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Climate change is increasing the severity of pest and pathogen infestations affecting forests. Resulting shifts in disturbance patterns can have substantial ecological, social, and economic impacts on forested ecosystems and their dependent communities. Researchers are actively investigating methods to improve tree resistance to specific pests and pathogens and enhance forest resilience. This could include using biotechnologies to genetically engineer tree species with particular resistance mechanisms, such as the American chestnut. Genetic engineering has been widely controversial in the agricultural industry due to concerns about potential human health and environmental impacts. However, less is known about how people perceive the use of biotechnologies in forested settings. Previous research shows that an individual's environmental beliefs influence their risk perceptions and attitudes about forest management. This study addresses two overarching research questions: (1) how do the risks and benefits conservation professionals and volunteers perceive about forest biotechnology influence their attitudes toward using it?; and (2) how do conservation professionals and volunteers invoke their environmental ethics and beliefs to describe and justify their attitudes toward forest biotechnology? To answer these questions, we conducted 33 semi-structured interviews with conservation and land management professionals within the U.S. Pacific Northwest during summer

2019. Results suggest that participants are most commonly concerned about potential unintended ecological consequences that might arise from forest biotechnology and rely on their knowledge and beliefs about agricultural biotechnology to inform their beliefs and attitudes toward forest biotechnology. Further, participants' environmental beliefs and ethics influenced their attitudes toward using forest biotechnology. Commonly, interviewees justified their attitudes toward using forest biotechnology using arguments based in their ethical position about whether humans should be involved in protecting or managing natural environments. This research contributes to our understandings of the contexts and conditions that influence attitudes toward forest biotechnology – considerations that are critically important as the scientific community investigates ways to address the pest and pathogen outbreaks that climate change is exacerbating.

# What Do People Think about Genetically Engineering Trees? A Qualitative Inquiry to Understand How People Reason about Using Forest Biotechnology to Address Forest Health Threats.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Elizabeth Emery, Author

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# Chapter 1: General Introduction

Forests comprise nearly one-third of the United States land base and account for more than 1 million square miles of land (Nelson et al., 2020). Forest ecosystems provide substantial benefits for humans and other organisms, such as habitat, ecosystem services, and other resources. In terms of human benefits, forests filter air and water, in addition to providing wood and other natural resources that support society. Therefore, it is important to manage our forest ecosystems in ways that maintain these benefits, resources, and services. One way land managers do this is by attempting to prevent forest pests and pathogens from causing widespread infestation and disease, which can wreak havoc on valuable tree species and ecosystems.

Climate change is increasing the distribution, frequency, and severity of disturbances threatening western U.S. forests, including pests, pathogens, and invasive species (Krist Jr. et al., 2014). These threats lead to a variety of direct and indirect impacts to forest ecosystems; for example, increased drought or temperature stress can reduce tree vigor and establish conditions for some insects to thrive (Kliejunas et al., 2009). Cumulatively, these impacts may fundamentally affect the structural and functional integrity of forest ecosystems. In a review of scientific studies related to climate change and forest diseases, Kliejunas et al. (2009) determined that pests and pathogens impact 45 times more forested area than fire in the U.S., suggesting substantial economic and environmental impacts are associated with these forest threats. Further, in 2012, the U.S. Forest Service concluded that approximately 7% of forested land in the U.S. (approximately 81 million acres) is at risk of experiencing at least 25% tree mortality as a direct result of insects and diseases by 2027 (Krist Jr. et al., 2014). In Oregon, the area of tree damage and mortality resulting from forest pests and pathogens increased from 615,000 to approximately 700,000 between 2012 and 2016 (Buhl et al., 2016). Although forest threats are diverse and complex, one thing is clear: shifts in pest and pathogen disturbance patterns can have substantial ecological, social, and economic impacts to forests and forest-dependent communities. These impacts are more worrisome as climate change promotes

conditions that allow pests to extend their range into forests with species that have limited or no natural resistance to them (Sturrock, 2012).

Therefore, researchers are investigating potential methods to enhance tree resistance to specific pests and pathogens in an effort to make forests more resilient. Approaches range from low-technology, more traditionally used strategies such as breeding from resistant individuals within the species, to more technologically advanced management options, such as migrating resistant populations into new areas through intentional planting (Sturrock, 2012). With the advent and development of biotechnologies, some researchers are investigating using cutting-edge genetic and biology-based technologies to protect forests from various threats, including pests and pathogens. The United Nations Convention on Biological Diversity defined biotechnology as "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use" (United Nations, 1992, pg. 3). There are many different types of biotechnology, including *transgenesis* (inserting genes or DNA from an unrelated species into the cells of a target species), *cisgensis* (inserting genes or DNA from a related species into the cells of a target species), and *genome editing* (using CRISPR/Cas-9 to make specific and targeted changes to an organism's DNA). In this thesis, I use the term "forest biotechnology" to refer to the use of any of these technologies to genetically engineer individual trees with improved qualities or traits, such as improved growth rates or resistance to specific pests or pathogens (National Academies of Sciences, Engineering, and Medicine, 2019). In this context, forest biotechnology can be used to engineer genetically modified (GM) trees that are planted in forests.

Forest biotechnology is being studied for potential commercial and restoration purposes. In terms of commercial applications, researchers at the University of Arizona and Oregon State University are investigating how to use forest biotechnology to engineer GM poplar trees that emit fewer greenhouses gases without compromising the structural integrity of the wood (Kart, 2020). This type of application could help some forest product producers remain viable in the context of carbon markets. As for environmental restoration uses, the American Chestnut Foundation and the State University of New York have been using forest biotechnology to potentially restore American chestnut – a previously iconic species that has

been decimated by chestnut blight (Hill, 2019). This type of application could be widely useful in addressing pests and pathogens that are increasingly threatening our forests.

Although there is a wealth of scientific literature investigating public perceptions and attitudes toward GM agriculture and foods, there are substantially fewer studies investigating these types of social psychological questions in regard to forest biotechnology. It is especially important to study this application independently considering that agricultural and forestry applications of biotechnology are different in a variety of aspects (Table 1).

**Table 1:** Differences between applications of biotechnology in agriculture and forestry.

| **Agricultural Biotechnology** | **Forest Biotechnology** |
|---|---|
| Annual species (single year lifespan) | Long-lived species (40+ years) |
| More domesticated | Less domesticated |
| Well studied genomes | Less studied genomes |
| Regulatory process in place | No established regulatory process |
| Limited dispersal/gene flow | Substantial dispersal/gene flow |
| Planted in farms (controlled environment) | Planted in tree farms *and* wild forests (uncontrolled environment) |
| Food crops | Usually food crops |
| Already common in U.S. | Not common in the U.S. |

Recently, there has been a scientific push to investigate public perceptions about using forest biotechnology as a strategy to manage forests. These studies have diverse research questions, populations, methods, and results, but they provide an initial understanding of how different populations consider using forest biotechnology as a management tool. Most of these studies have been conducted in Canada and Europe (Hajjar & Kozak, 2015; Hajjar, McGuigan, Moshofsky, & Kozak, 2014; Kazana et al., 2015; Peterson St-Laurent, Hagerman, & Kozak, 2018), while very few have been conducted in the U.S. (Friedman & Foster, 1997; Needham, Howe, & Petit, 2015; Strauss et al., 2009). These studies have primarily used survey methods to quantify levels of public support toward different types of forest management strategies, including forest biotechnology, among (more or less) representative samples of different populations

(National Academies of Sciences, Engineering, and Medicine, 2019). These studies provide initial information about the influence of a variety of social psychological constructs on public perceptions and attitudes toward forest biotechnology. They also provide insight about the types of individuals who are more likely to support forest biotechnology in general, namely men (vs. women), rural residents (vs. urban residents), younger people (vs. older people), and people who are employed in the forestry sector (vs. those who are not as familiar with forestry practices). Further, individuals with high levels of factual knowledge about forest biotechnology, educational attainment, income, and/or trust in federal agencies and/or science tend to have more positive attitudes toward forest biotechnology. Factual knowledge and trust in organizations/science can influence individuals to perceive fewer risks and greater benefits. Regardless of where they gained their knowledge, perceiving benefits about forest biotechnology prompts more favorable attitudes toward it, whereas perceiving risks about it tends to promote more negative attitudes.

Many of these existing studies have assessed public perceptions of forest biotechnology in commercial contexts, such as increasing biofuel production (Maruta, Boxall, & Mohapatra, 2018) or tree growth rates (Rollins, Boxall, & Luckert, 2015), or assessing consumers' willingness to pay for GM wood products (Kazana et al., 2015). These types of forest applications are arguably similar to agricultural applications of biotechnology given that they focus on enhancing production-related traits, such as growth and structural characteristics. Further, these commercial GM trees would presumably be grown in intensively managed forests, such as tree farms or plantations, which may be perceived similarly as industrial agricultural farms. However, social scientists are starting to ask questions about public perceptions and attitudes toward using forest biotechnology in more "natural" forests as a potential solution to address forest health threats, such as pests and pathogens. This is a relatively new line of scientific inquiry; many of the existing studies evaluate forest biotechnology in the context of other, more traditional forest health management strategies, such as breeding or assisted migration (Hajjar & Kozak, 2015; Hajjar et al., 2014; Nonic, Vettori, Boscaleri, Milovanovic, & Sijacic-Nikolic, 2012; Peterson St-Laurent et al., 2018). This provides an initial understanding of how cognitions and acceptance of forest biotechnology compare with traditional forest health

management actions that are very well studied, in turn providing researchers with an understanding of the various values, beliefs, and ethics that may be influencing attitudes toward using forest biotechnology as a forest restoration tool.

These studies highlight that attitudes toward using forest biotechnology to address forest health threats are generally positive, although respondents tend to prefer more traditional, low-technology options for establishing resistance to pests and pathogens. However, forest biotechnology is often more accepted than not doing anything to address a threat (Hajjar & Kozak, 2015; Hajjar et al., 2014; Peterson St-Laurent et al., 2018). While some studies have been broadly focused on using forest biotechnology for genetic conservation on public lands (Friedman & Foster, 1997) or reforestation strategies in a changing climate (Hajjar et al., 2014; Peterson St-Laurent et al., 2018), others have focused on more specific attitude objects, such as developing disease tolerant ash trees (Jepson & Arakelyan, 2017). Although these studies suggest that people have generally positive attitudes toward using forest biotechnology, they also suggest that these attitudes are context-specific – the conditions and context of the scenario included in the study influenced attitudes and other cognitions (Stangor, Jhangiani, & Tarry, 2011). For example, multiple studies have found that respondents are more likely to have more positive attitudes toward using biotechnology to address tangible and current threats in the environment, such as a specific pathogen, than they do toward using biotechnology as a general tool to address unspecified forest threats associated with climate change (Fuller, Marzano, Peace, Quine, & Dandy, 2016; Needham et al., 2015; Nonic et al., 2012). In addition to the literature highlighting differences in attitudes and other cognitions associated with attitude objects that are general (e.g., climate change) versus concrete (e.g., specific forest pests), these forest biotechnology studies suggest respondents' attitudes could be influenced by other factors, such as their attitudes about how humans should manage lands, risks or benefits that might result from forest biotechnology, the specific forest health threat needing to be addressed, and/or how the environment functions. This may be why these studies present different (and sometimes conflicting) results regarding the psychological factors that relate to attitudes toward forest biotechnology, such as environmental values (National Academies of Sciences, Engineering, and Medicine, 2019).

Given that environmental ethics and beliefs play an important role in shaping attitudes about whether it is appropriate or acceptable to intervene in environmental problems (Stern, Dietz, Abel, Guagnano, & Kalof, 1999), one can assume that different environmental ethics may influence the types of justifications and arguments underpinning people's environmental attitudes. Presumably, people with different opinions about how humans should interact with nature may consider forest biotechnology from different perspectives, as highlighted by the variety of results of recent studies investigating how ethical orientations shape public perceptions and attitudes toward forest biotechnology. For example, Needham et al. (2015) concluded that biocentric Americans were slightly more accepting than anthropocentrists of using biotechnology to address chestnut blight. Conversely, Hajjar and Kozak (2015) reported that western Canadians with mixed environmental ethics (a blend of anthropocentric and ecocentric views) were slightly more accepting than biocentrists of using biotechnology to address impacts of climate change. Another study showed that anthropocentrists were the most supportive of using biotechnology as a reforestation strategy in the context of climate change (Peterson St-Laurent et al., 2018). All of these studies investigated public perceptions of forest biotechnology to be used in forest restoration and enhancing resilience, and despite theory saying that cognitions should be aligned with each other, the data don't in fact show that. Studies report substantial variation in acceptance about which ethics promote acceptance. Unfortunately, given that these studies used quantitative methods and relied on surveys to gather data, they did not provide an opportunity for the researchers to theorize about *why* some people might be more accepting of forest biotechnology than others. Instead of being influenced by environmental ethics, variation in these results may be due to contradictory environmental beliefs, such as how forest biotechnology might influence environmental processes or how biotechnology might influence the perceived naturalness of forests (National Academies of Sciences, Engineering, and Medince, 2019). Consequently, how environmental ethics and beliefs influence attitudes about forest biotechnology is currently unclear in the literature and requires additional scientific investigation (National Academies of Sciences, Engineering, and Medicine, 2019).

These existing quantitative studies provide insight into various factors that influence attitudes toward forest biotechnology and how they differ from attitudes toward other forest management strategies. However, the existing scientific literature doesn't yet provide robust data about the various contextual factors of an application that influence attitudes toward forest biotechnology or how attitudes are shaped by environmental beliefs about potential outcomes that may arise, how the environment functions, or whether humans should intervene to protect nature from threats. The general finding that forest biotechnology may be something the public would support is useful, but the existing literature doesn't provide many insights into the arguments people use to justify their beliefs and attitudes toward forest biotechnology. This type of understanding is crucial to effectively describe and discuss forest biotechnology projects with interested publics because it highlights the specific issues about which people are concerned. Further, this type of study is needed to inform how people might respond to different types of messages about forest biotechnology – assumptions that can be tested by further quantitative research.

## Research Questions and Thesis Organization

This thesis used data from 33 semi-structured interviews with professionals and volunteers affiliated with a variety of conservation-related organizations mostly in Oregon and a few in Washington. These interviews were designed to elicit data to understand how various constructs of interest, including familiarity with forest biotechnology, beliefs (i.e., risk perceptions, benefit perceptions, and perceptions of naturalness), and environmental ethics influence attitudes toward using forest biotechnology to address forest health threats. These data were used to answer four different research questions which are discussed in two separate studies in this thesis (Chapters 2 and 3).

The first study is titled, "The role of risk and benefit perceptions in shaping conservation professionals' attitudes and arguments toward using forest biotechnology to address forest health threats." As the title describes, this study investigated the types of risks and benefits conservation professionals and volunteers perceived about using biotechnology to establish resistance to forest health threats. This study also investigated how familiarity with forest biotechnology influenced the types of risks and benefits participants perceived about its use.

Further, this chapter explores how those perceptions informed overall attitudes toward forest biotechnology, including how respondents navigated trade-offs in their beliefs about potential positive and negative outcomes that may arise from forest biotechnology. More specifically, the study presented in Chapter 2 addressed two research questions:

- **RQ 1**: How do individuals' risk and benefit perceptions inform their attitudes toward the use of biotechnology to address forest health threats?
- **RQ 2**: How does familiarity with forest biotechnology influence the types of risks and benefits people perceive in association with using forest biotechnology to address forest health threats?

The second study is titled, "Perceptions of naturalness and environmental ethics influence attitudes and arguments about using forest biotechnology to address forest health threats." This study describes how respondents articulated their environmental beliefs and ethics in the arguments they used to justify their attitudes toward forest biotechnology. More specifically, the study presented in Chapter 3 addressed two research questions:

- **RQ 3:** How do conservation professionals invoke perceptions of naturalness when reasoning about using forest biotechnology to address forest health threats?
- **RQ 4:** How do conservation professionals' environmental ethics influence the types of arguments they use to support their attitudes about using forest biotechnology to address forest health threats?

Aside from these two chapters, the first chapter (the present chapter) provides a general introduction to the research questions and the purpose of the research. The fourth chapter is an overall conclusion and reflection on the results of this research.

## Implications of this Research

This research provides important contextual data about the beliefs that influence attitudes toward forest biotechnology, including people's beliefs about the types of risks and benefits that might arise from using this technology, as well as how this technology might influence natural systems or functions. This insight will help clarify the contradictory results in the existing literature and improve future interpretation of quantitative data. Most importantly,

this understanding builds on our existing scientific understanding that there are generally positive attitudes toward forest biotechnology by providing insight into the contextual factors and environmental beliefs that underpin those positive attitudes. Further, this study will provide data about ways individuals communicate about this topic and the arguments they provide to defend their existing attitudes and beliefs. Lastly, this study provides insight about how some messages might be received by people with different types of environmental ethics. Insights from this study provides can guide future studies that are explicitly designed to investigate how various communication strategies and messages may or may not be related to support or acceptance of forest biotechnology.

