., 2013). Given their influence on behavior, it is critical we evaluate the specific types of constraints faced in an effort to help stakeholders overcome them (Gifford et al., 2011).

Conversely, understanding specific incentives that may help overcome barriers to climate change adaptation are also critical for designing effective communication efforts. Economic incentives can help land managers and landowners cover the costs of sustainable forest practices (Leahy et al., 2008). Other market-based incentives, including social licensing or certification can also encourage sustainable land management via public approval and market demands. Social licensing, or gaining local legitimacy or acceptability, is useful for seeking public approval for management activities (Franklin & Johnson, 2014), and can be increased via forest certification or stronger biodiversity policies (Hagan et al., 2005). Forest, or green, certification is a strategy to monitor and label timber and forest products that have met certain environmental standards (Jonsson & Swartling, 2014).

3.3 Methods

We conducted an online survey via Qualtrics from October - November 2019 of two Maine forest stakeholders: Maine Woodland Owners Association (MWO) and University of Maine's Cooperative Forestry Research Unit (CFRU). MWO is a group of over 2,000 small private woodland owners whose goal is to promote stewardship in forest management and support woodland owners in the state. UMaine's CFRU is a group of 500 foresters and land managers from the forest products industry, government, and research that focus on forest ecology, management, and operations.

Using a stratified probability random sample (Visser et al., 2000; Scheaffer et al., 2012), we selected 1,000 MWO members and 400 CFRU members to receive the survey. Gatekeepers sent the initial email invitation to their randomly selected members notifying them about the survey, its goals, and the potential benefits to their members in an effort to increase response rate by utilizing a trusted information source to bolster the legitimacy of the survey (Bartholomew &

Smith, 2006). Following Dillman's Tailored Design method we sent two follow up reminders to CFRU participants to increase the response rate, and hence reduce nonresponse error (Dillman et al., 2014). We compared and contrasted the stakeholder groups in terms of their climate change risk perceptions, socio-cultural influences, self-efficacy, barriers and incentives to adaptation implementation, commonly used sources of information, and their management preferences. Most measures were assessed using 5-point Likert scale questions (i.e. strongly disagree to strongly agree) using previously tested scales to reduce measurement error (McNabb, 2014). We pre-tested the survey (Visser et al., 2000) with 10 participants who have experience in research, forest land management, professional services, and pulp and paper mills. We created mean scores for several of the constructs and calculated a Cronbach's alpha (α) of reliability to estimate internal consistency of the items in a construct (Vaske, 2008; Cronbach, 1951).

3.3.1 Survey measures

3.3.1.1 Climate change risk perceptions

We assessed climate change risk perceptions using seven items on a 5-point Likert-scale modified from Ameztegui et al. (2018) and Guariguata et al. (2012). The questions related to climate change impacting and posing a threat to *forest ecosystems*, *Maine's forest sector*, and *them personally*. We created a risk perception index using the mean score ($\alpha = 0.921$).

3.3.1.2 Socio-cultural influences

Participants assessed the importance of 12 values as "guiding principles in their lives" on a 5-point Likert-scale, ranging from not important at all to very important (De Groot and Steg, 2007). The 12 measures were composed of four items representing three different broad value orientations: egoistic ($\alpha = 0.755$), socio-altruistic ($\alpha = 0.817$), and biospheric ($\alpha = 0.839$). We created mean scores for each of the three value orientations. We also assessed perceptions of norms using seven items modified from van der Linden (2015). On a 5-point Likert-scale, participants answered questions about the extent to which they feel socially pressured to reduce the risk of climate change impacts, and how likely they think their important social contacts are doing something to reduce the risk of climate change. We created a mean score for norms (α = 0.871).

3.3.1.3 Self-efficacy

We assessed participants level of self-efficacy using seven items modified from Lenart & Jones (2014) and Guariguata et al., (2012) that included questions related to *knowing which adaptation efforts to make; where to find answers to climate change questions;* and *having access to specific information and management practices to adapt*. We created a mean index of self-efficacy, where higher values indicate higher perceived self-efficacy (α = 0.760).

3.3.1.4 Barriers and incentives to adaptation

We measured participants' perceptions of barriers to implementing climate change adaptation strategies using eight items modified from Guariguata et al. (2012), including, *complexity of information, lack of time, lack of financial capital,* and *uncertainty about climate change impact*s. Participants ranked their agreement with each item as a barrier on a 5-point Likert-scale. We also measured desired incentives for increasing implementation of climate change adaptation strategies. Participants ranked the following incentives from one to six: *microgrants, tax breaks, social licensing*, and *green certification* with the option of adding up to two other incentives.

3.3.1.5 Information sources

It is also important that messages come from a preferred information channel/medium (Renn, 2010), as targeting forest stakeholders via trusted sources can increase support for adaptation strategies (St-Laurent et al., 2019). Participants were asked if they obtained information about climate conditions in Maine within the last month. Of those participants that selected 'yes,' they checked off the specific information sources (e.g. Maine Forest Service, journal articles, friends/family, etc.) from a list of 12 sources.

3.3.1.6 Management strategies

We assessed current willingness to engage in a variety of adaptation actions to serve as a benchmark for what is already accepted among stakeholders. We asked participants to rank their willingness to implement a variety of management strategies (e.g. *improve road/culvert maintenance, improve forest inventory methods, thin overly dense forests*) on a 4-point Likert-scale (not willing to very willing) based on strategies suggested in Lenart & Jones (2014) and Swanston et al. (2016). For each strategy we asked participants which ones they would adopt as part of their effort to adapt to climate change. We compared results of participant willingness to adopt individual management strategies only for those strategies where the majority of participants selected they would adopt to adapt to climate change.

3.3.2 Analysis

A total of 302 participants started the survey (176 MWO and 126 CFRU members); therefore the response rate was 17.6% for MWO and 31.5% for CFRU members. While a total of 190 participants completed the survey (102 MWO and 88 CFRU members); therefore the completion rate was 58% for MWO and 70% for CFRU. After meeting the assumption of missing completely at random, we used pairwise deletion for each measure of interest to preserve sample size and statistical power (Roth, 1994). We assessed non-response bias by comparing the first wave of responses to the second wave of responses (i.e. before and after the first reminder) (Fillion, 1976) for the following key variables: primary subsector, years of experience, climate change risk perceptions, experience, values, norms, and self-efficacy using independent samples t-tests for continuous variables and chi-square for categorical variables (Lankford et al., 1995). There was no significant difference for any of the measures of norms, experience, self-efficacy, or climate change risk perception; or in primary subsector or years of experience. Only one of the items in the altruistic values construct, *having social justice,* was significantly different between groups, with the first response wave (M=2.97) ranking social justice as less important than the second response wave (M=3.39) ($t(1) = -2.49$, $p = 0.01$, $d = 0.32$).

Independent samples t-tests were used to test for differences at a 95% confidence interval in (1) climate change risk perceptions, (2) socio-cultural factors, (3) self-efficacy, (4) barriers and incentives to adaptation, and (5) adaptation and management preferences among stakeholder groups according to Ranacher et al. (2017) and Ameztegui et al. (2018). Each variable was examined by stakeholder groups to assess skewness and univariate outliers. The cutoff for skewness was ±1.0 as based on Vaske (2008), and all variables were normally distributed. Univariate outliers were those that fell outside of the 1.5 times interquartile range (IQR) beyond the 25th and 75th percentiles based on Tukey's (1997) box plot method. Outliers were winsorized to the maximum/minimum values (Vaske, 2008) and their order was maintained using 0.01 increments where appropriate. Levene's statistic was used to test the assumption of equal variances of groups (Gastwirth et al., 2009). If homogeneity of variance was violated an adjustment was made using the Welch-Satterthwaite method (Delacre et al., 2017). Cohen's d was used to assess effect size for independent samples and Welch's t-test results (Fritz et al., 2012).

Lastly, chi-square tests were run to examine the differences in information sources, for each stakeholder group (Ameztegui et al., 2018) using Cramer's V for effect size on the categorical variable (Vaske, 2008). All data analysis was done in SPSS 25.0 (Armonk, NY: IBM Corp.). We report the results from mean scores and selected measures of interest to communication efforts.

3.4 Results

3.4.1 Socio-demographics

The CFRU group was composed primarily of those in forest land management (48%), followed by government (19%). The MWO group was also composed primarily of those in forest land management (37%), followed by land ownership (30%), and conservation (10%). CFRU members held primary positions as foresters (41%) and land managers (15%), with the majority of those as foresters working in the land management subsector. The majority of MWO members were land owners (76%), followed by foresters (10%). MWO members had significantly higher years of experience (M=30) compared to CFRU members (M=20) (Table 3.1). CFRU members belong to organizations that employ more workers (M=48) compared with MWO members (M=2), and also receive a higher percentage of their household income (M=63%) from the forest sector compared with the MWO members (M=14%). Based on primary positions and company/organization size, hereafter we will refer to the CFRU group as land managers and the MWO group as small woodlot owners.

Table 3.1. Socio-demographics of stakeholder groups.

	Cooperative Forestry Research Unit (%)	**Maine Woodland Owners (%)**	**Total (%)**
Primary Subsector	**(n=117)**	**(n=123)**	**(n=240)**
Conservation	7 (5.9)	12 (9.8)	19 (7.9)
Forest Land Management	57 (48.3)	46 (37.4)	103 (42.9)
Government	22 (18.6)	2 (1.6)	24 (10.0)
Harvesting	2 (1.7)	5 (4.1)	7 (2.9)
Professional Services	11 (9.3)	4 (3.3)	15 (6.3)
Mills	8 (6.7)	4 (3.3)	12 (5.0)
Land Ownership	0 (0.0)	38 (30.9)	38 (15.8)
Other*	10 (8.3)	12 (9.8)	22 (9.2)
Primary Position	**(n=113)**	**(n=135)**	**(n=248)**
Land Manager	18 (15.4)	6 (4.3)	18 (7.3)
Landowner	3 (2.6)	106 (75.7)	109 (44.0)
Government Official	6 (5.1)	2 (1.4)	7 (2.8)
Biologist	9 (7.7)	1 (0.7)	10 (4.0)
Planner	4 (3.4)	1 (0.7)	5 (2.0)
Forester	48 (41.0)	14 (10)	62 (25)
Procurement	5 (4.3)	1 (0.7)	6 (2.4)
Researcher	12 (10.3)	0 (0.0)	12 (4.8)
Other**	8 (6.8)	4 (2.8)	12 (4.8)
Years of Experience	*M*=20.49	*M*=29.38	

* includes: bioenergy, research, education, capital investment, and tourism and recreation

** includes: appraiser, teacher, engineer, logger, consultant, and technician

3.4.2 Climate change risk perceptions

There was no significant difference between land managers (*M*=3.35) and small woodlot owners (*M*=3.57) climate change risk perceptions ($t(1) = -1.79$, $p = 0.08$, $d = 0.26$) (Table 3.2).

Table 3.2 Comparisons of climate change risk perceptions and beliefs.

(reported as mean values where 1=strongly disagree and 5=strongly agree)

Variable	Land managers (n=89)	Small woodlot owners (n=109)	Levene Stat (sig)	t-test (sig)	Cohen's d
Climate Change Risk Perception (a = 0.921)	3.35	3.57	1.49 (0.22)	-1.79 (0.08)	0.26
Climate change will have a significant impact on...within the next 50 years					
Forest ecosystems	3.85	4.01	0.30 (0.59)	-1.15 (0.25)	0.16
Forest sector	3.69	3.91	4.33 (0.04)	-1.64 (0.10)	0.24
Climate change is a threat to...					
Forest ecosystems	3.42	3.74	2.74 (0.10)	-1.96 (0.052)	0.27
Forest sector	3.35	3.72	1.33 (0.25)	**-2.31** (0.02*)	0.33
Me personally	2.98	2.89	4.34 (0.04)	-1.17 (0.24)	0.16

* Indicates *p-value* < 0.05

A large percentage of both stakeholder groups perceived that climate change will have a significant impact on forest ecosystems, and to a slightly lesser extent, Maine's forest sector within the next 50 years. While there is high agreement that climate change will have a significant impact on forest ecosystems and the forest sector within the next 50 years, a relatively fewer percentage of both stakeholder groups perceive climate change as a serious threat. Additionally, small woodlot owners perceive that climate change presents a more serious threat to Maine's forest sector compared with land managers ($t(1) = -2.31$, $p = 0.02$, $d = 0.33$).

3.4.4 Socio-cultural influences

There was no significant difference in perceptions of social norms between land managers (*M*=3.61) and small woodlot owners (*M*=3.48) (Table 3.3). However, 69% of land managers (*M*=3.82) agreed that people that they worked with would support their efforts to reduce the risk of climate change on forest ecosystems, compared with only 55% of small woodlot owners (*M*=3.54) ($t(1) = 2.22$, $p = 0.03$, $d = 0.32$).

There was no significant difference in altruistic values between land managers (*M*=3.76) and small woodlot owners (*M*=3.89), or egoistic values between land managers (*M*=2.74) and small woodlot owners (*M*=2.62) (Table 3.3). Small woodlot owners however, had higher biospheric values (*M*=4.12) compared with land managers (*M*=3.98) ($t(1) = -2.25$, $p = 0.03$, $d = 0.33$).

Table 3.3. Socio-cultural group comparisons.

(reported as mean values where 1=strongly disagree to 5=strongly agree).

Variable	Land managers (n=88)	Small woodlot owners (n=109)	Levene Stat (sig)	t-test (sig)	Cohen's d
Biospheric values	3.98	4.12	0.26 (0.61)	**-2.25** (0.03*)	0.33
Egoistic values	2.74	2.62	1.66 (0.20)	1.17 (0.25)	0.17
Altruistic values	3.76	3.89	0.42 (0.52)	-1.18 (0.24)	0.17
Norms	3.61	3.48	1.81 (0.18)	1.38 (0.17)	0.20
______ would support my efforts to reduce risks of climate change impacts on forest ecosystems					

Table 3.3 continued

People I work with	3.82	3.54	0.29 (0.59)	**2.22** (0.03*)	0.32
Leaders of my company/organization	3.88	3.49	0.56 (0.46)	**3.06** (0.003**)	0.45
People that are important to me	3.83	3.79	0.17 (0.68)	0.33 (0.74)	0.05

Indicates * *p-value* < 0.05; ** *p-value* < 0.01

3.4.5 Self-efficacy

There was no significant difference in perceived self-efficacy between land managers (*M*=3.19) and small woodlot owners (*M*=3.05) (Table 3.4). Only 18% of land managers and 16% of small woodlot owners agreed that there is sufficient information available for understanding climate change impacts on Maine's forests. In addition, only 31% of land managers and 30% of small woodlot owners agreed that there are specific management practices available to help land managers adapt to climate change in Maine's forests. Despite the relatively low perceptions of information and management availability, a higher percentage, 41%, of land managers (*M*=3.17) know what adaptation efforts to make to address climate change compared with only 22% of small woodlot owners (*M*=2.82) ($t(1)$ =2.70 , p = 0.01, d = 0.38).

Table 3.4. Self-efficacy of climate change adaptation.

(reported as mean values where 0=strongly disagree to 5=strongly agree).

Variable	Land managers (n=89)	Small woodlot owners (n=112)	Levene Stat (sig)	t-test (sig)	Cohen's d
Self efficacy	3.19	3.05	0.120 (0.73)	1.75 (0.08)	0.24
I know what adaptation efforts to make	3.17	2.82	2.24 (0.14)	**2.70** (0.007**)	0.38

Table 3.4 continued

There is sufficient information available to understand climate change impacts	2.61	2.59	0.56 (0.45)	0.07 (0.95)	0.02
There are specific management practices available to help land managers adapt to climate change	3.01	2.94	0.06 (0.81)	0.49 (0.63)	0.06
I have access to professional development opportunities to keep me informed on climate change adaptation	3.49	3.11	1.09 (0.29)	**2.96** (0.003**)	0.40

* Indicates *p-value* < 0.05; ** *p-value* < 0.01

3.4.5 Barriers and incentives to adaptation implementation

Sixty-two percent of land managers (M=3.58) and 56% of small woodlot owners (M=3.52) perceive complexity of information as a barrier to climate change adaptation implementation (Table 3.5). However, there were differences in perceptions of barriers to adaptation, with 34% of small woodlot owners (M=3.13) perceiving lack of access to information as a barrier compared with only 23% of land managers (M=2.84) ($t(1) = -2.12$, p = 0.04, d = 0.33). In addition, 63% of small woodlot owners (M=3.61) perceived lack of financial capital as a barrier to adaptation compared with only 46% of land managers (M=3.31) ($t(1) = -2.03$, p = 0.04, d = 0.31).

Forty percent of land managers (M=4.62) and 28% of small woodlot owners (M=4.59) identified green certification as their number one desired incentive to implement adaptation strategies (Table 3.5). Forty-three percent of small woodlot owners prioritized tax breaks as their top incentive (M=4.97), compared with only 25% of land managers (M=4.45) ($t(1) = -2.66$, p = 0.01, d = 0.35). Nineteen percent of small woodlot owners (M=4.77) identified microgrants as their number one incentive, compared with only 6% of land managers (*M*=4.14) ($t(1) = -3.73$, $p = 0.00$, $d = 0.78$). Finally, 16% of land managers identified social licensing as their top incentive (*M*=4.32) compared with only 5% of small woodlot owners (*M*=3.84) ($t(1) = 2.71$, $p = 0.00$, $d = 0.62$).

Table 3.5. Barriers and incentives to implementing adaptation strategies to address climate change.

(reported as mean values where 0=strongly disagree to 5=strongly agree).

Variable	Land managers	Small woodlot owners	Levene Stat (sig)	t-test (sig)	Cohen's d
Barriers	(n=86)	(n=87)			
Complexity of information	3.58	3.52	1.81 (0.18)	0.45 (0.65)	0.07
Lack of access to information	2.84	3.13	0.29 (0.59)	**-2.12 (0.04*)**	0.33
Lack of financial capital	3.31	3.61	2.61 (0.11)	**-2.03 (0.04*)**	0.31
Lack of information	3.19	3.08	0.03 (0.87)	0.83 (0.41)	0.13
Lack of human capacity	3.29	3.36	0.05 (0.83)	-0.48 (0.63)	0.07
Lack of time	3.45	3.52	0.38 (0.54)	-0.48 (0.63)	0.07
Incentives	(n=73)	(n=74)			
Microgrants	4.14	4.77	0.194 (0.66)	**-3.73** (0.00***)	0.78
Social Licensing	4.32	3.84	3.34 (0.07)	**2.71** (0.00***)	0.62
Tax breaks	4.45	4.97	0.84 (0.36)	**-2.66** (0.009**)	0.35
Green certification	4.62	4.59	3.70 (0.06)	0.09 (0.93)	0.006

* Indicates *p-value* < 0.05; ** *p-value* < 0.01; and *** *p-value* < 0.001

3.4.6 Information sources

A large percentage of both land managers (60%) and small woodlot owners (79%) obtained climate information from journal articles within the last month (Figure 3.2). Thirty-eight percent of land managers obtained climate information from the University of Maine, compared with only 16% of small woodlot owners ($\chi2$ (1, N = 83) = 4.79, p = 0.03, ΦC = 0.24). While 56% and 40% of small woodlot owners obtained climate information from newspapers and TV programs, respectively, compared with only 33% and 15%, respectively, of land managers ($\chi2$ (1, N = 83) = 4.56, p = 0.03, ΦC = 0.23), ($\chi2$ (1, N = 83) = 6.23, p = 0.01, ΦC = 0.27).

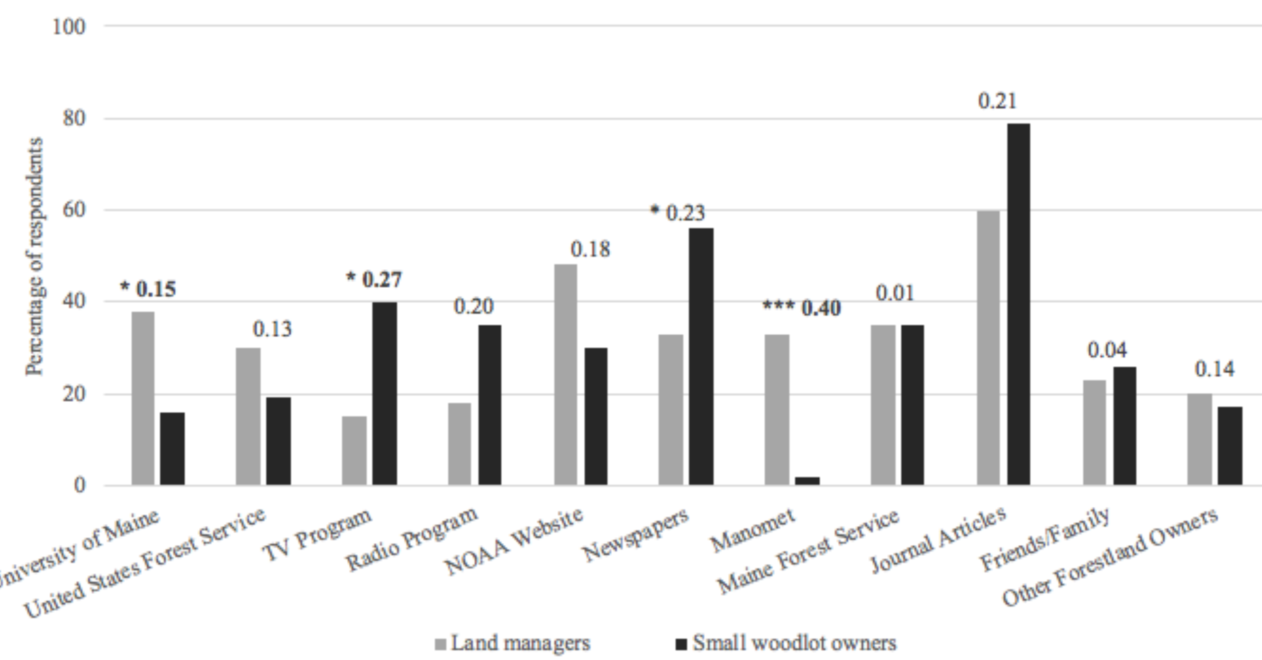

Figure 3.2. Sources of climate information for stakeholder groups reported as percentage of respondents.

Significance level (* p-value < 0.05; ** p-value < 0.01; and *** p-value < 0.001) and Cramer's V for chi-square test results for the two stakeholder groups.

3.4.7 Adaptation and management preferences

Both stakeholder groups were willing to implement most of the adaptation strategies listed, with highest willingness to *improve road/culvert maintenance*, *thin trees*, and employ strategies that *promote and enhance stand-level and structural diversity* (Figure 3.3). Improving road/culvert maintenance was the most accepted management strategy by land managers (M=3.34), and was significantly higher than small woodlot owners (M=3.06) ($t(1) = 2.79$, p = 0.01, d = 0.43). Land managers (M=3.30) were also more willing to improve forest inventory methodologies than small woodlot owners (M=2.94) ($t(1)$ =3.31 , p = 0.001, d = 0.52).

3.5 Discussion

We surveyed two stakeholder groups, land managers and small woodlot owners, to understand their differences and similarities regarding key factors that may influence the communication of adaptation strategies. We found that climate change risk perceptions were relatively high in both land managers and small woodlot owners, and these findings are similar to other studies conducted among diverse forest stakeholder groups elsewhere. Seventy-six percent of stakeholders believed that climate change will have a significant impact on forest ecosystems within the next 50 years, similar to 89% of stakeholders in Canada (Ameztegui et al., 2018) and 71% of forest managers in Belgium (Sousa-Silva et al., 2016). However, in contrast to the findings of Ameztegui et al. (2018), who noted that those land managers working in industry were less concerned about the impacts of climate change on forest ecosystems into the future compared with other stakeholder types (i.e. small woodlot owners, government), we found that there were high levels of risk perception across both stakeholder groups, regardless of their position.

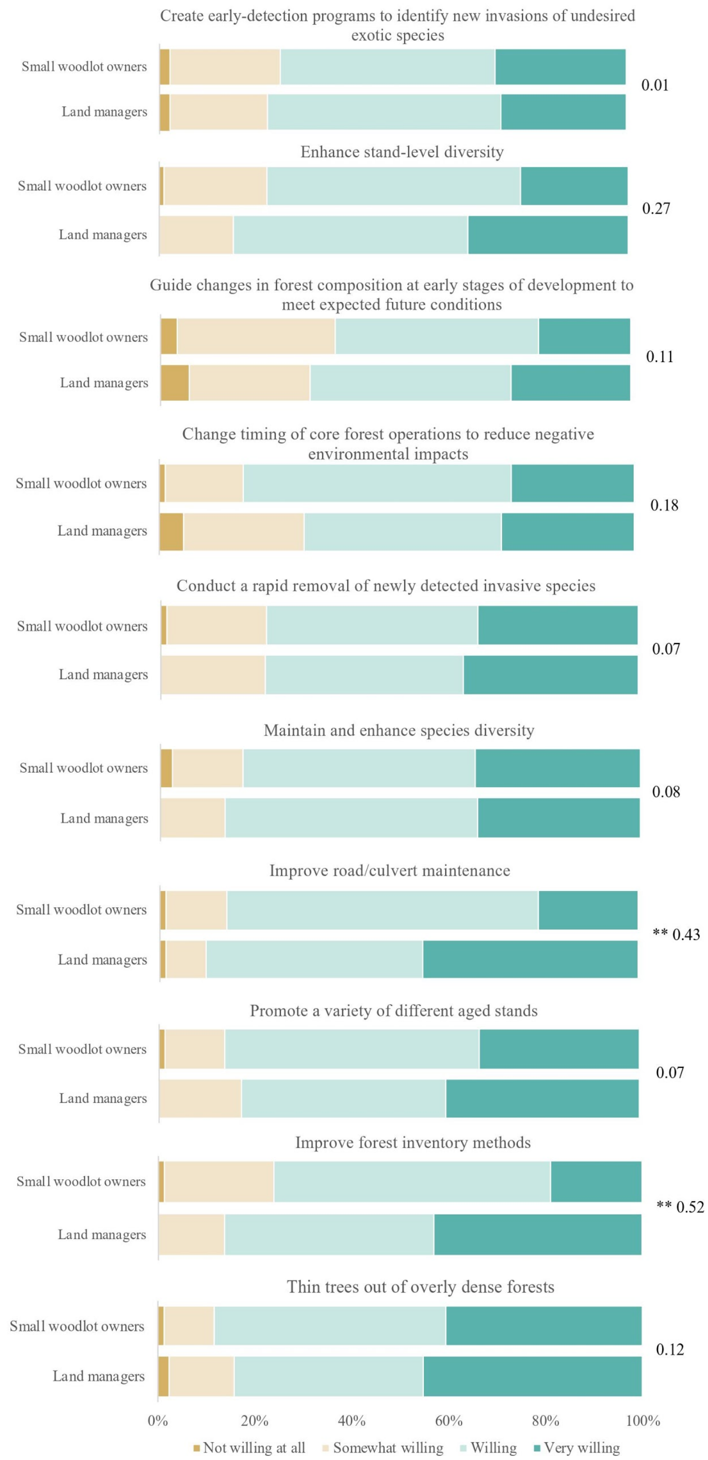

Figure 3.3. Management strategies (reported as percentage of respondents) that were identified as part of the participants' effort to adapt to climate change by the majority of respondents.

Significance level (* p-value < 0.05; ** p-value < 0.01; and *** p-value < 0.001) and Cohen's d for t-test results for the two stakeholder groups are displayed next chart.

There are a variety of other factors, such as self-efficacy or constraints that may also hinder adaptation implementation (Sousa-Silva et al., 2016). Thirty-one percent of forest stakeholders know what adaptation efforts to make, yet only 17% believed that there was sufficient information available to understand climate change impacts and 31% believed that specific management practices are available to land managers to adapt to climate change. Perceptions of self-efficacy are similar to the findings of Boby et al. (2016), who found that only 25% of southern, U.S. foresters felt knowledgeable about climate science, and Guariguata et al. (2012) who found that the majority of foresters in tropical regions did not believe there was sufficient information to understand climate change impacts. Overall, perceptions of self-efficacy were low among forest stakeholders, particularly in regards to information and specific management action availability. However, we found that confidence in knowing what adaptation efforts to make was higher among Maine forest professionals compared with a similar study by Lenart & Jones (2014) conducted among U.S. foresters. Barriers and incentives to adaptation implementation are also key to understanding and increasing differential adoption (Sousa-Silva et al., 2016). Complexity of information and perceived lack of information were perceived as top barriers to adaptation implementation for both stakeholder groups, with perceptions of lack of information in line with Belgium forest stakeholders (Sousa-Silva et al., 2016).

We found that the most commonly cited sources of climate information included: journal articles, newspapers, National Oceanic and Atmospheric Association (NOAA), and Maine Forest Service. In other studies of forest stakeholders in Sweden and Canada, other forest owners and family, along with forestry associations, were the most common sources of climate information

(André et al., 2017; Williamson et al., 2012). It is therefore surprising that the top source of climate change information is journal articles among Maine forest stakeholders, given the importance of social networks identified in other studies of forest land managers and landowners.

Understanding current willingness to implement adaptation strategies can be important when connecting with forest stakeholders to increase the support for management actions (Lenart & Jones, 2014). Forest stakeholders in Maine are currently highly willing to implement management strategies aimed at detecting and removing invasive species, enhancing diversity, improving forest inventory methods, and improving road/culvert maintenance all as part of their effort to adapt to climate change. However, stakeholders were less willing to guide changes in species composition to meet expected future conditions - a strategy that may be related to assisted migration (Ste-Marie et al., 2011), which is introducing or expanding the range of species to future suitable habitats (McLachlan et al., 2007). These findings are also consistent with studies of U.S. (Lenart & Jones, 2014) and Canadian (Moshofsky et al., 2019) foresters; therefore, widespread lack of willingness may be a result of the uncertainty in regards to the risks of introducing new species into ecosystems (Sandler, 2010).

To engage in a process of meaningful dialogue regarding adaptation, we must consider the characteristics among forest land managers and small woodlot owners in order to identify a message frame that connects with both groups based on their shared values and beliefs (Nerlich et al., 2010; Nisbet & Mooney, 2007). We found that climate change risk perceptions were high among both stakeholder groups; however, both groups believed that climate change would have a significant impact on forest ecosystems in the next 50 years more so than they perceived climate change as a serious threat to forest ecosystems. This may indicate that climate change is perceived as a temporally distant phenomenon (Spence et al., 2012) and/or 'impact' may be perceived either positively or negatively, or even an opportunity (Chapter two). Forest stakeholders may consider climate change risks as being mostly in the future, and therefore may be reluctant to take action given the short-term costs and long-term benefits of adaptation (Vulturius & Swartling, 2015).

Both forest land managers and small woodlot owners noted that their top barrier to climate change adaptation was complexity of information, a commonly cited constraint to decision-making (Bierbaum et al., 2013). At the same time, only 31% of participants believed that specific management practices are available to land managers to adapt to climate change and 17% that there is sufficient information available to understand climate change impacts, a result that is similar to the findings of Guariguata et al. (2012) of tropical production forests. Providing incentives in the form of green certification, a highly ranked incentive among both groups, can reward foresters financially for the time required to implement adaptation actions (Leahy et al., 2008). Discussing concrete actions that can be taken to address specific impacts with foresters may be a way to connect with audiences in a way that centers around locally relevant solutions, and reduce the constraint of complexity of information (Moser, 2014) and the perception that sufficient information and specific management practices do not exist.

Given forest land managers and small woodlot owners' relatively high biospheric values, framing climate change adaptation as a forest and wildlife health concern may be one way to connect with stakeholders in a way that makes the issue more appealing and meaningful (Nerlich et al., 2010). In doing so, scientists, forest stakeholders, and policy-makers could engage in conversations for adaptation that provide salient solutions for what people care about most (Moser & Dilling, 2012; Boby et al., 2016; Quartuch & Beckley, 2013). Communicating climate change adaptation through commonly used information sources (e.g. journal articles, and newspapers) and relevant messengers (e.g. wildlife biologists, forest health experts) that frame adaptation as described above may be most successful in engaging diverse forest stakeholders (Moser & Dilling, 2012).

Identifying and connecting with specific segments of the forest stakeholder population can increase willingness to discuss and engage in adaptation actions (Bostrom et al., 2013). In a study of private woodland owners in Maine, Huff et al. (2017) found that private woodlot owners perceive forest management as an abstract and distant concept. Despite the diversity that exists within small woodlot owners (Kline et al., 2000), we provide general suggestions for message framing that resonates with their perceptions, values, and needs. Small woodlot owners perceive lack of access to information and lack of financial capacity as a barrier to climate change adaptation, and only 22% know what adaptation efforts to make to address climate change. It is therefore not surprising that small woodlot owners rank financial incentives higher than forest land managers. Increasing small woodlot owners' access to information via professional development and social learning opportunities may overcome the perceived low self-efficacy and lack of access to information, thereby making adaptation more personally and locally relevant, and empowering individuals to engage in deliberative processes that lead to action (Moser, 2016). Also, Boag et al. (2018) identify potential financial incentives in the western U.S. for private forest owners that may be applicable to Maine’s small woodlot owners, these include: rental programs for equipment, cooperative agreements to pool timber and financial resources, and cost-share programs to improve affordability of adaptive management.

In Maine, where the majority of productive timberland is owned by private corporations, it is essential to understand how the perceptions of forest land managers differ from small woodlot owners. Land managers have high social norms in regards to people that they work with supporting their efforts to reduce the risks of climate change impacts on forest ecosystems. Discussing relevant climate change adaptation options with leaders of corporations or companies may result in increased willingness to adapt among all employees as there is a high importance placed on organizational norms (Lidskog & Löfmarck, 2016). Also, given the high ranking of market-based incentives, framing climate change adaptation as a socio-economic issue, while emphasizing the public's desire for sustainably produced forest products, may be a way to engage land managers in such a way that connects to what they care about most (Nelson et al., 2016).

3.5.1 Limitations

Given that the first wave of responses was not statistically different from the second wave of responses, with the exception of one item, non-response bias was not present in our study. However, we were only able to send survey reminders to the CFRU, while MWO did not receive any survey reminders. It is possible the lack of survey reminders resulted in the lower response rate for MWO members (18%). In addition, we only surveyed MWO members with an email address on file, which accounts for roughly half of the total MWO members. There is a possibility of coverage error with this group.

3.6 Conclusion

We surveyed forest land managers and small woodlot owners in Maine, U.S. to understand their climate change perceptions, socio-cultural influences, sources of information, self-efficacy, barriers and incentives to adaptation, and management actions to determine appropriate communication strategies to increase adaptation implementation among both stakeholder groups. Increasing adaptive forest management is necessary to ensure that forests continue to provide ecosystem services. Understanding existing stakeholder perceptions, values, needs, and barriers are critical for designing effective communication strategies. We found that both forest land managers and small woodlot owners have a high perception of climate change impacting forest ecosystems and view the complexity of climate change information as a barrier to implementing adaptation strategies.

Discussing concrete actions that can be taken to specifically address climate change adaptation is one way scientists, policy-makers, and communication professionals can engage in conversations with forest stakeholders. Importantly, framing messages to connect with specific audiences based on their values, needs, and beliefs is important for engaging dialogue that seeks to promote broad support for adaptation implementation. Forest land managers may be more motivated when individuals in their organization encourage consideration of climate change adaptation strategies. On the other hand, appealing to existing biospheric values may be more successful among small woodlot owners. Given the acceptability of adaptation strategies that increase diversity, and the generally high biospheric values across both land managers and small woodlot owners, framing adaptation under the unifying concept of forest productivity and forest health concerns may appeal to a broad range of forestry professionals. Finally, it is important to note that communication is only one part of the process of engaging broad support for adaptation implementation, as behaviors can only be performed when supported by government initiatives that remove institutional constraints. Therefore, there is a place for policy support that enables both financial and market-based incentives, as well as dialogue among scientists, forest stakeholders, and policy-makers to discuss locally relevant solutions for addressing the institutional barriers to adaptation. Our study begins to identify message frames for both broad and specific audiences; however, scientists, policy-makers, and forest stakeholders must continue to engage in conversations to address locally relevant adaptation options.

CHAPTER 4: A SPATIALLY EXPLICIT VULNERABILITY ASSESSMENT OF MAINE'S FOREST INDUSTRY TO CLIMATE CHANGE

4.1 Introduction

Climate change is currently impacting New England forests in the U.S. as changes in seasonal temperature and precipitation patterns alter growing season length and timing, and the frequency and intensity of natural disasters (Janowiak et al, 2018). Extreme weather events have been increasing in the Northeast over the last decade (Huang et al., 2017) and future climate change projections suggest continued increases in extreme climatic events (Horton & McKenzie, 2009), and warmer temperatures that may allow some pest and pathogen species to become an even greater threat in forest ecosystems (Weed et al., 2013). The forest industry, composed of those who rely on forest products for their livelihoods, will likely continue to be exposed to climate-related impacts and will be particularly sensitive to climatic changes due to its reliance on forested land (Lindner et al., 2002). Tree species ranges have already migrated north and the quality and availability of harvestable timber has also reduced with climate change (Brecka et al., 2018). Climate change will continue to alter the quality of timber, the types of species that can naturally regenerate, and the timing of key forest operations (Spittlehouse, 2005) but effective forest management decisions can increase forests' ability to adapt to climatic changes (Evans & Perschel, 2009).

The impacts of climate change will necessitate adaptation as a way to respond to environmental changes (Jantarasami et al., 2010). Adaptation is an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects" (McCarthy et al., 2001). For example, insects and pathogens, extreme weather events, and seasonal temperature and precipitation shifts may require unique forest management strategies to reduce negative, as well as take advantage of positive, socio-economic and ecological impacts. Adapting to climate change involves monitoring and anticipating change that leads to decision-making within complex and dynamic socio-ecological systems (Gauthier et al., 2014). However, given the uncertainty in magnitude and timing of future climate change impacts it can be difficult to develop and implement appropriate adaptation measures (Spittlehouse, 2005). Identifying and assessing vulnerabilities is an important first step before adaptation planning (Swanston et al., 2016). *Vulnerability* can be viewed as a property of the relationship between the system and its environment (Gallopin, 2006) and is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change… [and] is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Parry et al., 2007, p.6).

Vulnerability assessments are increasingly being used to spatially map impacts in order to effectively adapt to climate change at a local level (Galicia et al., 2015). Biophysical assessments have become common for evaluating vulnerability of forest ecosystems to climate change (Swanston et al., 2018; Gonzalez et al., 2010). However, there is growing recognition that vulnerability analyses must take into consideration how the human system interacts with the biophysical environment (Turner et al. 2003; Guidu et al., 2018). There are several studies on vulnerability assessments of forest ecosystems (Chakraborty et al., 2018; Fischer & Frazier, 2017), forest goods and services (Chakraborty et al., 2018; Dixit et al., 2015), and forest-dependent communities (Dixit et al., 2015; Peras et al., 2017) that incorporate both biophysical and social climate change impacts (Table 4.1). While several studies note the importance of the forest industry to understanding vulnerability (e.g. Fischer & Frazier, 2017), there is a lack of a comprehensive framework that explicitly evaluates vulnerability of the forest industry to climate change (Johnston & Williamson, 2007; Locatelli et al., 2008). Additionally, studies that do assess climate change vulnerability of the forest industry are not spatial in nature (Keskitalo, 2008; Sonwa et al., 2012). Despite the challenges associated with mapping climate change vulnerability, spatially explicit assessments are useful tools for building shared understanding in complex human-environment systems that require place-specific adaptation by stakeholders (Preston et al., 2011). The goal of this study is to present a spatially explicit assessment of vulnerability to climate change in the forestry industry in Maine, U.S. Maine's forest industry, with a highly diverse forest system of over 50 tree species and approximately 89% forested land (Butler, 2017), is especially susceptible to climate variability given the variety of biophysical impacts (Fernandez et al., 2020), and high socio-economic dependency on natural resources (Correia, 2010; Friedland et al., 2004). We evaluated exposure, sensitivity, and adaptive capacity of Maine's forest industry to climate change in an effort to (1) target specific regional areas that may be more susceptible to climatic change, and (2) provide a method for spatially mapping the vulnerability of the forest sector using both biophysical and social indicators.

4.1.1 Vulnerability in socio-ecological systems

Vulnerability is highly dynamic and a function of interactive processes operating on different geographic scales that change over space and time (Adger et al., 2004). There is an increasing recognition that vulnerability assessments must address complexity through analysis of linked human-environment systems (Turner et al., 2003) that incorporate the human dimensions of climate change (i.e. beliefs and experiences) to effectively address adaptation (Seidl et al., 2016).

Table 4.1. Selected studies on forest vulnerability assessments to climate change.

Study	Description	Method	Vulnerability of ____
Chakraborty, Saha, Sachdeva, & Joshi (2018)	An assessment of forest climate change impacts for forest management in the Himalayas	Systematic literature review on climate change impacts	Forest ecosystem and services
Dixit, Karkia, & Shukla (2015)	A *spatial* assessment of biophysical and social changes of climate change in Nepal	Spatially explicit top-down and bottom-up indicator approach	Ecosystem services and livelihoods
Fischer & Frazier (2017)	A *spatial* assessment of social vulnerability of temperate forests to climate change in the Northwest, U.S.	An indicator approach combining biophysical and social indexes	Forest ecosystems
Gauthier et al. (2014)	An assessment of vulnerabilities of managed boreal forest to climate change in Canada	Qualitative vulnerability descriptions of socio-ecological systems	Managed boreal forest
Keskitalo (2008)	An assessment of vulnerability and adaptive capacity in the forestry sector of northern Sweden	Literature reviews and stakeholder interviews to describe climate change impacts	Forestry sector
Peras, Pulhin, & Inoue (2017)	An assessment of livelihood vulnerability in two communities from the Philippines	Indicator approach based on household questionnaire data	Forest-dependent communities
Swanston et al. (2017)	An assessment of biophysical vulnerabilities of upland and coastal forests in Midwest and Northeast, U.S.	Literature review of impacts on ecological provinces	Forest ecosystems

At the same time, climate change impacts are locally experienced and influenced by socio-economic community characteristics (e.g financial assets, access to information); therefore an understanding of risk perceptions is critical (Keskitalo, 2008) and social science can contribute to improved understanding of climate vulnerability (Lynn et al., 2011). Within the forest industry, complex interactions between multiple climate stressors, land-use, and management strategies necessitate a multi-faceted socio-ecological system approach (Fischer, 2018) (Figure 4.1).

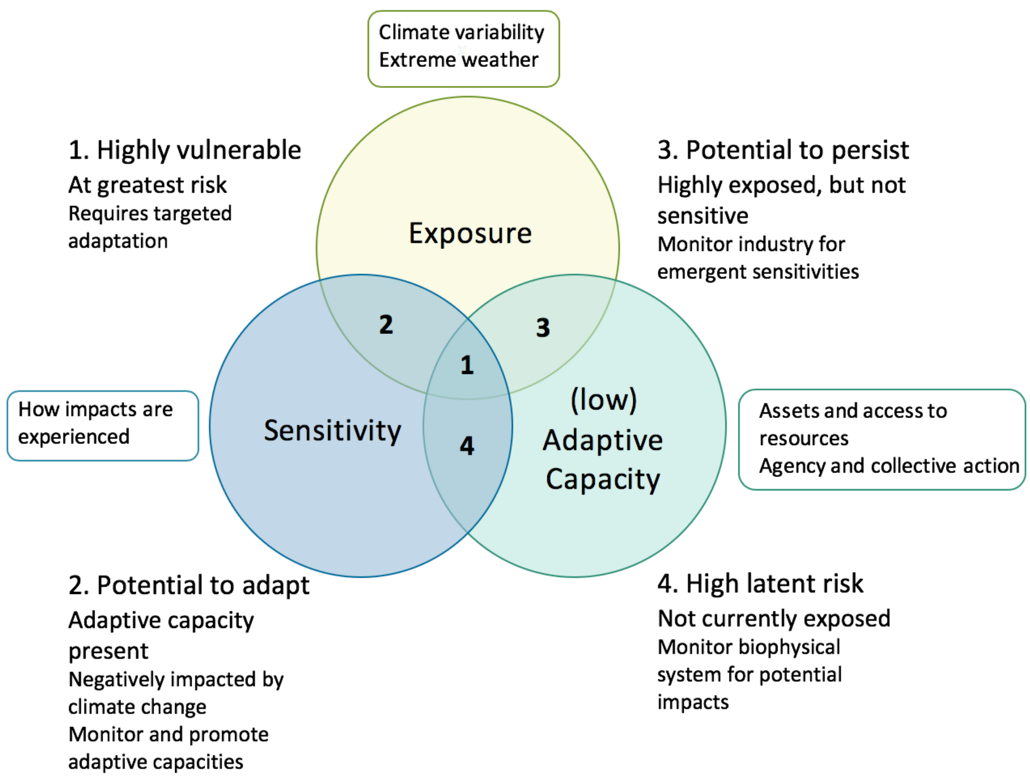

Figure 4.1. Conceptualization of exposure, sensitivity, and adaptive capacity. Drivers of exposure operate in the biophysical and impact the social system based on sensitivity. Adaptive capacity is driven by human, political, social, and cultural conditions (representing both assets and access), and is actively shaped by (and shapes) agency and collective action. The unique combination of exposure, sensitivity, and adaptive capacity determine overall vulnerability. Adapted from Foden et al. (2013).

A socio-ecological perspective is necessary to incorporate the human dimensions of adaptive capacity, such as risk perceptions, adaptation, learning, governance, and social networks, with the biophysical impacts that may lead to high exposure and sensitivity to climatic change. Exposure and sensitivity comprise the potential impact of climate change on the system (Fellmann, 2012). *Exposure* is "the nature and degree to which a system is exposed to significant climatic variations" (IPCC, 2001). This can be conceptualized as changes in climate variability or extreme weather events that can negatively impact the forest industry. *Sensitivity* is "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli " (IPCC, 2001), and relates to the responsiveness of the system (Preston & Stafford-Smith, 2009). For example, sensitivity may include the degree to which a community relies on the forest sector for employment, where increased reliance might make the region more susceptible to the effects of climate change impacts. While exposure is largely a function of biophysical impacts, sensitivity is determined by human-environment conditions that include both social and biophysical forces (Turner et al., 2003).

Adaptive capacity is "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC, 2001), and is manifested in adjustments and adaptations (Turner et al., 2003). Adaptive capacity is often viewed as an inherent property of the system (Smit & Wandel, 2006; Chapman et al., 2017), and represents the potential for adaptation (Adger et al., 2004). Determinants of adaptive capacity include social, cultural, human, and political factors, which interact and change over time to reflect both local and more general socio-economic and political conditions (Smit & Wandel, 2006). We consider factors, or conditions, as the forces that influence the ability of the system to adapt, and therefore represent the drivers of adaptive capacity (Adger, 2003). We rely in part on existing literature from the fields of community development and planning, to understand and operationalize the conditions (UNDP, 2017; Emery & Flora, 2006). Social, cultural, human, and political conditions are influenced by access to resources/assets (e.g. education, finances, or power brokers) (Akamani, 2012), as well as the ability to act individually (agency), and collectively as a group (Adger, 2003). We view agency and collective action as (1) necessary to activate adaptive capacity (Berkes & Ross, 2013), and as (2) potential outcomes that are shaped by social, cultural, human, and political conditions. Agency and collective action are facilitated by social learning and community strength building (Berkes & Ross, 2013). Social learning is learning that occurs through observations of others via social interactions serve as guides for future action (Bandura, 1986; Reed et al., 2010), and can play a major role in adaptation and natural resource management (Muro & Jeffrey, 2008; Preston & Stafford-Smith, 2009).

Vulnerability assessments are a useful tool for building shared understanding of complexity in coupled human-environmental systems at local scales (Preston et al., 2011). Assessments can aid in evaluating and implementing adaptation actions (Preston & Stafford-Smith, 2009), and understanding community and environmental needs required for capacity-building (Adger et al., 2004). There is a lack of consensus regarding frames and methods for mapping vulnerability with studies using a variety of approaches including iterative designs, indicator-based top-down and bottom-up approaches, agent-based models, bayesian models, and cluster analyses (Preston et al., 2011). Indicator-based approaches use simple measures to understand complex conditions that provide a ‘snapshot’ of a community in a single place and time (Fischer et al., 2013). While indicators are limited by the availability of data at relevant spatial and temporal scales (Kienberger et al., 2013; Fekete et al., 2010), indicator-based approaches are an efficient method to understand the vulnerability of socio-ecological systems at county and state scales (Fischer et al., 2013).

With the advance in technology of Geographic Information Systems (GIS), it is now possible to quantify, spatially map, and integrate indicators of human perceptions and behaviors with biophysical trends and changes on the landscape (Herrmann et al., 2014; Kosmowski et al., 2016). Spatial vulnerability assessments largely originated in the field of emergency planning and natural hazards (Cutter et al., 2000); however, recent advances in both indicator-based top-down and bottom-up approaches has resulted in many spatial vulnerability assessments that address climate change impacts more broadly (Frazier et al., 2014; Ludena & Yoon, 2015). Some assessments have made use of climate change projections (Fischer & Frazier, 2018; Seenath et al., 2016) and models of socio-economic pathways (Windfeld et al., 2019), while others have extended vulnerability to include social indicators of human capacity to adapt (Dixit et al., 2015; Ludena & Yoon, 2015). GIS overlay analysis is a common method to quantify vulnerability, when incorporating biophysical with social data (Lee, 2014) as it provides critical information regarding exposed regions and identifies socio-economic resources (Frazier et al., 2013). Relatively few researchers have used a bottom-up indicator approach to spatially quantify and map *both* biophysical and social vulnerability to climate change within the context of forest-dependent communities or the forest industry.

4.2 Materials and Methods

4.2.1 Maine's forest industry and climate change

Maine is divided into 16 counties, with variable areas ranging from 960 km^2 in Sagadahoc to 17.690 km^2 in Aroostook, and populations ranging from 6,931 people in Piscataquis to 289,977 people in Cumberland. We evaluate vulnerability at the county level (Fischer & Frazier, 2018) due to the spatial resolution of available social data and the relevance of county boundaries for decision-making (Feket, 2010). Forest industry stakeholders, markets, and local communities make up Maine's forest industry. At the same time, rural communities in Maine rely on the forest products industry for their livelihoods and economic well-being. Communities are an essential component to the function of the forest industry, as they provide assets in the form of labor and forest resources, and can also have an impact on the direction of the industry via social licensing (Dare, 2014).

Climate change is already impacting Maine's forests (Fernandez, 2020) and future projections suggest increasing extreme precipitation events (Huang et al., 2017), milder winters (Spittlehouse, 2005), insects and pathogens (Weed et al., 2013), increased herbivory (Frelich et al., 2012), and shifts in forest composition (Janowiak et al., 2018). The impacts of climate change have implications for the commercial value of forest products as well as forestry operations via decreases in operation length, changes in access to timber, road and culvert damage, and decreased tree regeneration (see Chapter two). Disturbance agents may also interact resulting in cascading effects on forest ecosystems and substantial socioeconomic losses (Weed et al., 2013).

Maine is also particularly sensitive to climatic changes given its high percentage of forested lands as well as individuals that rely on the forest products industry for their economic well-being (Butler, 2017). Additionally, the forest products industry requires a skilled labor force, and declines in the working age population presents a major challenge for Maine's forest industry (Maine Development Foundation, 2017). Similarly, maintaining employee health via access to healthcare providers is essential, given the physical and psychologically-demanding nature of forest industry work (Mylek & Schirmer, 2015). Finally, road densities and conditions can influence the ability to harvest timber and access markets, which also contribute to the vulnerability of the forest industry (Lundmark et al., 2005). Despite Maine's sensitivities to climate change, the future of Maine's forests will in part be determined by the ongoing human influences on the landscape via forest management practices (Kittredge et al., 2003). Within Maine there are currently no climate change regulations related to forest management; instead, the adoption of adaptation strategies rests with individual landowners. Therefore, the adaptive capacity of Maine's forest sector largely relies on individuals and companies/organizations to have flexible management practices that include climate change adaptation.

4.2.2 Data collection and analysis

We used a bottom-up indicator approach that is driven by the variables that contribute to overall vulnerability of the socio-ecological system (Preston & Stafford-Smith, 2009) (Figure 4.2). The identification of indicators for forest industry vulnerability assessments must take into consideration local contexts and stakeholder expertise and perceptions (Brandt et al., 2017; Lexer & Seidl, 2009) in order for the assessments to be relevant for forest management (Keskitalo, 2008; Bardsley & Sweeney, 2010). Similarly, given the complexity of managing socio-ecological systems, we need to make progress towards creating an enhanced picture of the vulnerability of the forest sector using different types of knowledge systems (Tengö et al., 2014), which require the incorporation of multiple disciplines (Keenen, 2015). At the same time, given the variety of methods used for vulnerability assessments, there is a need for precision, transparency and objectivity of robust indicator selection that is based on understanding the multiple processes that shape vulnerability (Adger, 2004).

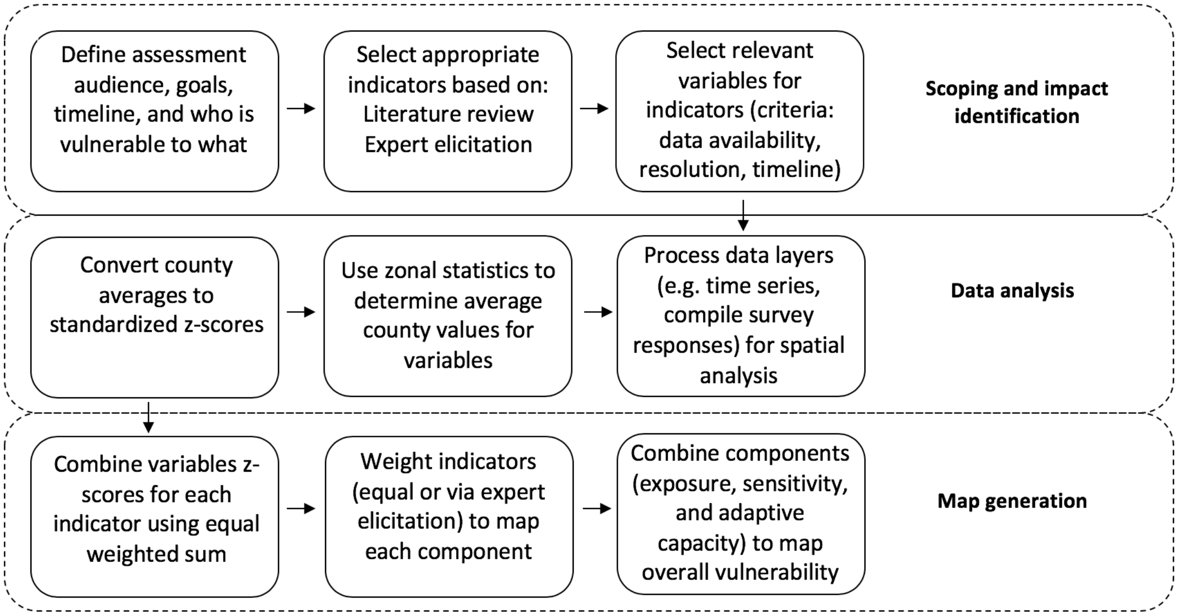

Figure 4.2. Overview of vulnerability assessment methods used in this study.

To increase transparency and legitimacy and ensure that the vulnerability assessment is relevant to forest managers (Keskitalo, 2008), we relied on stakeholder perceptions of climate change impacts to guide indicator selection (Dixit et al., 2015; Locatelli et al., 2008). Specifically, we used nominal group technique (NGT), a structured meeting to elicit expert opinions by building consensus through brainstorming and ranking priorities (Delbecq et al., 1975), and key informant semi-structured interviews (Seidman, 2013) to select indicators that were identified by stakeholders as top concerns and likely impacts. In this study, stakeholders include forest managers and landowners, researchers, government officials, and non-governmental organization employees. We refined the initial list of indicators based on the availability of data at appropriate spatial and temporal scales. In addition, we shared preliminary results of the vulnerability assessment to forest stakeholders during a climate change adaptation forum, so that we were able to incorporate their feedback into the assessment. In an effort to maintain some degree of complexity in a coupled socio-ecological system that works across a variety of scales (Turner et al., 2003) the indicators we have chosen draw on both external (e.g. environmental changes, community age structure) and internal (e.g. stakeholder behaviors and perceptions, market access) factors that may influence the vulnerability of Maine's forest industry (Locatelli et al., 2008).

We assessed the vulnerability of Maine's forest industry to climate change by analyzing and mapping variables of exposure, sensitivity, and adaptive capacity at the county level (Table 4.2). Indicators are expressed as one or more variables.

Table 4.2. Indicators of exposure, sensitivity, and adaptive capacity used in the study.

Component	Indicators
Exposure	Extreme precipitation events
	Change in winter conditions
	Change in mud season
	Pest and insect related tree mortality
	Deer browsing
	Changes in forest composition
Sensitivity	Market accessibility
	Density of transportation networks
	Ability to meet employment needs
	Dependency on forestry
	Proportion of county land forested
	Employee health
Adaptive Capacity	Social factors
	Cultural
	Human factors
	Political factors
	Agency
	Collective action

Regardless of original data format, all biophysical variables used in exposure and sensitivity were converted to raster format at a resolution of 250 m, prior to further analysis. Additionally, the social data (from Chapter three and census data) was converted from a tabular format to vector data using zonal statistics in ArcGIS. We first normalized all variables using county z-scores so that zero represents the mean and one the standard deviation, so that the z-score is equal to the number of standard deviations away from the mean (Fischer & Frazier, 2017). This allowed us to identify areas in Maine that were relatively more or less vulnerable compared with the entire state. For each indicator with more than one variable, we averaged the variable z-scores, and converted that average to a z-score to represent the indicator. We then calculated a weighted sum of the indicators for each component and converted the sum to a z-score. There are several common methods for aggregating indicators, including assigning equal weights and differentially weighting indicators, both presenting their own unique challenges (Adger et al., 2004). Expert elicitation, principal components analysis (PCA), and author selected weights are three common methods for weighting variables (Vincent, 2004). We rely on expert elicitation from the NGT (refer to Chapter two) to determine weights for exposure (Brooks et al., 2005). However, we used equal weights for sensitivity and adaptive capacity indicators as participants only focused on climate impacts for the NGT. While we do recognize the importance of weighting variables, (Papathoma-Kohle et al., 2019) as each indicator may differentially impact the vulnerability of Maine's forest industry, author selected weights were too subjective for this analysis and PCA requires large datasets (at a minimum of 40 samples) (Shaukat et al., 2016) of which we do not have. Additionally, PCA assumes no prior relationship with variables (de Sherbinin et al., 2015); however, we are largely relying on theory and practice to conceptualize and aggregate indicators of sensitivity and adaptive capacity for which we acknowledge that relationships do exist. While we realize equal weights may be seen as a limitation of this study, PCA has been found to produce similar results to normalizing and averaging indicators (de Sherbinin et al., 2015).

4.2.2.1 Evaluation of exposure

We evaluated exposure to climate change using variables indicated in Table 4.3. All of the variables of exposure were identified by stakeholders during the NGT activity and/or key informant interviews (Chapter two). Several of the indicators used weather station data that constitute a time series, including: extreme precipitation events, changing winter conditions, and mud season severity. For all of the weather station data, we first required an 80% completeness threshold for all years and all seasons (Huang et al., 2017) before creating interpolated surfaces using inverse distance weighted (IDW) interpolation for each year for each variable. We then identified annual trends using Sen's slope (Sen, 1968) and Mann-Kendall test (Mann, 1945; Kendall, 1975). The Mann-Kendall test is a non-parametric statistical procedure widely used to detect significance of trends in meteorological data (Tabari et al., 2011). Sen's slope is a non-parametric test used to evaluate the magnitude, or slope, of a trend and is also widely used in meteorological time series (Gocic & Trajkovic, 2013). We reclassified non-significant trends ($p > 0.05$) based on the Mann-Kendall test to a slope of zero before calculating the average Sen's slope within each county. We classified each county according to their standard deviation from the mean by converting the slopes into z-scores and classifying them into five classes for interpretation (Fischer & Frazer, 2017).

Table 4.3. Indicators and variables of exposure, their definitions and sources of data.

Indicator	Variable	Variable Definition	Data Source/Format (resolution)
1 Extreme Precipitation Events	Extreme precipitation days	Annual trend (1950-2018) in extreme precipitation event days	GHCN-D/Station data (interpolated to 250 m)
	Extreme precipitation total	Annual trend (1950-2018) in total precipitation falling on extreme precipitation days	

Table 4.3
continued

2 Change in winter conditions	Frozen ground duration	Annual trend (1950-2018) in total number of days with soil temperatures less than 0°C	GHCN-D/Station data (interpolated to 250 m)
3 Change in mud season	Soil moisture	Annual trend (1979-2019) in soil moisture between last frost day and leaf out (February-May)	NASA NLDAS Noah Land Surface Model/raster (13 km)
4 Pest and insect related tree mortality	Basal area loss	Total percent basal area loss by pest and disease outbreaks (2013-2027)	USDA National Insect and Disease Forest Risk Assessment/raster (240 m)
5 Deer browsing	Deer population	Deer population (deer/mile^2) estimates (2019) in wildlife management district (WMD)	Maine Department of Inland, Fisheries and Wildlife/tabular (WMD)
	Forest disturbance	The percentage of recently disturbed land (2000-2010)	NACP NAFD/raster (30 m)
6 Changes in forest composition *	Change in biodiversity	Change in Shannon's Diversity Index (2010-2050)	Duveneck & Thompson (2019)/raster (250 m)
	Dissimilarity	Bray-Curtis dissimilarity index (2010-2050)	
	Changes in biomass (2010 - 2050)	Change in biomass (2010-2050)	

* for 9 commercially valuable tree species

We define extreme precipitation events as the top 1% of wet days (or 99th percentile) (Huang et al., 2017). Following Huang et al. (2017), we used station data from the Global Historical Climate Network Daily (GHCN-D) for the time period 1950 - 2018. We calculated the following variables to evaluate changes in extreme precipitation: number of extreme precipitation days (Agel et al., 2015), and total precipitation falling on extreme precipitation days (Huang et al., 2017). We determined the 99th percentile of wet days for each station over the time period and evaluated the number of days and amount of precipitation on those days for each station each year. Using the method described above for time series data, we then calculated the slope and trend of extreme precipitation events to determine exposure, where increasing extreme precipitation events corresponds with higher exposure as extreme rainfall can lead to road and culvert damage as well as soil erosion (Bradley & Forrester, 2018).

We used Global Historical Climatology Network - Daily (GHCN-D) from the National Climatic Data Center, National Oceanic and Atmospheric Administration for the time period 1950 - 2018 to evaluate changes in frozen ground duration. Milder winters are cause for concern as limited and shorter frozen ground conditions required for harvesting (Conrad et al., 2017) will increase operation costs (Spittlehouse, 2005; Kuloglu et al., 2019). We obtained daily station data for maximum air temperature, minimum air temperature, snow depth, and snowfall amount. We calculated frozen ground duration for each station for each year following Rittenhouse & Rissman (2015). We defined winter as the period between November 1st and April 30th, and calculated the total number of days with soil temperatures lower than 0°C per winter. Using the method described above for time series data, we then evaluated the slope and trend of extreme frozen ground duration to determine exposure, where decreases in frozen ground duration indicate higher exposure to climate change.