# Chapter 2: The role of risk and benefit perceptions in shaping conservation professionals' attitudes and arguments toward using forest biotechnology to address forest health threats

## Introduction

### Overview of Research Goals

Climate change is increasing the frequency, distribution, and severity of pests and pathogens affecting forests, potentially causing severe ecological, social, and economic impacts to forests and forest-dependent communities. To address these threats, researchers are investigating methods to improve tree resistance to specific pests and pathogens as a means to enhance forest resilience. Some approaches do not require technology (e.g., reducing density and preventing spread by cutting trees), while others are low-technology options, such as controlled breeding, and some are more high-technology options, such as assisted migration and biotechnology (Sturrock, 2012). Some researchers are investigating the use of cutting-edge biotechnologies, which the United Nations Convention on Biological Diversity defined as "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use" (United Nations, 1992, pg. 3). Biotechnologies such as Crispr/Cas9 could be important tools that allow researchers to engineer tree species to have resistance to specific pests or pathogens (National Academies of Sciences, Engineering, and Medicine, 2019).

Given that biotechnology has been especially controversial in agricultural applications (Scott, Inbar, Wirz, Brossard, & Rozin, 2018), it is important to consider public attitudes and perceptions about using biotechnology in other types of applications, such as addressing forest health threats. Understanding these attitudes and perceptions will help scientists and land managers understand if the public considers biotechnology as an acceptable tool to address forest health threats, which in turn can inform whether it is worth investing time, money, and/or other resources into developing such solutions. Further, understanding public acceptability of forest biotechnology is especially important given that it requires substantial time to develop, test, and approve these types of solutions (Strauss et al., 2009).

This study used semi-structured interviews to understand the risks and benefits conservation professionals and volunteers perceive about using biotechnology to establish resistance to specific pests and pathogens, as well as how familiarity with forest biotechnology influences the types of risks and benefits these participants perceived about its use. In addition, I aimed to understand how those perceptions inform overall attitudes toward forest biotechnology. What follows is an introduction to social psychological theories of risk perception and attitude formation. I have also provided an overview of the risk and benefit perceptions and attitudes toward forest biotechnology that have been identified in existing literature. In the methods, I introduce the research design, sampling strategy, interview guide, and data analysis process used to conduct this study. The results highlight interviewees' attitudes toward forest biotechnology, the common arguments interviewees used to support their attitude toward forest biotechnology, and the various risks and benefits interviewees perceived about forest biotechnology. The discussion describes the way risk and benefit perceptions informed these various arguments and conditional attitudes toward forest biotechnology, with a special focus on two emergent themes: (1) concern about unintended consequences and (2) interviewees' beliefs about tampering with nature. I conclude with a discussion of limitations and potential future research.

## Risk Perception Overview

Risk and benefit perceptions can be defined as personal subjective beliefs about the potential negative or positive outcomes associated with a specific action (Slovic, 1987). Some psychological theories suggest that the way people perceive risk and the types of risks they perceive can be influenced by their individual cognitive characteristics, such as their values, beliefs, and familiarity with the action or hazard. Other theories of risk perception suggest that the types of risks perceived are influenced by social factors, such as cultural worldview, group affiliation, or identify (Renn & Rohrmann, 2000). The psychometric paradigm is one cognitive theory of risk perception suggesting that how individuals assess specific characteristics of a potential hazard influences the way they perceive risk (Slovic, 1987). Social psychologists commonly use the psychometric paradigm to understand public acceptance of new technologies that are unfamiliar and have potential for catastrophic impacts, such as forest

biotechnology. Primarily, characteristics of the hazard are related to its "dread factor," namely whether the risk is seen as voluntary, controllable, or potentially leading to catastrophic impacts. The psychometric paradigm also proposes that perceived certainty about the potential magnitude of impacts influences risk perception (Slovic, 1987). Additionally, the paradigm proposes that an individual's familiarity with a hazard influences how that person will perceive its riskiness. People often express concerns about new, unfamiliar, and unnatural hazards that they do not understand or cannot control (Slovic, 2000).

In addition to the psychometric characteristics of the risk or hazard, personal sensitivity or comfort with assuming risk (e.g., personality) and affective or emotional responses to the action or hazard can influence how people perceive risk (Gifford & Sussman, 2012; Loewenstein, Weber, Welch, & Hsee, 2001; Sjöberg, 2000; Slovic, Finucane, Peters, & MacGregor, 2004). While "dread" within the psychometric paradigm is an emotion of extreme fear and apprehension, these other theories incorporate a broader set of emotions, with either positive or negative affect. Actions that promote negative affect often promote perception of more risks than benefits, whereas actions that elicit a sense of goodness are often assessed as having more benefits than risks (Loewenstein et al., 2001). It is important to note that these relationships are reciprocal – while negative affect can cause an individual to perceive more risks about an object, increased risk perception can likewise influence an individual to have negative affect about an object.

These personal intuitions and emotional responses have been shown as important predictors of risk perception and attitudes toward GM and forest biotechnology. Studies investigating attitudes toward forest biotechnology have shown that respondents' intuitive responses to forest biotechnology substantially influenced their risk perception. For example, in some studies, respondents' convictions about whether forest biotechnology is morally acceptable or a form of tampering with nature were stronger predictors of attitudes toward forest biotechnology than the dread and uncertainty dimensions of the psychometric paradigm (Peterson St-Laurent et al., 2018; Scott, Inbar, & Rozin, 2016; Siegrist, Hartmann, & Sütterlin, 2016; Sjöberg, 2000).

**Table 2:** Social/cultural and cognitive factors that can influence risk perception, as identified in the literature. Cognitive factors designated with a * are components of the psychometric paradigm.

| Social / Cultural Factors | Cognitive Factors |
|---|---|
| Worldview | Values |
| Group membership/affiliation | Beliefs |
| Identity | Familiarity/knowledge |
| | Personal sensitivity to risk |
| | Emotional response to the proposed action |
| | Uncertainty about what risks would arise* |
| | Dread/apprehension about magnitude of risk* |

Most commonly, individuals have fast and intuitive reactions to risk, especially when they have less knowledge about, or familiarity with, the action or hazard (Loewenstein et al., 2001). However, responses to risk can also take a more analytical form. In this case, perceived risks are assessed objectively using logical reasoning involving information about the magnitude and probability of risk associated with the action or hazard. These risks are then weighed against other factors to identify potential trade-offs. This deliberative process is more commonly used by people who have greater knowledge about the action or hazard and may lead to different attitudes than those arising through intuitive responses (Slovic, 1987; Slovic et al., 2004). Therefore, it is important to understand two aspects of risk perception in the context of forest biotechnology and if risk perception is largely intuitive or analytical. Such insights can inform the development of messaging campaigns aimed at reducing intuitive risk perception and promote more analytical reasoning about the use of forest biotechnology. People who are able to analytically assess the potential risks associated with forest biotechnology may be able to more reliably determine trade-offs among these potential risks in the context of the benefits forest biotechnology will provide. This type of analytical reasoning may result in more positive or negative attitudes toward using forest biotechnology to address forest health threats, potentially avoiding the public controversy that is associated with using biotechnology in other applications.

## Risk Perceptions about Genetic Modification and Forest Biotechnology in Existing Literature

The theories and concepts in the previous section have been applied to understand public perception of various hazards, including GM agriculture. However, studies investigating public perceptions of forest biotechnology are not as prevalent as studies investigating GM agriculture. According to a recent meta-analysis of studies investigating public acceptance of GM foods, there are five major categories of risks that individuals perceive to be associated with these technologies: physical risks (e.g., human health concerns or long-term unpredictable effects), psychological risks (e.g., feelings of concern, dread, or worry), informational risks (e.g., lack of scientific understanding or uncertainty), ecological risks (e.g., environmental impacts, undesirable effects on other species), and societal/economic risks (e.g., economic gaps between developing and developed countries) (Bearth & Siegrist, 2016). In addition to these perceived risks, studies have shown that individuals also tend to express a variety of ethical concerns about GM agriculture and foods (Hielscher, Pies, Valentinov, & Chatalova, 2016; Weale, 2010). Ethical opinions influencing attitudes and arguments about forest biotechnology are discussed in more detail in Chapter 3 of this thesis.

Although we have a wealth of scientific information about the types of risks individuals perceive in association with GM agriculture, as described above, only a few studies have investigated the types of risks perceived about forest biotechnology. Of these few studies, several concluded that people perceive forest biotechnology to be riskier than familiar and traditional strategies to address forest health threats, although forest biotechnology is more supported than doing nothing to address environmental threats (Hajjar & Kozak, 2015; Hajjar et al., 2014; Jepson & Arakelyan, 2017; Kronberger, Wagner, & Nagata, 2013; Needham et al., 2015; Peterson St-Laurent et al., 2018). The types of risks individuals perceive about forest biotechnology share many similarities with the types of risk perceived about GM agriculture. For example, studies investigating public perceptions toward using forest biotechnology in commercial applications (e.g., increasing tree growth or yield) identify risks such as long term unpredictable impacts (i.e., unintended consequences, permanent impacts to ecosystem function), ecological risks (e.g., potential impacts to species that interact with the GM tree), and

societal/economic risks (e.g., concerns about economic impacts of patenting tree species) (Friedman & Foster, 1997; Hajjar & Kozak, 2015; Kazana et al., 2015; Maruta et al., 2018; Needham et al., 2015; Peterson St-Laurent et al., 2018; Petit, 2019; Rollins et al., 2015).

However, using forest biotechnology in commercial applications, such as increasing tree growth rates or the structural characteristics of timber is a very different application than using this technology to engineer GM trees that are resistant to specific forest health threats and planting those genetically modified trees in natural forests to enhance species' resistance. Because commercial applications and forest health applications of forest biotechnology are so different in their goals and how they are applied, risks associated with using forest biotechnology to address forest health threats include reducing the genetic diversity of wild or native trees (Friedman & Foster, 1997; Hajjar & Kozak, 2015; Jepson & Arakelyan, 2017; Kazana et al., 2015; Nonic et al., 2012)

Recent studies suggest that these differences in perceived risks among commercial and forest health applications of biotechnology may be due to ethical concerns about tampering with nature (Peterson St-Laurent et al., 2018), even more so than concerns about uncertainty associated with the technology or potential for catastrophic impacts, as proposed by the psychometric paradigm (Slovic, 1987). This includes concerns about whether the GM tree was engineered using DNA from a related ("cisgenic") or unrelated ("transgenic") species (Needham et al., 2015) or whether the GM tree will negatively impact the perceived naturalness of the area where it is planted (Peterson St-Laurent et al., 2018).

As highlighted in this section, there is an initial understanding of the types of risks individuals perceive in association with using forest biotechnology, although many of these studies focused on commercial applications of forest biotechnology. This study provides information about how conservation professionals and volunteers perceive and discuss risks and benefits when considering the use of forest biotechnology in an application very different from commercial forestry – in forested settings that are less intensively managed than tree farms.

## Benefit Perceptions

In addition to perceiving risks from forest biotechnology, people also perceive benefits from its use (National Academies of Sciences, Engineering, and Medicine, 2019). Similar to risk perceptions, the types of benefits individuals perceive vary depending on the type of modification or application being considered. For example, individuals are more supportive of cisgenic approaches of forest biotechnology and tend to perceive greater benefits from it in contrast with transgenic approaches. Similarly, individuals are more supportive of using forest biotechnology to protect forests from insects and diseases – an application that is perceived to provide more benefits – than using forest biotechnology for commercial applications, such as increasing timber yield (Strauss et al., 2017).

A recent meta-analysis of studies investigating public perceptions of GM foods defined four types of benefits that are commonly associated with GM agriculture (Bearth & Siegrist, 2016). Aside from the physical benefits that are often perceived in association with GM agriculture (e.g., nutritional benefits, "golden rice"), several of the benefits associated with GM agriculture would presumably apply to forest biotechnology as well. These include societal/economic benefits (e.g., general benefits for society, improved quality of life), qualitative benefits (e.g., pest resistance and reduced crop losses), and environmental benefits (e.g., environmental protection).

More specifically, existing studies investigating public perceptions of commercial applications of forest biotechnology provide insight into the specific types of benefits respondents perceive in association with commercial applications of forest biotechnology. These include:

- ***Societal/economic benefits,*** such as greater employment and income for people working in the forestry sector, or improved consumer choice (Hajjar & Kozak, 2015; Hajjar et al., 2014)
- ***Qualitative benefits,*** such as increased tree growth, yield, and productivity (Kazana et al., 2015)

- ***Environmental benefits,*** such as restoring contaminated soils; reducing insecticide, pesticide, and herbicide use in forestry plantations; and reducing pressure to harvest trees in natural forests (Kazana et al., 2015)

These benefit perceptions were documented in studies that investigated using forest biotechnology in a commercial context. Given the substantial differences of using biotechnology in commercial vs. forest health-related applications previously described, many of the existing benefit perceptions documented in scientific literature may not apply to using forest biotechnology to address forest health threats. For example, it seems unlikely that someone would associate benefits to soils or employment with using forest biotechnology to establish resistance to specific pests or pathogens.

Additionally, responses in existing studies have been limited to perceived benefits provided in a pre-determined list in a survey, as opposed to open-ended opportunities for elicitation. Consequently, there is a need for additional scientific investigations to catalog the types of benefits individuals perceive about using forest biotechnology to address specific types of forest health threats. There is a need to better understand the contextual factors that may influence how perceived benefits are assessed or considered alongside potential risks. This is especially important given that existing literature has shown that benefit perceptions can have a strong influence on attitudes toward forest biotechnology (Azodi & Dietz, 2019; Hajjar & Kozak, 2015; Hajjar et al., 2014; Needham et al., 2015; Petit, 2019). Further, this study builds on our existing quantitative understanding of public perception towards forest biotechnology by providing insight on how interviewees navigate trade-offs among potential benefits and risks that they believe will arise from using a potentially risky technology, such as forest biotechnology to address a forest health threat. Further, this study provides insight into how the results of these initial studies investigating public perceptions toward commercial applications of forest biotechnology do or do not relate to a less studied application of forest biotechnology.

## Attitudes toward Forest Biotechnology

Social psychologists define an attitude as an individual's abstract, stable, and enduring positive or negative evaluation of a specific attitude object, such as forest biotechnology (Evans,

1993). Attitudes are associated with a degree of like or dislike, or support or opposition for the object (Heberlein, 2012). Attitudes are comprised of evaluations of various beliefs the individual holds related to the topic – beliefs that are not necessarily factually "true." For example, risk and benefit perceptions are among the important beliefs that give rise to one's overall attitude toward an attitude object. When many beliefs that are consistent with one another comprise an attitude, the attitude tends to be very strong and difficult to change. However, attitudes about things that are new or less important to a person tend to be more malleable; these attitudes are often not yet supported by multiple consistent beliefs (Krosnik & Petty, 1995).

Despite research identifying substantial perceived risks and benefits associated with forest biotechnology broadly, existing literature shows that attitudes about using forest biotechnology to address various forest health threats are generally positive in comparison to doing nothing to address the threat (National Academies of Sciences, Engineering, and Medicine, 2019). However, many studies suggest that attitudes might be specific to the conditions and context of the application (Stangor et al., 2011). Some of these studies have broadly focused on genetic conservation on public lands (Friedman & Foster, 1997) or using forest biotechnology as a reforestation strategy in response to changing climate (Hajjar et al., 2014; Peterson St-Laurent et al., 2018). Other studies have focused on more specific attitude objects, such as planting genetically modified poplar trees to improve biofuel production (Rollins et al., 2015), purchasing wood products derived from GM trees (Kazana et al., 2015), or developing disease-tolerant ash trees (Jepson & Arakelyan, 2017). Overall, respondents are more likely to have positive attitudes toward using biotechnology to address tangible and current environmental issues, such as developing disease resistance ash trees, as opposed to using biotechnology as a general tool to address broad environmental threats, such as reforesting natural areas in response to climate change (Fuller et al., 2016; Needham et al., 2015; Nonic et al., 2012). Additionally, respondents' attitudes may be influenced by other factors besides risk and benefit perceptions, such as beliefs about land management, forest health threats, or how the environment functions.

## Research Questions

Existing research has shown that risk and benefit perceptions exist with regard to GM agriculture and using forest biotechnology for commercial applications; further, these are important drivers of attitudes toward GM and forest biotechnology. However, few studies have investigated risk and benefit perceptions associated with using forest biotechnology to address forest health threats, an application that is very different from commercial applications of this technology. Unlike commercial applications to establish GM trees that will be planted in tree farms, using forest biotechnology to address forest health threats involves planting GM trees in less managed landscapes; the express goal is that the GM trait will spread within the tree species and the natural area. Thus, there is a need to investigate perceptions and attitudes toward using forest biotechnology to address forest health threats explicitly, instead of inferring what these perceptions and attitudes might be based on studies investigating GM agriculture and commercial applications of forest biotechnology.

Even fewer studies use qualitative methods to describe the types of risks and benefits individuals perceive and *how* those perceptions inform their attitudes toward using biotechnology to address forest health threats. Although existing quantitative data provide initial results about how perceptions and attitudes toward forest biotechnology differ from perceptions and attitudes toward other forest health management strategies, such as proactively thinning trees to prevent the disease from spreading through the forest, these initial results do not provide in-depth insight into *why* people perceive forest biotechnology differently from these other management options. These studies also do not provide insight into how individuals navigate trade-offs in their beliefs about potential outcomes of forest biotechnology, and how those trade-offs influence their attitudes toward forest biotechnology. Therefore, I conducted a qualitative study to gather robust data about how various cognitions affect attitudes toward forest biotechnology.

Specifically, this study addressed risk and benefit perceptions associated with genetically modifying tanoak trees to be resistant to a specific forest health threat, sudden oak death (the choice of this threat is explained in the methods section). The overarching research questions for this study were:

**RQ 1**: How do conservation professionals and volunteers' risk and benefit perceptions inform attitudes toward the use of biotechnology to address forest health threats?