We define mud season as the period of time between when the ground thaws and when leaf out occurs, and use soil moisture during this time period as a proxy to evaluate the severity of mud season. Increasing soil moisture represents higher exposure, as it becomes difficult to operate heavy equipment during severe mud seasons as the potential for site damage increases (McEvoy, 2004). We used GHCN-D from NOAA to determine the last frozen ground day based on Rittenhouse & Rissman (2015) and the USA National Phenology Network to determine leaf out in Spring. We used these two dates to bookend our analysis for soil moisture changes (February - May). To evaluate soil moisture we used monthly reanalysis soil moisture data (100 cm depth) from the North American Land Data Assimilation System (NLDAS) Noah Land Surface Model for 1979 - 2019 (Xia et al., 2012). We evaluated trends across the entire mud season by averaging soil moisture from February - May for each year. Using the method described above for time series data, we then evaluated the slope and trend of soil moisture events to determine exposure.

We used the USDA National Insect and Disease Forest Risk Assessment to evaluate percent total basal area (TBA) loss, from the period of 2013 to 2027 (projected) using a GIS-based multi-criteria process (Krist et al., 2014). The risk model combines spatially explicit tree species hosts, forests pests, climate, and physiographic data to develop predictive layers of basal area loss. We used the composite map of total basal area loss, represented as a total percentage, to calculate exposure. Following Fischer & Frazier (2018), we calculated the relative area of TBA losses of 25% or greater for each county. We then converted the percentages into z-scores for each county so that higher loss represents higher exposure to climate change as insect and pathogen disturbance can result in tree mortality and substantial socioeconomic costs (Weed et al., 2013).

Deer browsing may also limit the ability of tree species to respond to climate change (Fisichelli et al., 2012), as preferential herbivory can result in decreases in tree regeneration (Tremblay et al., 2007). The relationship between deer density and regeneration is particularly strong in sites that have been recently disturbed, or have undergone a recent clear-cut (Curtis & Rushmore, 1958). We used current deer density estimates for Maine’s wildlife management districts (WMD) (MDIFW, personal communication) and recent disturbance data (2000 - 2010) from the National Land Cover Database (NLCD) Forest Disturbance Dataset. Given the cumulative effects of recent disturbances and high deer browse (Barrette et al., 2014; Bachand et al., 2015), we combined deer density estimates with recent disturbances to generate the exposure of forests to deer browse. First, we extracted disturbances that occurred between 2000 and 2010, and calculated the percentage of area within each county that has been recently disturbed. We also calculated the average deer density in each county. After converting deer density and disturbance to county z-scores, we took the average of the scores and rescaled them to z-scores so that areas where deer density and disturbance are high represent high exposure.

We used tree species models developed by Duveneck & Thompson (2019) to assess changes in forest composition between 2010 and 2050 (projected). Shifts in species composition have both environmental and economic implications (Luo & Chen, 2013) given the importance of commercially valuable tree species for Maine's forest-based economy. Duveneck & Thompson (2019) developed models for over 40 tree species that incorporated forest growth and succession dynamics, land use, land conversion, and climate change. We analyzed changes in diversity, biomass, and dissimilarity only in the top nine tree species identified by experts during the NGT as commercially important and/or vulnerable to climate change. The nine tree species included: red spruce, sugar maple, balsam fir, black ash, white pine, yellow birch, northern white cedar, eastern hemlock, black spruce. We calculated diversity using Shannon's H Diversity Index for the nine species in 2010 and 2050, using the following equation:

$$\text{Shannon's H} = \sum_{i=1}^{S}[\,(\frac{n}{N}) * (ln(\frac{n}{N})] \qquad \text{(Equation 4.1)}$$

where n = the total biomass of individual species and N = total biomass of all species for all S number of species. We subtracted Shannon's H from 2010 from Shannon's H from 2050 to evaluate change in diversity. We calculated the mean change in diversity for each county before converting the values into z-scores where larger decreases in diversity indicate higher exposure. We analyzed changes in biomass (g/m^2) by calculating the total biomass of the nine tree species for every 250 m pixel. We evaluated the mean biomass within each county for 2010 and 2050, subtracted the biomass values, and then converted the change to z-scores so that larger decreases in biomass represent higher exposure. Finally, we used the Bray-Curtis Dissimilarity Index to understand how tree species composition changed from 2010 to 2050, using the following equation:

$$\text{Bray Curtis} = \sum_{i=1}^{S} \frac{|n_i - n_j|}{(n_i + n_j)} \qquad \text{(Equation 4.2)}$$

where *n*=biomass, *i*=2010 and *j*=2050 for all *S* number of species, so that 0 = 2010 and 2050 identical species composition and 1 = 2010 and 2050 dissimilar species composition. We calculated the average dissimilarity index for each county before converting the averages to county level z-scores so that higher levels of dissimilarity indicate higher exposure. Finally, we combined diversity, biomass, and dissimilarity to determine changes in forest composition.

We relied on expert judgement from the NGT to assign weights to indicators of exposure (Brooks et al., 2005). Mud season and deer browse were not explicitly mentioned or ranked during the NGT, while all other indicators were identified as top concerns. For this reason, we weighted mud season and deer browse less than all other indicators using the following equation:

Exposure = 0.20**extreme precipitation* + 0.20**changing winters* + 0.20**pest and insects* + 0.20**forest composition* + 0.10**mud season* + 0.10**deer browse* (Equation 4.3)

Finally, we converted the index of exposure to z-scores and used bivariate mapping for display purposes.

4.2.2.2 Sensitivity

We evaluated sensitivity to climate change using the following indicators: (1) market access, (2) transportation density, (3) dependency on the forest sector, (4) ability to meet employment needs, (5) forested land, and (6) employee health (Table 4.4). Indicators of sensitivity, like exposure, were also largely influenced by the NGT activity and key stakeholder interviews. In addition, we relied on existing literature to identify additional biophysical and social indicators of sensitivity (Ludena & Yoon, 2015; Keskitalo, 2007).

Table 4.4. Indicators and variables of sensitivity, their definitions and data sources.

Indicator	**Variable**	**Variable Definition**	**Data Source/Format (resolution)**
1 Market access	Market accessibility	Travel time (minutes) to mills	Maine Office of GIS E911 Roads/vector; Presetemon et al. (2005)/tabular
2 Transportation density	Road networks	Density of road networks within county	Maine Office of GIS E911 Roads/vector
3 Dependency on forest sector	Dependency on forestry	Relative number of employees working in NAICS 113, 1153, 321, 322 sectors	2017 County Business Patterns/tabular (county)
4 Ability to meet employment needs	Age structure	Age-dependency ratio	2017 5-year estimates American Community Survey/tabular (county)
	Population flows	Outbound migration / inbound migration	2017 5-year estimates American Community Survey Census Flow Mapper/tabular (county)
5 Forested Land	Forested Land	Percentage of forested land in county	2016 NLCD/raster (30 m)

Table 4.4 continued

6 Employee health	Tick-borne disease risk	Anaplasmosis, Babeiosis, Lyme disease relative population rate	Maine Environmental Public Health Track (EPHT) Network/tabular (county)
	Healthcare access	Travel time to closest healthcare provider	Maine Office of GIS E911 Hospitals/vector; Health Resources and Service Administration (HRSA)/tabular; Maine Office of GIS E911 Roads/vector

We created a service area layer based on drive times to closest wood-using mills using data from Maine Office of GIS E911 Roads and 2011 Census Road Network (Canadian roads), and locations of U.S. mills from Presetemon et al. (2005) and Canadian mills that work closely with Maine companies (Ryan Wishart, personal communication). Using the service area raster layer, we calculated the average drive time to the closest mill for each county before converting them to z-scores. Additionally, we used the Maine Office of GIS E911 Roads layer to determine the average road density for each Maine county. In Maine, higher road densities decrease sensitivity to climate change as foresters can access timber stands for harvesting and transportation to markets more easily.

Next, we evaluated dependency on the forest sector using the 2017 County Business Patterns from the U.S. Census Bureau. We totaled the number of employees working in the following North American Industry Classification System (NAICS) industries: 113 (forestry and logging), 1153 (support activities for forestry), 321 (wood product manufacturing), and 322 (paper manufacturing). We then divided the number of employees in forest industries by the number of employees working in all sectors to calculate the relative percentage of employees working in forestry dependent fields. With more employees working in the forest sector, counties would therefore be more sensitive to climatic changes given the heavy reliance on forest products to make a living (Parkins & MacKendrick, 2007).

Maine is one of the oldest states in the U.S., with a median age of 45 years old it can be difficult to meet industry labor needs for skilled workers (Miltiades & Kaye, 2003). We calculated the age-dependency ratio, which is the ratio of under 18 and over 65 to those 18-65. The age-dependency ratio is therefore an estimate of the relative amount of potential workers, and can indicate which populations have a low dependency ratio and therefore may be least vulnerable to climatic change (Vincent, 2004). We used 5-year population estimates from the 2017 American Community Survey to calculate the age-dependency ratio for each county. Additionally, as Maine communities become older, some are also experiencing an outflow of populations and require people to move into their communities. If communities become older and the population shrinks they are more sensitive to climatic change in the forest industry as they may not be able to keep up with employer demands for skilled labor. We measured population flows by calculating the ratio of those migrating out of the county to those migrating into the county using the 5-years estimates from the 2017 American Community Survey Census Flow Mapper, where higher ratios (or more outbound migration compared to inbound migration) are indicative of higher sensitivity. We calculated the average of age-dependency z-scores and population flow z-scores to determine the indicator for ability to meet employment needs.

Following Fischer & Frazier (2017) we calculated the relative proportion of county forested land using the 2016 NLCD. We divided the forested land area by the total amount of land for each county, excluding any open water, whereby areas with higher percentages of forested land were more sensitive to climate change.

Finally, we evaluated employee health using the following two variables: (1) tick-borne disease, and (2) healthcare access. During key informant interviews, some stakeholders noted the increases in ticks and tick-borne diseases, which result in difficulties surrounding workplace safety. Additionally, access to healthcare is an important factor in maintaining employees' physical and mental well-being given the taxing demands of forest industry work (Haapakoski et al., 2015), especially in rural regions where employees may be required to pay higher travel costs to access healthcare facilities (Lal et al., 2011). Forest industry employees whose health needs are not met, may increase the sensitivity of the forest industry to climate change as employee retention and well-being may decrease. To evaluate healthcare access we used data from the Maine Office of GIS E911 Roads and Hospitals and healthcare facilities from Health Resources and Service Administration (HRSA) to create a service area layer for drive times to the closest healthcare facility (e.g. hospital, health care centers, health clinics). Using the service area raster layer, we calculated the average drive time to the closest facility for each county. Climate change may have direct (e.g. extreme heat and precipitation events) and indirect (e.g. tick-borne diseases) effects on human health (Ebi et al., 2006; Moser et al., 2008); therefore, larger drive times to healthcare facilities indicate higher sensitivity to climate change. To evaluate tick-borne disease risk we used Maine Environmental Public Health Track (EPHT) Network, which reports incidents of anaplasmosis, babesiosis, and Lyme disease for each Maine county for the 5-year time period 2014-2018. We divided the total incident for each county by the 5-year population estimates to determine tick-borne disease population rate. We combined healthcare access and tick-borne disease risk to determine the indicator of employee health.

We calculated overall sensitivity using an equally weighted sum with the following equation:

$$\text{Sensitivity} = 0.17*\textit{market access} + 0.17*\textit{transportation density} + 0.17*\textit{forest sector dependency} + 0.17*\textit{forested land} + 0.17*\textit{employment needs} + 0.17*\textit{employee health} \quad \text{(Equation 4.4)}$$

We converted the weighted sum to z-scores to evaluate sensitivity and used bivariate mapping for display purposes.

4.2.2.3 Adaptive capacity

We evaluated adaptive capacity of the forest industry to climate change using the following indicators: (1) cultural conditions, (2) social conditions, (3) human conditions, (4) political conditions, (5) agency, and (6) collective action (Table 4.5). The indicators and variables in adaptive capacity were largely determined by existing literature surrounding the determinants of adaptive capacity (e.g. Adger, 2003; Akamani, 2012; Smit & Wandel, 2006), with a consideration of those unique to Maine's forest industry. Specifically, we sought to measure variables that address both resources as well as access to those resources. Given the importance of understanding local socio-economic conditions and perceptions of climate change to ensure we adequately measured the adaptive capacity of the forest industry, we conducted a survey of forest stakeholders in Maine from October - November 2019 to understand their perceptions of climate change and adaptation (Chapter three). We used survey responses for many of the variables of adaptive capacity where census or industry-specific information was insufficient or unavailable. We administered an electronic survey via Qualtrics to Maine's Woodland Owners Association and the University of Maine's Cooperative Forestry Research Unit (CFRU).

Table 4.5. Indicators and variables of adaptive capacity, their definitions and data sources.

Indicator	Variables	Variable definitions	Data Source/Format
1 Cultural conditions	Climate change beliefs	Mean score from two questions regarding belief in anthropogenic climate change	Survey (tabular)
	Climate change adaptation norms	Mean score from seven questions regarding social pressure to adapt to climate change	Survey (tabular)
2 Social conditions	Organization membership	Total number of organizations participants belong to	Survey (tabular)
	Access to professional development	Having access to professional development opportunities to stay informed on climate change adaptation	Survey (tabular)
3 Human conditions	Stewardship foresters	Number of licensed stewardship foresters normalized by county population	Maine WoodsWISE Stewardship Forester List (tabular)
	Formal education	Percentage of population with at least an associate's degree	2018 American Community Survey 5- yr education estimates/tabular
	Climate change risk perceptions	Mean score from seven questions regarding the threat that climate change poses	Survey/tabular
4 Political conditions	Access to power brokers	Mean score from: having effective leaders in power, working with government, and being considered by local leaders	Survey/tabular
	Voter turnout	Percentage of voting age population who participated in 2016 general election	2016 Maine Bureau of Corporations, Elections President General Election/tabular
5 Agency	Self-efficacy	Mean score from: knowing what adaptation and mitigation efforts to make, knowing where to find answers, and knowing what questions to ask	Survey/tabular
	Management flexibility	Total number of management strategies participants willing to implement	Survey/tabular
6 Collective action	Shared goal	Mean score from questions regarding collaborating, sharing information, and working with others to get things done	Survey/tabular

Most questions were measured on a 5 point Likert-scale (i.e. strongly disagree to strongly agree). Some variables represented several questions, or survey items, that we averaged to determine participant mean score and report measures of internal consistency (Pearson correlation coefficient (r) for two items and Cronbach's alpha (α) for three or more). In total we sent the survey to 1,400 forest stakeholders, including land managers, land owners, foresters, consultants, and researchers. A total of 302 participants started the survey (22% response rate), of those, 190 participants completed the survey (63% completion rate).

We measured cultural conditions, or those factors related to the way people know the world and act within it (Emery & Flora, 2006), using two variables: (1) climate change beliefs, and (2) social norms regarding adaptation. From a human dimensions standpoint, climate change beliefs, and norms can impact the extent to which stakeholders implement adaptation strategies to cope with climate variability and therefore promote sustainable socio-ecological systems (Chatrchyan et al., 2017; Jemison et al., 2014). We measured climate change beliefs using the following two items from the survey: *climate change is currently occurring* and *climate change is caused primarily by human actions* (r = 0.65). Research has shown that stronger beliefs in anthropogenic climate change significantly explain management responses (Blennow et al., 2012) and hence mitigate the impacts of climate change on forest ecosystems by human action; therefore, higher beliefs are related to higher adaptive capacity in our assessment. We also measured social norms (i.e. social pressure to reduce climate change risk) related to climate change adaptation using seven items modified from van der Linden (2015), and created a mean score (α = 0.871). Increased social norms for forest adaptation can enhance individual actions (Vulturius et al., 2020); therefore, higher social norms correspond to higher adaptive capacity.

We combined climate change risk perceptions, climate change beliefs, and social norms to determine the indicator for cultural conditions.

We measured social conditions, or the connections among people and organizations through their social networks (Magis, 2010; Berkes & Ross, 2013), using two variables: (1) organization membership, and (2) access to professional development. Survey participants selected the organizations they belonged to (i.e. Manomet, Maine Woodland Owners, etc.). We calculated the total number of organizations for each participant before calculating the average county organization membership, where higher values indicate stronger social networks and therefore higher adaptive capacity. We measured access to professional development opportunities on a 5 point Likert-scale question (i.e. strongly agree to strongly disagree that I have access to professional development). Social learning plays a role in both variables as learning occurs through organization membership via informal meetings, newsletters, forums etc., and in professional development opportunities via informal learning opportunities that involve stakeholder interactions. Social change through climate change adaptation is largely determined by the capacity of the socio-ecological system to learn and adjust responses (Folke et al., 2010); therefore, higher organization memberships and more access to professional development indicate higher adaptive capacity. We combined organization membership and access to professional development to determine the indicator for social conditions.

We measured human conditions, or access to the skills and knowledge of individuals to enhance their resources and increase understanding (Emery & Flora, 2006), using three variables: (1) climate change risk perceptions, (2) stewardship foresters, and (3) formal education. We measured climate change risk perceptions from the survey using seven items on a 5-point Likert-scale modified from Ameztegui et al. (2018) and Guariguata et al. (2012). The questions related to the threat of climate change on forest ecosystems, forest industry, and participants personally. We created a mean score to determine climate change risk perceptions ($\alpha = 0.921$). Increased risk perceptions have been linked to readiness for adaptation within forest management (Parkins & MacKendick, 2007); therefore, high risk perceptions indicate higher adaptive capacity in our assessment. Using Maine Forest Service's WoodsWISE stewardship foresters directory, we normalized the number of stewardship foresters within each county by population. Stewardship foresters are private consultants who are trained to help forest managers and landowners prepare WoodsWISE forest management plans based on stewardship principles. A higher relative amount of stewardship foresters represents greater access to skilled individuals to increase forest adaptation, and therefore indicates higher adaptive capacity. We measured formal education using 2018 5-year estimates of the percentage of population with at least an associate's degree from the American Community Survey. A lack of formal education may limit opportunities for building climate awareness to reduce exposure and sensitivity or implement adaptation strategies (Fischer & Frazier, 2018; Preston & Stafford-Smith, 2009); therefore, higher formal education indicates higher adaptive capacity. Additionally, learning plays a role in human conditions as access to stewardship foresters and formal education can facilitate learning opportunities that result in knowledge sharing for long-term adaptation planning.

We measured political conditions, or access to power and power brokers that can enhance the ability of the socio-ecological system to adapt to change (Flora et al., 2004), using two indicators: (1) access to power brokers, and (2) voter turnout. We evaluated access to power brokers (e.g. effective leaders, government) using three items from the survey on a 5 point Likert-scale ($\alpha = 0.66$). More access to power brokers indicate higher adaptive capacity. In addition, using the total number of votes cast for the 2016 presidential election for each county from the Maine Bureau of Corporations, Elections, and Commissions and voting age population estimates from the American Community Survey 2016 5-year estimates, we calculated county voter turnout. Higher voter turnout indicates higher adaptive capacity as more citizens are engaged in political processes and can suggest capacity for fostering access to resources and/or self-organization and collaboration (Fischer et al., 2013). We combined access to power brokers and voter turnout to determine the indicator of political conditions.

We measured agency, or an individuals' ability to act independently to make their own choices (Berkes & Ross, 2013), using two variables: (1) perceptions of self-efficacy, and (2) management flexibility. We used survey responses from four items modified from Lenart & Jones (2014) that ask participants about their self-efficacy, or beliefs in one's ability to perform a task or manage a situation (Brown & Westaway, 2011) (e.g. knowing what adaptation efforts to make and where to find answers) ($\alpha = 0.78$). Self-efficacy enables individuals to plan and adapt in the face of change (Brown & Westaway, 2011); therefore, higher self-efficacy indicates increased agency and therefore increased adaptive capacity. We asked participants their willingness to adopt 15 management strategies (e.g thinning trees, fostering connected landscapes, promoting diversity, etc.) and calculated the number of strategies participants were at least willing to implement. Greater willingness to implement a variety of management strategies indicates a higher degree of flexibility and ability to problem solve, which is key for adapting to uncertain conditions (Downing & Patwardhan, 2015; Berkes & Ross, 2013). We combined self-efficacy and management flexibility to determine agency.

We measured collective action, or the ability to self-organize within a group to work towards a common objective, using three items from the survey that evaluated perceptions of working with others towards a common goal (e.g. collaborating, sharing information, and working together to get things done) ($\alpha = 0.78$). Collective action requires networks and information flows to help in decision-making (or high social capital) (Adger, 2003) as a group works towards a common goal or cause. Therefore, social learning also plays a key role in collective action as it in part facilitates collective action via shared learning experiences and learning from others to unify communities towards a common goal. Collective action is a key mechanism for which adaptation takes place (Adger, 2003); therefore, increased collective action indicates higher adaptive capacity.

We asked survey participants for the zip code of the town they primarily work in and used this information to group participants based on their county of work. We then took the mean score of the participants within each county to determine county averages before converting the averages to z-scores. We calculated overall adaptive capacity using an equal weighted sum with the following equation:

$$\text{Adaptive capacity} = 0.17*\textit{cultural conditions} + 0.17*\textit{social conditions} + 0.17*\textit{human conditions} + 0.17*\textit{political conditions} + 0.17*\textit{agency} + 0.17*\textit{collective action} \quad \text{(Equation 4.5)}$$

We converted the weighted sum to z-scores to evaluate adaptive capacity and used bivariate mapping for display purposes.

We combined exposure, sensitivity, and adaptive capacity using the following equation:

$$\text{Vulnerability Index} = (\text{Exposure} + \text{Sensitivity}) - \text{Adaptive capacity} \quad \text{(Equation 4.6)}$$

Finally, we again converted the vulnerability index to a z-score to represent overall vulnerability. We describe each of the indicators and their variables for exposure, sensitivity, and adaptive capacity below.

4.3 Results

4.3.1 Exposure

Five out of 16 counties are significantly more exposed (greater than 0.5 standard deviations) to climatic changes compared to the state average (Table 4.6). The majority of highly exposed counties are located in western Maine (Somerset, Franklin, Oxford, and York) with the exception of Lincoln County along the coast (Figure 4.3). Not all counties, however, experience exposure in the same way as each has their own unique combination of climate-related impacts. High exposure in western Maine is particularly driven by decreases in biomass, increases in pest and pathogen related mortality, deer browse, and extreme precipitation. High exposure in Lincoln County is driven instead by decreases in diversity, decreases in frozen ground condition, and increases in pest and pathogen related mortality.

Table 4.6. Exposure variables found to be above average for each Maine county.

County	Pests & Insects	Deer Browse	Soil Moisture	Frozen Ground	Extreme Precipitation	Forest Composition	Exposure
Androscoggin		light grey				light grey	
Aroostook			light grey				
Cumberland		light grey				light grey	
Franklin	light grey	light grey			light grey		light grey
Hancock	light grey						
Kennebec							
Knox						light grey	
Lincoln	light grey			dark grey		light grey	dark grey
Oxford		light grey			light grey		light grey
Penobscot		light grey					
Piscataquis	light grey		dark grey				
Sagadahoc						dark grey	
Somerset	light grey	light grey			dark grey		light grey
Waldo		light grey					
Washington	light grey		light grey				
York		light grey			dark grey	light grey	light grey

Note: light grey indicates above average from the state mean (0.5-1.5 SD) while dark grey indicates well above state average (>1.5 SD)

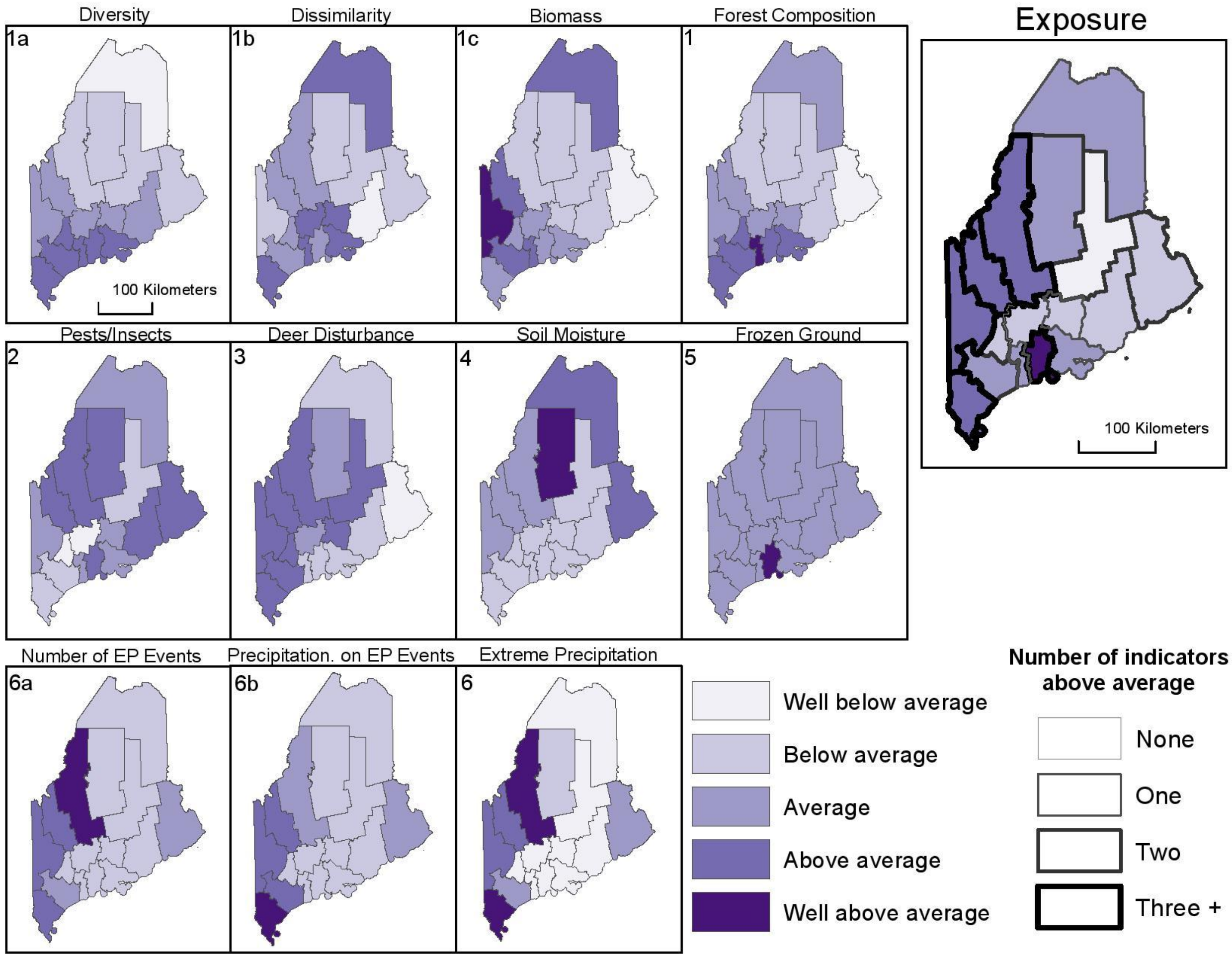

Figure 4.3. Indicator and variable maps of exposure.

Note: Well below average (light purple) is less than 1.5 standard deviations (SD) from the mean, below average is between -0.5 and -1.5 SD from the mean, average is -0.5 - 0.5 SD from the mean, above average is between 0.5 and 1.5 SD from the mean, while well above average (dark purple) is greater than 1.5 SD from mean.

Both the number of extreme precipitation days and total precipitation on extreme precipitation days have increased over the past 60 years in western and southern coastal Maine. Total precipitation falling on extreme precipitation days is increasing up to 19 mm/decade in the state. Four counties are significantly more exposed to extreme precipitation compared to the state average, with York and Somerset counties both being greater than 1.5 standard deviations above the state mean. The number of days of frozen ground conditions has on average decreased in Maine at a rate of -0.09 days/year (decrease of 5.30 frozen ground days since 1950), with significant decreases in southern coastal Maine, resulting in Lincoln County having significantly higher exposure to frozen ground conditions compared with the state average. Soil moisture during mud season is increasing on average across Maine at a rate of 0.17 kg/m^2 per year, equivalent to an increase in 0.02 % saturation/decade. Mud season soil moisture increases across the majority of Maine at upwards of 0.11 % saturation/decade but decreases up to -0.42 % saturation/decade along coastal Maine. In southern Maine, increases in soil moisture are largest in February, whereas in northern Maine they are greatest in May. Three counties in Maine are more exposed to changes in mud season compared with the state average where soil moisture is increasing into late spring.

Six counties across Maine are projected to have higher rates of pest and insect-related tree mortality compared with the rest of the state. Krist et al. (2012) predicts that 4% of Maine's treed acres are at risk of a 25% loss in basal area from 2013 to 2027, which amounts to 726,000 acres. Tree mortality is concentrated along the mountainous regions of western Maine and northern coastal Maine. In northern and western Maine, spruce budworm and maple decline are largely responsible for the high levels of tree mortality in the region. In coastal Maine, balsam and hemlock woolly adelgid are responsible for the losses. Eight counties are significantly more exposed to deer browse compared with the state average. Recent disturbances are concentrated in northwestern Maine, where large harvest activities occur; while, deer densities are highest in southern Maine and along the coast. When combined, southern and western Maine are the most exposed to deer browsing given high deer densities coupled with patches of relatively high disturbances. Six counties are highly exposed to changes in forest composition compared with the state average, all in southern coastal Maine. However, diversity and biomass are projected to increase, on average, in all Maine counties for 2050 in nine valuable tree species. Despite increases, some parts of the state are projected to experience relatively larger decreases in diversity and biomass. For example, southern Maine is more exposed to decreases in diversity and biomass compared with the state average. Counties in both southern and northern Maine are also more dissimilar in 2050 compared to 2010 than the state average. Higher exposure to forest composition changes in southern Maine is largely driven by changes in balsam fir, sugar maple, and yellow birch.

4.3.2 Sensitivity

Three out of 16 counties are more sensitive to climate change compared to the state average, all of which are located in northwestern Maine: Aroostook, Piscataquis, and Somerset (Figure 4.4; Table 4.7). Piscataquis County is highly sensitive for five out of six indicators compared to the state average as it is highly dependent on the forest sector, has fewer roads (impacting road density, market access, and employee health), and also has a higher outbound migration to inbound migration ratio compared to the other counties. Unlike exposure, where each county had its own unique combination of higher than average exposure indicators, patterns emerge among the sensitivity indicators so that some counties are more similar when compared with others. For example, all three of the highly sensitive counties share several above average indicators, including market access, road density, and forest sector dependency. Additionally, Aroostook and Piscataquis both have more limited access to health care compared with other Maine counties. Several other counties who had smaller road densities also had more limited access to health care (e.g. Hancock and Knox), which is unsurprising given the dependency on road networks for healthcare access. Finally, counties that have more difficulty meeting employment needs also have more difficulty meeting employee health needs, including Knox and Lincoln counties, both located along the middle coast of Maine.

Table 4.7. Sensitivity variables found to be above average for each Maine county.

County	Market Accessibility	Transportation Density	Forested Lands	Forest Dependency	Employment Needs	Employee Health	Sensitivity
Androscoggin							
Aroostook	light grey	light grey		light grey		light grey	light grey
Cumberland							
Franklin	light grey	light grey	light grey				
Hancock		light grey	light grey			light grey	
Kennebec							
Knox		light grey			light grey	dark grey	
Lincoln					light grey	light grey	
Oxford			light grey	light grey			
Penobscot			light grey	light grey			
Piscataquis	dark grey	light grey		dark grey	dark grey	dark grey	dark grey
Sagadahoc							
Somerset	dark grey	light grey		dark grey			light grey
Waldo							
Washington		light grey	light grey				
York							

Note: light grey indicates above average from the state mean (0.5-1.5 SD) while dark grey indicates well above state average (>1.5 SD).

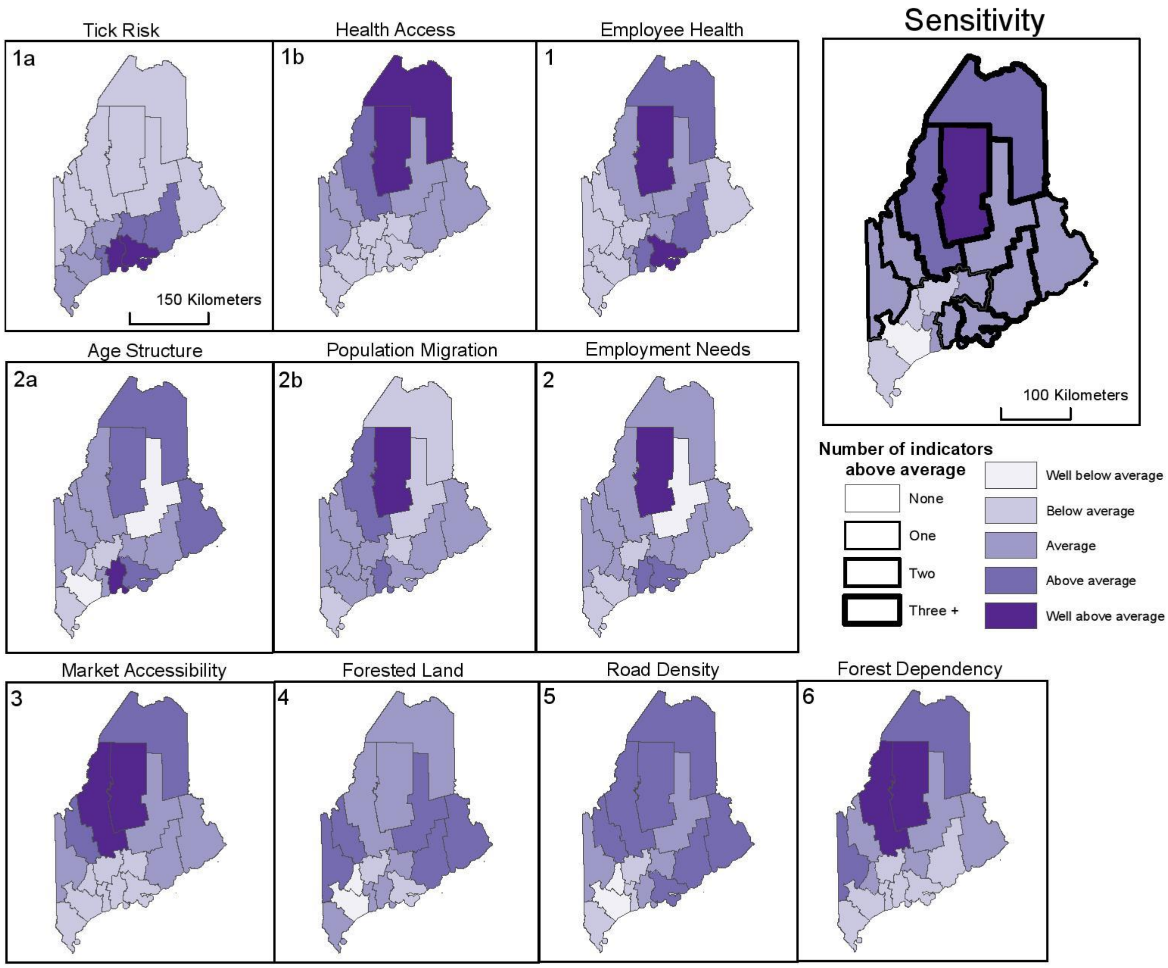

Figure 4.4. Indicator and variable maps for sensitivity. See Figure 4.3 caption for explanations.

Four counties in northwestern Maine have longer travel times to major mills compared with the rest of the state. The average travel time to a wood-using mill is 30 minutes in Maine, with as high as 75 minutes in northwestern Maine where some of the closest mills are in Canada (but still require a lengthy travel time compared to other Maine counties). Nearly half (7) of Maine's counties have a smaller road density compared with the state average and are concentrated both in northwestern Maine as well as along the northern coast. Five counties have a higher than average percentage of forested land, and are located both along the northern coast and western Maine. On average, 78% of the lands of Maine counties are classified as forests, with as high as 85% in Franklin and as low as 65% in Knox. Four counties have a higher dependence on the forest sector for employment compared with the state average. On average within each county, 3.5% of the labor force is employed in a forestry-related sector, with as much as 14% in Piscataquis.

Five counties are more sensitive to employee health compared with the state average. The counties are spatially dispersed, with some counties in northern Maine and some along the coast. The average population rate for tick-borne disease is 0.8%, with a high of 1.5% in Knox County and 0.03% in Aroostook County. The average travel time to healthcare facilities is 16 minutes across counties, with longer travel times in northern Maine, reaching 52 minutes in Piscataquis County. Three counties are above average for meeting employment needs, with no distinct spatial pattern present. The average age dependency ratio for all Maine counties is 0.65, meaning that for every 65 dependents there are 100 independents in the population, with the highest at 0.75 in Lincoln County and the lowest at 0.55 in Penobscot county. With the exception of Lincoln County, the age dependency ratio is highest in northern Maine. The average migration ratio (outbound:inbound) is 1.02, indicating that more people are moving out of Maine counties overall than moving in. The lowest migration ratio, and therefore the least sensitive is Penobscot county at 0.59, and the highest is Piscataquis County at 1.92.

4.3.3 Adaptive capacity

Six out of 16 Maine counties have low adaptive capacity compared to the state average, including: Aroostook, Kennebec, Penobscot, Lincoln, Oxford, and Somerset (Table 4.8). The six counties are located throughout the state, with no clear spatial pattern (Figure 4.5). Similar to exposure, each county has its own unique pattern of above and below average adaptive capacity indicators. As an example, Lincoln County is lower than average in social conditions and collective action, while Penobscot County is lower than average in cultural conditions and agency. It is also interesting to note that Waldo County is average, or above average, for all indicators of adaptive capacity.

Table 4.8. Adaptive capacity indicators found to be above average for each Maine county.

COUNTY	Cultural Conditions	Human Conditions	Social Conditions	Political Conditions	Collective Action	Agency	Adaptive Capacity
Androscoggin		dark grey					
Aroostook	light grey	light grey	light grey				light grey
Cumberland					light grey	light grey	
Franklin			light grey	light grey			
Hancock	light grey		light grey			light grey	
Kennebec	light grey	light grey				light grey	light grey
Knox		light grey					
Lincoln			dark grey		dark grey		light grey
Oxford	dark grey		light grey	light grey	light grey	light grey	dark grey
Penobscot	light grey					light grey	light grey
Piscataquis				dark grey	dark grey		
Sagadahoc			light grey				
Somerset		light grey		dark grey			light grey
Waldo							
Washington		light grey				light grey	
York			light grey				

Note: light grey indicates above average from the state mean (0.5-1.5 SD) while dark grey indicates well above state average (>1.5 SD).

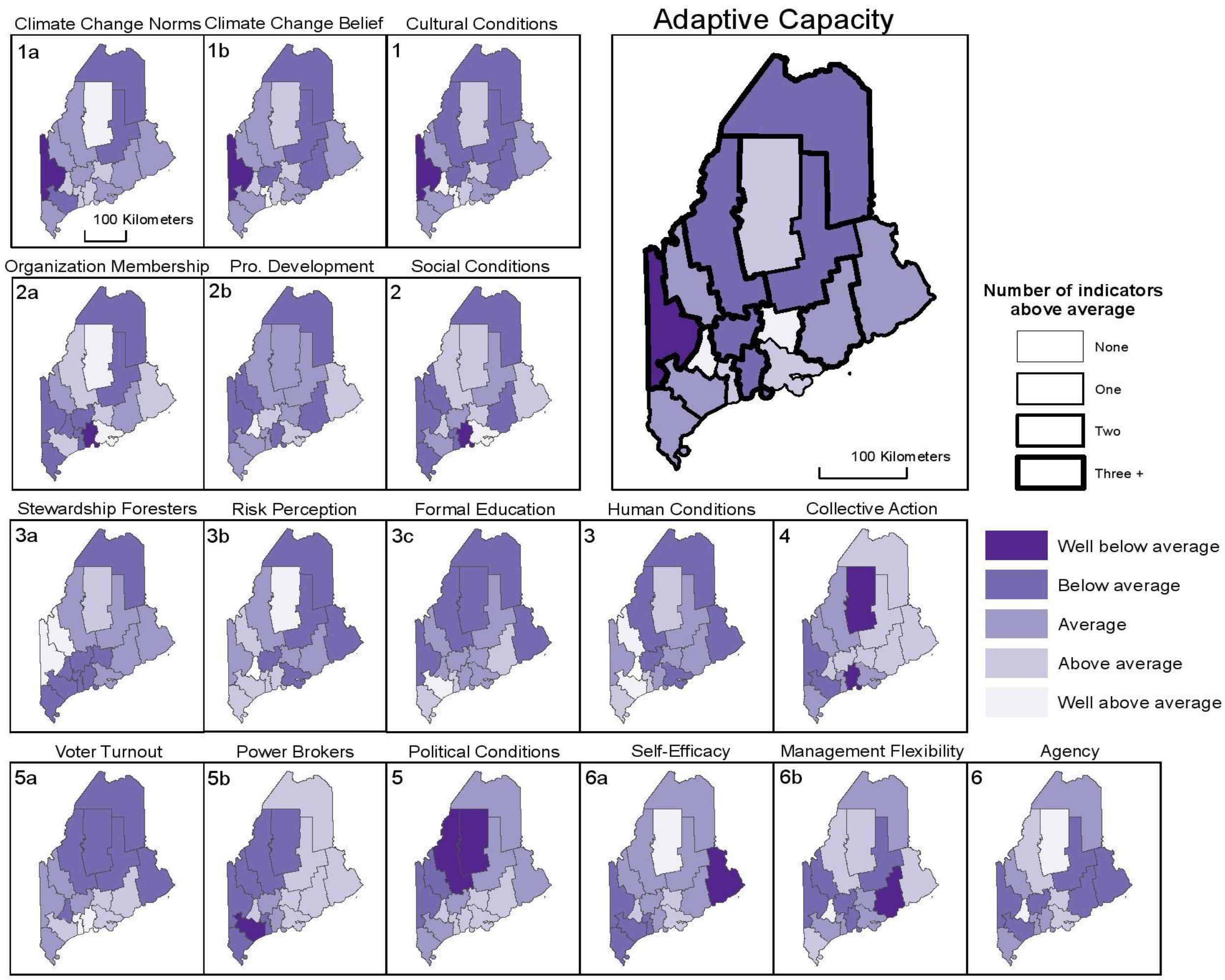

Figure 4.5. Indicator and variable maps for adaptive capacity. See Figure 4.3 caption for explanations.

Five counties are lower than average for cultural conditions (i.e. social norms and climate change beliefs), with the majority of counties located in the northern part of Maine with the exception of Oxford County. Social norms related to climate change adaptation and belief in climate change have similar spatial distributions. Across all Maine counties the average score for climate change norms is 3.69 out of 5, indicating a high level of social norms regarding climate change adaptation in Maine's forests. Belief in climate change is also high in Maine, with 90% of participants agreeing that climate change is occurring, and 70% agreeing that it is primarily caused by human activities. In Oxford, where cultural conditions are well below average, 70% of participants believe climate change is occurring, and 60% believe human activities are the primary cause. Seven counties are lower than average for social conditions, with a spatial distribution that is scattered throughout the state. The average organization membership is 1.86 organizations for all Maine counties, with the highest number in Piscataquis county (*M*=2.5 organizations). On average, 45% of participants feel that they have access to professional development opportunities to keep them informed on climate change, with as many as 100% in Androscoggin, and as low as 10% in Franklin. Lincoln County has the lowest average organization membership and lower than average access to professional development, resulting in Lincoln County being much lower than average for social conditions compared to the rest of the state.

Six counties are lower than average for human conditions compared to the state average, with the majority of those counties being located along coastal and northern Maine. The average number of licensed stewardship foresters in each county is 8.25, with southern Maine counties and Aroostook having relatively fewer stewardship foresters. On average, participants generally have high climate change risk perceptions (*M*=3.63 out of 5), with the highest perceptions of risk in Piscataquis County, and the lowest in northeastern Maine. On average 38% of Maine's population has at least an associate's degree, with the lowest percentage in northern Maine in Somerset at 29%. Four counties are lower than average for political conditions compared to the state average, located primarily in central Maine. Access to power brokers is below average in western Maine, while voter turnout is below average in northern Maine. Average voter turnout among Maine counties is 72%, with the lowest at 64% in Aroostook and the highest at 79% in Sagadahoc.

Six counties are lower than the state average for agency, with the majority in eastern Maine (with the exception of Oxford County in western Maine). Average self-efficacy is high among all Maine counties (*M*=3.25 out of 5), with the lowest at 2.5 in Washington County and the highest at 4.13 in Piscataquis County. On average, participants were willing to adopt/implement 12 out of 15 management strategies, with the lowest being nine strategies in Hancock County, and highest 15 strategies in Androscoggin County. Four counties have lower than average collective action compared to the state average. Across all counties the average collective action is 3.83 out of 5, with the highest in Waldo County (4.33) and the lowest in Piscataquis County (3.16), indicating that even in relatively lower counties collective action is still high.

4.3.4 Overall vulnerability

Only one county, Somerset County, has higher than average exposure and sensitivity and lower than average adaptive capacity (Figure 4.6). With the exception of Somerset there are no counties for which both exposure and sensitivity are higher than average. However, in Lincoln and Oxford counties exposure is high and adaptive capacity is low, while in Aroostook County sensitivity is high and adaptive capacity is low. Overall vulnerability is above average in five counties, including Aroostook, Franklin, Lincoln, Oxford, and Somerset. With the exception of Lincoln County located along the middle coast, vulnerability is generally above average in western and northern Maine.

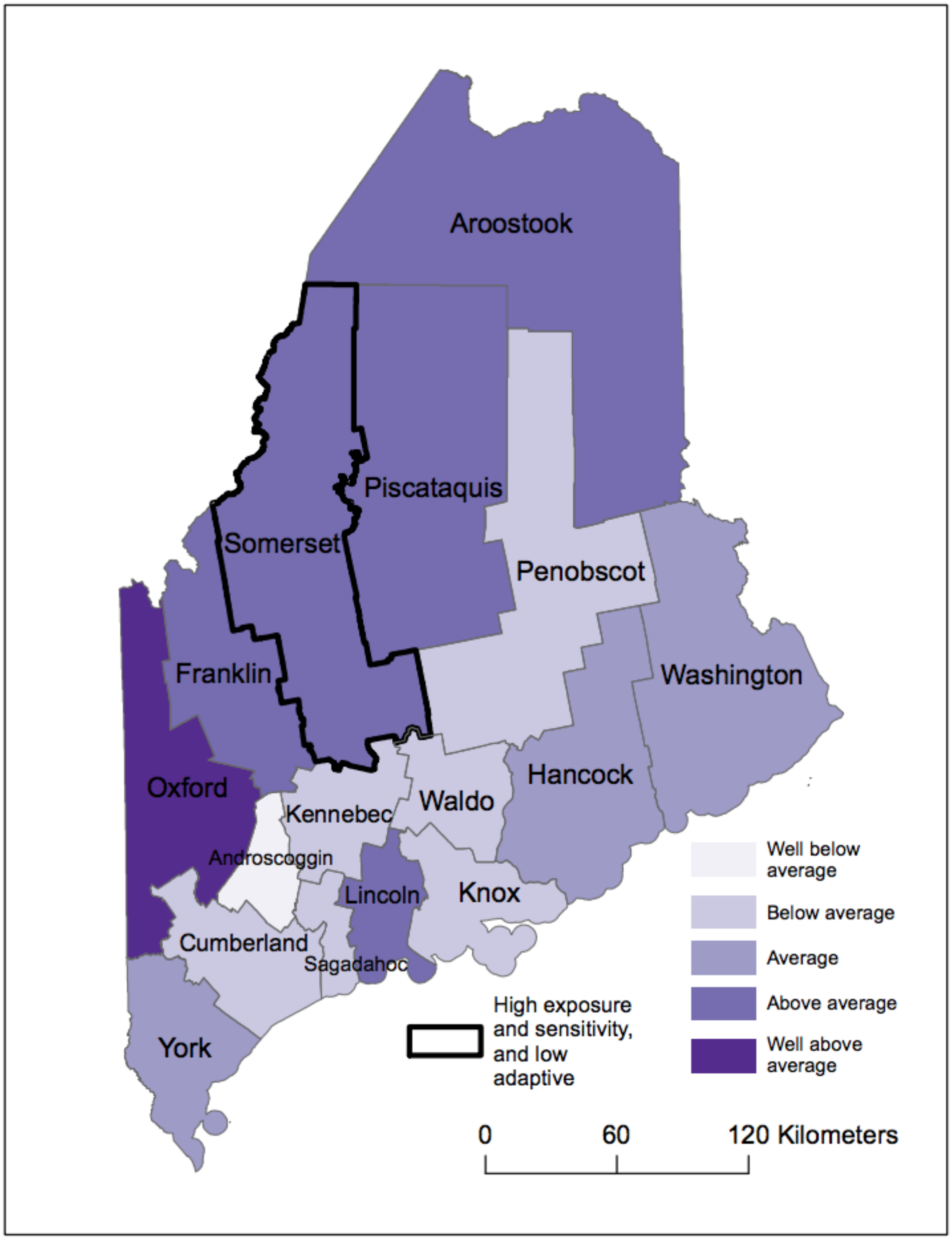

Figure 4.6. Overall vulnerability as a function of exposure, sensitivity, and adaptive capacity for Maine counties.

4.4 Discussion

Five out of 16 Maine counties are more exposed to climate-related impacts (Figure 4.3), three counties are more sensitive to the effects of the impacts (Figure 4.4), and six counties have lower adaptive capacity to deal with climatic changes (Figure 4.5) compared to the state average.

While increased stress from climate-related changes can negatively impact Maine's forest industry via increased operation costs, tree mortality, and/or decreases in commercially valuable species (identified in Chapter two), reduced sensitivities and increased adaptive capacity have the potential to largely decrease overall vulnerability in several parts of the state. By integrating biophysical data with socio-economic information we were able to identify counties that may be more threatened by climate change, but also counties that may be well suited to address negative impacts from a changing climate. A bottom-up indicator approach informed by stakeholder perceptions and existing literature (Chapter two) enabled us to evaluate individual impacts, sensitivities, and adaptive capacities to view each indicator on its own but also collectively; this tool can be modified and applied to examine vulnerability of the forest industry in many geographic locations. The vulnerability assessment also provides a tool to forest stakeholders and policy-makers to make informed management decisions based on regional patterns.

There has been considerable research regarding the impacts of climate change in Maine and the greater northeastern U.S. forests (Janowiak et al., 2018; Fernandez et al., 2020); therefore, we can situate our findings from exposure within the larger context of scientific understanding. It is also important to note that in vulnerability assessments of forest ecosystems for the northeastern U.S. nearly all of the indicators of exposure we analyzed are identified by experts as climate change impacts (Brandt et al., 2017). We found that extreme precipitation events have increased the most in western and southern coastal Maine, consistent with the findings of Fernandez et al. (2020), who also noted that stations in western Maine experience 10-15 more extreme precipitation events in a year than during the previous century. Additionally, winter is the fastest changing season (Fernandez et al., 2020) and we noted a decrease in frozen ground duration in southern coastal Maine, consistent with the findings of Contosta et al. (2019)

who also identified decreases in frost days and snow cover in southern Maine over the past 100 years. We did not identify any weather stations in central or northern Maine with significant decreases in frozen ground days; to understand this, we must consider the effect of both air temperature *and* snow cover on frozen ground duration (Hardy et al., 2001). Brown and DeGaetano (2011) in a model of soil temperatures to the end of the century, project soil temperature to increase only in the southern and coastal regions of Maine, given decreases in snow cover in northern Maine resulting in colder soils. Next, we found increases in soil moisture during mud season primarily in northeastern Maine of 0.012% saturation/decade, which is within the range of that modeled by Hayhoe et al. (2007) for the past century. The spatial pattern of increasing soil moisture largely mimics that of increasing springtime precipitation over the past century (Janowiak et al., 2018), and may suggest that mud season could last longer in northern Maine where soil moisture is increasing later into the spring. A recent study by McWilliams et al. (2018) used Forest Inventory and Analysis (FIA) data to estimate the probability of moderate to high ungulate browse impacts in the Midwest and Northeast. Despite the different methods employed in their assessment, the overall patterns are largely similar to our results, with increased probabilities of deer browse in southern Maine, along the coast, and patchily in central and northern Maine. Our exposure findings for each indicator largely coincide with results from other scientific studies in terms of historical ranges and spatial patterns, indicating a high level of agreement between our results and existing research. The aggregation of indicators, however, is a unique approach to evaluate vulnerability in Maine's forest industry, and therefore allows us to simultaneously examine combinations of potential changes.

In regards to sensitivity to climate change, we found that those counties that have more difficulty meeting employment needs (access to a skilled workforce) also have more difficulty meeting employee health needs, and that those highly sensitive counties are concentrated in the northwestern part of the state (e.g. Pisctaquis, Aroostook, Somerset). Vail (2010) describes these counties as 'rim counties' and notes that their lack of a mild climate and metropolitan centers makes it difficult to attract young skilled workers. However, making quality-of-place investments to incentivize current residents to stay, thereby reducing out-migration, can reduce sensitivity in these counties (Vail, 2010).

It is important that we discuss the complexity of Maine's forest industry as a socio-ecological system within the vulnerability assessment context as to increase its usefulness, and draw attention to the possible dynamics occurring in the coupled system (Turner et al., 2003). Therefore we consider how the indicators of vulnerability may interact with each other, which may result in either positive or negative cascading effects, as linear changes in stressors can result in nonlinear changes in socio-ecological systems (Angeler at al., 2016). For example, several valuable tree species, including ash and balsam fir, are projected to have some of the largest losses (greater than 20%) from insect and pest related tree mortality (Krist et al., 2014). In addition, increased pressure from deer herbivory occurring along western and central Maine can limit regeneration, especially of hardwood species (e.g. red maple, and oak) (LaRouche et al., 2010; Russell et al., 2001). As deer migrate northwards, replacing moose (Frelich et al., 2012), there is a possibility that increasing deer populations may coincide with increased disturbances in northern Maine, resulting in increased difficulty in regeneration. At the same time, deer selectively browse hardwood species, which are expected to shift their ranges north in Maine (Andreozzi et al., 2014). Given the interdependence of several variables, it is possible that small changes in several indicators may result in high levels of vulnerability due to their interactions. Additionally, the determinants of adaptive capacity are not independent of one another, as adaptive capacity is generated by the interaction of determinants which vary in space and time (Smit & Wandel, 2006). For this reason, it is extremely difficult to isolate the determinants of adaptive capacity (Smit & Wandel, 2006). As an example, determinants of collective action and social conditions are closely related (Adger, 2003) and both are facilitated by processes of social learning. Emery and Flora (2006) found that opportunities for more community interaction towards a common goal (similar to social conditions and collective action in our study) led to a process of 'spiraling-up,' or a non-linear increase of all other assets. Therefore, small increases in certain indicators can lead to large increases in adaptive capacity and, as a result, decrease overall vulnerability. Despite the challenges associated with identifying individual drivers, it is valuable to quantify and spatially map adaptive capacity to aid in decision-making (Fischer & Frazier, 2017).

To increase the implementation of forest management practices that enhance the adaptive capacity of Maine's forest industry, there is a current need to better link scientific information to specific adaptation actions (Moser et al., 2008). We attempt to connect the findings of the vulnerability assessment to possible management strategies. Counties that may have high exposure and low adaptive capacity may not be sensitive to climate change, which could therefore affect the degree to which those exposure indicators are experienced. For example, while southern coastal Maine has high exposure and low adaptive capacity it does not experience higher than average sensitivity. Additionally, where sensitivity is high in northern Maine, adaptive capacity may buffer effects of exposure (e.g. Piscataquis or Franklin County). Considering the combination of exposure, sensitivity, and adaptive capacity is important for designing appropriate and relevant adaptation actions for different regions across the state (Baca et al., 2014). For example, northwestern Maine counties are both exposed and highly sensitive to climate change. These same counties also have lower voter turnout, access to power brokers and professional development, formal education, and collective action. Strengthening social conditions, human conditions, and political conditions within these communities through, for example, targeted workshops may be one way to increase access to specific assets that could improve the industry's ability to adapt. Additionally, unique combinations of exposure impacts may lead to specific adaptation strategies that address multiple climate stressors. As an example, northern and western Maine areas are exposed to deer disturbance, shifting forest compositions of commercially valuable species, and pest and insect related tree mortality. Adaptation strategies that promote and enhance species diversity, promote landscape connectivity, and facilitate adjustments through species transitions may be useful in targeting all three of the climate change impacts.

It is critical, however, that adaptation planning considers local context and stakeholder perceptions and needs (Brandt et al., 2017; Lexer & Seidl, 2009). In a study of forestry and natural resource professionals in the northeastern US, Janowiak et al. (2019) found that the majority of respondents were implementing adaptation strategies; however, complexity of information, desire for customized management recommendations, and a need for real-world examples to demonstrate adaptation in action limited adoption of adaptation strategies for some stakeholders. Therefore, communication with stakeholders that hope to increase adaptation implementation must attempt to not only connect scientific information with specific adaptation actions, but also address perceived barriers to adaptation (Moser, 2014). In particular, within Maine's forest industry there exists a diversity of forest stakeholder types, with different perceptions of adaptation (Kline et al., 2000) that require tailored communications (Lähtinen et al., 2017). Communicating vulnerability to increase adaptation will therefore require targeted and tailored messaging based on the vulnerability assessment, as well as knowledge of stakeholder needs and perceptions. In addition, we must consider communication that fosters trust, multi-directional information flows, and iterative understanding among groups (Lindenfeld et al., 2014). Creating spaces for social learning where stakeholders can share their experiences and ideas with others (Armitage et al., 2008) can address the ongoing learning process involved in stakeholder engagement of adaptive management (Reed et al., 2010; Schusler et al., 2003). Social learning processes can transform how stakeholders adapt to uncertainty in a changing climate (Armitage et al., 2011; Restrepo et al., 2018), and enhance social capital to respond to these changes (Hahn et al., 2006). Flexibility in managing socio-ecological systems that are open to learning (Folke et al., 2002) is key to the increasing adaptive capacity of Maine's forest industry to reduce vulnerability.

4.4.1 Limitations

Vulnerability assessments cannot consider the totality of the socio-ecological system given nonlinear interacting forces operating across different spatial and temporal scales (Adger, 2004). For this reason, real-world data and constraints necessitate a "reduced" vulnerability assessment (Turner et al., 2003), and it is important to note the uncertainties and limitations of the indicators (Fellmann, 2012). First, given data availability and quality we were unable to include road conditions and intense wind events in the assessment despite participants ranking them highly during the NGT. Additionally, the weather station data (i.e. soil moisture, extreme precipitation, and frozen ground duration) was not uniformly distributed throughout the state; therefore, certain areas of the state (particularly northwestern Maine) were underrepresented. It is also important to note that in the analysis of market access and road conditions we did not consider temporary winter roads, which change yearly and provide an important access to timber stands for harvesting.

In regards to the variables of adaptive capacity that rely on survey data, we must acknowledge differential participation within each county. For example, some counties have only 10 participants while others have close to 30. It is possible we may not have enough cases for some counties (e.g. Piscataquis, Somerset, Androscoggin) to generalize results. This is exacerbated by the fact that we did not include all types of forest industry stakeholders in the survey, for example, mill workers and loggers. Additionally, participants may work in multiple counties across the state, but categorized respondents based on their *primary* location. To further examine the representativeness of the survey results we compared survey participant distribution to forest industry dependency (Figure 4.7). Counties along the northwestern part of the state are underrepresented compared to forest sector employment. Piscataquis County is particularly underrepresented given the high forest dependency and low survey response there. However, within counties with low participation, survey responses were generally consistent in terms of experiences with climate change impacts, management strategies, and risk perceptions.

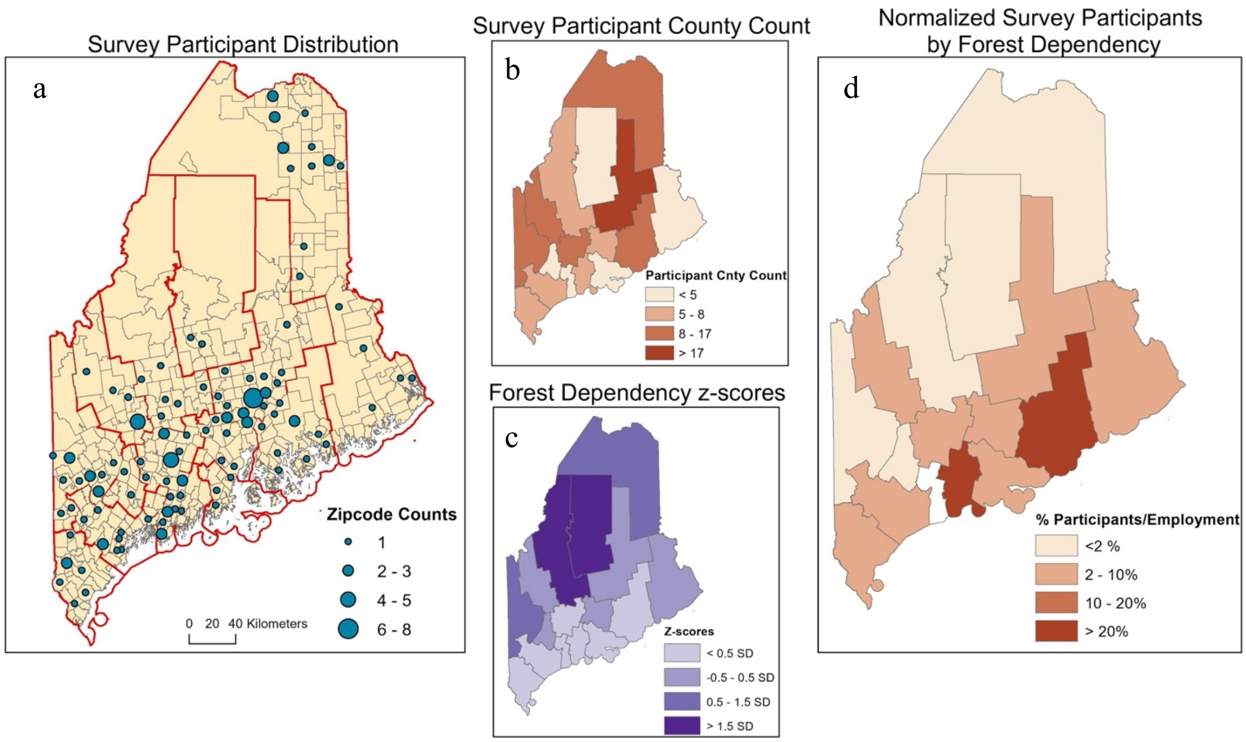

Figure 4.7. Survey participation distribution by a) zip code and b) within each county compared with c) forest dependency z-scores.

Note: To evaluate survey representation within counties based on forest sector employment d) is the percentage of survey participants within each county to 2017 forest sector employment counties from the County Business Patterns. Note: Sagadahoc County has no forest sector employment in 2017 based on the NAICS codes; however, four survey respondents noted working in Sagadahoc.