**RQ 2**: How does familiarity with forest biotechnology influence the types of risks and benefits that conservation professionals and volunteers perceive in association with using forest biotechnology to address forest health threats?

## Methods

### Research Design

This study incorporated dimensions of both post-positivist and constructivist research approaches to investigate attitudes and beliefs (Creswell, 2014). Post-positivist and constructivist research approaches emerge from a belief that individuals develop their own meanings about the world around them – meanings that are shaped by various social, cultural, and personal contextual factors (Blackstone, 2012). In this study, I aimed to explore the ways people describe risk and benefit perceptions and how those perceptions inform attitudes and arguments toward using forest biotechnology to address forest health threats.

Qualitative methods allow the researcher to gather rich data about a specific research topic and are especially useful when investigating how people think (Bernard, 2006). Additionally, qualitative methods are especially appropriate to understand a phenomenon about which little is known or when current understandings appear to be inadequate (Richards & Morse, 2013), such as this topic. I used semi-structured interviews to address the research questions. This interview format provided participants with an opportunity to identify and discuss the factors that influence the various risks and benefits they perceived about using forest biotechnology without assuming a priori what factors would emerge. However, the semi-structured format also ensured that each interviewee was able to share their thoughts about the preestablished constructs in the interview guide. The format provided flexibility to investigate interesting responses through follow-up probing questions.

### Sampling and Data Generation

Given that existing literature suggests that attitudes toward forest biotechnology are influenced by the risk and benefits individuals perceive, I sought to locate individuals who would perceive risks and benefits differently. To do this, I used a purposive sampling strategy to

recruit participants affiliated with a cross-section of conservation and environmental organizations, a research protocol that was reviewed and authorized by the Oregon State University Institutional Review Board (IRB-2019-0219). These organizations (e.g., agency, non-profit, private, and landowner) represent a cross-section of different types of conservation missions – on-the-ground land management, forest research, environmental policy and decision making, advocacy, and stewardship. These affiliations served as a proxy for identifying conservation professionals in the Pacific Northwest who would likely have different risk perceptions, benefit perceptions, familiarity with, and/or attitudes toward forest biotechnology and land management more broadly. Effectively, the sample included individuals from communities of interest concerned about, or affected by, forest management, either professionally or through service activities.

After identifying a spectrum of approximately 35 conservation and environmental organizations in the Pacific Northwest, mostly in Oregon, I emailed all of the staff and volunteers with contact information listed on their "staff" webpages to invite them to participate in a one-hour interview. This recruitment email included information about this specific study and general information about the scientific endeavors underway at various academic institutions to use forest biotechnology as a potential solution to address pests and pathogens affecting forests (Appendix A). The informed consent document outlining the responsibilities and potential risks associated with participation was also attached to this email (Appendix B). Individuals were asked to respond if they were interested in participating. Of the initial 94 recruitment emails, 52 individuals did not respond and 13 were not interested in participating, establishing an initial sample of 29 individuals (30% response rate). I personally conducted all of these interviews between July and December 2019 to reduce the potential of differential "interviewer effects" – biases that result from different interview styles, question framing, and overall interviewer demeanor (West & Blom, 2017).

Upon reviewing demographic and interviewee characteristics associated with the initial sample (n=29), we realized that there wasn't saturation in the sample for individuals who were familiar with forest biotechnology or supportive of its use to address forest health issues. Given the study's aims, it was important to have participants with a range of familiarity with and

attitudes toward forest biotechnology. Consequently, I solicited additional interviews from individuals who were familiar with and supportive of forest biotechnology. To do this, I contacted gatekeepers to share the recruitment information with members of the Pacific Northwest Tree Improvement Research Cooperative and conducted an additional four interviews. Upon reviewing these additional interviews, we determined that we had reached content saturation, given that these interviews were not providing new perspectives about the research questions (Morse, Barrett, Mayan, Olson, & Spiers, 2002). In total, 33 individuals participated in this study.

## Interview Topics and Questions

The semi-structured interviews utilized the technique of funneling, where interviewees were asked broad questions at first and questions became more specific throughout the interview (Mandel, 1972). Each interview had three distinct sections (Appendix C and Table 3). First, interviewees were asked questions about how they define nature and naturalness (those data are discussed in chapter 3 of this thesis). Then, interviewees were asked to describe their general attitudes and beliefs about genetic modification as a technology and their familiarity with forest biotechnology specifically. Interviewees also discussed their opinions about using biotechnology in forests, as opposed to agricultural applications. Additionally, in this section of the interview, a majority of interviewees were asked to share their opinions about using biotechnology for commercial forestry applications (e.g., increasing timber yield, improving structural characteristics) as opposed to more resistance-based applications (e.g., establishing resistance to specific forest health threats). The differences in how interviewees thought about these two different applications of forest biotechnology emerged as an important consideration during initial interviews, so this probing question was incorporated into the interview guide to ensure that all subsequent interviewees would be asked to share their thoughts about these different applications of forest biotechnology. To refine the interview guide and my interview style to be most effective and minimize bias, while ensuring questions adequately covered the topics of interest, I conducted five pilot interviews, which were not included as data in the present study.

**Table 3:** Concepts of interest and description of the interview questions associated with each of the concepts of interest in this study.

| Concept of Interest | Examples of Interview Questions | Interview Questions |
|---|---|---|
| Environmental ethics | Some say that humans are more important than nature, while others say that nature is still important even if it doesn't provide things for humans to use. How do you feel about these statements? | Q1 |
| Perceptions of naturalness | Would you describe nature as more resilient or fragile? What kinds of landscapes would you use the word "nature" to describe? | Q2-6 |
| Attitudes toward GM and forest biotechnology trees | What are your opinions toward genetic modification more broadly? How do you feel about using GM on trees instead of crops? How do you feel about genetically modifying tanoak? How do you feel about researching forest biotechnology? Would it matter whether the DNA was from a closely related species? Would it matter if the threat was native or non-native? Would it matter if there were other options available? | Q7-10; Q13; Q16 – 19 |
| Benefit perceptions of GM and forest biotechnology trees | Do you see any advantages to using GM to create a tanoak resistant to SOD? | Q14 |
| Risk perceptions of GM and forest biotechnology trees | Do you see any disadvantages to using GM to create a tanoak resistant to SOD? What type of information would you want to know before making your opinion? | Q15; Q20 |

The last part of the interview was focused on a specific scenario: using biotechnology to establish a genetically modified variety of tanoak (*Notholithocarpus densiflorus*) that is resistant to sudden oak death (*Phytophthora ramorum*). Sudden oak death (SOD) is a catastrophic, non-native fungal pathogen causing high mortality in tanoak trees. Tanoak, a dominant understory species endemic in coastal Douglas-fir forests in southwestern Oregon and northern California, is one of the species most susceptible to SOD (Fryer, 2007). Consequently, the Oregon Department of Agriculture issued an emergency quarantine of SOD when it was first detected in the state in January, 2001, to prevent its spread. Because of its catastrophic potential and ability to infect a wide range of host species, SOD has been federally quarantined. Multiple land

management agencies collaborate on the SOD Task Force to contain SOD to Curry County in southern Oregon.

It is important to note that researchers are not currently investigating any type of forest biotechnology solution to engineer tanoak to be resistant to SOD. Instead, the research team selected this hypothetical scenario as the attitude object for this study because SOD is a high priority forest health threat of substantial concern in Oregon. Given the publicity surrounding SOD throughout the state, we assumed that it would be a familiar forest health threat with a sense of urgency and severity – considerations that have been shown to be important influences on attitude in existing scientific literature investigating public perception of forest biotechnology. We chose to use SOD instead of bark beetle, Swiss needle cast, or another commonly discussed forest health threat because SOD is a regionally specific, severe threat for a rare and endemic forest type to OR. Therefore, SOD exhibited the primary risk characteristics of the psychometric paradigm: potential catastrophic nature given the rate of spread and mortality of the disease as well as potential dread given that the tanoak species is endemic to the state. Additionally, SOD could be a viable issue to address with forest biotechnology given the nature of the pathogen, whereas bark beetle is not; outbreaks of these pests are primarily managed using established forest management techniques, such as thinning or prescribed fire.

Mid-way through the interview, interviewees read a short informational overview of SOD (Appendix D) that was adapted from the 2018 *Forest Health Highlights in Oregon* report produced by the United Stated Department of Agriculture. This scenario included general information about tanoak, including an explanation that it is endemic to northern California and southern Oregon, as well as information about SOD. It described the State's response to eradicate SOD once it was discovered, including landowner requirements to remove any trees exhibiting symptoms on their property. It also described how the pathogen spreads and its 4-mile annual rate of spread. Lastly, the scenario included a short paragraph about the potential impacts of this water mold on tanoak trees and fire-dependent communities, including increased fire risk, reduced habitat quality, and other ecological impacts to wildlife and forest structure. This information was selected because it provides general context of the issue for

those that aren't familiar with SOD or tanoak, while also providing factual information about why forest managers are addressing this substantial threat.

After reading this information, interviewees were asked to describe their general attitude and emotional response to using forest biotechnology to engineer a tanoak tree that would be resistant to SOD, followed by a series of questions related to contextual factors that existing literature suggests influence attitudes and/or risk and benefit perceptions about GM and forest biotechnology. Specifically, this section of the interview included questions investigating the following:

- the ***DNA source*** (i.e., transgenic or cisgenic). Studies of public perception of crop and forest biotechnology suggest that individuals are more supportive of using forest biotechnology approaches that source DNA from a closely-related organism ("cisgenesis") versus an unrelated species ("transgenesis") (Kronberger et al., 2013; Mielby, Sandøe, & Lassen, 2013; Scott et al., 2016).
- the type of ***threat*** (i.e., native or non-native). Given that this study investigated attitudes and risk perceptions toward forest biotechnology, we included questions regarding views on threats that are native vs non-native to the ecosystem to understand whether that influences how respondents perceive risk and their attitudes toward using forest biotechnology.
- the presence of ***other options*** (e.g., selective breeding). Prior studies on this topic suggest that the public tends to support solutions that require less intervention (e.g., breeding resistant individuals) more than GM-based approaches (Hajjar & Kozak, 2015; Hajjar et al., 2014; Needham et al., 2015). Consequently, we were interested in understanding how attitudes were influenced by the ability to pursue other options to address SOD instead of FB.

In addition to being asked to share their opinions about these various characteristics of the SOD scenario in this section, interviewees were also asked to describe the risks and benefits they perceived in association with using forest biotechnology to engineer a variety of tanoak resistant to SOD. Finally, interviewees were asked to describe what type of information they would want shared with them about a GM tanoak before making a decision about whether to

move forward with planting (i.e., during a public meeting). This question was included to provide insight into the type of information people felt they would need in order to make an informed opinion about this topic.

It is important to note that, given the semi-structured nature of these interviews and the one-hour time allotted by most interviewees, not all of the questions in the interview guide were asked in all of the interviews. As the interviewer, I made strategic choices to allow interviewees enough time to fully elaborate on concepts of interest in lieu of asking all of the interview questions in order. When I had to remove questions from the interview due to time constraints, I often chose not to ask the question about what type of information they would want to know about the GM tanoak, although there were multiple instances in which I didn't have enough time to ask other questions in the interview guide as well. The shortest interview was 18 minutes and the longest interview was 75 minutes, while the average interview lasted approximately 46 minutes.

## Data Analysis and Coding

All participants consented to having their interview audio-recorded for transcription purposes; interviews were transcribed using Nvivo Transcription voice recognition software and reviewed for accuracy. I reviewed transcripts to refine the *a priori* codebook with codes that emerged from the data associated with each of the constructs of interest. Although the unit of observation for this study was the individual, the unit of analysis was the individuals' cognitions about the constructs of interest (risk/benefit perceptions, justifications, and attitudes). Statements in each interview were coded to specific codes within these various constructs and analyzed to understand the role each of these codes and constructs played in interviewees' overall attitudes toward forest biotechnology. The completed code book includes separate codes for each construct of interest: risk perceptions, benefit perceptions, justifications (i.e., arguments), and attitudes (Appendix E).

The data were coded using Nvivo 12 software. The process was iterative; my major advisor and I each independently reviewed transcripts between meetings to discuss themes within the data, such as common arguments and conditional attitudes, and how the data answered the research questions. During this phase of open coding, we met weekly to debrief

the content in the transcripts and confirm codes and decision rules to include in the final codebook (Appendix E). When we disagreed about coding, we reviewed and discussed the interview in depth until we agreed on a code classification. The coding was reconciled in the data accordingly. Both of us read each interview in its entirety; some were read multiple times.

Once this open coding process was complete, I used the crosstab query functions in Nvivo to investigate patterns in the coded data. Primarily, I investigated how risk and benefit perceptions varied among attitudinal classification and familiarity with forest biotechnology . This process allowed me to identify patterns in these constructs of interest associated with interviewee characteristics (i.e., attitude, familiarity with forest biotechnology) and determine which results were prevalent enough in the data to include in this thesis. The raw results of these crosstab queries are provided in tables in Appendices F (risk perception queries) and G (benefit perception queries).

## Sample Variation

Given that the research questions of this study were focused on familiarity, beliefs, and attitudes toward forest biotechnology, it was especially important to have variation in attitudes toward, and familiarity with, forest biotechnology in addition to the other constructs of interest (Table 3). To identify interviewees' overarching attitudes toward forest biotechnology, we independently reviewed each interview transcript as a whole. We had difficulty assigning interviewees to the three categories we had developed a priori: support, ambivalent, and oppose. Instead of expressing unilateral attitudes toward forest biotechnology, many interviewees conditioned their attitudes by describing specific situations or contexts in which they would be more (or less) willing to use forest biotechnology. We did not want to misrepresent these conditioned and contextual attitudes by including them in unequivocal categories of "support" and "opposed." Moreover, these attitudes were usually not truly ambivalent (i.e., they were not equally positive and negative). Often, these interviewees were opposed to or supportive of many aspects of forest biotechnology but would describe specific conditions in which they would not be fully supportive or opposed to forest biotechnology. Therefore, we ultimately classified interviewees as completely supportive, mostly supportive, ambivalent, mostly opposed, or completely opposed to forest biotechnology (Table 4).

Although we developed coding rules, during initial independent coding, we disagreed about our attitudinal classifications for approximately 33% of interviewees. However, there was only one instance in which our independent classifications were on opposite sides of this spectrum: one of us indicated the respondent was mostly supportive and the other indicated the respondent was mostly opposed. Otherwise, disagreements were primarily between adjacent categories, especially the "mostly opposed" and "ambivalent" categories. When we disagreed on attitudinal classifications, we reviewed and discussed the interview transcript until we reached agreement about their overall attitude toward forest biotechnology. Our reconciled attitudinal classifications are presented in Table 4.

**Table 4**: Descriptions of each of the attitudinal classifications to which interviewees were assigned and the number of interviewees assigned to that classification.

| **Attitudinal Classification** | **Attitude Description** | **Number of Interviewees (n=33)** |
|---|---|---|
| Completely Supportive | An entirely positive attitude toward forest biotechnology and comfort using it in a variety of contexts and situations without identifying explicit conditions limiting their support | 4 |
| Mostly Supportive | A predominantly positive attitude toward forest biotechnology, with a few conditions in which it would not be supported as a solution<br><br>*Example:* An interviewee who supported using forest biotechnology in most situations discussed throughout the interview, but was opposed to using it to address native pests or pathogens specifically. | 8 |
| Ambivalent | A balanced mix of opinions or contradictory beliefs about forest biotechnology, such as references to being able to see both sides of the issue<br><br>*Example:* An interviewee who was supportive of restorative applications of forest biotechnology that will provide substantial environmental benefits but opposed commercial applications of forest biotechnology that will contribute to commodification of living organisms. | 6 |
| Mostly Opposed | A predominantly negative attitude toward forest biotechnology, with few conditions in which it would be acceptable as a solution (e.g., only in specific types of settings, in specific contexts, or for specific types of threats) | 9 |

| | | |
|---|---|---|
| | *Example:* An interviewee who opposed using forest biotechnology in most situations discussed throughout the interview but was supportive of using it if the pest has catastrophic impacts and there aren't any other viable options to address it. | |
| Completely Opposed | A universally negative attitude toward forest biotechnology and opposition toward using it whatsoever in any type of situation | 6 |

Since existing research has shown that familiarity with forest biotechnology can be an important influence on attitudes toward forest biotechnology, I also sought variation among participants in regards to their familiarity with forest biotechnology. During the interview, participants were asked whether they were familiar with efforts to genetically engineer trees. Their answer to this question, as well as the level of detail and knowledge they used throughout the interview to describe forest biotechnology, was used to determine whether they were familiar with this technology. For example, using specific language about different GM techniques (e.g., "knock out," Crisper/Cas9") reflected a degree of familiarity with forest biotechnology (n=15), whereas explicit statements about being unfamiliar with or not having heard of forest biotechnology clearly displayed a lack of familiarity. Some interviewees claimed that they had heard about this technology but didn't use any type of specific or explicit language to describe the technology or how it could be used in a forestry setting during their interview, suggesting that they weren't actually familiar. I classified these 18 interviewees as being unfamiliar with forest biotechnology technology.

## Results

### Sample Description

Nearly all participants in this study were Caucasian (Table 5); this is consistent with the July 2019 U.S. Census estimate that ~87% of Oregon residents are Caucasian. Approximately 60% of participants were raised in urban areas, whereas 40% of participants were raised in rural areas (Table 5). Twelve women and 21 men over the age of 25 participated in the study, with the average age being 52 years.