4.4.2 Future directions

Continued efforts can be made to improve our understanding of forest industry vulnerability to climate change. In particular, developing state-wide assessments of intense wind events and road conditions that were not included in the vulnerability model, would help to further refine indicators of exposure. Additionally, integrating the spatially explicit vulnerability assessment with stakeholder perceptions via local participatory mapping workshops would enable a more enhanced picture of forest industry vulnerability in the state as well as increase the reliability of adaptive capacity measures through stakeholder input and experience. Local participatory mapping would also provide finer resolution data that is currently not possible using weather station information alone. Workshops that encourage social learning would also serve to further connect the vulnerability assessment to specific adaptation actions, as stakeholders share their own experiences. Finally, scaling-up the vulnerability assessments to larger geographic regions, such as the northeastern U.S. would provide a much-needed analysis of region-level vulnerability for forest adaptation and decision-making.

4.5 Conclusions

We conducted a spatially explicit vulnerability assessment of Maine's forest industry to climate change using a bottom-up indicator approach informed by forest stakeholder perceptions and existing literature. We defined vulnerability in terms of exposure, sensitivity, and adaptive capacity, utilizing both biophysical and social data. Five out of 16 Maine counties are more exposed to climate-related impacts, three counties are more sensitive to the effects of the impacts, and six counties have lower adaptive capacity to deal with climatic changes compared to the state average. Overall vulnerability is above average in five counties, primarily in northern and western Maine, with the exception of Lincoln County. Each county has its own unique combination of exposure, sensitivity, and adaptive capacity indicators which can be leveraged to determine appropriate and relevant adaptation actions. Communicating with stakeholders to link the vulnerability assessment with specific adaptation actions will require tailored and targeted efforts that promote two-way communication and social learning. Given the diversity of climate-related impacts and socio-economic conditions in Maine, the methods employed in this study can be modified, improved, and applied to other geographic regions.

CHAPTER 5: CONCLUSION

This thesis research used a mixed-methods approach to evaluate and help enhance the ability of Maine's forest socio-ecological system to respond to climate change. Maine's forest industry is exposed to a variety of biophysical impacts and is highly sensitive to climatic change given their economic reliance on natural resources (Lucash et al., 2017; Butler, 2017). Socioeconomic pressures and biophysical impacts require forest managers to implement adaptation strategies to respond to climate change to ensure the future of their businesses and maintain and enhance healthy forest systems in Maine. However, given the uncertainties involved in managing forests for long-term planning it is essential to first identify impacts, evaluate vulnerabilities, and then determine appropriate adaptation actions (Swanston et al., 2016). The results from this thesis provide a critical understanding of perceptions of climate change risks and adaptation, as well as an assessment of biophysical and social vulnerability.

5.1 Integration of research

Chapter two presented an overview of stakeholder perceptions of climate change impacts via an expert elicitation technique, stakeholder interviews, and a review of the existing literature. Chapter three evaluated several factors, including socio-cultural influences, climate change risk perceptions, sources of information, and barriers and incentives to adaptation to discuss potential communication strategies to increase adaptation implementation. Finally, chapter four presented a spatially explicit vulnerability assessment of Maine's forest industry to climate change by combining biophysical and social indicators of exposure, sensitivity, and adaptive capacity. This final chapter integrates the findings from the mixed-methods approach to allow for a more complete understanding of the problem (Creswell, 2015). Three key topics emerge from the convergence of the research components: experiences with climate change, climate change as an opportunity, and uncertainty and complexity. This final chapter also discusses the implications for adaptation as well as future research needs.

5.1.1 Experiences and perceptions of climate change impacts

There is growing evidence that climate change has been personally experienced by forestry professionals (Yousefpour & Hanewinkel, 2015). In particular, experiences with disturbance-related tree mortality or extreme weather events such as wind or intense precipitation were reported in a study of forest owners in Europe (Sousa-Silva et al., 2016). Experience with climate change can increase risk perceptions (Akerlof et al., 2013), and has also been directly related with willingness to engage in adaptation management (Blennow et al., 2012). Chapter two presented results of prioritized climate change impacts, while chapter four mapped many of these same impacts. In addition, participants noted how often they experienced specific climate change impacts as part of the survey in chapter three (see Appendix L). Evaluating the similarities and differences between perceptions of climate change impacts and biophysical data can therefore illuminate which climate-related impacts may garner the most (and least) response via adaptation implementation.

Forest health issues imposed by insects and pathogens, as well as increasing extreme precipitation events were highly prioritized as negative impacts during the NGT, frequently experienced by survey respondents, and present a threat based on the vulnerability assessment results. When the results are integrated, despite risk of exposure, there is a high possibility (given stakeholders' perceptions and experiences) that implementation of adaptation strategies by forest stakeholders may increase the adaptive capacity of Maine's forest socio-ecological system to respond to insects/pathogens and extreme precipitation events. Given the presence across all methods, willingness to adopt management strategies may be high. This is also supported by survey respondents' high willingness to detect and remove invasive species, and improve road/culvert maintenance (related to extreme precipitation events by interview results). Conversely, NGT participants prioritized winter thaw relatively lower, despite a high percentage of survey participants experiencing winter thaw events. The vulnerability assessment results indicated that the number of frozen ground days are decreasing on average in most of Maine’s counties, presenting a threat to forest operations. Given the lower prioritization, even while winter thaw events may be highly experienced, the potential for implementing adaptation that addresses changing winters may be hindered by the perception that thaw events do not pose a great or likely impact to the forest industry. A greater understanding of the potential reasons for the lower prioritization, however, may be required as interview participants did discuss the negative impacts changing winter conditions were already having on harvesting operations.

Finally, NGT participants ranked shifts in forest composition as a top climate change impact, indicating both positive and negative effects on the forest industry as a result. While highly prioritized as likely and great, changes in forest biodiversity, productivity, and shifts in forest composition were the least experienced impacts from survey respondents and the vulnerability assessment results indicated that on average biomass and diversity of commercially important species are projected to *increase* in every Maine county. The absence of experience may in part explain the lack of willingness to guide changes in species composition to meet future expected needs. In addition, the perceived positive effects of shifts in forest composition, and the uncertainty involved in managing for future climates, may hinder widespread implementation of adaptation strategies that address shifting species composition. This could be of concern if shifts in forest composition interact with other disturbances, such as insects and pathogens and deer browse, resulting in negative cascading effects in the forest ecosystem that may decrease the availability of commercially valuable species into the future (Figure 5.1).

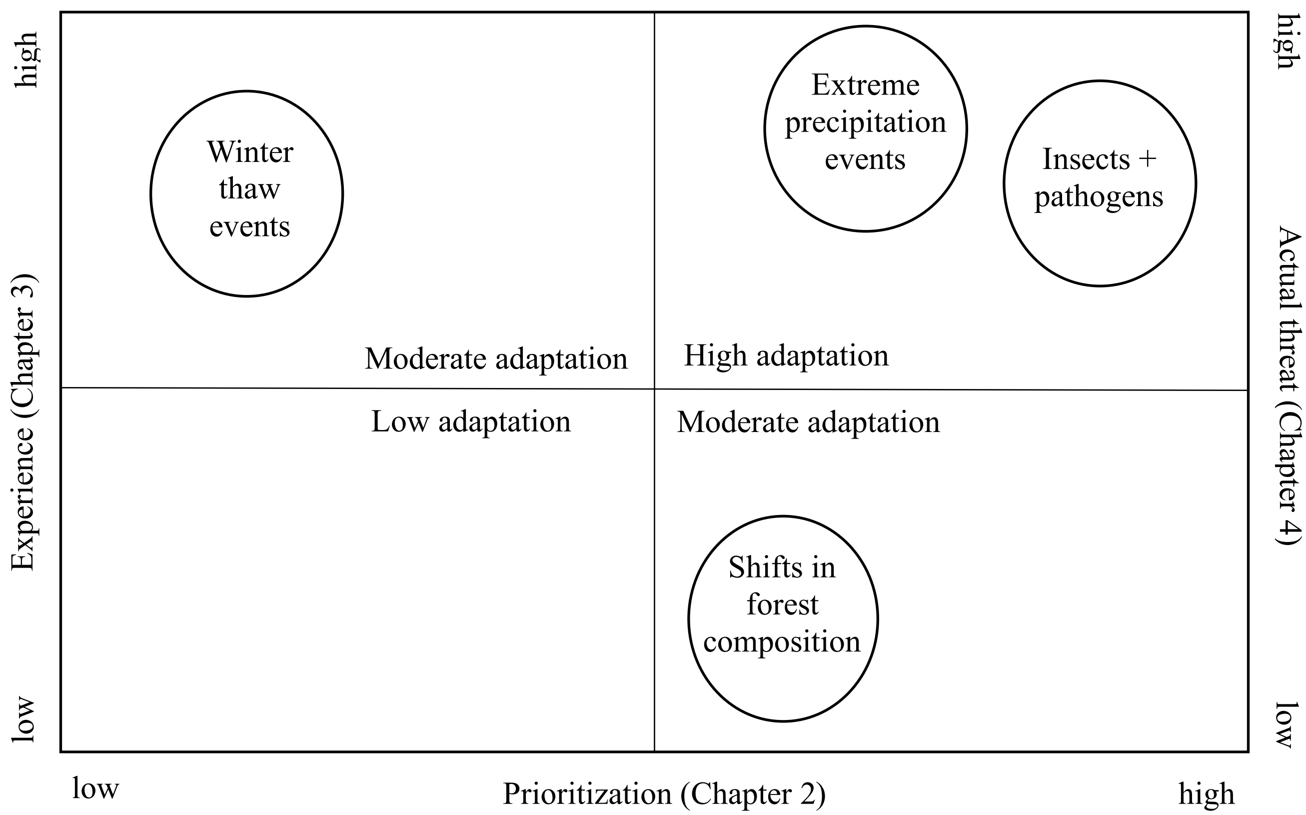

Figure 5.1. Integration of results shows impacts most willing to be addressed via adaptation.

5.1.2 Climate change as both a threat and opportunity

It is important to note that climate change presents not only a threat to Maine's forest industry, but also an opportunity. For example, shifts in forest composition and longer growing seasons were perceived by some as having a positive impact on the forest industry, and vulnerability assessment results indicated increases in biomass of commercially valuable tree species. Results from chapter three may also support this, as a large percentage of Maine's forest stakeholders perceived that climate change will have a significant impact on forest ecosystems within the next 50 years; however, far fewer perceived climate change as a threat to forest ecosystems, which may indicate climate change is in part viewed as an opportunity. While increased stress from climate-related changes can negatively impact Maine's forest industry via increased operation costs, tree mortality, and/or decreases in commercially valuable species, reduced sensitivities and increased adaptive capacity have the potential to largely decrease overall vulnerability in many parts of the state. For example, only one county (Somerset) has higher than average exposure and sensitivity and lower than average adaptive capacity. With the exception of Somerset there are no counties for which both exposure and sensitivity are higher than average.

5.1.3 Uncertainty and complexity as a common theme

There is a large degree of uncertainty and complexity involved in climate change adaptation (Spittlehouse, 2005). Chapter two revealed perceptions of uncertainty in regards to forest productivity and shifting forest composition, as well as an acknowledgment of the uncertainties involved in adapting to climate change impacts. Chapter three largely supported the results from Chapter two, as survey participants identified complexity of information and uncertainty about climate change impacts as barriers to climate change adaptation. In addition, the majority of participants believed there was insufficient information for understanding climate change impacts on Maine's forests. This is particularly concerning given that the uncertainty of management strategies and perceptions of impacts occurring far into the future may also result in a lack of urgency to adapt (Rodriguez-Franco & Haan, 2015). Complexity and uncertainty of the interactions of indicators within the vulnerability assessment was also present in chapter four. Chapter three describes specific communication strategies to reduce complexity and uncertainty, including describing concrete actions that can be taken to address specific impacts in a language that resonates with foresters (Moser, 2014).

5.2 Implications for adaptation

Increasing adaptive capacity involves promoting opportunities for *learning* and enhancing *management flexibility*. Social learning opportunities have the potential to increase perceptions of self-efficacy to adapt to climate change, and through sharing experiences and information, may result in increases in knowledge about adaptation actions and engagement in adaptive management (Armitage et al., 2011; Reed et al., 2010). Flexibility in managing socio-ecological systems is key to increasing the adaptive capacity (Folke et al., 2002) of Maine's forest industry. As evidenced from the integration of perceptions and experiences of climate change impacts, and the potential exposure the impacts may result in, there are several adaptation strategies that might be more widely accepted by stakeholders (e.g. adaptation strategies that address insects/pathogens and extreme precipitation events). Management flexibility was lower than average in Oxford, Franklin, Kennebec, Lincoln, Penobscot, and Hancock counties. Most of these counties were less willing to implement strategies to create local refuges, increase species diversity, and foster connected landscapes; while all three strategies were widely accepted in most other counties. Promoting these adaptation actions to address climate change in these counties may therefore generate the greatest increase in management flexibility. While only 65% of survey participants were willing to formally incorporate climate change into their forest management planning process, framing climate change adaptation as a forest health concern may allow stakeholders to view the time and money they already put into management as a response to climate change.

However, a small percentage of survey participants believed they knew what adaptation efforts to make to address climate change impacts and felt that current management strategies implemented in Maine were insufficient to adapt to climate change. Therefore, there is a growing need to better link scientific information to specific adaptation actions (Moser et al., 2008), especially given the perceptions of complexity and uncertainty of climate change impacts. Tailored communications that target audiences based on the combination of local context/vulnerability and their perceptions of climate change impacts and adaptation are key to increasing implementation of climate change adaptation strategies (Brandt et al., 2017). Chapter three highlighted differences between land managers and small woodlot owners in Maine, particularly in terms of their perceived self-efficacy, and barriers and incentives to adaptation. Given that participants also provided their work zip code, we can leverage the results of stakeholder differences and the vulnerability assessment to provide locally relevant communication strategies based on vulnerability and prominent stakeholder group. For example, Aroostook and Penobscot counties have more industry land managers than small woodlot owners. Both counties have lower than average adaptive capacity, particularly within the cultural, social, and human conditions category. Strengthening adaptive capacity within these counties, that are primarily composed of land managers, may include appealing to social norms and improving market incentives (i.e. social licensing and green certification). Lincoln and York countiescounties have more small woodlot owners and are also highly exposed to climate change. Addressing stakeholder perceptions of low self-efficacy, and increasing access to professional development for social learning opportunities can increase adaptive capacity in these counties with more small woodlot owners.

5.3 Future research

Continued efforts can be made to improve our understanding of forest industry vulnerability to climate change. In particular, participatory mapping workshops can continue to connect climate change impacts with specific adaptation strategies that stakeholders are already implementing. Integrating the participatory mapping with the current vulnerability assessment will continue to provide insights into the differences between perceptions of impacts and current weather data, and help further validate the results of the vulnerability assessment. Given the nature of data resolution in Maine, the vulnerability assessment was evaluated at the county-level, which is not always relevant for individual forest stakeholders who must consider local contexts. Participatory workshops can also serve to provide a finer resolution assessment of impacts and adaptation that can aid in decision-making. Next, continued analysis of the survey results from Chapter three can contribute to our understanding of the socio-psychological determinants of climate change via regression analysis. This will be a particularly interesting result as the CCRPM is applied to forest industry stakeholders. Finally, this thesis research has policy implications in terms of decision-support tools, perceptions of Maine policy, and barriers and incentives to adaptation. Sharing the results with key stakeholders and decision-makers to influence policy in the state is an important next step.

5.4 Final thoughts

The results can be leveraged to increase resilience of Maine's forest socio-ecological system to climate change by (1) influencing appropriate communication strategies that aim to increase adaptation implementation among forest stakeholders; (2) providing a spatially explicit assessment of vulnerabilities that can be used by policy and decision-makers to allocate resources as well as by stakeholders to guide management decisions; and (3) guiding future research needs (as well as policy) based on the top climate change impacts stakeholders identified, and their top needs and incentives for implementing forest adaptation strategies. Unlike forest ecosystems or forest-based communities, assessments of forest industry-specific vulnerabilities and perceptions of risks and adaptation have received minimal attention in the existing literature (Fischer & Frazier, 2018). Therefore, the framework presented in this thesis, established on theoretical and methodological groundings, is a novel multi-method approach that can have widespread application elsewhere.

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APPENDIX A: NGT INSTRUMENT

Please rank the top 5 greatest impacts that climate change poses to the forestry industry (5 = greatest impact; 1 = least impact).

No. from flip chart	Item Description	Rank order (1-5)	Increase (+)/Decrease (-)/ Not Applicable
1	Insects and pathogens	________	________
2	Invasive species	________	________
3	Shifts in forest composition	________	________
4	Drought	________	________
5	Intense wind events	________	________
6	Changes in wildlife populations	________	________
7	Changes in operation length	________	________
8	Extreme precipitation events	________	________
9	Wildfire	________	________
10	Changes in soil moisture	________	________
11	Thaw events in winter	________	________
12	Change in forest productivity	________	________
13	Changes in winter snow cover	________	________
14	Changes in road condition	________	________
15	Changes in growing season length	________	________
16	Changes in seasonal temperatures	________	________
17	________________________	________	________
18	________________________	________	________
19	________________________	________	________
20	________________________	________	________
21	________________________	________	________
22	________________________	________	________
23	________________________	________	________
24	________________________	________	________
25	________________________	________	________
26	________________________	________	________
27	________________________	________	________
28	________________________	________	________
29	________________________	________	________
30	________________________	________	________

Please rank the 5 most likely impacts that climate change poses to the forestry industry (5 = most likely; 1 = least likely).

No. from flip chart	Item Description	Rank order (1-5)	Increase (+)/Decrease (-)/ Not Applicable
1	Insects and pathogens	________	________
2	Invasive species	________	________
3	Shifts in forest composition	________	________
4	Drought	________	________
5	Intense wind events	________	________
6	Changes in wildlife populations	________	________
7	Changes in operation length	________	________
8	Extreme precipitation events	________	________
9	Wildfire	________	________
10	Changes in soil moisture	________	________
11	Thaw events in winter	________	________
12	Change in forest productivity	________	________
13	Changes in winter snow cover	________	________
14	Changes in road condition	________	________
15	Changes in growing season length	________	________
16	Changes in seasonal temperatures	________	________
17	____________________	________	________
18	____________________	________	________
19	____________________	________	________
20	____________________	________	________
21	____________________	________	________
22	____________________	________	________
23	____________________	________	________
24	____________________	________	________
25	____________________	________	________
26	____________________	________	________
27	____________________	________	________
28	____________________	________	________
29	____________________	________	________
30	____________________	________	________

Questionnaire

Which forest industry sub-sector do you represent (Please check ALL that apply)?

- ☐ Bioenergy
- ☐ Investment
- ☐ Land managers
- ☐ Land owners
- ☐ Loggers
- ☐ Profession services (mapping, surveying)
- ☐ Pulp and paper mills
- ☐ Sawmills
- ☐ Transportation
- ☐ Tourism
- ☐ Recreation
- ☐ Research
- ☐ Other (please specify)____

How many years of experience do you have with the forestry industry (administrative/field)?

Number of years administrative work: ____
Number of years fieldwork: ____
Number of years other forestry work (please specify): ________________________________

Current geographic area of work (Please check ALL that apply):

- ☐ Maine: Androscoggin County
- ☐ Maine: Aroostook County
- ☐ Maine: Cumberland County
- ☐ Maine: Franklin County
- ☐ Maine: Kennebec County
- ☐ Maine: Hancock County
- ☐ Maine: Knox County
- ☐ Maine: Lincoln County
- ☐ Maine: Oxford County
- ☐ Maine: Penobscot County
- ☐ Maine: Piscataquis County
- ☐ Maine: Sagadahoc County
- ☐ Maine: Somerset County
- ☐ Maine: Waldo County
- ☐ Maine: Washington County
- ☐ Maine: York County
- ☐ Other State in New England
- ☐ Canada
- ☐ Other (specify) __________________________________

Please rank the top 3 tree species that are most important to your business operations.

1. ____
2. ____
3. ____

Please rank the top 3 tree species that are most vulnerable to climate change.

1. ____
2. ____
3. ____

Please rank the top 3 tree species that are most resilient to climate change.

1. ____
2. ____
3. ____

Please circle the area(s) that you think will be most impacted by climate change, indicating whether this is a positive impact (+) or negative impact (-).


QUEBEC
CANADA
NEW BRUNSWICK
CANADA
AROOSTOOK
PISCATAQUIS
Houlton
SOMERSET
PENOBSCOT
Dover-Foxcroft
FRANKLIN
WASHINGTON
Skowhegan
Bangor
Farmington
Machias
HANCOCK
OXFORD
WALDO
Ellsworth
KENNEBEC
Belfast
Augusta
N.H.
South Paris
Auburn
Rockland
LINCOLN
ANDROSCOGGIN
Wiscasset
KNOX
Bath
CUMBERLAND
SAGADAHOC
Portland
Alfred
YORK
MA.
ATLANTIC OCEAN
MAINE
CITIES
State capitals
County seats
BOUNDARIES
International
State and Provincial
County
0 20 40 mi
0 32 64 km
©1998, Encyclopædia Britannica, Inc.

How willing would you be to adopt or advise on the following management practices as a means to adapt to, or cope with, climate change?

	Not willing at all	Hesitant to adopt or advise	Willing	Very willing	Extremely willing	Willing to learn more about it
Thin trees out of overly dense forests to reduce the risk of large-scale stand mortality from drought and/or fire.	○	○	○	○	○	○
Conduct prescribed burns in forests in an effort to restore or retain natural fire cycles.	○	○	○	○	○	○
Foster connected landscapes, such as by retaining or gaining protection of riparian zones, to promote the natural migration of species.	○	○	○	○	○	○
Create monitoring programs to assess forest health.	○	○	○	○	○	○
Improve road and culvert maintenance/construction	○	○	○	○	○	○
Create early-detection programs to detect new invasions of undesired exotic species.	○	○	○	○	○	○
Conduct rapid removal programs on newly detected species considered invasive.	○	○	○	○	○	○
Plant seedlings from local plants only (i.e., following the existing standard of using local species only).	○	○	○	○	○	○
Create local refuge for endangered species.	○	○	○	○	○	○
Erect snow fences where early snowmelt could be a problem.	○	○	○	○	○	○
Make an effort to use redundancy (such as also planting on sites that are historically non- optimal for a specific species or community) when restoring a site following disturbance.	○	○	○	○	○	○

Plant seedlings from plants outside of the standard range (i.e., those from environments suitable to future climate)- *using different genotypes of the same species that exist locally.*	○	○	○	○	○	○
Plant seedlings from plants outside of the standard range (i.e., those from environments suitable to future climate) - *using species that do not currently occur in the local area.*	○	○	○	○	○	○
Allow the invasion of species that seem likely to be suited to changing climate (“neo-native” species).	○	○	○	○	○	○
Promote the expansion—following major disturbance—of plants or animals into different locations that may be climatically suitable for them.	○	○	○	○	○	○
Consider “re-aligning” the system with different species if it has been pushed too far out of historic conditions—whether by manipulation or disturbance—when considering restoration.	○	○	○	○	○	○

APPENDIX B: INTERVIEW PROTOCOL

Time of interview:

Date of interview:

Interviewee ID #:

Interviewee activity or characteristics (profile: age, gender, role, type of organization):

Materials to check: tape recorder, batteries, consent form

Questions

1. How important is the forest system to your business?
2. How do you define a healthy forest system?

Now I'd like to ask you about some of the challenges, threats, and opportunities you see your business encountering due to environmental and climatic changes.

3. Have you noticed any environmental changes that affect your business? What have you noticed and what have been the indicators of this change?
    a. What have you done to respond to these changes? To prepare to any changes?
    b. How concerned are you about climate change?

4. Have you seen any changes in weather conditions in Maine in the last 10 years?
    a. If so, what changes have you seen/observed?

5. What are the greatest risks that climate change currently poses to your business's success?

6. Do you envision any future climate change risks that may affect your business's economic security?

7. Do you envision communities being affected by climate change in the future?
    a. How?
    b. Are they currently being affected by changing weather conditions

8. How might climate change help your business?

9. How informed do you feel you are about climate change?

10. What kinds of sources do you receive information about climate change from?
    a. Why do you use these sources?
    b. If you were to receive more information about climate change, which sources would you be most likely to trust?
        i. Why?

c. What kind of information about climate change effects on Maine's forest industry would you find most helpful for making informed management decisions?

For this last section, I would like to ask you about any potential mitigation and adaptation strategies your business is employing or thinking of employing.
Mitigation: refers to efforts to reduce or prevent emission of greenhouse gases or carbon dioxide (can involve using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior)
Adaptation: involves taking actions to manage risks from climate impacts, protect communities and strengthen the resilience of the economy (changes you make to remain in a stable state)

11. Are there any changes your business has made in response to climate change?

12. Are there any changes your business intends to make in the next five years to adapt to potential effects of climate change?

Remember to thank the participants for the information provided.
Do not forget to emphasize on the confidentiality of their information.

APPENDIX C: SURVEY INSTRUMENT

PART A. ***In this section, we would like to learn more about your experience in the forest sector.***

Which forest sub-sector(s) do you represent? (Please check ALL that apply)

- ☐ Bioenergy
- ☐ Capital Investment
- ☐ Conservation
- ☐ Education
- ☐ Forest Land Management
- ☐ Government
- ☐ Harvesting
- ☐ Professional Services (mapping, surveying, consulting)
- ☐ Pulp and Paper Mills
- ☐ Sawmills
- ☐ Tourism and Recreation
- ☐ Transportation
- ☐ Other (*Please specify*) ____

Of those selected, which sub-sector do you primarily work in?

- ◯ Bioenergy
- ◯ Capital Investment
- ◯ Conservation
- ◯ Education
- ◯ Forest Land Management
- ◯ Government
- ◯ Harvesting
- ◯ Professional Services (mapping, surveying, consulting)
- ◯ Pulp and Paper Mills
- ◯ Sawmills
- ◯ Tourism and Recreation
- ◯ Transportation
- ◯ Other

How would you best describe your primary position?

- ◯ Appraiser
- ◯ Biologist
- ◯ Consultant
- ◯ Engineer
- ◯ Forester
- ◯ Government Official
- ◯ Land Manager
- ◯ Landowner
- ◯ Logger

- ◯ Planner
- ◯ Researcher
- ◯ Teacher
- ◯ Technician
- ◯ Other (*Please specify*) ____

How many total years of experience do you have working in the forest sector in Maine?

- ◯ Less than 1
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ …
- ◯ 60
- ◯ 61
- ◯ 62
- ◯ 63
- ◯ 64
- ◯ 65
- ◯ 66
- ◯ 67

○ 68

○ 69

○ 70

○ Greater than 70

To what extent have you noticed the following conditions in the last 5 years in Maine?

	Never	Rarely	Occasionally	Frequently	Very Frequently
Changes in Biodiversity	○	○	○	○	○
Changes in Forest Productivity	○	○	○	○	○
Changes in Growing Season Length	○	○	○	○	○
Changes in Seasonal Temperatures	○	○	○	○	○
Changes in Seasonal Precipitation	○	○	○	○	○
Changes in Wildlife Populations	○	○	○	○	○
Changes in Wood Quality	○	○	○	○	○
Deer Browse	○	○	○	○	○
Drought Conditions	○	○	○	○	○
Extreme Precipitation Events	○	○	○	○	○
Forest Health Issues	○	○	○	○	○
Insect Damage	○	○	○	○	○
Intense Wind Events	○	○	○	○	○
Invasive Plant Species	○	○	○	○	○

Lyme Disease	○	○	○	○	○
Poor Road Conditions	○	○	○	○	○
Shifts in Forest Composition	○	○	○	○	○
Soil Erosion	○	○	○	○	○
Winter Thaw Events	○	○	○	○	○

Of those that you've noticed, how would you describe their <u>impact on the forest sector in Maine</u>?

	Negative Impact	Positive Impact	Both Positive and Negative Impact	No Impact
Changes in Biodiversity	○	○	○	○
Changes in Forest Productivity	○	○	○	○
Changes in Growing Season Length	○	○	○	○
Changes in Seasonal Temperatures	○	○	○	○
Changes in Seasonal Precipitation	○	○	○	○
Changes in Wildlife Populations	○	○	○	○
Changes in Wood Quality	○	○	○	○
Deer Browse	○	○	○	○
Drought Conditions	○	○	○	○
Extreme Precipitation Events	○	○	○	○
Forest Health Issues	○	○	○	○

Insect Damage	○	○	○	○
Intense Wind Events	○	○	○	○
Invasive Plant Species	○	○	○	○
Lyme Disease	○	○	○	○
Poor Road Conditions	○	○	○	○
Shifts in Forest Composition	○	○	○	○
Soil Erosion	○	○	○	○
Winter Thaw Events	○	○	○	○

Of those that you've observed, which ones do you attribute (**at least** in part) to a changing climate? (Please check ALL that apply)

- Changes in Biodiversity
- Changes in Forest Productivity
- Changes in Growing Season Length
- Changes in Seasonal Temperatures
- Changes in Seasonal Precipitation
- Changes in Wildlife Populations
- Changes in Wood Quality
- Deer Browse
- Drought Conditions
- Extreme Precipitation Events
- Forest Health Issues
- Insect Damage
- Intense Wind Events
- Invasive Species
- Lyme Disease
- Poor Road Conditions
- Shifts in Forest Composition
- Soil Erosion
- Winter Thaw Events

Impacts from a changing climate on the <u>forest sector in Maine</u> make me feel...

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Angry	○	○	○	○	○
Concerned	○	○	○	○	○
Excited	○	○	○	○	○
Fearful	○	○	○	○	○
Happy	○	○	○	○	○
Hopeful	○	○	○	○	○
Sad	○	○	○	○	○
Uncertain	○	○	○	○	○

PART B. ***In this section, we are interested to learn more about where you go to for information related to forests and climate change.***

During the last month, did you obtain/seek any information about changes in <u>climate conditions</u> in Maine?

○ Yes

○ No

From which sources did you receive information about changes in climate conditions in Maine? *(Please check ALL that apply)*

- ☐ Friends/Family
- ☐ Journal articles
- ☐ Maine Forest Service
- ☐ Manomet
- ☐ Newspapers
- ☐ NOAA Website
- ☐ Other Website (*Please specify*) ____________________________
- ☐ Other Forestland Owners
- ☐ Radio Program
- ☐ TV Program
- ☐ United States Forest Service
- ☐ University of Maine (*Please specify either person, department, or campus*) ________
- ☐ Other (*Please specify*) ____

In general, to what extent do you trust these groups when it comes to providing information about changes in climate conditions in Maine?

	Strongly Distrust	Distrust	Neutral	Trust	Strongly Trust
Friends/Family	○	○	○	○	○
Journal Articles	○	○	○	○	○
Maine Forest Service	○	○	○	○	○
Manomet	○	○	○	○	○
Newspapers	○	○	○	○	○
NOAA Website	○	○	○	○	○
Other Website - ______	○	○	○	○	○
Other Forestland Owners	○	○	○	○	○
Radio Program	○	○	○	○	○
TV Program	○	○	○	○	○
United States Forest Service	○	○	○	○	○
University of Maine - _____	○	○	○	○	○
Other	○	○	○	○	○

Please indicate the extent to which you agree or disagree with the following statements regarding climate change.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Climate change is currently occurring	○	○	○	○	○
Climate change is primarily caused by natural forces	○	○	○	○	○
Climate change is primarily caused by human activities	○	○	○	○	○
Climate change is caused equally by natural forces and human activities	○	○	○	○	○
Climate change is currently occurring but I am unsure of its causes	○	○	○	○	○
I am unsure whether or not climate change is currently occurring	○	○	○	○	○

We are interested in learning more about your management strategies. Please indicate the extent to which you agree or disagree with the following statements related to management in **Maine's forests**.