\

| **Table 5:** Socio-demographic characteristics of the final sample (n=33). | | |
|---|---|---|
| **Characteristic** | **Count** | **Percent** |
| **Childhood Residence** | | |
| Urban | 20 | 60% |
| Rural | 13 | 40% |
| **Ethnicity** | | |
| Caucasian | 32 | 97% |
| Hispanic | 1 | 3% |
| **Age** | | |
| 25-34 | 3 | 9% |
| 35-44 | 8 | 24% |
| 45-54 | 5 | 15% |
| 55-64 | 9 | 27% |
| 65+ | 8 | 24% |
| **Gender** | | |
| Female | 12 | 36% |
| Male | 21 | 64% |

As described in the "Sampling and Data Generation" section, the sampling strategy involved recruiting participants from a variety of organizations, including private (9 interviewees; 27% of sample), non-profit (12 interviewees; 36% of sample), agency (9 interviewees; 27% of sample), and private landowners (3 interviewees; 9% of sample). Additionally, given the employment requirements for specialized knowledge within the environmental and conservation field, there were more highly educated individuals in this sample than the general public, with 91% of interviewees having college degrees. Of those degrees, 63% were in environmental fields such as environmental science, forestry, or wildlife management. The other 27% were in non-environmental degrees, in disciplines such as urban planning or business.

### Respondents who were familiar with forest biotechnology were more likely to have a defined attitude.

Almost half of the participants who were familiar with forest biotechnology were either completely opposed or completely supportive of forest biotechnology, suggesting that they had a concrete and determined attitude towards forest biotechnology. Further, all six of the interviewees who were completely opposed to using forest biotechnology were familiar with it

as a technology. Nearly all participants who were unfamiliar with forest biotechnology tended to be more conditional about their support or opposition for biotechnology, with attitudes ranging from mostly supportive to mostly opposed (Figure 1). These interviewees discussed both positive and negative considerations of forest biotechnology or identified specific conditions in which they would support or oppose forest biotechnology.

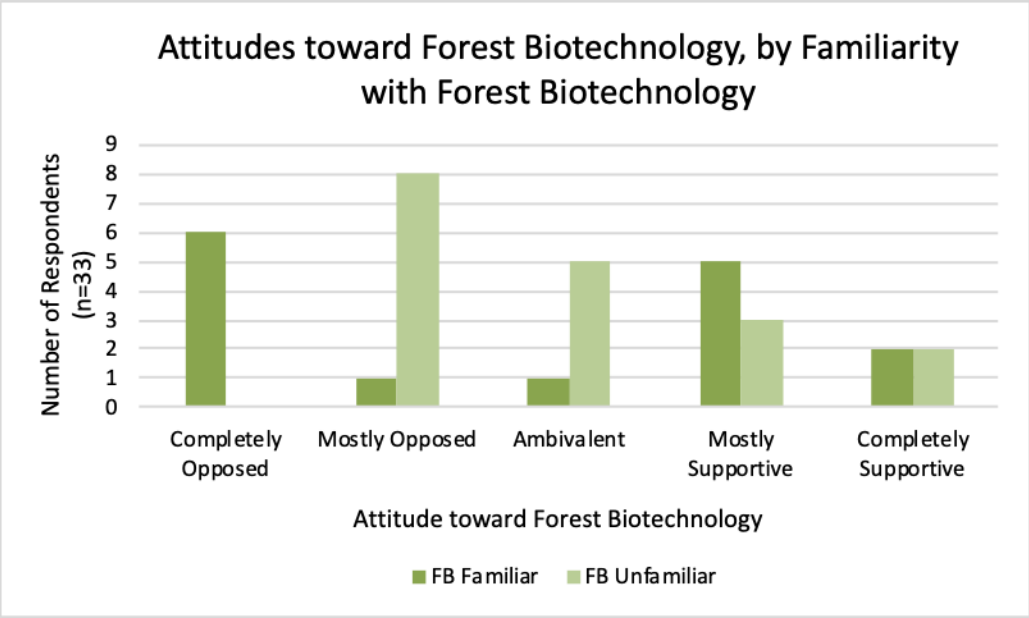


***Figure 1:*** *Attitudes toward forest biotechnology grouped by familiarity with forest biotechnology.*

## Respondents experienced difficulty identifying concrete benefits about using forest biotechnology to address sudden oak death.

Interviewees who were more supportive of using forest biotechnology to address forest health threats tended to identify more benefits when discussing using forest biotechnology to address SOD than interviewees who were more opposed to using forest biotechnology. Most commonly, interviewees perceived ecological benefits and increased scientific knowledge as positive outcomes of this application of forest biotechnology (Figure 2). Very few interviewees explicitly identified cultural, economic, or social benefits associated with using forest biotechnology to address forest health threats. Although interviewees did describe increased scientific knowledge and ecological benefits, it appeared to be difficult for them to identify concrete benefits about using forest biotechnology specifically. Instead, interviewees described benefits broadly in the context of protecting tanoak from sudden oak death, regardless of the method used.

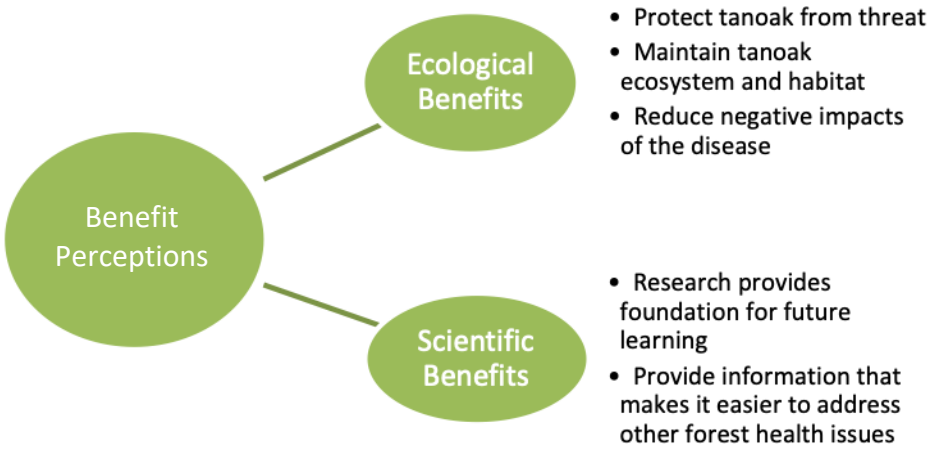


***Figure 2:*** *Common benefits interviewees perceived about using forest biotechnology to address forest health threats.*

Primarily, interviewees referenced information they read in the scenario about SOD when asked about potential benefits of forest biotechnology. The SOD scenario described multiple risks that the pathogen poses, including ecological (e.g., tanoak mortality, fire risk), social (e.g., reduced aesthetics and property values), and cultural (e.g., impacts to Indigenous food sources) risks. Interviewees often described surmounting these risks as potential benefits of using forest biotechnology to address SOD (e.g., creating a GM tanoak will reduce fire risk, maintain aesthetics and property values, and maintain native American food sources). For example, one interviewee described the benefits she perceived about using forest biotechnology to create an SOD-resistant tanoak: *"then we'd still have tanoaks. With all of the benefits in that second to the last paragraph" (F3*[1]*; completely support).*

Some interviewees built on these perceived benefits by citing other broad ecological benefits that forest biotechnology could provide. Most commonly, these interviewees referenced benefits associated with maintaining the tanoak species, such as "*being able to maintain the species throughout the landscape… in its native range" (F13; completely support),* or the potential to *"prevent widespread destruction of … natural habitat" (F2; mostly opposed).*

[1] The identity of each of the interviewees was protected by coding their transcript with the first initial of their gender (determined by physical presentation) and the number of the interview. In this case, "F3" refers to the third female-presenting interviewee in the sample. "M3" would refer to the third male-presenting interviewee I interviewed.

The scenario described tanoak as a keystone species, and respondents took that into consideration when discussing benefits:

> *It's [forest biotechnology is] a means of potentially protecting the landscape, the value… the quality of that ecosystem. And all of the flora and fauna that presumably depend upon it… those would be the benefits I would see. (M16; mostly supportive)*

Ecological benefits were often mentioned immediately by interviewees when they were asked to identify benefits associated with forest biotechnology, regardless of their familiarity with forest biotechnology. Interviewees perceived these types of broad ecological benefits regardless of their attitudes toward forest biotechnology, although ecological benefits, and benefit perceptions more broadly, were substantially more common among interviewees who were more supportive of using forest biotechnology. This suggests that these types of ecological benefits were most salient for interviewees.

Aside from these broader ecological benefits, many interviewees also perceived a variety of benefits associated with the increased scientific understanding of forests and forest ecology that this type of research and application of forest biotechnology would provide. One interviewee described the benefit of this knowledge in addressing other forest health threats:

> *I think that it would be pretty cool… if we found something that made one species resistant to one fungus species, made those trees resistant to one type of Phytophthora, it might have applications in other tree host Phytophthora pathogen relationships. (F13; completely supportive)*

Although interviewees who were familiar with forest biotechnology more commonly identified increased scientific knowledge as a potential benefit of forest biotechnology than those who were unfamiliar, interviewees identified this as a benefit regardless of their overall attitude toward forest biotechnology. One interviewee who mostly opposed forest biotechnology described the benefit this knowledge could provide other disciplines: "*Like if it does work-- if during the course of experiments new knowledge is found that can help other disciplines… even other… experiments with modifying genes. I can see that, and that would be a benefit" (F6; mostly opposed).*

### Respondents perceived some risks from forest biotechnology to be similar to risks from agricultural biotechnology.

As previous research indicates, interviewees felt that many of the risks they associated with GM in agriculture would occur with forest biotechnology. However, although human health concerns are one of the most common risks individuals associate with agricultural biotechnology, that type of risk perception was not common among interviewees in this study. Although I did not explicitly ask interviewees about health-related risks associated with forest biotechnology, I believe this risk rarely emerged because the interview was primarily focused on using forest biotechnology to address forest health threats, an application that does not inherently involve the human body or human health.

Sometimes, interviewees simply referenced general types of risks that have surfaced in studies of GM agriculture, such as lack of control, unintended consequences, or irreversibility. Other interviewees cited more explicit risks that have materialized in GM agriculture and associated them with forest biotechnology as well (Figure 3). This included specific concerns about lack of control, as one interviewee described: "*As soon as you plant something, whatever you've put in there, if it's viable, will spread to other things. And now you can't control what will happen" (F1; mostly opposed).* Another interviewee described concerns about the potential GM tree impacting other species in the ecosystem, especially non-tree species that may interact with the GM tree: *"What is the effect on bird life? How does nature react to it?" (F12; mostly opposed).* Interviewees also expressed similar concerns about corporate greed and commodification as are commonly associated with GM agriculture. One interviewee stated, *"If I feel like the question about genetic modification is coming from that sort of capitalistic mentality, I'm much more opposed to it" (F3; ambivalent).*

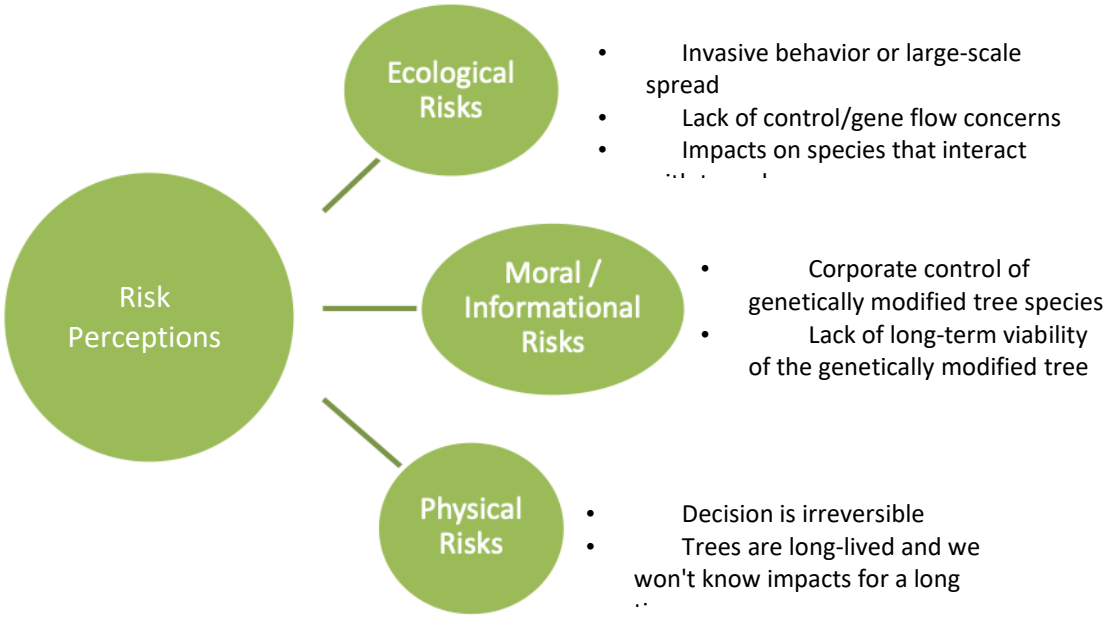


***Figure 3**: Risk perceptions interviewees commonly perceived about using forest biotechnology to address forest health threats.*

## Participants' risk perceptions about forest biotechnology were informed by uncertainty and dread.

Interviewees commonly perceived risks falling within the two components of the psychometric paradigm (Slovic, 1987): uncertainty and dread. Uncertainty manifested in two ways. First, interviewees expressed substantial concern about the scientific uncertainty associated with the types of unintended consequences that might arise from using forest biotechnology. Second, interviewees expressed uncertainty about whether the risks they perceived would actually occur. Dread emerged in a variety of risk perceptions as well, including substantial apprehension toward the GM tree potentially exhibiting invasive or uncontrollable behavior. Further, interviewees expressed dread when discussing their concerns about the long lifespans of trees and the amount of time it will take before we fully understand how the GM tree impacts the environment, either positively or negatively.

### *Uncertainty and Unintended Consequences.*

Interviewees expressed uncertainty in a variety of ways when discussing forest biotechnology. Some people were uncertain about the validity of their beliefs and whether the risks they perceived would actually occur. For example, when asked to describe the types of risks associated with forest biotechnology, one interviewee said, "*I don't know if I know enough*

*about it to comment. I suppose there's potential that you genetically modify an organism to behave in some way that you didn't intend. Although I don't know what that looks like" (M19; ambivalent).* Another interviewee questioned whether the risks he believed might occur actually would, speculating that *"maybe the grassland bird population declines because the [GM] trees are taking over [exhibiting invasive behavior/uncontrollability]. I don't know if that would happen or not" (M6; completely supportive).* Data suggest that many interviewees did not feel confident or strongly about the types of risks they associated with using forest biotechnology to address forest health threats.

Interviewees most commonly expressed uncertainty in their concerns about various potential unintended environmental consequences that they believed would result from using forest biotechnology. These were, by far, the most common risks interviewees associated with forest biotechnology. Every interviewee expressed some level of concern about the potential unintended consequences associated with forest biotechnology; this concern was present regardless of familiarity with biotechnology or attitudes towards its use. However, participants who were unfamiliar with, or more opposed to forest biotechnology referenced concerns about unintended consequences more frequently during their interviews, and the number of references to unintended consequences increased with degree of opposition toward forest biotechnology. This suggests that concerns about unintended consequences may be related to opposition toward using forest biotechnology. For example, some people asserted that it would be very difficult to predict what impacts might be associated with planting a GM tree in the wild because we do not know enough about how these ecosystems function, the relationship between the tree and the pathogen, or how a genetically modified tree would evolve over time. Therefore, we need "*to do studies of unintended consequences*" *(F12; mostly opposed)* to better understand potential impacts associated with the specific GM tree and be sure we "*know what we're doing and make sure it's going to be ok" (F7; mostly opposed)*. Additionally, concerns about unintended consequences led individuals to suggest that we, as a society, should take a thoughtful and cautious approach when implementing forest biotechnology in natural areas and develop long-term monitoring plans so that we are able to quickly identify and respond to any potential negative consequences that arise.

Though all of the interviewees acknowledged the possibility of unintended consequences, they referenced such consequences with varying degrees of detail. At the simplest level, participants referred to the potential for either "unintended consequences" or "negative side effects," without explicitly identifying what those risks could be. For example, one interviewee asserted that "*pretty much 'unintended consequences' covers… a spectrum of things that could happen that would not be good" (F6; mostly opposed).*

Others discussed unintended consequences in more detailed, but still somewhat abstract ways. In contrast to people who mentioned nebulous consequences, these people hypothesized and theorized about the types of potential impacts that might occur. For example, one person speculated that forest biotechnology "*could give a competitive advantage that wouldn't be natural to that oak species,*" which could lead to "*more dominance of the oak species in systems where it shouldn't necessarily be dominant" (F2; mostly opposed).* Others talked about how a GM tree might become "*more invasive in some way" (M19; ambivalent).*

Lastly, some interviewees explicitly identified potential unintended consequences that could arise from forest biotechnology as a result of the complex nature of environmental systems and natural processes. These explicit examples were often informed by unintended consequences that have resulted from other forest management strategies or in GM agriculture. One interviewee described that "*adding* Bacillus thuringiensis *genes into corn was harmful to bees. Pollinators all of a sudden start dying because… they touched the corn… Animals that rely on some things like that may be adversely impacted" (M15; completely opposed).* Conversely, some interviewees referred to issues with GM agriculture to describe how the risks of forest biotechnology are different:

> *Even if there was an unintended pollen or gene movement, I just don't see that having any effect in that ecosystem. It's very different than a GMO crop pollinating a plot of land that does not have genetically modified crops… There's just no analogue to that in my mind. (M21; mostly supportive)*

Another way that interviewees' concerns about unintended consequences emerged was in the restricted set of contexts in which they would support using forest biotechnology. People often stated that, in order to determine whether we should use forest biotechnology, we would

need to weigh *"the benefits against the risks of unintended consequences" (M8; mostly supportive)*. This argument sometimes included explicit references to using cost-benefit or risk-benefit analyses to determine whether forest biotechnology is the most effective or efficient option to address the specific threat. If the case-specific benefits outweigh the potential risks associated with forest biotechnology, or the risks of not doing anything, these respondents saw it as worth investigating forest biotechnology as a potential solution. This line of reasoning involves the argument that forest biotechnology should only be used in situations where the benefits are much more substantial than simply saving the tree; the GM must provide more concrete benefits that justify any potential unintended consequences. Not surprisingly, interviewees making this argument tended to have more ambivalent attitudes toward forest biotechnology.

### *Dread.*

In addition to perceiving risks associated with unintended consequences and uncertainty, some of the risks interviewees perceived and discussed exhibited elements of dread – an emotion that is defined as a sense of great apprehension or fear about something. These comments were distinguished from other risk perceptions based on the weight that interviewees seemed to place on these concerns; these were more than just shallow concerns. Instead, comments that were identified as expressing dread were more substantial worries that clearly displayed a sense of apprehension toward using forest biotechnology.

Interviewees most obviously expressed dread in the context of their concerns about the GM tree exhibiting invasive behavior or the lack of ability for people to control the species once it is planted in natural forest settings. Although gene flow is a natural process among plants and other organisms, it was commonly perceived as a risk associated with GM and forest biotechnology and used as an argument against using forest biotechnology. For example, one interviewee who was completely opposed to forest biotechnology described his apprehension toward using it given the potential for invasive behavior:

> *We don't know what could happen. Once you put it out there you can't control it anymore. So you don't know how -- It's like you think you have control, and you have*

> *this control in the lab, but once it gets out into the environment there is no control anymore. So, I think that's irresponsible. (M7)*

Similarly, another respondent said,

> *I do worry… when lab setting situations are put out in the field for implementation and use. It can be challenging to foresee all the expressions or the situations that might arise… In a lab setting it's very controlled. I feel pretty safe about that, but once put out into the natural environment… there's just so many variables that it could be hard to forecast… I'm more apprehensive about that. (F11; mostly supportive)*

One interviewee's apprehension toward these types of potential impacts was so strong that she advocated drastic control measures if something went wrong: "*I'd like to see some safety measures to say, '…if something goes wrong, we're going to… burn the test forest'" (F9; completely opposed).* This dreadful apprehension about the potential for spread and invasiveness was likely salient for interviewees in this study because such concerns are common in oppositional messages toward GM agriculture (Blancke, Van Breusegem, De Jaeger, Braeckman, & Van Montagu, 2015; Hielscher et al., 2016; Scott et al., 2016).

A related concern was evident among interviewees who exhibited a sense of dread when referencing the long lifespans of trees and how that will impact scientists' ability to fully assess the impacts that planting a GM tree will have on the ecosystem. As one respondent said, we might be getting "*another Frankentree out there*" and not find out for years "*that this genetic modification killed off all the understory… And, you know, we will have screwed it up again*" (F12; mostly opposed). Another interviewee who was mostly opposed to forest biotechnology described his apprehension: "*I think that in our hubris, we will do a lot of things that will… have negative impacts… that you won't know until it's too late. Until the genes are out there" (M15; completely opposed).* Similarly, some interviewees expressed dreadful concerns about the permanence of the decision of planting forest biotechnology trees because these modified trees cannot be easily removed once they are planted in forests. One interviewee who was completely supportive of forest biotechnology asserted that it "*can be incredibly difficult to reverse, if not totally irreversible" (F13).*

## Concerns about tampering with nature influenced arguments interviewees used to support their attitude toward forest biotechnology.

A variety of the risk perceptions presented in the "Uncertainty" and "Dread" sections above are also related to views about tampering with nature. There were two primary themes used as explanations for support or opposition to forest biotechnology. First, some participants believed people cause more impacts when they tamper with nature to "fix" a problem. This argument was converse to the second, substantially less common, argument that forest biotechnology is not a new form of tampering with nature and is therefore acceptable.

### *Humans Can't Fix Nature*

Frequently, interviewees expressed concern about tampering with nature given that humanity's prior attempts to intervene to solve environmental problems have often resulted in more environmental problems. Interviewees suggested that our hubris makes us feel that we are capable of solving complex environmental problems, but that is rarely the case given how little we know about how the natural world functions. One interviewee explained her complete opposition toward forest biotechnology by saying,

> *We don't know enough. And over and over and over we do these interventions without enough information… when you look at the history of forestry management or any human management of nature, that's what stands out… we screw up. (F10; completely opposed)*

Another interviewee expressed a similar sentiment:

> *Humans are like the kings of not realizing until 50 years later that we're creating a catastrophe and then in hindsight we're like, 'that was really stupid,' but we're like creating another catastrophe while we're like cleaning up the other one. (F4; ambivalent)*

Interviewees argued that humans repeatedly intervene and tamper with nature by implementing management strategies that we are confident will be a solution, only to learn that these interventions were not successful. One interviewee described his apprehension toward forestry management actions given this history of failure:

> *That's the darn problem with doing things like this again and again. 'We got it wrong last time, but we're going to get it right this time.' Well, that's what we've been saying for the last many thousands of years and it just hasn't turned out to be true ever. (M1; completely opposed)*

Consequently, many interviewees argued that we shouldn't tamper with nature by using forest biotechnology to address forest health threats or SOD specifically because we are likely to cause more environmental problems or risks that we will then have to face.

### *Forest Biotechnology is Not a Form of Tampering with Nature.*

Although many interviewees felt that forest biotechnology is simply another way that humans interfere with nature, some interviewees did not. Instead, these interviewees articulated how humans have been modifying the genetics of organisms for millennia; this belief buttressed positive attitudes about using forest biotechnology. For example, one interviewee stated that "*humans have been manipulating the natural environment for forever, right, for eons" (F11; mostly supportive).* These interviewees considered forest biotechnology as an extension of the technologies and methods humans have commonly applied in agriculture and forestry to modify plants for thousands of years (e.g., scientific breeding, domestication). This same interviewee asserted that "*genetic modification is a practice that humans have been using for a long, long, long time for our benefit" (F11; mostly supportive).* Another interviewee said, "*The way I see it, this is just another breeding technique" (F13; completely supportive).* As society and science have evolved, our tools to address environmental issues have also evolved. Consequently, these interviewees believed that forest biotechnology is a useful tool that can and should be used to address a variety of environmental issues, given that it could provide substantial benefits. The interviewees who used this argument tended to be familiar with forest biotechnology and supportive of its use.

## Common Arguments Interviewees Used to Condition their Attitude toward Forest Biotechnology.

As noted earlier, few respondents were entirely opposed or entirely supportive of using forest biotechnology. Indeed, many interviewees articulated reasons to qualify the extent of their support or opposition and describe the contextual factors that influence their attitudes

toward using forest biotechnology to address forest health threats. These included arguments related to the intent behind the modification, the viability of the GM tree to withstand the pest, the severity of the threat being addressed, and whether other options are available to address the threat.

### *Intent*

A majority of interviewees with ambivalent or conditional attitudes (i.e., mostly supportive or mostly opposed) distinguished between the types of applications and intents for which they felt it was appropriate to use forest biotechnology. Interviewees' attitudes toward using forest biotechnology for commercial applications often differed from their attitudes toward restoration-focused applications. Specifically, many interviewees were more supportive of using forest biotechnology to engineer trees that are resistant to severe pests or to "save a species" than of using forest biotechnology to generate financial profits and economic incentives for companies or corporations. For example, one respondent questioned, "*what's the intention behind using this particular tool? Is it just to make more money for industries at a faster rate …? [Or] is it to save a species?" (F1; mostly opposed).* Another respondent articulated further, saying,

> *If there is a pest that's going to wipe the species out, I'd be more interested in hearing… ideas on what could be done with genetics, whereas if there was just a way to get a Douglas-fir to grow a little quicker I'd be like, "don't mess with it just for that" (M10, ambivalent)*

Even respondents who were largely supportive of forest biotechnology questioned its use for purely profit-driven motives, as articulated by F11, who valued the *"restorative goal more than the commercial harvest goal."* Even though she could *"see there's definitely values for both,"* she concluded that, overall, she would *"rather [forest biotechnology] be applied for building a more resilient landscape" (F11; mostly supportive)*

Some interviewees elaborated on the importance of intent by arguing that each application of forest biotechnology should be assessed on a case-by-case basis. Instead of deciding that all restoration or commercial applications of this technology are or are not appropriate, *"there are different reasons for doing that [using forest biotechnology]. And in*

*some cases… they're beneficial and in some cases, maybe more harmful than beneficial. I guess it really depends on a specific case example how I feel about it" (M19; ambivalent).* Therefore, to these respondents, it was important to know "*what you're trying to modify and especially why… It's so case-by-case" (M22; completely supportive).* Each application should be reviewed in light of the specific trait being modified and why that modification is necessary to achieve the desired outcome.

Interviewees also supported their attitudes toward forest biotechnology using arguments related to corporate greed and commodification of natural resources. Interviewees raised these concerns regardless of their attitude toward forest biotechnology. For example, one interviewee expressed concerns about GM research promoting industrial uses of forest lands: *"If this sort of research gives any more strength and argument to those extractive industries to continue to log old growth forests and interrupt really important corridors… then I'm going to be concerned" (F3; ambivalent).* Another interviewee was concerned about who is involved: *"Who is doing it? Is it some big corporation that's going to go out and do it? ...Do they have a hidden agenda? …Or is it the good guy who's doing it?" (F7; mostly opposed).* Another articulated concerns about corporations that have been involved in GM: *"I think that their motivations are primarily about making more money and not about the health of the planet" (M15; completely opposed).*

## *Viability*

A majority of interviewees used arguments about the viability of the GM tree to describe the types of conditions and contextual factors in which they would be more (or less) supportive of using forest biotechnology. Commonly, interviewees questioned whether the modified trait would remain viable over time given natural selection and adaptation processes. Also, trees are long-lived organisms, which could extend the time necessary for research to ensure the efficacy of the modification and its lack of negative impacts to the environment. One interviewee described the difference in researching trees versus annual crops as a limitation:

> *The learning happens faster [in annual crops] because it's on an annual basis. It can be changed every year, whereas a tree is slow growing and it takes 10, 20, 30… It takes decades instead of years… to measure the consequences. (M17; completely supportive)*

Another interviewee said, "*as opposed to an experiment you can do in a lab in two months or three weeks... forestry experiments take 20 years, 50 years or more… It's not a short-term cure" (M2; completely supportive).* Moreover, while scientists would be conducting longitudinal and ecological studies to develop the tree, the pathogen would continue to adapt. One interviewee expressed his concern saying, "*I don't know how the fungus, if it would evolve over time. And now you just have all this money spent and these [GM] trees that are still going to die because the fungus evolved" (M6; completely supportive).* Consequently, forest biotechnology might not be a viable tool for all forest health threats because of the time involved to engineer, test, and plant the GM tree in comparison to the rate that the pest or pathogen evolves, as described by one interviewee: "*The trees grow in decades. The fungi grow in months. So, if there is a race here, the fungus is going to win it" (M9; ambivalent).* Further, the GM tree might not be able to maintain its viability in the future, after it is planted in the forest, as the pathogen continues to evolve in a much shorter evolutionary lifespan than the tree.

### *Severity of the Threat*

Another argument that interviewees frequently used to qualify the conditions in which they would support using forest biotechnology was related to the perceived severity or catastrophic nature of the threat being addressed with forest biotechnology. Mostly, interviewees were more supportive of using forest biotechnology to address threats that they perceived to have catastrophic and severe impacts on the forest. Interviewees tended to support using forest biotechnology to address threats that spread quickly through forests or have high mortality rates for familiar tree species. For example, one respondent said,

> *If something was going to kill all of the last Oregon white oaks that we still have in the valley, I probably would be willing to entertain some thoughts on if there was a genetic thing that could be done to keep that, because it's kind of a unique species… It is worth it if you really feel like we're going to, in these forests or in these ecosystems, we're going to lose this species if we don't do anything. (M10; ambivalent)*

Another interviewee explicitly mentioned that the mortality rate of the pest needs to be more than 75% before he would consider forest biotechnology as an option:

> *Where I would tend to not be as supportive is if, you know, say this [pest] is [causing] seventy-five percent mortality or something. And even though that is huge for that system at that time, you have a lot of trees that are showing some resistance to this [pest] and so there is that opportunity for… natural selection to kind of play out. (M11; ambivalent)*

### *As A Last Resort*

In addition to the arguments related to the intent of using forest biotechnology, the viability of forest biotechnology, and severity of the problem being addressed, interviewees also commonly used arguments related to the availability of other options that could potentially address the forest health threat. Specifically, when interviewees were asked about pursuing forest biotechnology in the context of other potential solutions (e.g., breeding), it was clear that they perceived forest biotechnology as having more risk than other options. However, interviewees acknowledged that breeding might not be an appropriate solution for all threats and qualified their attitude toward forest biotechnology by suggesting that it might be appropriate to pursue as a last resort in those specific situations. For example, one respondent said her support for genetic modification in the scenario "*would depend,"* and she would only entertain forest biotechnology *"if this was the last thing we had thought about" (F1; mostly opposed).* Another interviewee expressed interest in trying *"to figure it out before resorting to what I think of as… a last resort of genetic modification. There may be other ways to make sure it doesn't spread other than genetically modifying the trees" (F2; mostly opposed).* Another interviewee stated, "*I would only want to see it [forest biotechnology] used when it felt like you were starting to be out of options… we feel like we've exhausted other ideas" (M10; ambivalent).*

## Discussion

It is important to note that the sample of this study is not representative of a specific population. The strategy of recruiting individuals who were affiliated with conservation organizations yielded a sample that was predominantly highly educated, white, male, and greater than 55 years of age. The results discussed in this section need to be confirmed in other populations. However, these data are useful in that they provide insight about how the

conservation professionals and volunteers in this sample -- individuals who presumably have strong values for conserving and preserving the functional integrity of the natural environment – perceive risks and benefits about using forest biotechnology as a tool to address forest health threats. Understanding how people who are close to the issue consider trade-offs among potential risks and benefits when describing and justifying their attitudes toward forest biotechnology provides insight about what contexts and considerations of forest biotechnology or the forest health threat influence risk perception and attitudes. Further, these data provide a foundational understanding of how some individuals conceptualize the potential of using forest biotechnology in natural forested settings, information that isn't captured in existing quantitative investigations of perceptions of forest biotechnology (as described in the introduction).

### Few Interviewees Had Strong Attitudes Toward Forest Biotechnology

Attitude strength is defined by three principles: consistency in the beliefs that are underpinning the attitude, direct experience with the topic (in this case, forest biotechnology), and personal identity in relation to the topic (Krosnik & Petty, 1995). Given that attitudes are comprised of various beliefs about an object, attitudes tend to be stronger when they are supported by multiple beliefs that are consistent with one another. Additionally, direct experience with the topic can increase the number of beliefs that are associated with topic. Lastly, identities can be an important influence on attitude strength (e.g., a geneticist may have stronger attitudes toward forest biotechnology because it may relate to their occupational identity).

Participants expressed a range of attitudes toward using forest biotechnology with variation in attitude strength, suggesting that interviewees generally had weak attitudes toward forest biotechnology. The strength of interviewees' attitudes toward forest biotechnology appeared to be influenced by their familiarity with forest biotechnology. A vast majority of interviewees who were unfamiliar with forest biotechnology had ambivalent or conditional attitudes toward using forest biotechnology, suggesting that those who were unfamiliar with forest biotechnology did not have as strong and well-formed attitudes toward it as those who were familiar with forest biotechnology. This makes sense within the principles of attitude

strength: interviewees who are unfamiliar with a topic generally do not have as many specific beliefs about it to support a strong attitude. For example, multiple interviewees vocalized that the interview questions were prompting them to think about things they had never thought about before and conditioned their responses with explicit statements about their lack of knowledge about these topics.

The only interviewees within this sample who did express strong, unilateral oppositional attitudes toward forest biotechnology were all familiar with it as a technology, either through their profession (e.g., research scientist) or service (e.g., activist). These results are consistent with other research showing that people with more interest and familiarity about a topic tend to have stronger, more defined attitudes about that topic, including studies investigating public perceptions of biotechnology (Azodi & Dietz, 2019; Lassen, Madsen, & Sandoe, 2002). The increased familiarity may result in more consistent beliefs about that topic that underpin a firmer attitude toward forest biotechnology. However, it is important to note that, although increased familiarity results in a more defined attitude, it doesn't necessarily determine whether that attitude will be positive or negative (Azodi & Dietz, 2019; Lassen et al., 2002). People's familiarity with the forest biotechnology can develop through different channels, some of which may promote positive beliefs toward forest biotechnology, while others may promote negative beliefs. Therefore, familiarity can promote positive or negative attitudes toward forest biotechnology, depending on how familiarity arises. Additionally, attitudes about forest biotechnology that result from familiarity with the topic are likely stronger because familiarity promotes multiple, integrated beliefs about the topic.