- Climate change mitigation refers to actions that an individual or group may use to reduce greenhouse gases (i.e. reducing emissions) while climate change adaptation refers to strategies that an individual or group may use to adjust to actual or expected future climate.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I know what adaptation efforts to make regarding climate change impacts	○	○	○	○	○
I know what mitigation efforts to make regarding climate change	○	○	○	○	○
I am confident in my ability to ask questions about climate change	○	○	○	○	○
I know where to find the answers to my questions about climate change	○	○	○	○	○
There is sufficient information available for understanding climate change impacts on Maine's forests	○	○	○	○	○
There are specific management practices available to help land managers adapt to climate change in Maine's forests	○	○	○	○	○
I have access to professional development opportunities to keep me informed on climate change adaptation	○	○	○	○	○

PART C. ***In this next section, we are interested in your views regarding opportunities and challenges associated with a changing climate and forests.***

Please indicate the extent to which you agree or disagree with the following statements regarding your perceptions of climate change impacts in Maine.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Within the next 50 years climate change is going to have a significant impact on forest ecosystems in Maine	○	○	○	○	○
Within the next 50 years climate change is going to have a significant impact on the forest sector in Maine	○	○	○	○	○
The effects of climate change in Maine are understood by forest managers	○	○	○	○	○

Forest managers have the <u>ability to control climate change impacts</u> on forest ecosystems in Maine	○	○	○	○	○
There is still <u>plenty of time to implement forest adaptation</u> strategies to address climate change in Maine	○	○	○	○	○
Climate change presents a serious threat to <u>forest ecosystems</u> in Maine	○	○	○	○	○
Climate change presents a serious threat to Maine's <u>forest sector</u>	○	○	○	○	○
Climate change presents a serious threat to <u>me personally</u>	○	○	○	○	○
Climate change presents a serious threat to the <u>company/organization that I work for</u>	○	○	○	○	○

For each value listed below, please rate the extent to which you consider it to be a <u>guiding principle in your life</u>

	Not Important At All	Of Little Importance	Somewhat Important	Important	Very Important
Being wealthy	○	○	○	○	○
Preventing pollution	○	○	○	○	○
Promoting peace	○	○	○	○	○
Protecting the environment	○	○	○	○	○
Having social power	○	○	○	○	○
Having authority	○	○	○	○	○
Being helpful	○	○	○	○	○

Having social justice	○	○	○	○	○
Respecting the earth	○	○	○	○	○
Being influential	○	○	○	○	○
Being unified with nature	○	○	○	○	○
Having equality	○	○	○	○	○

We are interested in learning more about the people that are important to you. Please indicate the extent to which you agree or disagree with the following statements in regards to climate change in Maine's forests.

There are several questions below that refer to the **company/organization** that you work for.
- The company/organization that you work for within the forestry sector can either be the one in which you are employed or the one in which you are the owner.

- Companies/organizations include, but are not limited to, federal/state agencies, nonprofits, consulting firms, pulp/paper mills, private management companies, transportation companies.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Most people who are important to me (i.e. close friends, family, and/or colleagues) are personally doing something to help reduce the risk of climate change impacts on forest ecosystems	○	○	○	○	○
Other companies/organizations within my sector are doing something to help reduce the risk of climate change impacts on forest ecosystems	○	○	○	○	○
I feel that reducing the risk of climate change impacts on forest ecosystems is something that is expected of me	○	○	○	○	○
Most people I care about believe in climate change	○	○	○	○	○

People who are important to me would support my efforts to reduce the risks of climate change on forest ecosystems	○	○	○	○	○
People that I work with would support my efforts to reduce the risks of climate change on forest ecosystems	○	○	○	○	○
The leader(s) of the company/organization that I work for would support my efforts to reduce the risks of climate change on forest ecosystems	○	○	○	○	○

Please indicate the extent to which you agree or disagree with the following statements in regards to the company/organization that you work for in Maine's forest sector.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
My company/organization has effective leaders	○	○	○	○	○
My company/organization collaborates with other companies/organizations to get things done	○	○	○	○	○
My company/organization works with the government to promote healthy forest systems	○	○	○	○	○
People in my company/organization work together to get things done	○	○	○	○	○
People in the sector that I work in are willing to share information to learn from one another	○	○	○	○	○
People in my company/organization are committed to the well-being of the company/organization	○	○	○	○	○
My company/organization has access to skilled people	○	○	○	○	○
The interests of my company/organization are considered by local community leaders	○	○	○	○	○

PART D. ***In this section, we would like to know more about your company or organization's current forest management practices.***

Please indicate the extent to which you are agree or disagree with the following statements regarding forest practices and policies in Maine.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Current State forest policies in Maine take into account the impacts of climate change on forest ecosystems	○	○	○	○	○
The forest practices currently implemented in Maine are sufficient to face the impacts of climate change on forests	○	○	○	○	○
We need to create and design new forest practices in Maine to deal with the impacts of climate change on forests	○	○	○	○	○
We need to adopt policies that have been successful in other states/countries to deal with the impacts of climate change on forests	○	○	○	○	○

My company/organization plans for how many years in advance?

- ○ Less than 1
- ○ 1 - 5
- ○ 6 - 10
- ○ 11 - 20
- ○ 21 - 30
- ○ 31 - 50
- ○ 50 - 75
- ○ 75 - 100
- ○ Greater than 100

In an ideal world (regardless of available resources or feasibility), how willing would your organization/company be to adopt (or advise if serving as a consultant) the following practices as part of their forest management toolbox?

	Not Willing At All	Somewhat Willing	Willing	Very Willing

Change the timing of core forest operation activities to reduce negative environmental impacts	○	○	○	○
Conduct rapid removal of newly detected invasive species	○	○	○	○
Consider adopting management practices even if they have a high level of uncertainty so they could serve as experimental efforts	○	○	○	○
Create early-detection programs to identify new invasions of undesired exotic species	○	○	○	○
Create local refuges for endangered species	○	○	○	○
Enhance stand-level diversity	○	○	○	○
Expand product portfolio (i.e. diversify investments)	○	○	○	○
Foster connected landscapes	○	○	○	○
Formally incorporate climate change into the forest management planning process	○	○	○	○
Guide changes in species composition at early stages of development to meet expected future conditions	○	○	○	○
Improve forest inventory methodologies	○	○	○	○
Improve road/culvert maintenance	○	○	○	○
Maintain and enhance species diversity	○	○	○	○
Promote a variety of different aged stands	○	○	○	○
Thin trees out of overly dense forests	○	○	○	○

Of those management practices, which ones would your company/organization adopt as part of their effort to adapt to climate change?

- ☐ Change the timing of core forest operation activities to reduce negative environmental impacts
- ☐ Conduct rapid removal on newly detected species considered invasive
- ☐ Consider adopting management practices even if they have a high level of uncertainty in some situations so they could serve as experimental efforts
- ☐ Create early-detection programs to identify new invasions of undesired exotic species
- ☐ Create local refuges for endangered species
- ☐ Enhance stand-level diversity
- ☐ Expand product portfolio (i.e. diversify investments)
- ☐ Formally incorporate climate change into the forest management planning process
- ☐ Foster connected landscapes
- ☐ Guide changes in species composition at early stages of development to meet expected future conditions
- ☐ Improve forest inventory methodologies
- ☐ Improve road/culvert maintenance
- ☐ Maintain and enhance species diversity
- ☐ Promote a variety of different aged stands
- ☐ Thin trees out of overly dense forests

Please indicate the extent to which you agree or disagree that the following statements are <u>obstacles to implementing adaptation strategies</u> to address climate change within your company/organization.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Complexity of information	○	○	○	○	○
Lack of access to information (you are aware that the information exists, but are unable to access it)	○	○	○	○	○
Lack of financial capacity	○	○	○	○	○
Lack of information	○	○	○	○	○
Lack of human capacity	○	○	○	○	○
Lack of time	○	○	○	○	○
Transportation costs	○	○	○	○	○
Uncertainty about climate change impacts	○	○	○	○	○

With respect to improved climate change adaptation, please indicate how much you agree or disagree that the following items would support your ability to <u>manage forests in Maine</u>.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Case studies/examples of successful implementation of adaptation or mitigation efforts	○	○	○	○	○
Improved science regarding climate impacts	○	○	○	○	○
More training	○	○	○	○	○

Opportunities for learning from others in a group setting	○	○	○	○	○
Opportunities to work across organizational/institutional borders	○	○	○	○	○
Other (*Please specify*)	○	○	○	○	○

With respect to improved climate change adaptation, please rank the importance of these incentives for adopting management strategies.

In order to rank these options, click and drag the choices to desired positions, where **1 = *most important*** **and 6 = *least important***. Fill in the 'other' option(s) if you would like to rank an incentive not listed.

______ Green Certification (market differentiation if products come from responsibly managed forests)
______ Micrograntsable (modest funds to help with sustainable efforts)
______ Social Licensing (public acceptance of company/organization practices)
______ Tax Breaks
______ Other (*Please specify*)
______ Other (*Please specify*)

PART E. ***This final section of the survey will give us some background information about you and the organization/business where you work. Your answers to these questions, as with all the other answers you provided in this survey, will remain confidential.***

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Other (*Please specify*) ____
- ◯ Prefer not to answer

What is your age?

- ◯ 18 - 24
- ◯ 25 - 34
- ◯ 35 - 44
- ◯ 45 - 54
- ◯ 55 - 64
- ◯ 65 - 74
- ◯ 75 - 84
- ◯ 85 or older

What is the highest level of school you have completed?

- ◯ Less than high school
- ◯ High school graduate
- ◯ Some college
- ◯ 2 year degree
- ◯ 4 year degree
- ◯ Professional degree
- ◯ Master's degree
- ◯ Doctorate

Do you currently hold a Maine Forester License?

- ◯ Yes
- ◯ No

What percentage of your household income is generated from the forest sector?

- ◯ Less than 10%
- ◯ 10% - 20%
- ◯ 20%-30%
- ◯ 30%-40%
- ◯ 40%-50%
- ◯ 50%-60%
- ◯ 60%-70%
- ◯ 70%-80%
- ◯ 80%-90%
- ◯ More than 90%

What percentage of the revenue from the company/organization that you work for is generated from the forest sector?

- ◯ Less than 10%
- ◯ 10% - 20%
- ◯ 20%-30%
- ◯ 30%-40%
- ◯ 40%-50%
- ◯ 50%-60%
- ◯ 60%-70%
- ◯ 70%-80%
- ◯ 80%-90%
- ◯ More than 90%

Do you belong to any of the following organizations? *(Please check ALL that apply)*

- ☐ Climate Smart Land Network
- ☐ Forest Guild
- ☐ Small Woodland Owners Association of Maine
- ☐ Society of American Foresters
- ☐ The Nature Conservancy
- ☐ University of Maine's Cooperative for Forestry Research Unit (CFRU)
- ☐ Other (*Please specify*) ____

Please enter the 5-digit zip code for where you primarily work

____

What is your current geographic area of work *(Please check ALL that apply)***?**

☐ Maine: Androscoggin County

☐ Maine: Aroostook County

☐ Maine: Cumberland County

☐ Maine: Franklin County

☐ Maine: Kennebec County

☐ Maine: Hancock County

☐ Maine: Knox County

☐ Maine: Lincoln County

☐ Maine: Oxford County

☐ Maine: Penobscot County

☐ Maine: Piscataquis County

☐ Maine: Sagadahoc County

☐ Maine: Somerset County

☐ Maine: Waldo County

☐ Maine: Washington County

☐ Maine: York County

☐ Other State in New England (*Please specify*)
____

☐ Canada

☐ Other (Please Specify) ____

Approximately how many employees currently work for your company/organization?

- ○ 1 (myself)
- ○ 2-10
- ○ 11-25
- ○ 25-60
- ○ 60-100
- ○ 100-200
- ○ Greater than 200

Please enter the 5-digit zip code for where you currently live

____

When it comes to politics...

	Very Conservative	Conservative	Neutral	Liberal	Very Liberal
I consider myself to be...	○	○	○	○	○

Thank you for your time! Please feel free to add any additional comments about the topics covered in this survey.

____

If you would like to enter your name into our L.L. Bean gift card raffle, please click here **to enter a mailing or email address**.

APPENDIX D: GATEKEEPER EMAIL
INITIAL RECRUITMENT SCRIPT FOR SURVEY

Dear CFRU Stakeholders,

In the coming days you will be receiving an email from Dr. Sandra De Urioste-Stone, a faculty member, and Alyssa Soucy, a graduate student, both in the School of Forest Resources requesting your participation in a research survey. The study aims to understand the factors that may be impacting the forest resources industry, while fostering effective adaptation and mitigation efforts that promote resilient and healthy forest systems.

I hope you will be able to find the time to complete the survey.

All the best,

Gatekeeper contact

APPENDIX E: RESEARCHER EMAIL RECRUITMENT SCRIPT FOR SURVEY

Dear member,

You are invited to participate in a research project being conducted by Dr. Sandra De Urioste-Stone, a faculty member, and Alyssa Soucy, a graduate student, both in the School of Forest Resources at the University of Maine. The goal of this project is to understand factors that may be impacting the forest resources industry, while fostering effective adaptation and mitigation efforts that promote resilient and healthy forest systems.

We would greatly appreciate if you **would be willing to share your views**. The **anonymous survey** should only take about 20 minutes to complete. To learn more about this study and to take the survey please go to the link below:
https://umaine.qualtrics.com/jfe/form/SV_6J7Pn1m4NdcnBmR

You have until November 30th to complete this survey. If you have already received this survey from a different distribution channel, and completed it, we kindly ask that you do not complete it twice.

Results of this survey will be shared with everyone on this mailing list and will be used to improve information and resources for those in the forest sector.

Your help is very much appreciated.

Respectfully yours,

Dr. Sandra De Urioste-Stone
Associate Professor
(207)-581-2885
sandra.de@maine.edu

Alyssa Soucy
Graduate Research Assistant
alyssa.r.soucy@maine.edu

APPENDIX F: GATEKEEPER EMAIL RECRUITMENT SCRIPT FOR SURVEY

Dear member,

You are invited to participate in a research project being conducted by Dr. Sandra De Urioste-Stone, a faculty member, and Alyssa Soucy, a graduate student, both in the School of Forest Resources at the University of Maine. The goal of this project is to understand factors that may be impacting the forest resources industry, while fostering effective adaptation and mitigation efforts that promote resilient and healthy forest systems.

We would greatly appreciate if you **would be willing to share your views**. The **anonymous survey** should only take about 20 minutes to complete. To learn more about this study and to take the survey please go to the link below:
https://umaine.qualtrics.com/jfe/form/SV_6J7Pn1m4NdcnBmR

You have until November 30th to complete this survey. If you have already received this survey from a different distribution channel, and completed it, we kindly ask that you do not complete it twice.

Results of this survey will be shared with everyone on this mailing list and will be used to improve information and resources for those in the forest sector.

Your help is very much appreciated.

Respectfully yours,

Gatekeeper contact

APPENDIX G: SURVEY EMAIL REMINDER

Dear member,

You have been invited to participate in a research project being conducted by Dr. Sandra De Urioste-Stone, a faculty member, and Alyssa Soucy, a graduate student, both in the School of Forest Resources at the University of Maine. The goal of this project is to understand factors that may be impacting the forest resources industry, while fostering effective adaptation and mitigation efforts that promote resilient and healthy forest systems.

If you have not yet completed the anonymous survey yet, we would like to urge you to do so. To learn more about this study and to take the survey please go to the link below:
https://umaine.qualtrics.com/jfe/form/SV_6J7Pn1m4NdcnBmR

You have until November 30th to complete this survey. If you have already received this survey from a different distribution channel, and completed it, we kindly ask that you do not complete it twice.

Upon completion of the survey you may enter to win one of three $50 L.L. Bean gifts cards. We will notify the winners once the survey period is concluded.

Your help is very much appreciated.

Respectfully yours,

[From sample 1]

Dr. Sandra De Urioste-Stone
Associate Professor
(207)-581-2885
sandra.de@maine.edu

Alyssa Soucy
Graduate Research Assistant
alyssa.r.soucy@maine.edu

APPENDIX H: INFORMED CONSENT FORM—INTERVIEW

You are invited to participate in a research project being conducted by Dr. Sandra De Urioste-Stone, faculty member in the School of Forest Resources. The goal of this project is to understand vulnerability of forest and forest resources industry to climate change, while fostering effective adaptation and mitigation efforts that promote resilient and healthy forest systems. You must be at least 18 years of age to participate.

What Will You Be Asked to Do?
You will be asked to participate in an interview (about 1 hour). With your permission this interview will be tape-recorded and transcribed.
Sample questions:

- Have you noticed any environmental changes that affect your business? What have you noticed and what have been the indicators of this change?

- Have you seen any changes in weather conditions in Maine in the last 5 years?
  - If so, what changes have you seen/observed?

Voluntary
Participation in the interview is voluntary; at any time you can stop and refrain from answering questions you do not want to address.

Risks
Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits
This study will have no direct benefits to you. The overall benefit of the research is to understand climate change risk perceptions and behaviors that can inform best management practices in the forest resources industry.

Confidentiality
Interview responses will be coded with identification numbers and an electronic key used to link names to identification numbers, and will be kept on a password protected computer using software that provides additional security, only to be accessed by the investigators. The electronic key linking participants' identities to data will be destroyed by August of 2021. Audio-recordings will be destroyed by August of 2025. Transcripts will be kept indefinitely.

Direct quotes from interviews may be used in the analysis, but no names or identifiable information will appear in written form.

Contact information
If you have any questions about this study, please contact:
Dr. Sandra De Urioste-Stone at (207) 581 2885; sandra.de@maine.edu; or 211 Nutting Hall, University of Maine, ME 04468-5755

If you have any questions about your rights as a research participant, please contact the Office of Research Compliance, University of Maine, (207) 581 2657 (or e-mail: umric@maine.edu).

APPENDIX I: INFORMED CONSENT—NGT AND QUESTIONNAIRE

You are invited to participate in a research project being conducted by Dr. Sandra De Urioste-Stone, faculty member in the School of Forest Resources. The goal of this project is to understand vulnerability of forest and forest resources industry to climate change, while fostering effective adaptation and mitigation efforts that promote resilient and healthy forest systems. You must be at least 18 years of age to participate.

What Will You Be Asked to Do?
During the next CRFU meeting held on January 31st, 2019 we will be conducting a 30-minute activity involving a nominal group exercise and a short questionnaire. During the nominal group exercise you will be asked to rank the greatest/most likely effects of climate change on the forestry industry. The short questionnaire will then ask you about specific tree species, management decisions, and areas of Maine that may see the greatest impacts from climate change.

Sample question:

- Please rank the top 3 tree species most vulnerable to climate change.

Voluntary
Participation in this activity is voluntary; at any time you can stop and refrain from answering questions you do not want to address.

Risks
Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits
This study will have no direct benefits to you. The overall benefit of the research is to understand climate change risk perceptions and behaviors that can inform best management practices in the forest resources industry.

Confidentiality
Nominal group and questionnaire responses will be coded with identification numbers and an electronic key used to link names to identification numbers, and will be kept on a password protected computer using software that provides additional security, only to be accessed by the investigators. Confidentiality of participants' ideas during the nominal group exercise cannot be guaranteed; however, the short questionnaire will remain confidential. The electronic key linking participants' identities to data will be destroyed by August of 2021. Paper copies of responses will be kept for no more than 5 years after the end of the project (August 2025). Data entered into Excel will be kept indefinitely.

Contact information

If you have any questions about this study, please contact:
Dr. Sandra De Urioste-Stone at (207) 581 2885; sandra.de@maine.edu; or 211 Nutting Hall, University of Maine, ME 04468-5755

If you have any questions about your rights as a research participant, please contact the Office of Research Compliance, University of Maine, (207) 581 2657 (or e-mail: umric@maine.edu).

APPENDIX J: INFORMED CONSENT—SURVEY

You are invited to participate in a research project being conducted by Dr. Sandra De Urioste-Stone, a faculty member, and Alyssa Soucy, a graduate student, both in the School of Forest Resources. The goal of this project is to understand perceptions of weather variability and extreme events, while encouraging management strategies that promote healthy forest systems. You must be at least 18 years of age to participate.

What Will You Be Asked to Do?
You will be asked to participate in a survey that will last about 20 minutes. You have until the November 30th, 2019 to complete the survey.

Sample questions:
1. Which forest industry Sub-Sector do you represent?
2. In the last five years, which of the following weather events have impacted your forest management or business operations?

Voluntary
Participation in the survey is voluntary; at any time you can stop and refrain from answering questions you do not want to address.

Risks
Except for your time and inconvenience, there are no risks to you from participating in this study.

Benefits
This study will have no direct benefits to you. The overall benefit of the research is to understand climate change risk perceptions and behaviors that can inform best management practices in the forest resources industry. Therefore, information gained from this survey will help improve information and climate change adaptation resources for land managers, landowners, foresters, and researchers.

Compensation
Upon reaching the end of the survey, you will have the opportunity to enter your name into a raffle for one of three $50 L.L.Bean gift cards.

Confidentiality
The survey is anonymous as your identity will not be shared or linked with the results. All survey data will be kept indefinitely on a password protected computer, only accessible to the investigators. IP addresses will not be collected.

Contact information
If you have any questions about this study, please contact:
Dr. Sandra De Urioste-Stone at (207) 581 2885; sandra.de@maine.edu; or 211 Nutting Hall, University of Maine, ME 04469-5755

Alyssa Soucy at alyssa.r.soucy@maine.edu; or 251 Nutting Hall, University of Maine, ME 04469-5755

If you have any questions about your rights as a research participant, please contact the Office of Research Compliance, University of Maine, or (207) 581 2657 (or e-mail: umric@maine.edu).

APPENDIX K: IRB APPROVAL

Fostering forest resources climate change resilience

1. Summary:

Maine's rural communities and natural resources-based industries rely heavily on the products and services provided by forest ecosystems. Given the complexity of the state's forest systems, with transition forests in early and mid-successional stages resulting from prior disturbances, the influence of climate change should be more evident than in other regions. Hence, the importance of this research to address the impacts of climate change on land cover and management.

Climate change risk perceptions can impact the extent to which stakeholders implement mitigation strategies to reduce emissions, develop adaptation strategies to cope with climate shocks, and promote resilient and sustainable SES (Chatrchyan et al. 2017). For this project, we define climate change risk perceptions as views that are directed to information processing related to climate change as an external threat (Shakeela and Becken 2014). With growing concerns about climate change and its effects on SES, several studies have focused on understanding stakeholder climate change risk perceptions that could potentially influence adaptation efforts (Etkin and Ho 2007; Leiserowitz 2006; Smith and Leiserowitz 2012).

Our research will enhance the resilience of forest socio-ecological systems (SES) by developing solutions-driven approaches to climate change. We pursue this through four research objectives:

1. Assess stakeholder awareness of climate variability and consequences on the landscape, perceptions of vulnerability, and land management decisions in response to climate change
2. Jointly identify best management strategies to increase resilience of forest SES and opportunities to enhance ecosystem services along the forest supply chain.

Methods

We will use a holistic, embedded sequential mixed methodologies approach (Creswell 2014), where multiple qualitative and quantitative social science research methods are applied and combined. Using multiple research methodologies will allow for triangulation across designs (Patton 2015); address the complexity of the problem that requires multiple data types (Creswell and Plano 2007); and generate stakeholder-driven strategies to enhance the resilience of the industry.

- **Key informant interviews:** up to 20 semi-structured one-on-one in person interviews (Creswell 2013; Flick 1998) will be conducted with a purposive sample of forestry industry stakeholders in Maine from government, non-governmental, and private sector (Emmel 2013). We will also use chain referral and maximum variation strategies (Emmel 2013) to select other potential participants. Participants will suggest the place and time to conduct the interview. Interviews will last about 60 minutes. Interviews will be tape-recorded with participants' permission, transcribed verbatim, and analyzed using thematic coding (Patton 2015). Trained graduate students and faculty will conduct the interviews. Interviews will be conducted in October 2018-Summer 2019.

- **Focus groups:** up to six, 90-minute focus group discussions, with 5-8 unique participants each will be conducted. We will rely on gatekeepers (i.e., Cooperative Forestry Research Unit (CFRU), Northern Forest Center, Small-Woodlot Owner Association,) to email their members, notifying them about the study purpose and goals and inviting them to participate on a focus group. Focus groups will be held at a location most convenient to the participants. Trained graduate students and faculty will conduct the focus groups. Focus groups (Krueger & Casey 2015) will be audio-recorded (with participants' permission) and transcribed verbatim. Transcriptions will be saved in a password protected computer, located in the locked office of the principal investigator. Focus groups will be conducted in October 2018-Summer 2019.
- **Nominal group technique and questionnaire:** expert opinions will be assessed using a two-part 30-minute activity in 4 groups of 5-8 consisting of a nominal group technique (NGT) method and short paper questionnaire. This activity will occur during a January 2019 meeting of the CRFU where we will invite members to participate. The goal of the NGT is to reach a consensus among experts (Delbecq et al. 1975) regarding which climate change impacts will have the greatest/most likely effect on the forestry industry. Half of the groups will address the greatest effects and the other half will address the most likely effects. We will begin the NGT by reading the question and providing some example answers. We will then allow participants to add to/modify the list in a round-robin style and conclude by allowing the participants to individually rank their top 5 answers. If time allows, we will present the results and allow the participants to re-rank. Following the NGT activity, a short paper questionnaire will be administered to the participants. Trained faculty, graduate students, undergraduate students will facilitate group discussions. Data will be manually entered and saved on a password protected computer, located in the locked office of the principal investigator.
- **Survey:** an electronic survey instrument will be used to explore perceptions of risk and forest management practices (20 minute). The survey instrument will be created and administered using Qualtrics. Following the interviews and focus groups, gatekeepers will send an email to their members inviting them to participate in the survey. Gatekeepers will also post a link of the survey on their websites (if in agreement) for members to complete the survey. Participants will be a mixture of those who participated in the interviews and focus groups and those that did not. The survey will be administered during fall 2019. Data will be downloaded and saved in a password protected computer, located in the locked office of the principal investigator.

Collected focus groups and key informant interviews will be transcribed by trained graduate (1) and undergraduate (2) students, be inputted into NVivo and analyzed using thematic coding. Collected NGT responses and short questionnaires will be entered into Excel by a trained graduate student. Survey data will be analyzed in SPSS and put into summary form. Representative quotes will be used in presentations and publications (no names will be disclosed).

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Participant recruitment:

We will rely on gatekeepers, including (i.e., Cooperative Forestry Research Unit (CFRU), Northern Forest Center, Maine Woodland Owners Association, Manomet, New England Forestry Foundation (NEFF)) to send an initial email to their members, notifying them about the study purpose and goals and inviting them to participate in a focus group or survey. These gatekeepers have a total of over 3,000 individual and corporate members. Interviews will be targeted to those who cannot attend a focus group. Gatekeepers will communicate the potential value of the research to their members, and encourage them to participate. We will also use chain referral to identify other potential participants.

We will use chain referral and maximum variation strategies (Emmel 2013) to select other potential interview participants who have valuable experiences in the forestry industry, but who may not be members of specific gatekeepers. An email invitation will be sent directly from us to potential participants to recruit them for a one-on-one interview or focus group. Participants will suggest the place and time to conduct the interview.

We will conduct the nominal group technique during a member meeting of the CFRU in January 2019. The CRFU will include the nominal group technique activity and questionnaire in the initial email to their members along with the meeting agenda. There will be between 20-30 participants in attendance from across all sectors of the forestry industry.

Following the focus groups and interviews, gatekeepers will send an email to their members inviting them to participate in the survey. We will use two strategies to recruit survey participants, and will be treated as separate samples.

- Recruitment for sample 1: the Cooperative Forestry Research Unit (CFRU) will send an initial email to their members describing the survey (Appendix H) as a form of introduction, after which the principal investigators will send the official invitation with the link to the survey.
- Recruitment for sample 2: the Maine Woodland Owners Association will send the official invitation with the link to the survey, eliminating the principal investigators from direct communication with their members.

To increase the response rate, either the principal investigators (sample 1) or the gatekeepers (sample 2) will send two to three survey reminders from the time the survey is released to the time responses are collected. We expect to send the invitation to the survey to approximately 1,400 participants via the CFRU and Maine Woodland Owners Association. We are also in conversations with Manomet, the New England Forestry Foundation (NEFF), and the Northern Forest Center in regards to surveying their members. With the addition of these groups we may expect to send invitation to 1,800 – 2,200 potential survey participants. Gatekeepers will also post a link of the survey on their websites (if in agreement) for members to complete the survey.

4. Informed consent

All participants will be adults (18 years of age or older) of undiminished autonomy, capable of making a truly voluntary decision whether or not to participate.

Interviewees and focus group participants will receive a consent form via an email prior to the in-person interview or focus group. The consent forms will include written details that will describe what they would be asked to do, the risks they will be undertaking by participating, the benefits they might receive by participating, the procedures for maintaining their confidentiality, and the contact information of the PI of the project.

Nominal group technique and questionnaire: participants will receive a consent form via email from the CFRU along with the agenda. We will read a shortened script to participants at the meeting prior to the activity detailing the goals of the project, what they will be asked to do, and key details from the consent form. The consent form will also be available during the meeting for those who were unable to read the email. The consent form will include details about the activity and questionnaire, the risks they will undertake as participants, the benefits they might receive by participating, the procedures for maintaining their confidentiality, and the contact information of the PI of the project.

Survey: Consent form will be included at the beginning of the self-administered online survey instrument.

Participation in focus groups, interviews, NGT and questionnaire, and/or survey indicates consent.

5. Confidentiality:

The following precautions will be addressed to ensure privacy of participants and confidentiality of data

Responses to the focus groups, interviews, and NGT will not have participants' names attached to their responses; only response data will be used. Interview, focus group, and NGT will be coded with identification numbers and an electronic encrypted key used to link names to identification numbers, only to be accessed by the investigators. Further, the NGT responses will be linked with the participant's questionnaire responses using the identification number. These documents will be entered into an electronic database for analysis in a password protected computer, only to be accessed by the investigators. The electronic key linking participants' identities to data will be destroyed by August 2021, one year by after the end of the project, August 2020.

Reports, presentations, and manuscripts will not include names of focus group participants, interviewees, or NGT and questionnaire participants to preserve privacy of participants.

Confidentiality of participants' responses cannot be guaranteed while conducting focus groups. In addition, confidentiality of participant ideas cannot be guaranteed during the round-robin portion of the NGT activity.

Online survey data will be collected using Qualtrics; no IP addresses will be collected. Data will be downloaded off Qualtrics to principal investigator's computer. Data will be deleted from Qualtrics two years after the end of the project (August 2022). The survey will be anonymous for those that receive the link from Maine Woodland Owners Association, given that participants will be recruited by gatekeepers and the principal investigators will not have access to any names or email addresses. The survey will remain confidential for those CFRU members as the principal investigators will have access to names and email addresses of potential participants; however, no names will be linked to the data.

Participants will be made aware of the fact that direct quotes may be used in the analysis, but that no names or identifiable information will appear in written form. All data will be entered and stored on a computer hard drive and kept in a secure location at the principal investigators' campus office indefinitely. Audio-recordings, focus group notes, and hard copies of paper NGT and questionnaires will be kept for no more than 5 years after the end of the project (August 2025). Survey responses, and transcripts will be kept indefinitely.

6. Risks to participants:

The study will entail no more harm than minimal risk of harm to subjects. The potential risks to participants may include time investment and inconvenience in answering some of the questions. Surveys and interview instruments will be pre-tested to narrow down the required questions, hence reducing the length of time. Participants will be instructed that they do not have to answer any question they do not want to answer.

7. Benefits:

Individuals participating in the interviews and surveys will not gain any direct benefit from participating in the study. The overall potential benefit of this research includes:

- Understanding of the impacts of climate change on forest systems and forest resources industry in Maine.
- Classifying the mitigation and adaptation strategies currently in place.
- Identifying and fostering the implementation of best management practices (including climate change mitigation and adaptation efforts) to enhance the health, productivity, and resilience of Maine's forest system.

8. Compensation:

There will be no compensation offered for participation in interviews, focus groups, or NGT and questionnaire activities.