The conclusion that many of the conservation professionals and volunteers in this study had weak attitudes toward forest biotechnology has a variety of implications. Despite the fact that all participants had an interest in conserving nature, a majority of them had completed advanced degrees, and half of the sample was familiar with forest biotechnology, many interviewees expressed weak attitudes toward forest biotechnology. If people with direct experience with a topic tend to have stronger attitudes, this result suggests that attitudes might be even less defined among a more general sample of the public -- a population that is arguably less interested in conserving nature, has less educational attainment, and is likely less familiar

with forest biotechnology. Consequently, there may be an opportunity to use information campaigns to promote stronger beliefs about, and attitudes toward forest biotechnology. Developing messaging campaigns that are based in positive beliefs and outcomes associated with specific applications of forest biotechnology may promote more positive attitudes toward forest biotechnology. For example, given that many participants in this study were not able to meaningfully describe benefits of using forest biotechnology to address a particular threat as opposed to other tools, there would be value in messaging campaigns designed to promote positive beliefs that can be assessed analytically against perceived risks. Additionally, given that participants relied on arguments related to the intent and viability of the GM tree to support their attitude, it would be useful to incorporate this type of information into messaging about a GM tree. If successful, these types of messages could promote public support for a technological solution when the solution begins to align with the dominant public attitudes (Heberlein, 2012).

### Interviewees' Risk Perceptions Were More Robust and Specific than Benefit Perceptions

Interviewees' attitudes were supported with a variety of beliefs, including the diverse lists of risks and benefits they perceived and discussed about using forest biotechnology to address forest health threats. In addition to influencing attitude strength, these perceived risks and benefits clearly influenced the valence of interviewees' attitudes toward forest biotechnology. Interviewees commonly relied on their risk and benefit perceptions to articulate and support their attitudes toward forest biotechnology, including the various conditions and contexts in which they were more or less supportive of its use.

Similar to what has been highlighted in studies investigating public perceptions of agricultural biotechnology (Scott et al., 2018), it was easier for participants in this study to identify and describe risks associated with forest biotechnology than it was for them to identify or describe benefits. As expected, interviewees who were more oppositional tended to perceive more risks than those who were more supportive, although risks were perceived by interviewees regardless of their attitude toward forest biotechnology. Although the interview questions inquiring about risks and benefits were asked during the section of the interview that was focused on the SOD scenario, interviewees described and identified risks throughout the

entire interview. Conversely, interviewees predominantly only described benefits in response to the specific question in that part of the interview. Further, when asked to describe potential risks of using forest biotechnology to address SOD, interviewees did not limit their responses to the context of SOD, unlike they did when describing their benefit perceptions. Consequently, risk perceptions were substantially more prevalent in the data and there was more variation in the types of risks interviewees perceived in comparison to types of benefit perceptions. In addition to more types of risks, interviewees discussed their risk perceptions in different ways, using analogies, metaphors, and examples to highlight the types of risks they perceived in association with forest biotechnology. The did not do so when discussing benefits.

Interviewees' benefit perceptions were much less defined and robust than their risk perceptions. Many of the people who participated in this study relied on high-level, broad descriptions of potential benefits associated with using forest biotechnology, even though their substantial education and familiarity with environmental processes might have suggested they would have more specific ideas about benefits. For example, interviewees described broad ecosystem benefits associated with protecting a tree species from specific threats (e.g., preserving habitat), as opposed to describing specific benefits of using forest biotechnology to protect tanoak. Instead of focusing on the benefits of using forest biotechnology to address the threat, interviewees commonly described benefits associated with protecting tanoak from SOD broadly, regardless of the type of solution used to protect the tree. That is, they felt SOD should be addressed, and any solution, including forest biotechnology, that could save tanoak would provide ecosystem benefits.

Additionally, many of the benefits interviewees discussed were informed by information provided in the scenario about SOD about the risks SOD poses to tanoak ecosystems; this suggests that they did not have such benefits in mind before the interview. Moreover, when referencing the benefits derived from the scenario, responses were brief, suggesting a shallow understanding of them. It is unclear whether the shallowness of these responses was due to respondents thinking that the interviewer was already aware of them or because respondents genuinely did not think deeply about the benefits of forest biotechnology in this context. The lack of depth in how interviewees described benefits might also have been influenced by the

sequencing of interview questions. Interviewees were not asked to describe any benefits of using forest biotechnology *generally* when broadly discussing forest biotechnology earlier in the interview. Instead, I asked them about benefits only after discussing SOD and tanoak – potentially limiting them to only think about benefits in the context of that specific example, instead of the technology more broadly. Nearly all interviewees who described benefits of forest biotechnology only did so after being asked that specific interview question or asked to describe their opinions about forest biotechnology research. However, a few interviewees – who were mostly supportive of forest biotechnology – described benefits of forest biotechnology without prompting when asked to describe their overall attitudes toward GM and forest biotechnology, familiarity with forest biotechnology, and attitudes toward using forest biotechnology to establish a GM tanoak.

Given that conservation professionals with substantial knowledge of ecosystem processes did not describe benefits of using forest biotechnology to address SOD in depth, it seems unlikely that the general public, non-scientific or non-environmental audiences would be able to identify substantive benefits associated with forest biotechnology without being provided information about what these benefits could be. Although several of the interviewees indicated some level of awareness about the types of benefits that could arise from using forest biotechnology in commercial context, they were commonly disinterested and unsupportive of using forest biotechnology to enhance commercial traits. This conclusion aligns with other studies that have reported it is difficult for individuals to perceive substantive benefits associated with using forest biotechnology in commercial contexts (Kazana et al., 2015). Kazana et al. (2015) concluded that there was a lack of knowledge among their sample about the types of benefits that could arise from commercial applications of forest biotechnology. More than half of their respondents indicated that they did not have enough information to assess whether the potential benefits listed in the survey (e.g., using fewer chemical inputs in forest plantations and harvesting fewer trees to meet consumption needs) were important to achieve (Kazana et al., 2015).

My method of providing information about SOD as a scenario within the interview aligns with methods used in other studies investigating public perceptions of biotechnologies, which

often provide participants with an overview of potential risks and benefits associated with the specific GM product or type of use (e.g., using forest biotechnology to reforest after climate change or in plantation forestry). However, instead of being asked in an open-ended format what types of risks and benefits they perceive forest biotechnology could provide, other studies ask respondents to indicate how likely they believe these risks and benefits are to occur and how important it is to obtain each benefit or avoid/minimize each risk using Likert scales (Azodi & Dietz, 2019; Bennett, Chi-ham, Barrows, Sexton, & Zilberman, 2013; Kazana et al., 2015; Scott et al., 2016, 2018; Siegrist et al., 2016). Because I used open-ended questioning techniques, the results of my study do provide insight into what types of risks and benefits are most salient for interviewees. Even though, as noted above, the scenario drew attention to particular risks of SOD, interviewees generally mentioned a wide variety of risks in various levels of detail and only a few benefits. Those risks and benefits that surfaced were likely the most important or salient to them. Additionally, this study provides qualitative context and richness as to *why* interviewees believed the risks and benefits they described are important, whether or not they were included in the scenario. However, it would be interesting for future research to investigate what types of risks and benefits people intuitively perceive about using forest biotechnology when they are not primed for specific topics as part of the study methods.

### Interviewees' Beliefs about Genetically Modified Agriculture Informed Their Beliefs about Forest Biotechnology

Interviewees commonly perceived similar risks in forestry as agricultural biotechnology. Several studies have concluded that pre-existing attitudes toward biotechnology -- and genetic modification more broadly -- often inform the risks and benefits people associate with subsequent GM products (Azodi & Dietz, 2019; Scott et al., 2016). Risk perceptions may be more prevalent and substantial in these data because they may be easier than benefit perceptions for interviewees to envision. Many of the risks interviewees discussed, such as impacts to other species, lack of control, and potential invasive behavior, are risks commonly used in anti-GM agriculture messages in the public and media through product labels, protests and politics (Rozin, Fischler, & Shields-Argelès, 2012). Therefore, these risks were likely salient for interviewees.

As opposed to individual theories of risk perception like the psychometric paradigm, the similarity in risk perceptions among GM agriculture and forest biotechnology products may be explained by a broader cultural theory of risk perception (Renn & Rohrmann, 2000). The cultural cognition theory of risk posits that how individuals perceive risks is influenced by cultural factors, such as their cultural worldviews and preferences about how society should function. In this context, "people notice, assign significance to, and recall instances of misfortune that fit into their values" (Kahan, Braman, Cohen, Gastil, & Slovic, 2010, pg. 503), and those examples serve as salient negative outcomes that influence their risk perception about the topic. In oppositional messaging about GM agriculture, there are many highlighted examples of GM crops "escaping" their confines, contaminating nearby farms, and exhibiting invasive behavior. These examples were likely easy for interviewees to recall as evidenced by how often they pulled from their existing beliefs about GM agriculture to inform their beliefs and attitudes about forest biotechnology. The salience of these types of risk perceptions is also highlighted by the fact that these risks were often the initial risks that interviewees described.

### Difficulty in Perceiving Concrete Risks and Benefits Promoted Interviewees to Turn to Scientific Studies

The lack of knowledge about benefits may have reduced participants' ability to engage in careful deliberation about forest biotechnology because they couldn't conjure up detailed examples of benefits to weigh against the multiple substantive and concrete risks they perceived. This might be why interviewees commonly described the need for additional scientific investigation to inform whether to move forward with producing a GM tree or to outplant it. In addition to exposing the costs and benefits associated with specific applications of forest biotechnology, interviewees commonly asserted that additional research would increase scientific knowledge and understanding about fungal pathogens and forest systems; these sentiments were independent of attitudes toward using forest biotechnology. The prevalence of this benefit perception suggests that people may be supportive of researching forest biotechnology because it could provide more information about whether to use it, in what types of settings it is appropriate, or what types of unintended consequences could arise from its use. However, it is important to note that the prevalence of this benefit perception

might be a function of the characteristics of the study sample; many participants had graduate degrees in science and therefore likely understood the process of scientific inquiry, the value of scientific knowledge, and the role science plays in decision making. Increased scientific understanding associated with forest biotechnology might not be a common benefit perception among a more general sample of the public. The prevalence of supportive attitudes toward researching forest biotechnology could also be the result of a social desirability bias – interviewees were aware of the nature of my research, and some were even aware of the forest biotechnology research occurring within OSU, potentially prompting these interviewees to say they support forest biotechnology more than they actually might.

### Familiarity with Forest Biotechnology Influenced the Types of Risks and Benefits Interviewees Perceived

Although interviewees in this study perceived risks and benefits regardless of their familiarity with forest biotechnology, it is clear that familiarity with forest biotechnology influenced the types of risks and benefits they mentioned. Interviewees who were unfamiliar with forest biotechnology discussed risks associated with unintended consequences and ecological integrity much more frequently than those who were familiar with forest biotechnology. Interviewees who were familiar with forest biotechnology more commonly perceived risks about the overall viability of the GM tree and expressed concerns about potential corporate greed and commodification.

Interviewees also perceived some benefits from forest biotechnology, regardless of their familiarity with it. However, interviewees who were unfamiliar with forest biotechnology more commonly resorted to reframing risks identified in the scenario as benefits of using forest biotechnology, such as cultural and economic benefits. Interviewees who were familiar with forest biotechnology were substantially more likely to acknowledge increased scientific knowledge as a type of benefit forest biotechnology could provide. These results somewhat align with existing literature, which highlights that familiarity with biotechnology is often positively associated with increased acknowledgement of benefits associated with GM; people who are more familiar with biotechnology typically identify and perceive more benefits associated with its use (Azodi & Dietz, 2019). Although interviewees in this study who were

familiar with forest biotechnology didn't necessarily acknowledge more benefits of using forest biotechnology, they commonly identified different types of benefits than those who were unfamiliar with forest biotechnology.

### Risk and Benefit Perceptions Varied Based on Attitudes toward Forest Biotechnology

Attitudes are defined by the beliefs individuals have about a specific topic and their personal evaluations of those beliefs (Krosnik & Petty, 1995). Given that risk and benefit perceptions are subjective beliefs about potential outcomes, they inherently influence attitudes (Krosnik & Petty, 1995). Within this study, interviewees who were more supportive of forest biotechnology tended to identify more benefits than those who were more oppositional toward using forest biotechnology. Conversely, those who were more opposed to using forest biotechnology tended to perceive more risks. This aligns with the results of other studies investigating public perception toward forest biotechnology, which conclude that as people perceive more benefits about a specific application of forest biotechnology, they are more likely to be supportive of it (Azodi & Dietz, 2019; Moravčíková et al., 2017; Needham et al., 2015). However, it is important to note that there are questions about the nature of this relationship. Did interviewees perceive or discuss more risks because they have a negative attitude, or do these risk perceptions influence them to express a negative attitude?

### Risk and Benefit Perceptions Were Key Factors Influencing Attitudes toward Forest Biotechnology

In this study, the role of risk and benefit perceptions in influencing attitudes is highlighted most clearly by the arguments that interviewees used to justify their attitudes toward forest biotechnology. For example, some interviewees argued that we need to conduct risk-benefit analyses to determine whether to use forest biotechnology in a specific situation. Interviewees argued that these analyses would quantify the risks and benefits associated with a specific application of forest biotechnology and ultimately inform whether forest biotechnology is the best option to address the specific threat. It appears as though many interviewees in this sample prefer that scientific evidence drive any decision making, which aligns with the results of other studies (Legge Jr & Durant, 2010).

Further, interviewees who perceived substantial risks about using forest biotechnology expressed a willingness to explore forest biotechnology only as a last resort in situations where other potential options to address the threat (e.g., breeding) are not viable. These findings suggest that interviewees were willing to tolerate a degree of risk and uncertainty if forest biotechnology will provide a benefit they feel is important and necessary, such as protecting forests from severe and catastrophic threats – a result that has been reported in other studies (Bearth & Siegrist, 2016). As aligned with cognitive theories of risk perception, judgements about the acceptability of risk are context specific; people navigate tradeoffs among risks and benefits differently depending on the specific context (Gregory & Satterfield, 2002).

### *Concerns about Unintended Consequences Promoted Interest in a Precautionary Approach*

Interviewees' concerns about uncertainty were an especially common way that risk perceptions informed their arguments about forest biotechnology. Interviewees made comments about uncertainty in a variety of ways during interviews, especially about the lack of understanding of forest biotechnology or the potential unintended consequences that may arise from its use. Similar to results reported in other studies, references to unintended consequences were more common among interviewees who were more opposed to using forest biotechnology. Other studies have attributed this phenomenon to the precautionary principle (Scott et al., 2016; Weale, 2010). The precautionary principle holds that actions or policies that could cause severe, systemic harm should not be pursued until there is near scientific certainty about their safety. Under this principle, the people proposing the action must provide scientific evidence proving that there will not be any substantially negative outcomes from the proposed action before people will support it (Taleb, Read, Douady, Norman, & Bar-Yam, 2014). For example, one study revealed that many people believe that there needs to be scientific certainty that a GM agricultural application is useful to society and risk-free in order to be acceptable (Lassen et al., 2002). In this present study, because forest biotechnology, and GM more broadly, might cause substantial ecological risk and unintended consequences, many respondents felt it should not be used until those uncertainties are fully understood and minimized, regardless of the types of benefits it might bring.

The precautionary principle comes from the general tendency for humans to try to avoid or minimize risks associated with a specific action, a phenomenon known as risk aversion which has been captured in prospect theory (Kahneman & Tversky, 1979). Prospect theory posits that, in situations with high risk and uncertainty, people do not make rational decisions. Instead, they tend to make decisions that they believe will minimize any perceived losses, as opposed to pursuing options that have a small chance of providing substantial benefits. This is also informed by loss aversion – the tendency for people to feel losses more strongly than they experience gains (Kahneman & Tversky, 1979). In this study, interviewees exhibited risk aversion by wanting to explore options that they believed had less risk before exploring forest biotechnology as a potential solution. One could argue that interviewees were exhibiting this type of loss aversion when describing concerns about GM trees potentially invading non-GM forests and leading to a loss of wild, unmodified landscapes. These types of fundamental changes in ecosystem functions and processes, which are often perceived as losses in terms of reduced wildness or naturalness, were cited as one of the greatest risks associated with forest biotechnology in a recent meta-analysis (National Academies of Sciences, Engineering, and Medicine, 2019).

The precautionary principle and prospect theory may also help explain why interviewees commonly supported scientific research about forest biotechnology regardless of their attitude toward it, as well as why some individuals specifically referenced the need for risk/benefit analyses about specific GM trees. Such research and analyses would provide empirical evidence about what risks are actually probable and reduce uncertainties. With increased scientific certainty about the safety of these products, the decision-making context is no longer uncertain, and the conditions of the precautionary principle will have been met. Therefore, individuals could more openly support forest biotechnology and GM if the benefits it provides align with their overarching values and interests.

However, many environmental systems are so complex that it is not possible for scientists to use controlled experiments to empirically observe outcomes of phenomena such as forest biotechnology; many risks will remain unknown until the technology is implemented (Taleb et al., 2014). Further complicating this are the regulatory requirements associated with

forest biotechnology, which do not allow scientists to conduct long-term field experiments over the life-span of the tree, preventing scientists from being able to provide scientific certainty about the specific environmental impacts, efficacy, and safety of the GM tree product (Strauss et al., 2009). Apart from the specifics of forest biotechnology, science rarely provides certainty. Instead, it is a process that aggregates strong evidence to support a specific idea or hypothesis. Given that scientific certainty is essentially impossible to provide at all, let alone in forest biotechnology studies that are substantially limited by federal regulations, it difficult for the scientific community to provide evidence that will overcome reliance on the precautionary principle (Weale, 2010). These results imply that any communication strategies designed to promote forest biotechnology should highlight the amount of scientific study and research involved in developing and testing the GM tree – a request that many interviewees explicitly made when describing the type of information they would like shared with them during a public meeting about moving forward with a GM tree initiative. Additionally, it would be useful for these communications to clearly articulate the amount of certainty that these scientific endeavors can actually provide to help individuals understand that complete scientific certainty is not common, especially when developing and implementing innovative technological solutions.

### *Concerns about Tampering with Nature Influenced Arguments to Oppose or Support Forest Biotechnology*

Interviewees also invoked concerns about tampering with nature when discussing their attitudes toward forest biotechnology. The risks that might arise from tampering with nature led some interviewees to argue that forest biotechnology is not the right answer to address an environmental problem, an argument that has also been used to explain attitudes toward genetic modification in agriculture (Lassen et al., 2002). Interviewees relied on examples of actualized risks from other failed attempts to address environmental issues (e.g., biocontrol initiatives) to argue that forest biotechnology would not be a successful option to address SOD.

Conversely, some interviewees believed that humans have always been intervening in natural systems, physically manipulating plants through domestication and breeding for centuries. For these interviewees, forest biotechnology was not considered to be a

fundamentally different form of intervention or tampering, because it is just the next step in a process that science has been refining for generations. This argument has been used by individuals to support positive attitudes toward genetic modification in agricultural settings as well (Bennett et al., 2013; Lassen et al., 2002). However, some interviewees felt that – even if GM is an extension of plant modifications – it is a step in an unacceptable direction of tampering with nature, especially because scientists continue to investigate ways to apply this technology despite the public's continued concerns. In this context, scientists are tampering with nature by moving forward with technology-based initiatives that are not considered acceptable. This counter-argument has also been documented in relation to public perceptions of GM agriculture (Lassen et al., 2002).

Similar to other studies investigating public perceptions of biotechnologies, the results of this study clearly suggest that concerns about tampering with nature are important to how people perceive and discuss forest biotechnology (Peterson St-Laurent et al., 2018). In fact, one study showed that concern about tampering with nature was a better predictor of attitudes toward GM, especially oppositional attitudes, than the dread and uncertainty dimensions of the psychometric paradigm (Sjöberg, 2000). In studies investigating public perceptions of genetic modification in agriculture, respondents tend to believe that genetic modification is an inappropriate way for humans to tamper with nature (Weale, 2010), and these concerns are closely tied to concerns about humans thinking they can identify solutions to environmental issues better than nature (Sjöberg, 2000). These themes are prevalent in the results of my study.

## Implications of this Study for Communication Strategies about Forest Biotechnology

Based on these results and other studies highlighting how risk and benefit perceptions influence attitudes toward biotechnology, any communications or outreach initiatives about that are trying to promote acceptance and positive attitudes toward forest biotechnology should clearly identify and promote the benefits associated with the specific GM tree, as well as using forest biotechnology to address the problem instead of another strategy. We should not assume that people will be able to identify these benefits on their own. Additionally, communication strategies should highlight the intent behind addressing the specific forest

health threat – especially describing the severity of the threat and whether the threat was introduced or caused by humans. Messages should clearly articulate the amount of scientific research involved in developing the GM tree and the degree of scientific certainty about the types of impacts that may (or may not) arise from planting this GM tree.

However, it is overly simplistic to believe that providing more information about these various considerations of forest biotechnology will substantially improve attitudes toward forest biotechnology, as evidenced by finding in the climate change communication literature (Kahan et al., 2012). Many studies have shown that individuals with strong oppositional attitudes cannot be influenced by information containing positive arguments about the benefits GM agriculture or forest biotechnology provides (Scott et al., 2016), although providing information about benefits can influence individuals with weaker attitudes that are not fully defined (Hajjar et al., 2014; Petit, 2019). One meta-analysis of studies investigating attitudes toward GM agriculture found that providing participants with more information about benefits did not always influence them to be more supportive. Instead, some individuals either did not experience any change in their pre-existing attitude or they became more opposed to GM agriculture as a result of the additional information (Scott et al., 2018). A similar finding was recently reported in a study investigating the role of message framing in influencing attitudes toward using forest biotechnology to address chestnut blight (Petit, 2019).

These conflicting conclusions about whether increased information about benefits influences attitudes toward forest biotechnology suggest that there may be other constructs mediating the relationship between beliefs (risk and benefit perceptions) and attitudes. One study suggested that the perception of GM as unnatural promotes biased weighting and consideration of risks and benefits (Bearth & Siegrist, 2016). In that study, the same benefits framed as resulting from breeding were evaluated more favorably than when they were framed as arising from GM. These authors argued that -- because affect is so influential in how risks are perceived – simply increasing awareness about the number and type of benefits associated with GM will not increase support for the GM product because they are not assessed rationally (Siegrist et al., 2016).

## Study Limitations

It is important to note the limitations of this study. First, the sampling strategy yielded a convenience sample that was predominantly Caucasian, greater than 55 years old, and highly educated. Therefore, the results of this study are not generalizable or representative of any population other than the sample.

Choosing SOD as the scenario for the interview was another important limitation of this study. My review of existing literature suggested that attitudes toward forest biotechnology would be context dependent. Therefore, it was important to use a scenario that would be relevant and complex enough to highlight different dimensions of the topic (Liedtka, 1992). I chose to use sudden oak death because it is a serious forest health concern in southern Oregon and it causes high mortality to tanoak trees. Given that this pathogen receives considerable attention in conservation and land management networks within Oregon, we thought it would be a familiar forest health threat to study participants. However, there are a few limitations related to this decision. First, I used only one scenario to reduce interview demands on respondents, but other scenarios might have revealed different considerations. For example, if I had chosen a forest health threat that had more of a direct impact on participants' lives, they may have expressed different views – interviewees may have felt the threat was more severe or been more familiar with the impacts it is having on ecosystems they are familiar with, and therefore may have been more supportive of using forest biotechnology as a potential solution to address the threat. Second, tanoak is not a commercial species, and this may have influenced people's responses. Finally, many interviewees either weren't familiar with SOD or repeatedly referred to other forest pests and pathogens to answer questions throughout the interview (e.g., emerald ash borer, Dutch elm disease, chestnut blight). A few studies have investigated public perceptions toward using biotechnology in the context of chestnut blight (Needham et al., 2015; Petit, 2019), but it would be interesting for additional investigations using pests or pathogens that are more widely known among the general public given how complex and contextual attitudes toward forest biotechnology are.

Lastly, it is important to note that, as with all interview-based research, there are inherent study limitations associated with acting as the primary research instrument of this

study. Although I became quite comfortable with the interview guide throughout the process and tended to phrase questions similarly across interviews, time constraints and the semi-structured nature of probing into uncommon responses yielded results that were not always consistent – I chose not to ask some questions when confronted with time constraints. These are important considerations that may affect the trustworthiness of these results.

## Conclusion

This study used semi-structured interviews to investigate the types of risks and benefits that conservation professionals and volunteers in the Pacific Northwest perceive about using forest biotechnology to genetically engineer trees to be resistant to sudden oak death. In addition, this study aimed to understand how familiarity with forest biotechnology influences risk and benefit perception, and in turn, how these perceived risks and benefits inform attitudes toward forest biotechnology or the arguments individuals use to support their attitudes.

Overall, it appears that familiarity with forest biotechnology influenced the types of risks and benefits interviewees perceived about forest biotechnology, attitudes toward forest biotechnology, and the strength of those attitudes. Those who were familiar with forest biotechnology were more likely to express strong, unconditional attitudes of support or opposition toward forest biotechnology. Additionally, those interviewees who were familiar with forest biotechnology tended to discuss concerns about the viability of the GM tree more commonly than interviewees who were unfamiliar, who tended to concentrate on concerns about ecological integrity. However, across the sample as a whole, interviewees were mostly concerned about uncertainty associated with forest biotechnology and potential unintended consequences that might arise from its use. Overall, interviewees discussed risks in much more depth and frequency than they discussed potential benefits – likely because interviewees pulled from their existing beliefs and attitudes about GM agriculture to inform their beliefs and attitudes about forest biotechnology.

Interviewees' difficulty in identifying concrete risks and benefits of forest biotechnology in-depth, as well as substantial concerns about uncertainty and unintended consequences, promoted them to support scientific research about forest biotechnology and case-specific

cost-benefit analyses to determine whether to proceed with forest biotechnology as a potential solution. Overall, many interviewees preferred a thoughtful and cautious approach to using forest biotechnology to address forest health threats, given the history of humans causing more environmental problems when trying to address environmental problems. Consequently, many interviewees argued that forest biotechnology should be used only for specific types of situations, especially when the threat is potentially catastrophic and other options are not viable solutions.

Ultimately, this study provides initial insights into how certain conservation professionals' and volunteers' beliefs distinguish forest biotechnology from other strategies to address forest health threats, as well as the types of arguments these individuals use to justify their attitudes about whether to pursue forest biotechnology. This builds on our existing understanding of beliefs that underpin attitudes toward forest biotechnology and confirms that many of these beliefs are informed by views about other applications of biotechnology, especially agricultural biotechnology. Although interviewees described their interest in assessing each case for using forest biotechnology on an individual basis to determine if it is appropriate, they relied on their existing attitudes and beliefs about GM agriculture and land management to inform their attitudes and beliefs toward a GM tanoak, instead of assessing it in its own right. Lastly, this study builds on existing understanding about public perceptions of forest biotechnology and suggests that tampering with nature and uncertainty are important considerations associated with how conservation professionals and volunteers assess risk associated with forest biotechnology, whereas dread and apprehension seem to be associated with concerns about tampering with nature and uncertainty of outcomes, as opposed to the technology itself.

More research is needed to determine whether similar findings would emerge with different groups of people, especially more general audiences that have less specialized knowledge about forestry and/or biotechnology. Additionally, given that risk perceptions and arguments are context specific, more work is needed to determine how people respond to different types of pests or pathogens, especially those that might be more familiar to participants. It would be especially interesting to assess attitudes and arguments about using

forest biotechnology to address a native forest health threat, as opposed to a non-native threat like sudden oak death. Finally, more work is needed to identify the types of benefits that individuals perceive about using forest biotechnology as a tool to address a forest health threat, as opposed to other potential solutions. Benefit perceptions were often described in the context of protecting the tree, as opposed to using the specific method instead of other methods to protect the tree.

# Chapter 3: Environmental beliefs, perceptions of naturalness and environmental ethics influence attitudes and arguments about using forest biotechnology to address forest health threats

## Introduction

### Overview of Research Goals

As climate change increases the frequency, distribution, and severity of threats facing forests, scientists and land managers are looking for new tools to enhance forest health and resilience. The types of tools and technologies available to address forest health threats have advanced as scientific understanding of the natural world has increased. With the development of CRISPR/Cas-9 and other biotechnologies, scientists are able to modify the genetic makeup of an organism so that it expresses specific traits, such as resistance to a pest or pathogen. Biotechnologies have been widely controversial in agricultural applications, but how will people feel about using biotechnology in trees and forests? Forests are perceived as *wild* and *natural* in ways that agricultural areas are not, potentially influencing the acceptance of biotechnology as a forest management strategy.

Given the regulatory requirements for public involvement under the National Environmental Policy Act and the National Forest Management Act, it is important to assess whether forest health management strategies are socially acceptable. This type of assessment is especially important as our technological abilities to control and intervene in nature increase, as with forest biotechnology (Rozin, 2005). Forest management strategies that are perceived as natural or as something that could have happened without human intervention tend to be more supported and acceptable (Brunson, 1993; Gamborg, 2001, 2002; Hull, Robertson, & Kendra, 2001). Therefore, it is important to understand how the public perceives the naturalness of forest biotechnology and how these perceptions influence their attitudes toward forest biotechnology.

### What is "Natural"?

Although the term "natural" is considered a positive attribute in most Western cultures, there is no single definition of "naturalness," nor is there agreement about what products or

technologies are "natural" (Scott et al., 2018). Instead, individual definitions and perceptions of whether something is natural are subjective and vary across cultures and groups. Most commonly, people define naturalness as an absence of processing (e.g., alterations, human intervention) or an absence of additives (e.g., chemicals) (Rozin et al., 2012).

A wealth of research shows that people tend to exhibit more positive attitudes toward and preference for things that they perceive as natural (Bearth & Siegrist, 2016; Rozin, 2005; Rozin et al., 2012; Scott et al., 2018). Positive attitudes towards naturalness can prompt people to rely on simplistic reasoning strategies, such as assuming that natural things are good and unnatural things are bad (Siegrist et al., 2016). Similarly, individuals may believe that natural things are inherently good for the environment (Rozin, 2005). Thus, the perception of naturalness is especially important in environmental contexts because people may believe that unnatural entities are a threat to the natural order or ecosystem integrity (Lassen et al., 2002; Mielby et al., 2013; Rozin, 2005). This type of belief about naturalness has been referred to as a harmony-based argument -- entities are considered natural if they are in harmony with the natural order of the environment (in the case of forests, if the product doesn't negatively impact ecological integrity or functions).

### Is Forest Biotechnology Natural?

Studies investigating public perceptions of genetic modification (GM) have shown that people tend to consider GM as less natural than scientific breeding techniques and domestication (Rozin, 2005; Scott et al., 2018; Siegrist et al., 2016). Further, people perceive GM as a form of chemical transformation because it often conjures mental images of lab settings (Rozin, 2005). This perception that GM is a type of chemical transformation influences individuals to perceive it as less natural than breeding, especially considering that breeding is often perceived as a strictly physical transformation of a plant (Rozin et al., 2012). In this context, processes that change the physical characteristics, as opposed to the chemical characteristics, of the plant are believed to be more natural. Additionally, studies have shown that introducing a gene from another species is seen as especially unnatural – a belief that is often explained using a substance-based argument of naturalness (Mielby et al., 2013; Rozin, 2005). According to this argument, GM products are unnatural because they have been

contaminated by coming in contact with a foreign substance, like DNA from an unrelated species. However, in most cases, this belief is, in fact, incorrect: domestication and scientific breeding involve changes to thousands of genes in the wild type variety of the species -- changes that are much more substantial than single-gene transfers using CRISPR, which tends to only change a specific sequence of DNA (Rozin, 2005; Strauss et al., 2009). The belief that GM is less natural than breeding is often supported using history- and acquaintance-based arguments of naturalness – GM is unnatural because the changes it produces are not ones that would arise through historical natural processes (history-based) and it is not a familiar, well-known process like breeding (acquaintance-based) (Mielby et al., 2013; Rozin, 2005).

Given that forest biotechnology is a form of GM, it is not surprising that many studies have reported that people also consider it as unnatural and a form of tampering with nature, especially in comparison with other options to address forest health threats, such as afforestation, breeding, or natural regeneration (Hajjar & Kozak, 2015; Jepson & Arakelyan, 2017; Peterson St-Laurent et al., 2018). Perceptions that forest biotechnology is less natural than other options seem to strongly influence the risks people associate with biotechnology (e.g., references to contamination or negative impacts to ecosystems services) and their subsequent attitudes towards its use. For example, many studies report that respondents prefer more traditional, low-technology options to establish resistance and resilience within forest ecosystems, presumably because they think such options are less risky. However, it is important to note that people often support using forest biotechnology more than they support doing nothing to address a specific forest health threat (Hajjar & Kozak, 2015; Hajjar et al., 2014; Peterson St-Laurent et al., 2018). This suggests that there are specific environmental contexts and conditions in which respondents are willing to support tampering with nature in an effort to preserve some type of “naturalness” in the landscape. However, existing study results do not provide rich insight into the nuances of attitudes toward using something unnatural to protect nature. Consequently, the National Academies of Sciences, Engineering, and Medicine (2019) have recommended research to better understand how perceptions of naturalness and environmental ethics influence attitudes toward forest biotechnology, a gap this study aims to fill.

## Will Forest Biotechnology Affect Naturalness?

Similar to the subjective nature of how people define natural products and processes, how people define and perceive the "naturalness" of landscapes is also subjective. Although the Cambridge Dictionary defines "natural" as "found in nature and not involving anything made or done by people," ("natural", n.d.) the types of landscapes that people consider to be "natural" or "wild" often represent a spectrum that is informed by their personal environmental values, beliefs, and prior experiences with nature (Buijs, 2009; Gamborg, 2001; Hull et al., 2001; Van den Born, 2008). That is, the landscape one person considers to be natural might be very different from what another person considers to be natural. Nevertheless, common characteristics that comprise natural landscapes include perceptions that the landscape is "primitive" or somehow untouched or unaffected by humans.

Often, people use the word "natural" to describe the their perception of the original status or authenticity of a landscape (Hull et al., 2001; Rozin et al., 2012). For example, many Euro-Americans describe the quintessential natural landscape as pristine and untouched versions of nature that are perceived as maintaining their original status or authentic state before European settlement. Often, this original or authentic state is also perceived as the healthiest condition of the forest (Hull et al., 2001). Consequently, individuals may evaluate potential management options and strategies based on how they will impact the authentic state of naturalness; if an action results in dramatic changes away from the authentic and natural state, it is perceived negatively.