At the end of the survey, participants will have the option of entering their email address to be entered into a raffle to win one of three $50 LL Bean gift cards. Participants will need to reach the end of the survey and submit the responses to be entered. The raffle will not be connected to survey responses.

APPENDIX L: SURVEY – CLIMATE CHANGE EXPERIENCES

Table 1. Climate change experience (report as mean scores)

Variable	% observe frequently + very frequently	Mean score
Changes in biodiversity	14	2.67
Changes in productivity	15	2.55
Extreme Precipitation events	40	3.26
Shifts in forest composition	16	2.68
Forest health issues	33	3.02
Insect damage	30	2.96
Deer browse	26	2.73
Lyme disease	40	3.08
Winter thaw events	38	3.26

APPENDIX M: SURVEY – SUPPLEMENTAL ANALYSIS

Given the amount of information collected in the survey, some of the questions were not analyzed as part of the thesis. However, this appendix shares some of the results from the survey previously not discussed. These include perceptions of Maine policy in regards to climate change adaptation among small woodlot owners and land managers (Figure 1) and perceptions of decision-support tools (Figure 2).

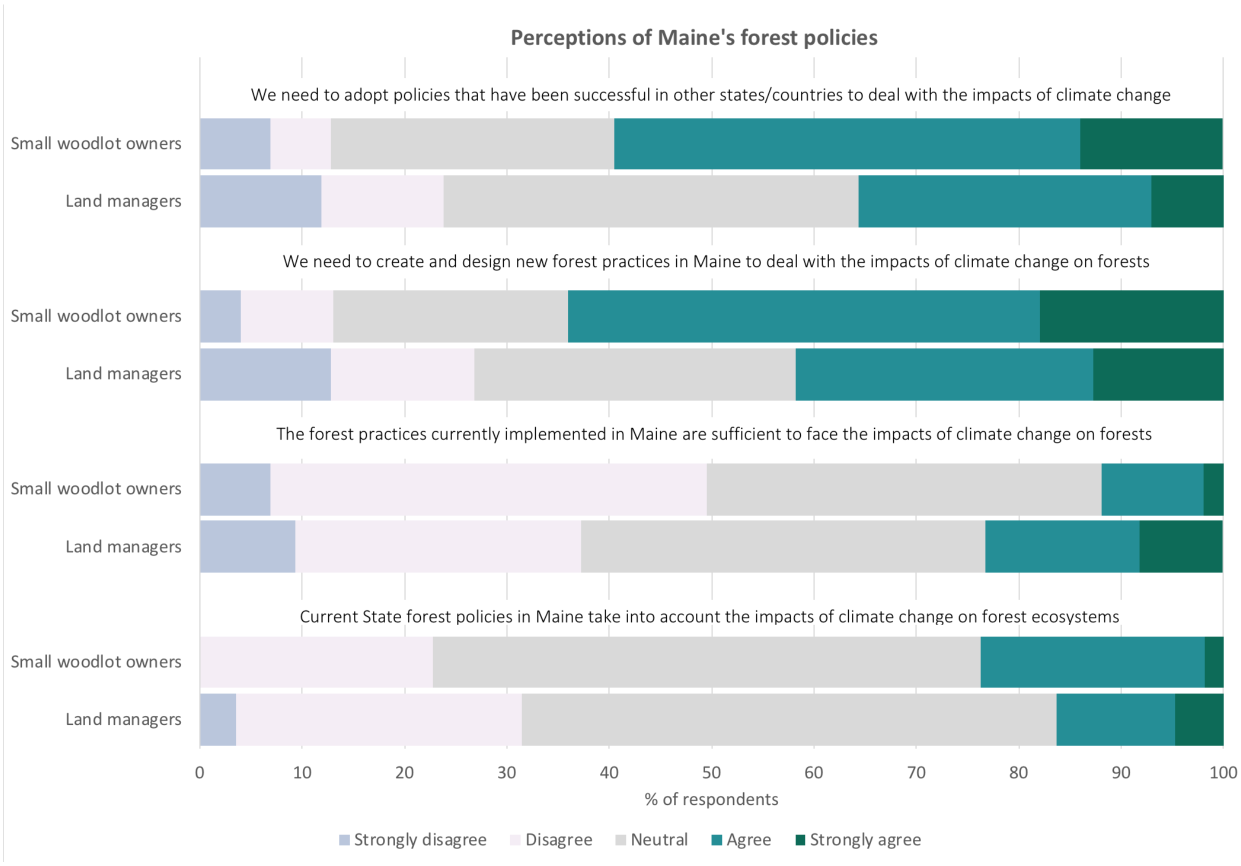

Figure 1. Perceptions of Maine’s forest policies and practices among small woodlot owners and land managers.

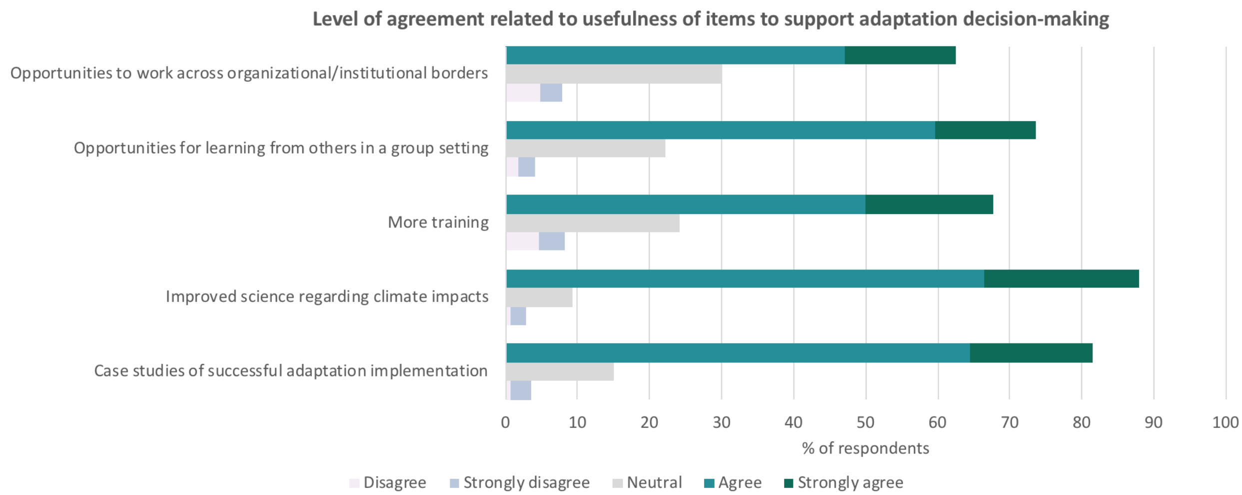

Figure 2. Perceptions of tools/activities that would support decision-making.

APPENDIX N: SUPPLEMENTAL VULNERABILITY ASSESSMENT DATA

Preliminary maps

The exposure component of the vulnerability assessment (Chapter four) involved preliminary data analysis and intermediate maps that were not presented as part of that chapter. The maps and data are included below to provide additional information related to the raw data used in exposure.

Forest composition

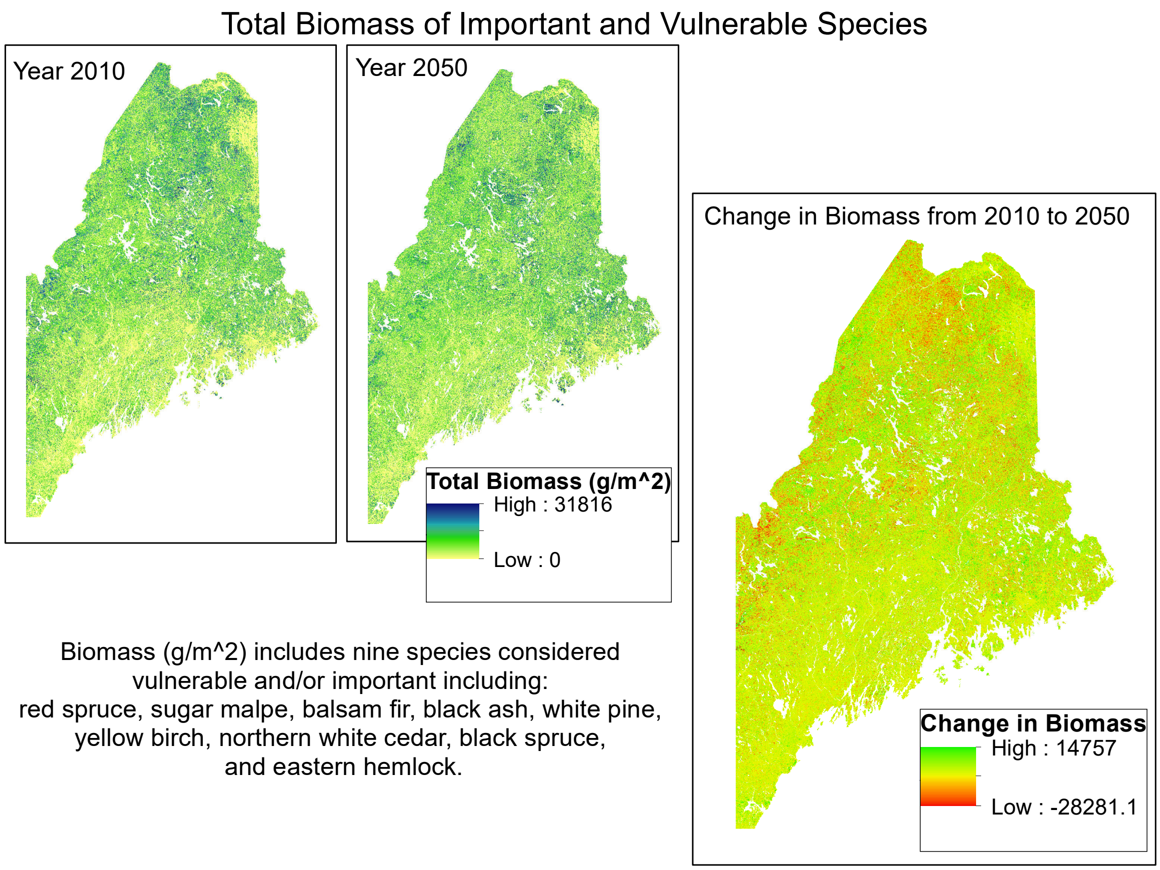

Figure 1. Change in biomass (g/m^2) among nine commercially important and vulnerable tree species

Insects and pathogens

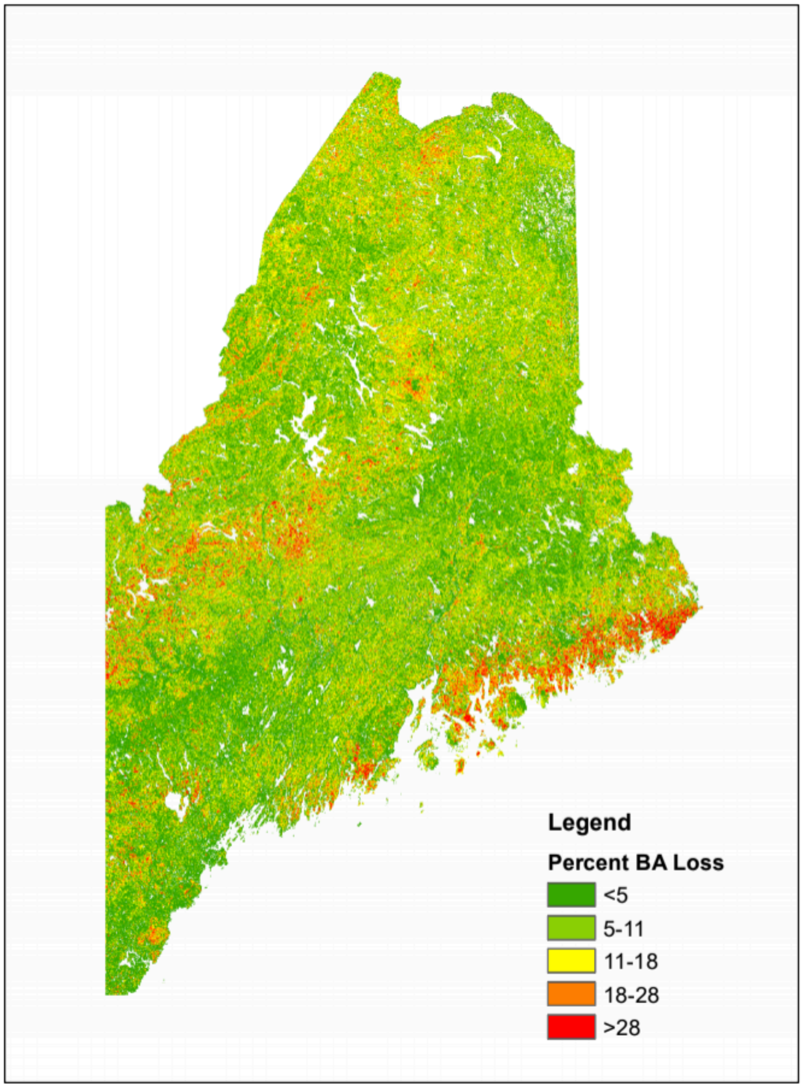

Figure 2. Classified percent TBA loss due to insects and pathogens

Deer browsing

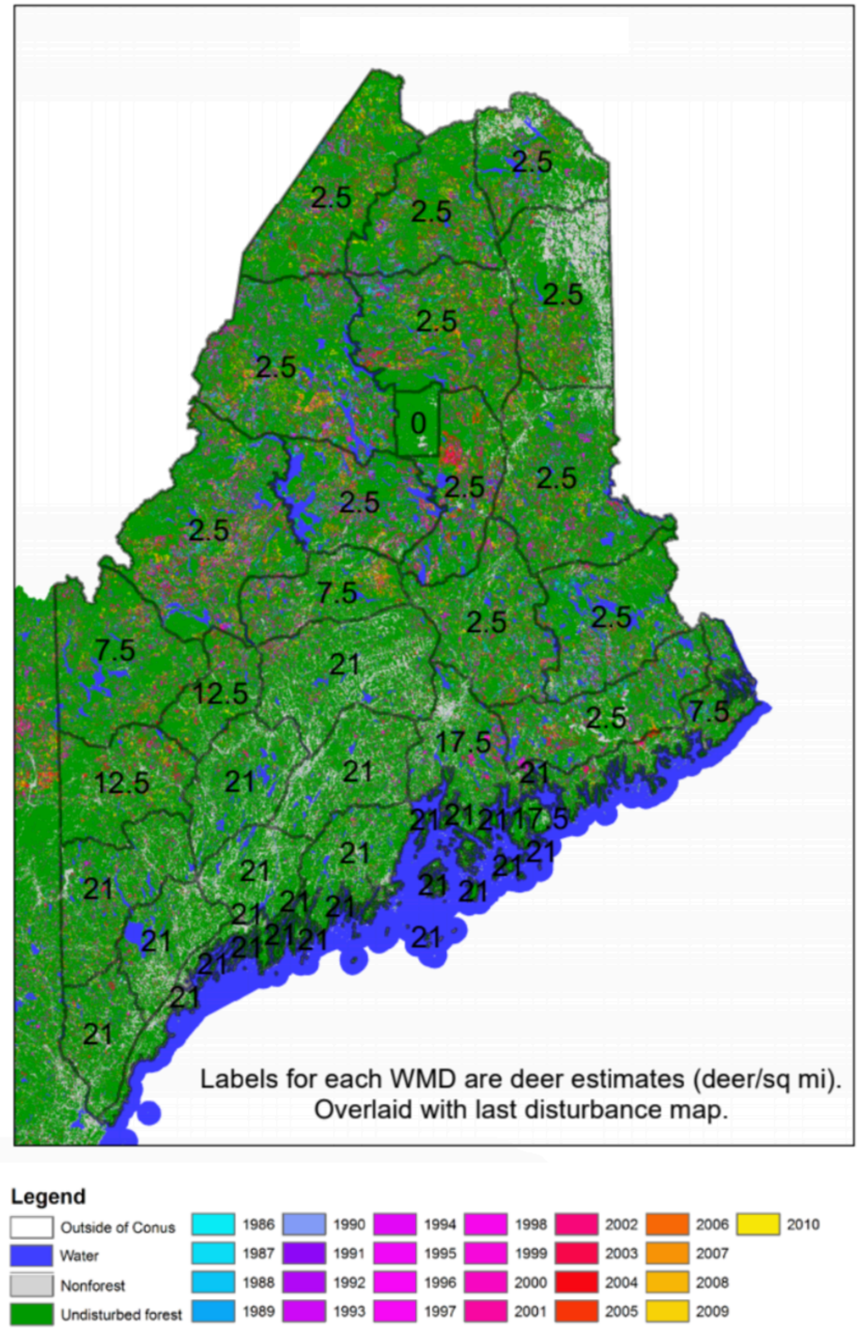

Figure 3. Recent disturbances (2000 – 2010; represented by reds, oranges, and yellows) overlaid with wildlife management districts (WMD) deer estimates (deer/mile^2)

Mud season

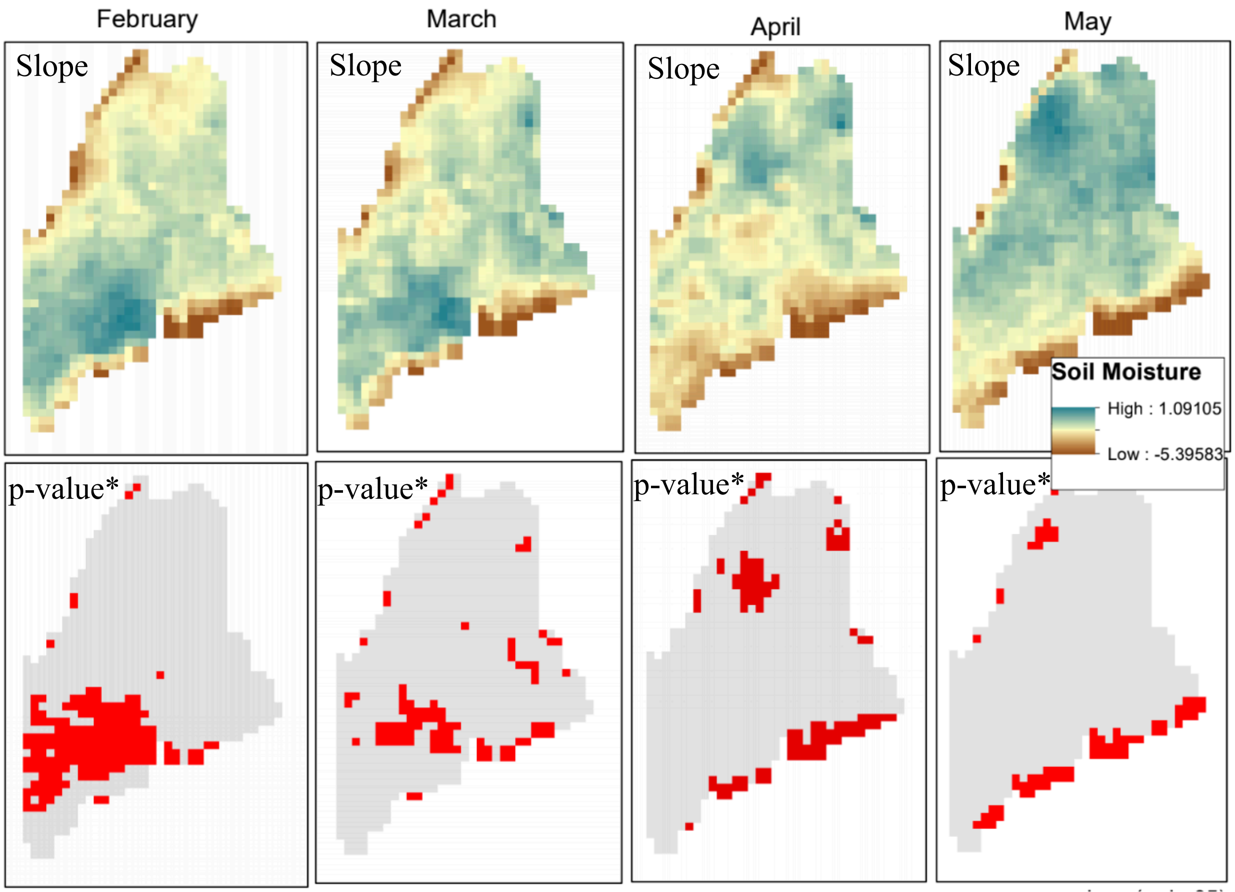

Figure 4. Monthly trends in mud season as an average of monthly soil moisture (root zone; kg/m^2/year) based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

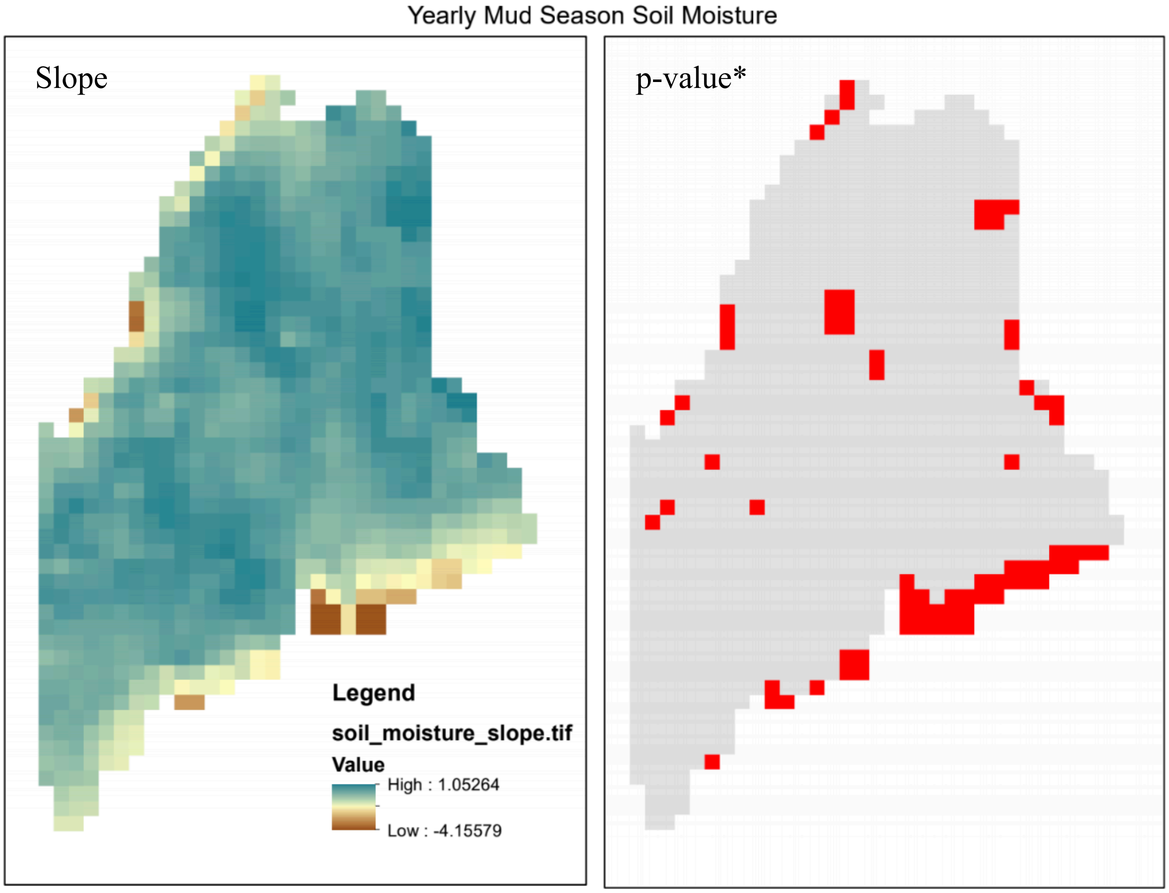

Figure 5. Trends in mud season as an average of February-May soil moisture (root zone; kg/m^2/year) based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

Changing winter conditions

We used Global Historical Climatology Network - Daily (GHCN-D) from the National Climatic Data Center, National Oceanic and Atmospheric Administration for the time period 1950 – 2018 to evaluate changes in frozen ground duration (presented in Chapter four) as well as to evaluate frozen ground season (the number of days between 1st and last frozen ground day) and the number of freeze-thaw cycles following Rittenhouse & Rissman (2015). Since 1950 the number of freeze-thaw cycles have remained the same on average in Maine. Trends are highly spatially variable. In southern Maine freeze-thaw cycles have decreased at a maximum rate of -0.035 cycles/year (decrease of 2.38 cycles over past 68 years). In northern Maine, however, freeze-thaw cycles have increased at a rate of 0.032 cycles/year (increase of 2.18 cycles over past 68 years) (Figure 6).

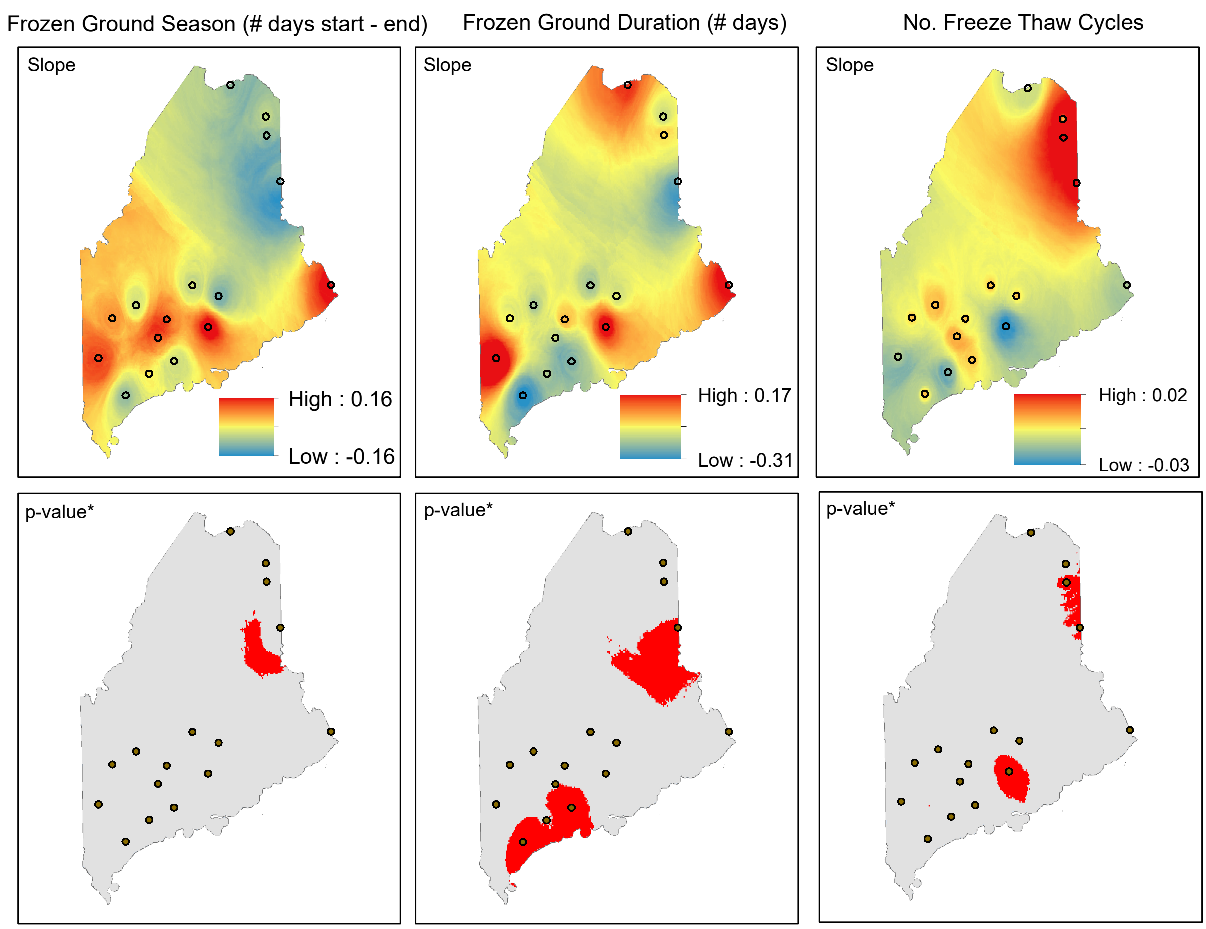

Figure 6. Trends in changing winter condition metrics including frozen ground season, frozen ground duration, and the number of freeze-thaw cycles based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

Extreme precipitation

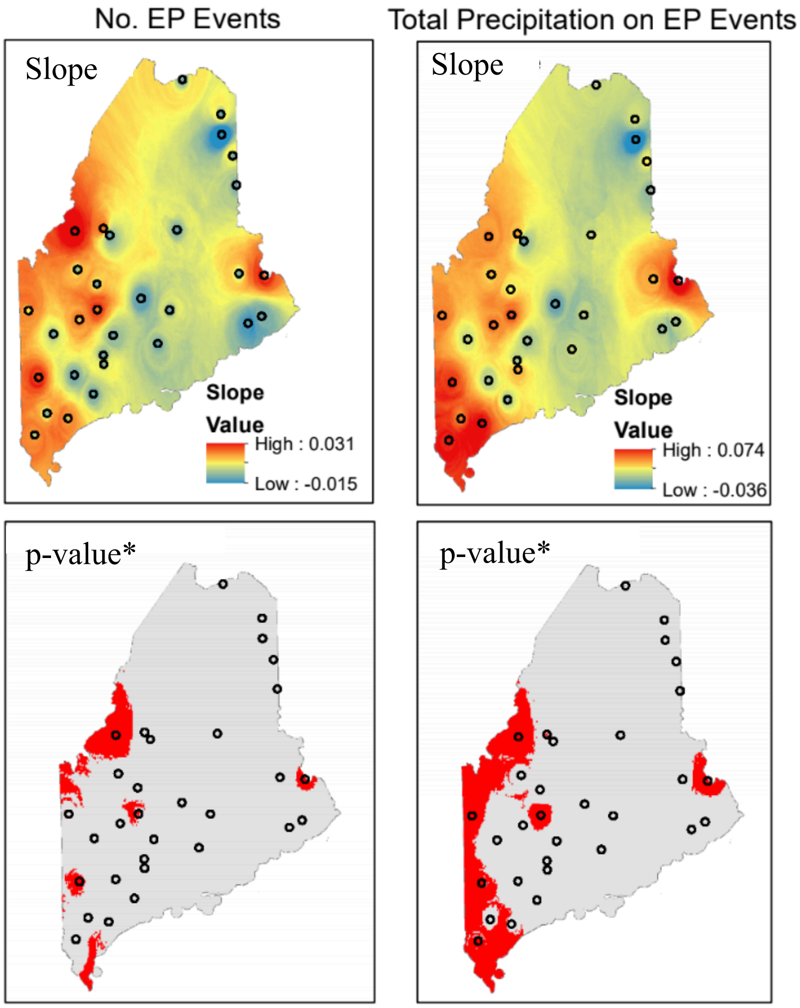

Figure 7. Trends in extreme precipitation variables based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

Table 1. Mean values from 1950-2018 for annual and seasonal extreme precipitation variables

	Annual	Winter	Spring	Summer	Fall
Number of extreme precipitation days	3.42	4.59	4.54	3.57	2.30
Total precipitation on extreme precipitation days (inches)	7.06	8.55	8.49	7.39	5.31

Additional exposure data

In addition to the exposure indicators in Chapter four, there were several indicators that were not included in the vulnerability assessment. These included: changes in temperature and precipitation, as well as intense wind events. Changes in temperature and precipitation were not included in the vulnerability assessment due to their lack of a direct and clear impact on the forest industry. Intense wind events were not included in the vulnerability assessment given data limitations of reported county events.

Temperature

To evaluate changes in annual and seasonal temperatures, monthly mean temperature were downloaded from the PRISM Climate Group for the period of 1981 – 2018 at 4 km^2 resolution. Annual and seasonal trends in temperature were assessed using a Mann-Kendall test and Sen's slope. Annual mean temperatures increase on average 0.022 °C/year, with a maximum of 0.044 °C/year (Figure 8). There are significant seasonal temperature increases in both winter and summer. Temperatures increase the most in winter, with an average increase of 0.012 °C/year, which is similar to that described in both Janowiak et al. (2018) and Fernandez et al. (2015). Temperatures do also increase in the spring and summer; however, these trends are not significant anywhere in the state (Figure 9). Spatially, temperature increases are concentrated in the central part of Maine and extend northwards.

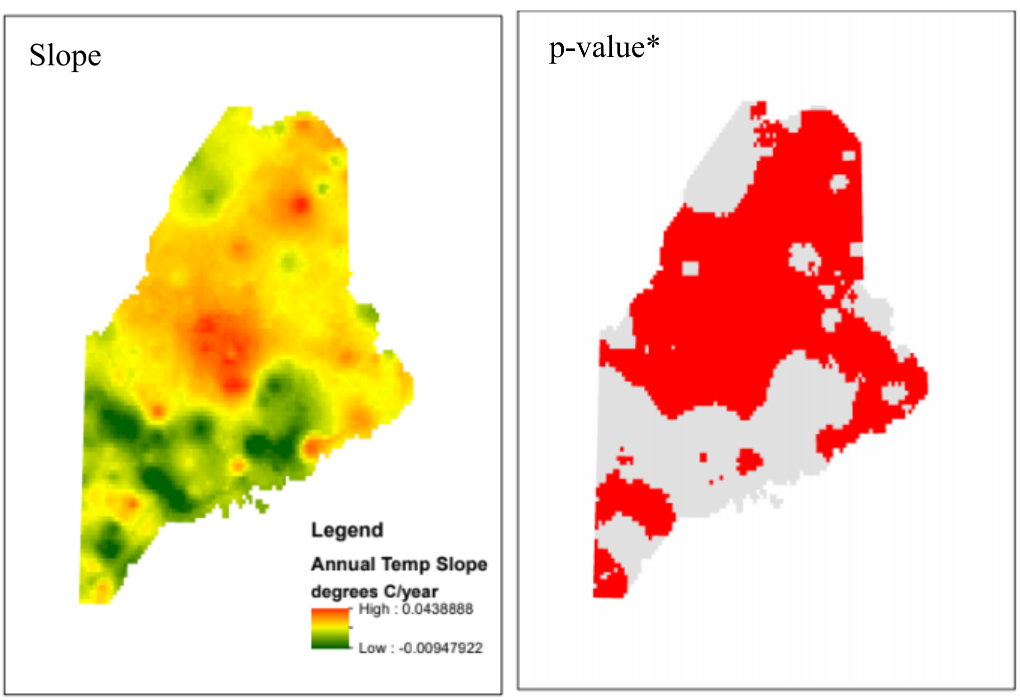

Figure 8. Annual trends in temperature (°C/year) based on based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

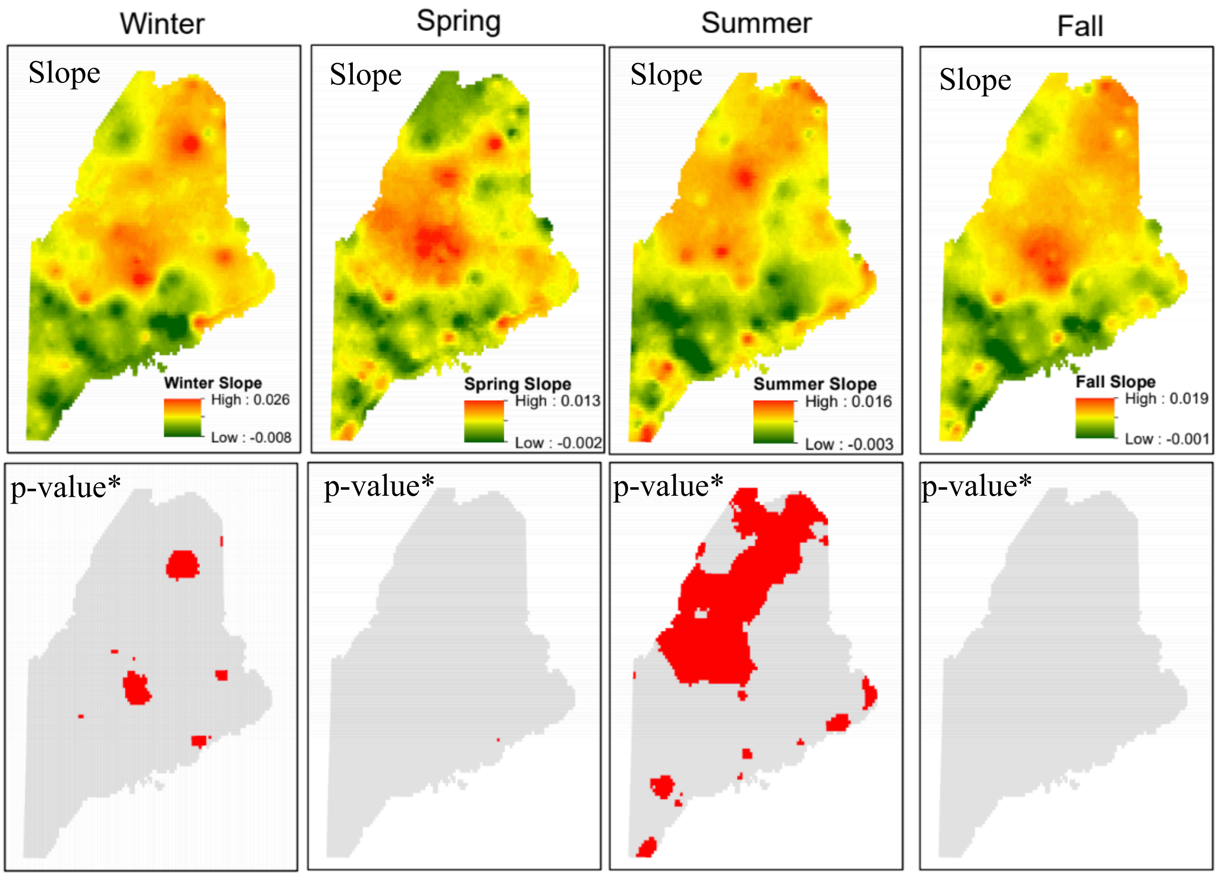

Figure 9. Seasonal trends in temperature (°C/year) based on based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

Precipitation

To evaluate changes in annual and seasonal precipitation, monthly total precipitation was downloaded from the PRISM Climate Group for the period of 1981 – 2018 at 4 km^2 resolution. Annual and seasonal trends in precipitation were assessed using a Mann-Kendall test and Sen's slope. Gridded observations show that average annual precipitation has increased since 1981 on average 0.40 mm/year (Figure 10). The maximum increase in average precipitation is 1 mm/year. Total annual precipitation has increased since 1981 on average 4.7 mm/year. The maximum increase in total precipitation is 12 mm/year. Increases in precipitation have been highest in the winter months, with increases as large as 0.59 mm/year (Figure 11). There are significant increases in precipitation for all seasons.

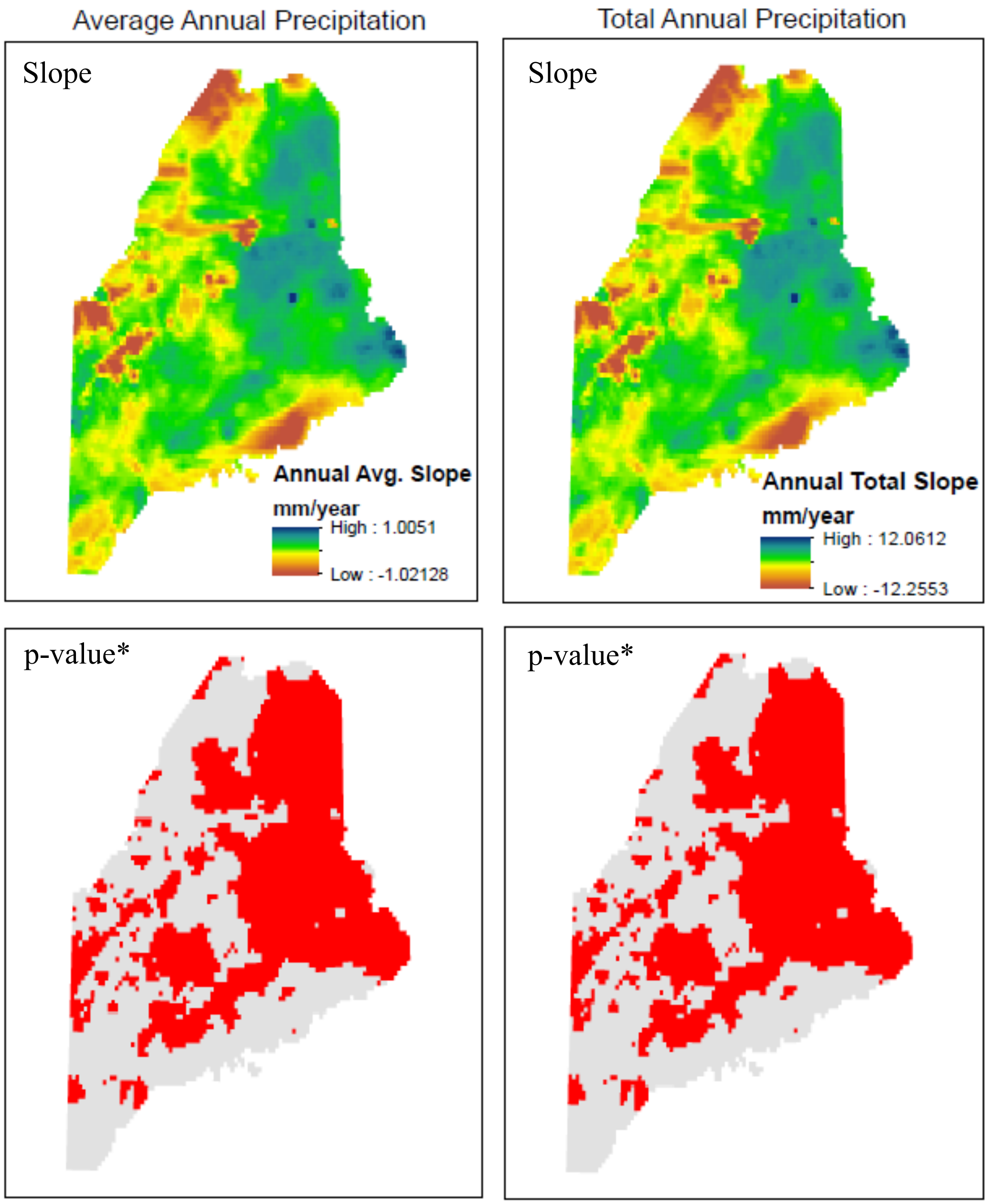

Figure 10. Trend in average and total annual precipitation (mm/year) based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

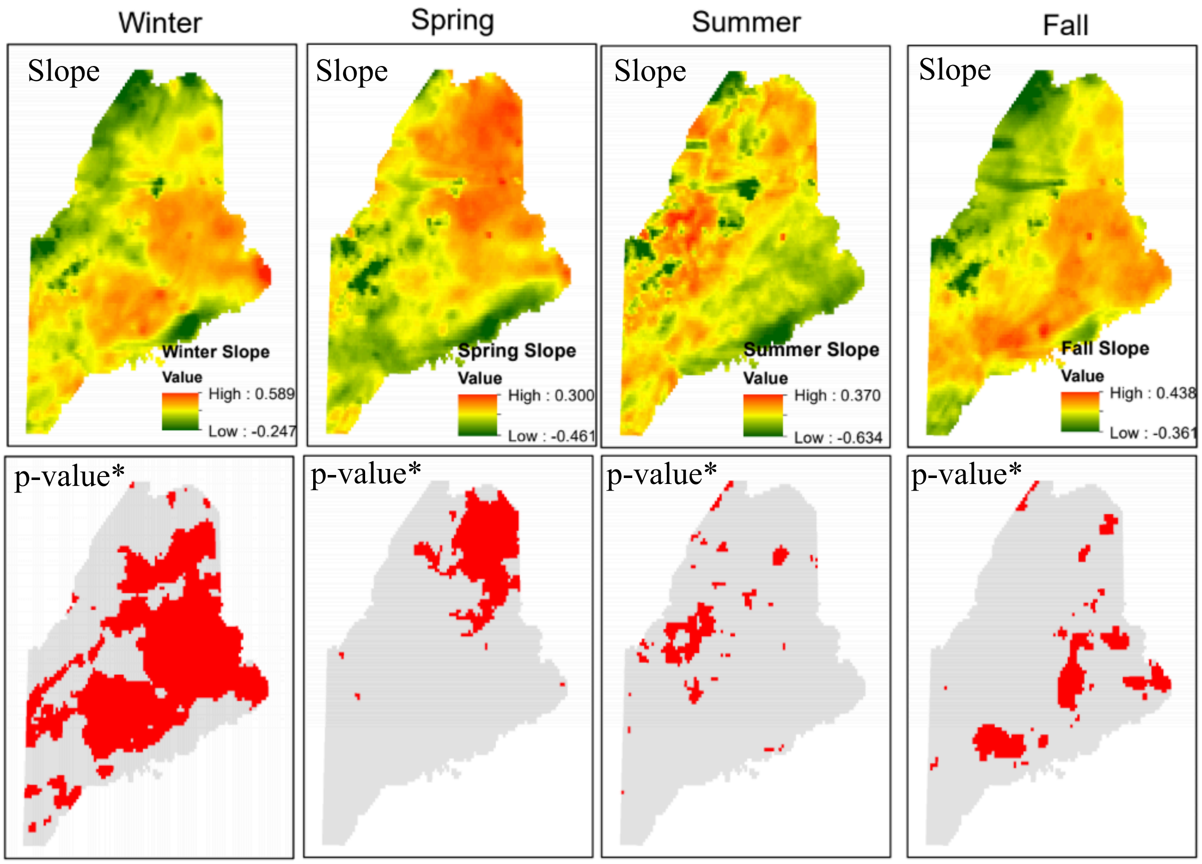

Figure 11. Trend in total seasonal precipitation (mm/year) using monthly precipitation values, based on Mann-Kendall (p-value) and Sen's Slope (slope) tests.
* Note: red represents p-value < 0.05.

Wind

To assess changes in intense wind events, historical records from 1996-2018 were obtained from NOAA's Storm Events Database. These records documents daily high wind events (defined as sustained non-convective winds of 35 knots (40 mph) or greater lasting for 1 hour or longer, or gusts of 50 knots (58 mph) or greater for any duration) at the county level. For each county, the total number of high wind events for every year was calculated. We then performed a Mann-Kendall and Sen's slope trend analysis to evaluate trends in the annual occurrence of high wind events. On average high wind events are decreasing by -0.03 events/year (an overall decrease of less than 1 annual event). The number of high wind events increases the most in Aroostook county at a rate of 0.923 wind events/year (increase of 20 annual events). Aroostook is the only county for which an increasing trend is significant ($p = 0.018$). High wind events significantly decrease in Lincoln (-0.25, $p = 0.008$) and Waldo (-0.43, $p = 0.005$). Though not significant, high wind events have also increased in Oxford, Penobscot, Piscataquis, and Cumberland (Figure 12).

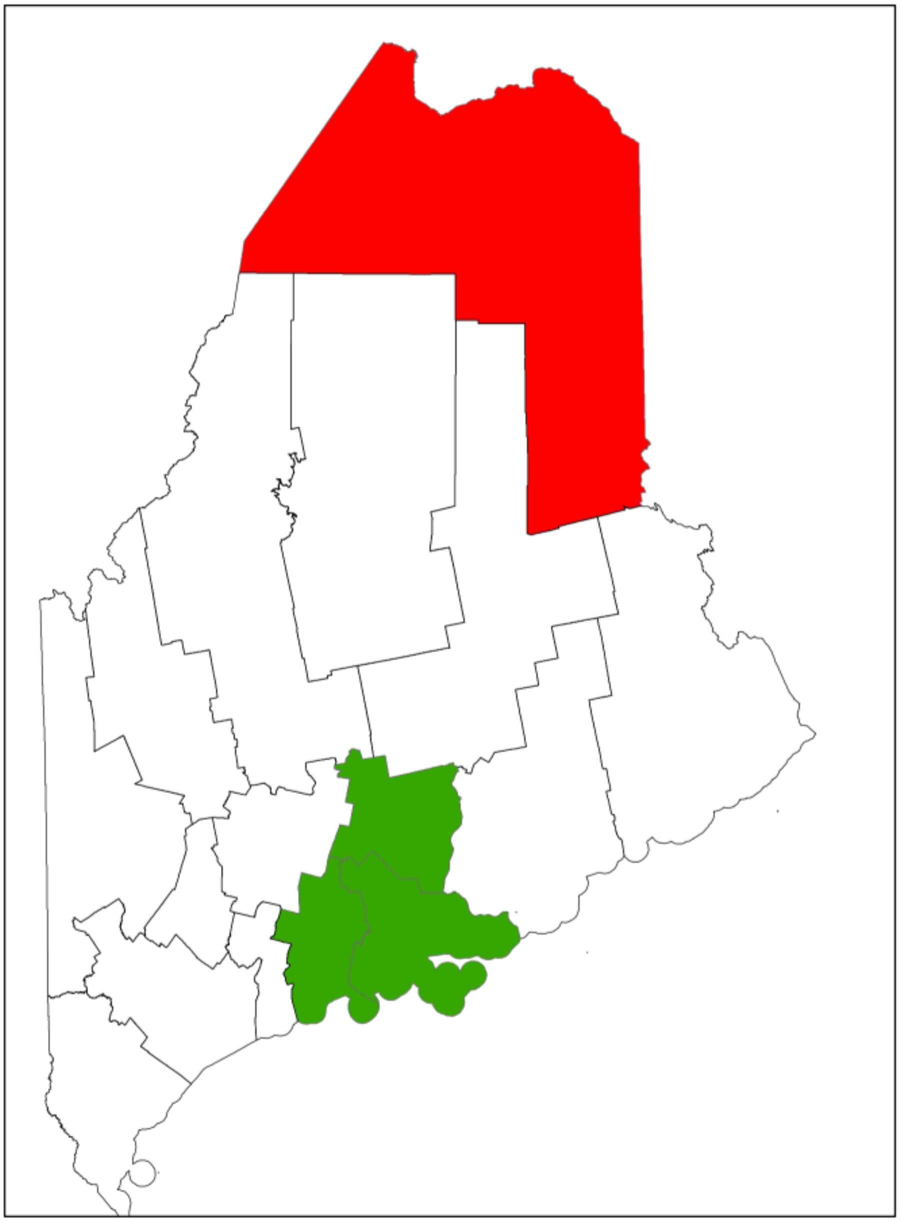

Figure 12. Trends in intense wind events at the county level, where significant increases in high wind events are displayed in red, significant decreases in high wind events in green, and non-significant trends in white.

APPENDIX O: ONE-PAGERS

As part of the thesis, results of the NGT (Chapter two) and survey (Chapter three) were shared with stakeholders to engage in collaborative process of dialogue among researchers and stakeholders. This helped to elicit stakeholder feedback in the research process and provide timely results to those most impacted by the findings. The NGT one-pager (Figure 1) was shared with CFRU members via email and Facebook. Survey results were shared with CFRU members (Figure 2) via email and Facebook and Woodlot Owners Association members (Figure 3) via their monthly newsletter.

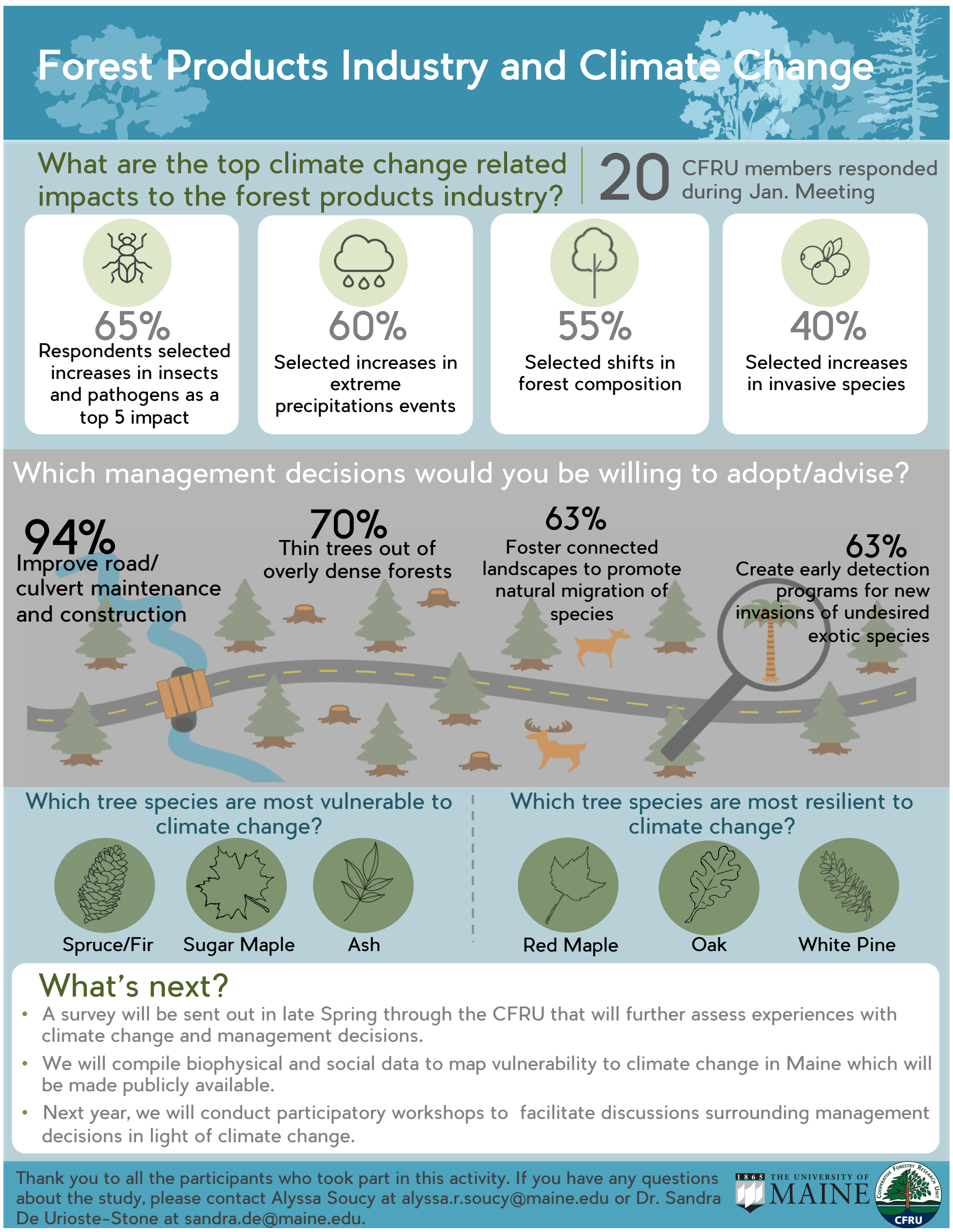

Figure 1. One-pager from the NGT (Chapter two) shared with CFRU members

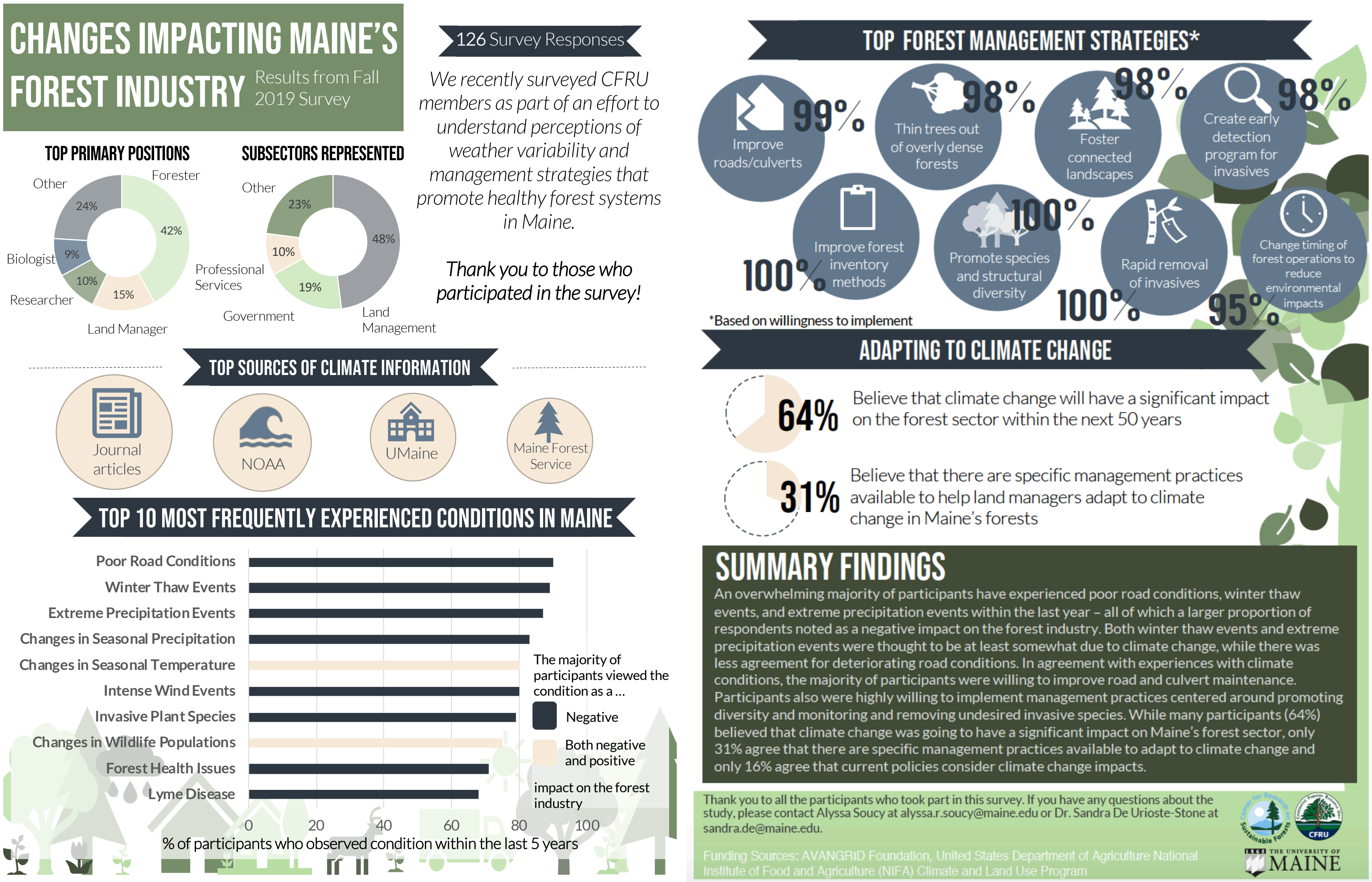

Figure 2. One-pager from survey (Chapter three) shared with CFRU members.

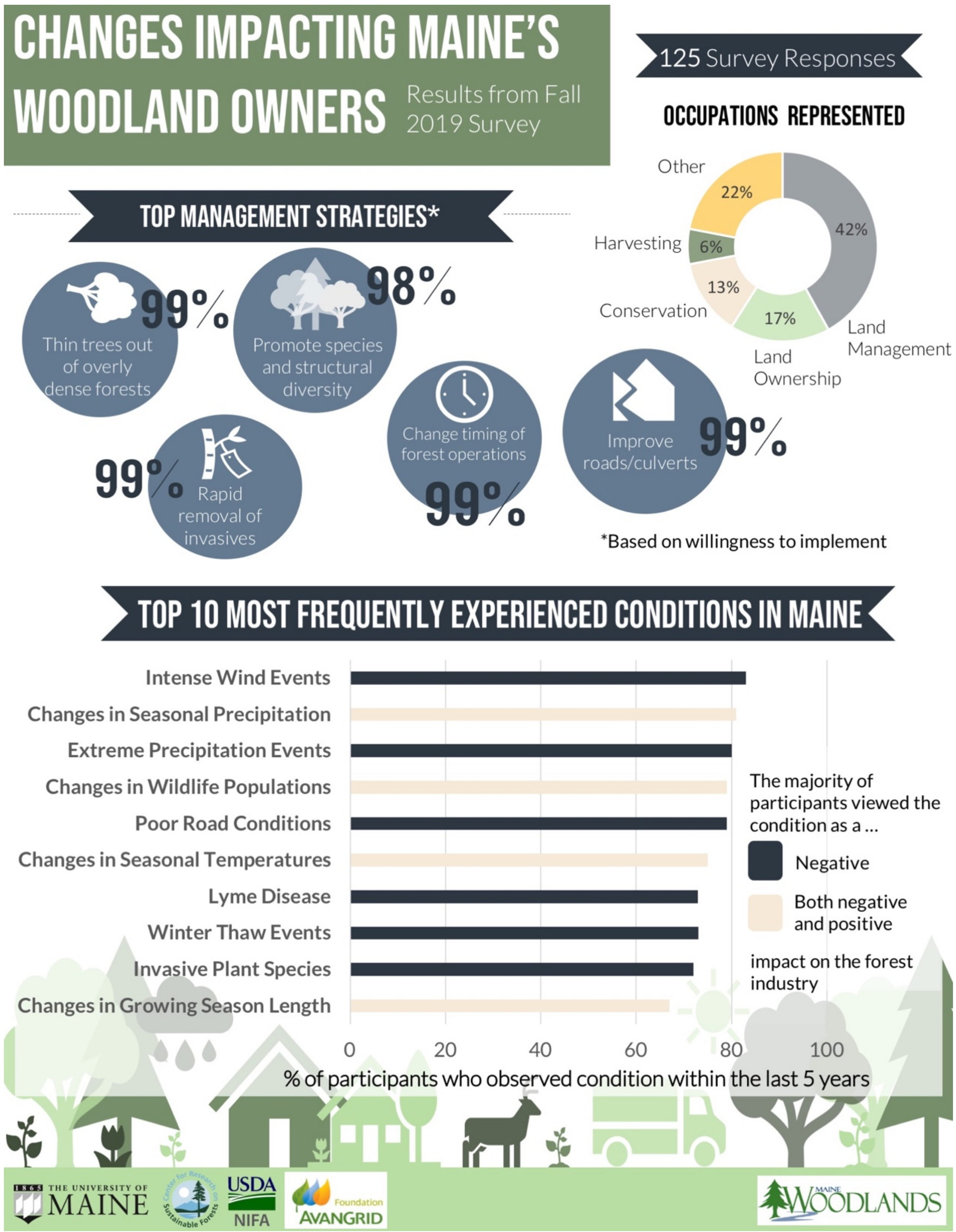

Figure 3. One-pager from survey (Chapter three) shared with Maine Woodland Owners Association members

BIOGRAPHY OF THE AUTHOR

Alyssa Soucy was born in Chelmsford, MA and graduated from Chelmsford High School in 2013. In 2017, she graduated from the University of Massachusetts, Lowell with a B.S. in Environmental Geosciences and a minor in Mathematics. Alyssa has worked in geochemistry laboratories at the University of Massachusetts and at Woods Hole Oceanographic Institution. She has also been employed by the Environmental Education Department at Rocky Mountain National Park as a Geoscientist-in-the-Park. Alyssa is a member of International Association for the Society of Natural Resources and Maine Environmental Education Association. She is a candidate for the Master of Science degree in Forest Resources from the University of Maine in August 2020.