Existing scientific literature suggests that people consider potential impacts to perceived naturalness substantially more when assessing if forest biotechnology is acceptable to use than they do when assessing agricultural applications of biotechnology (Connor & Siegrist, 2010). Agricultural applications of GM are less commonly associated with concerns about naturalness, likely because these products are planted in agricultural areas – landscapes that are not commonly perceived as natural or wild (Connor & Siegrist, 2010). The public may place more emphasis on how forest biotechnology might impact the perceived naturalness of places where it is used, especially if in natural or wild forests (Delborne, 2019; Gamborg, 2010; National Academies of Sciences, Engineering, and Medicine, 2019; Peterson St-Laurent et al., 2018). For

example, while some people may perceive forest biotechnology as a way of enhancing aspects of naturalness by protecting an at-risk tree species and all of the ecosystem benefits that species provides, others may think forest biotechnology will negatively impact naturalness, because it will increase the extent of human intervention in a landscape. Thus far, existing research has shown that negative impacts to the perceived naturalness of an area are especially salient for respondents, especially those who express concerns about GM trees contaminating "wild" and natural forests through gene flow (Kazana et al., 2015). However, research to date is limited. This study builds on those initial results by investigating the specific ways people believe forest biotechnology might impact naturalness, as well as how people articulate those beliefs to support their attitude toward using forest biotechnology to protect forest health.

## Environmental Ethics: Are Humans Morally Responsible to Protect Nature?

Humans have always relied on the natural environment to support and sustain our species with goods, products, and services. Over time, societies have developed various moral convictions and ethical codes about the appropriate ways humans should interact with nature, including if, how, and when humans should intervene to protect nature from different types of threats. These general beliefs, attitudes, and standards of what is personally or socially considered right or wrong are defined as ethics (Taylor, 1981). In addition to being socially created, environmental ethics are influenced by a person's individual environmental beliefs, such as their beliefs about how the environment functions or what constitutes "naturalness," as well as their worldviews about the role humans *should* have in protecting nature (Batavia & Nelson, 2017; Gamborg, 2001; Gamborg, Palmer, & Sandoe, 2012; Lassen et al., 2002; Palmer, McShane, & Sandler, 2014). Environmental ethicists define three distinct environmental ethics to describe differences in beliefs and worldviews about what organisms humans have moral responsibility to protect: anthropocentrism, biocentrism, and ecocentrism (Batavia & Nelson, 2017; Gamborg, 2001; Ives & Kendal, 2014; Lute, Navarrete, Nelson, & Gore, 2016; Palmer et al., 2014). In this chapter, I use the phrase "environmental beliefs" to refer to interviewees' beliefs about what is "natural" and how the environment functions, whereas I use the word "ethics" to refer specifically to their convictions about if and when humans should intervene to

protect nature. Further, the phrase "perceptions of naturalness" is often used to reference more specific environmental beliefs related to what is (not) natural and why.

People with anthropocentric environmental ethics tend to believe that only humans have intrinsic value and moral standing (i.e., the right to survive and flourish). Therefore, one of humanity's primary environmental responsibilities is to ensure that nature continues to provide high quality resources for future generations (Gamborg, 2001; Palmer et al., 2014). This environmental ethic relies on the belief that humans have dominion over nature (Palmer et al., 2014) – a belief that became solidified and perpetuated in many western, predominantly Christian civilizations. Original teachings in Christianity suggested nature was provided by God for humans to support themselves, thus promoting the belief that nature can be dominated by humans in order to continue supplying resources. In this context, humans perceive themselves to be separate from and superior to nature. Therefore, humans can and should intervene in environmental systems to protect nature from threats because nature provides important resources that are critical for societal existence. This moral responsibility to protect nature is most clearly exhibited through the "wise use" model of forestry that was originally proposed by Gifford Pinchot (Gamborg, 2001; Gamborg & Larson, 2003; Gamborg & Sandøe, 2004), the first chief of the U.S. Forest Service, founder of the first forestry school in the U.S., and the founder of the Society of American Foresters. Pinchot famously defined conservation in the U.S. in this anthropocentric ethic with his influential writing that

> "Conservation means the wise use of the earth and its resources for the lasting good of men. Conservation is the foresighted utilization, preservation, and/or renewal of forests, waters, lands, and minerals, for the greatest good of the greatest number for the longest time" (Pinchot, 1947, p. 505).

Clearly, Pinchot exhibited an environmental ethic based on managing nature to promote a sustainable supply of resources for humanity.

Conversely, some people exhibit an environmental ethic known as biocentrism. Biocentrists do not believe that humans are the only living organisms with moral standing and intrinsic value. Instead, they expand their moral circle to include all living organisms (Batavia & Nelson, 2017; Gamborg, 2001; Ives & Kendal, 2014; Manfredo, Teel, Sullivan, & Dietsch, 2017;

Palmer et al., 2014). Biocentrists believe that all living things have the capacity to be harmed and, therefore, should be considered and respected when making decisions that will directly or indirectly impact them (Palmer et al., 2014). In this context, humans have a moral responsibility to minimize harm to living organisms by protecting these organisms from threats; all of the organisms within natural systems have an intrinsic right to exist, regardless of whether they provide goods or services for humans. This need to protect and preserve nature has become a normatively accepted moral principle within most Western societies (Rozin et al., 2012). This ethic is most clearly exhibited by early preservationists such as John Muir, who contested Pinchot's "wise use" principle and instead argued that forests should be protected for non-economic reasons; humans should conserve nature, not resources. In this ethic, nature has intrinsic value and existing wildness should be preserved (Gamborg, 2001).

Lastly, some people expand on the biocentric environmental ethic and the conviction that living individuals have moral standing and exhibit an ecocentric environmental ethic. Ecocentrists ascribe value to ecological collections; ecosystems, biodiversity, and landscapes have intrinsic value and moral standing given that they support environmental processes that sustain all of the organisms within that landscape (Gamborg, 2001; Palmer et al., 2014). In this context, humans need to protect natural systems and preserve biodiversity to ensure a healthy functioning ecosystem. Protecting natural systems allows each of these living organisms and the processes to which they contribute continue functioning properly. This environmental ethic is most clearly expressed through Aldo Leopold's Land Ethic, which promotes the environmental belief that forests are communities, and management approaches should maximize beneficial outcomes for the ecosystem as a whole, as opposed to human- or species-centric outcomes (Callicott, 2013; Gamborg, 2001; Palmer et al., 2014).

Anthro-, bio-, and ecocentric environmental ethics can influence people to support various types of interventions to protect forests from threats, although these attitudes could be underpinned by very different values, such as protecting products and resources (anthropocentric), individual trees or species (biocentric), or ecosystem health and integrity (ecocentric) (Gamborg, 2001; Palmer et al., 2014). These various environmental ethics and beliefs about what organisms should be protected from harm and how the ecosystem functions

may be providing justifications for their support of using potentially risky technology to address forest health threats. However, it is important to understand these beliefs and how they are used and articulated in arguments and justifications about using forest biotechnology – an understanding that isn't available in the existing published quantitative studies investigating public perceptions of forest biotechnology.

While some people holding anthro-, bio- or ecocentric ethics may support interventions to protect nature -- albeit for different reasons -- some people believe humans should not intervene to protect nature from threats, regardless of the intention behind the intervention or the benefits the intervention might provide. For them, nature is at its best when humans leave it alone (Dizard, 1994). This ethical stance of leaving nature alone is substantially more common among bio- and ecocentrists, potentially because it can be supported by a variety of beliefs about how ecosystems function and what outcomes might arise from intervention, including potential harmful impacts to the environment, whether individual organisms or environmental collections (Gamborg, 2001, 2002; Gamborg & Larson, 2003; Hull et al., 2001; Kempton, Boster, & Hartley, 1995). For example, some people may feel that we should leave nature alone because of their underlying beliefs that nature is a self-regulating and homeostatic entity that is capable of developing its own solutions to environmental threats (Buijs et al., 2012). Others may express the ethical stance that we should leave nature alone because they believe that humans do not know enough about the complex relationships and interactions in natural systems and, therefore, our interventions might cause large-scale disturbances or other negative impacts to the environment (Kempton et al., 1995). Overall, the existing literature investigating public attitudes toward land management and forest biotechnology suggests that environmental beliefs about how the environment functions, whether forest biotechnology is perceived as natural, and how forest biotechnology might impact natural functions or cause additional environmental harm are important considerations that influence attitudes toward using interventionist approaches to manage forests and minimize harm to the natural world.

This study aimed to expand on this initial understanding and speculation to provide additional insight about how conservation professionals articulate their environmental beliefs in the arguments they use to justify their attitudes toward forest biotechnology. This study

provides insight about how these participants navigate trade-offs in their environmental beliefs and ethics when assessing the potential acceptability of using forest biotechnology.

## How do Environmental Ethics and Beliefs Influence Attitudes Toward Forest Biotechnology?

Given that environmental ethics and beliefs play an important role in shaping attitudes about whether it is appropriate or acceptable to intervene in environmental problems (Stern et al., 1999), one can assume that different environmental ethics may influence different types of justifications and arguments underpinning people's environmental attitudes. Presumably, people with different beliefs about how humans should interact with nature may consider forest biotechnology from different perspectives, as highlighted by the variety of results of recent studies investigating how ethical orientations influence public perceptions and attitudes toward forest biotechnology. For example, Needham et al. (2015) concluded that biocentric Americans were slightly more accepting than anthropocentrists of using biotechnology to address chestnut blight. Conversely, Hajjar and Kozak (2015) reported that western Canadians with mixed environmental ethics (a blend of anthropocentric and ecocentric views) were slightly more accepting than biocentrists of using biotechnology to address impacts of climate change. Another study showed that anthropocentrists were the most supportive of using biotechnology as a reforestation strategy in the context of climate change (Peterson St-Laurent et al., 2018). All of these studies investigated public perceptions of applications of forest biotechnology that were focused on forest restoration and enhancing resilience, yet there was substantial variation in their results about which ethics promote acceptance. Unfortunately, given that these studies used quantitative methods and relied on surveys to gather data, they did not provide an opportunity for the researchers to theorize about *why* some people might be more accepting of forest biotechnology than others. Variation may be due to differing environmental values among participants, such as whether forests have intrinsic value, how forest biotechnology might influence environmental processes, or concerns about how biotechnology might influence the perceived naturalness of forests (National Academies of Sciences, Engineering, and Medince, 2019). Consequently, how environmental ethics and beliefs influence attitudes about forest biotechnology seems unclear and requires additional

scientific investigation, as described in a recent report from the National Academies of Sciences, Engineering, and Medicine (National Academies of Sciences, Engineering, and Medicine, 2019). This study addressed this research gap by using qualitative methods that are able to address research questions focused on *how* and *why* people reason in different ways about forest biotechnology.

## Research Questions

Given that forest biotechnology is a new scientific endeavor that could be used to address forest health issues, it is important to assess the social acceptability of using this type of interventionist strategy to determine whether it is worth pursuing. In addition to the very limited scientific understanding about how the public perceives the naturalness of forest biotechnology or how it might impact the perceived naturalness of forests, there are very few studies investigating how people navigate their personal environmental ethics and beliefs when determining the acceptability of using forest biotechnology in this type of application. Managers and researchers need to know how stakeholders and the general public assess tradeoffs and conflicts among competing forest management goals and ethics, like the need to minimize harm to nature. Understanding these contextual considerations and adapting the use of forest biotechnology to fit within these parameters may increase the acceptability of forest management approaches (Gamborg, 2001).

This study used qualitative methods to address this gap in the scientific literature by investigating how conservation professionals and volunteers explain and justify their attitudes toward using forest biotechnology to address forest health threats in the context of their environmental ethics and beliefs. This study begins to document some of the fundamental beliefs and perspectives that people hold toward forest biotechnology, and how those considerations influence the acceptability of this technology in this specific context. Further, this study begins to shed light on the considerations of forest biotechnology that might be influencing why individuals distinguish FB from other applications of biotechnology. Ultimately, this type of understanding can reveal reasons why people think the way they do about forest biotechnology – understanding that is critically important in shaping acceptable forest

management policies and promoting ethical transparency (Gamborg, 2002, 2010; Gamborg et al., 2012). Specifically, the research questions for this study were:

**RQ 3:** How do conservation professionals and volunteers invoke their environmental beliefs when reasoning about the use of forest biotechnology to address forest health threats?

**RQ 4:** How do conservation professionals' and volunteers environmental ethics influence the arguments they use to support their attitudes about using forest biotechnology to address forest health threats?

## Methods

### Research Design

The design for this study is aligned with a constructivist research approach and the belief that individuals develop their own meanings about the world around them -- meanings that are shaped by various social, cultural, and personal contextual factors (Blackstone, 2012). This study used semi-structured interviews to understand the various ways that selected conservation professionals and volunteers invoked their environmental beliefs and used ethical arguments to justify their attitudes toward forest biotechnology. Qualitative methods, such as semi-structured interviews, are especially appropriate to understand a phenomenon about which little is known (Richards & Morse, 2013), such as how environmental ethics and beliefs influence attitudes toward forest biotechnology.

The research design for this study was described in depth in the methods section of Chapter 2 of this thesis. Elements specific to the present study are described below.

### Sampling and Data Generation

I recruited 33 conservation professionals and volunteers with various affiliations (e.g., agency, non-profit, private, and landowner) in the Pacific Northwest, primarily western Oregon to participate. Effectively, this included individuals from communities of interest concerned about, or affected by, forest management, either from a professional or service-based perspective. I sought to include entities with different types of conservation missions -- on-the-ground land management, forest research, environmental policy and decision making, advocacy, and stewardship -- to capture variation in the types of attitudes and perceptions participants might have towards forest biotechnology. Organizational affiliation served as a

proxy for identifying people who likely had different environmental beliefs and ethics attitudes toward forest biotechnology and land management more broadly.

The sampling and data generation protocol that were approved for this study by the Institutional Review Board at Oregon State University were described in the methods section of Chapter 2 of this thesis.

## Interview Topics and Questions

The sequence of interview questions followed a process of funneling, by starting with broad questions before transitioning into more specific questions (Mandel, 1972). Each interview had three sections (Appendix C). First, interviewees were asked about how they define nature and naturalness, including whether they believe nature is resilient (or fragile), what settings are more natural, and what type of relationship humans should have with nature. Interviewees were also asked to describe how they respond to statements describing the anthropocentrist and ecocentrist ethic[2] and what type of value they ascribe to natural landscapes. Interviewees also discussed whether they felt nature had more value than humans or society. Responses to these questions were used as data exclusively for this chapter.

During the second part of the interview, interviewees were asked to describe their general attitudes and beliefs about genetic modification as a technology and their familiarity with forest biotechnology more specifically. The last part of the interview was focused on specific scenario: using biotechnology to establish a genetically modified variety of tanoak (*Notholithocarpus densiflorus*) that is resistant to sudden oak death (*Phytophthera ramorum*). Interviewees read a half-page informational sheet about sudden oak death (SOD) (Appendix D). After reading this information, they were asked to describe their general attitude and response to using forest biotechnology to engineer a tanoak tree that was resistant to SOD, followed by questions related to two contextual factors that existing literature suggests influence attitudes and/or perceptions of naturalness toward biotechnology:

[2] It is important to note that the interview guide only provided very brief descriptions of the two extreme environmental ethics: anthropocentrism and ecocentrism. Thus, most respondents described their ethical stance as “somewhere in the middle,” requiring me to use a variety of probing questions to elicit data to help me understand how they conceptualize nature and the types of organisms and environmental processes that they feel the need to protect. This is one of the primary limitations of this study and is described in detail in the study limitations section of the discussion.

- the ***DNA source*** (i.e., transgenic or cisgenic). Studies of public perception of agricultural and forest biotechnology suggest that individuals have substantially different responses to biotechnology based on whether the modification uses DNA from a closely-related (cisgenic) or unrelated (transgenic) species (Kronberger et al., 2013; Scott et al., 2016), a phenomenon that may be associated with perceptions of naturalness.
- the type of ***threat*** (i.e., native or non-native). Given that this study investigated attitudes and perceptions of naturalness associated with forest biotechnology, I included questions regarding the nativity of the threat to understand whether that influenced how respondents invoked perceptions of naturalness or their attitudes toward using forest biotechnology to address native/non-native pests.

## Data Analysis and Coding

All interviews were transcribed verbatim. My advisor and I reviewed transcripts to refine the *a priori* codebook with codes that emerged from the data (Appendix E). The *a priori* codebook included descriptions of codes we expected to assign, such as environmental ethics (e.g., anthropocentrist, biocentrist, ecocentrist) and attitudes (i.e., ranging from completely supportive to completely opposed). All of the arguments and justification codes that we used in this study emerged directly from the interviews – we did not want to limit our potential results by identifying arguments and justifications that may arise *a priori* and instead chose to let the data guide what was included under those constructs. Although the unit of observation for this study was the individual, the unit of analysis was the individuals' cognitions (environmental beliefs, environmental ethics, attitudes toward forest biotechnology, and arguments/justifications used to support those attitudes). Statements in each interview were coded to these various constructs and analyzed to understand how these constructs were invoked and the role each of them played in interviewees' overall attitudes toward forest biotechnology.

In addition to the detailed description of data analysis and coding included in the methods section of Chapter 2, the present study involved additional data analysis to answer the specific research questions of this study. The first research question of the present study (RQ 3 of this thesis) is largely descriptive, investigating the types of environmental beliefs that are

invoked when considering the acceptability of forest biotechnology. Subsequently, after finalizing the codebook for environmental beliefs and arguments, the data included in each of these codes were reviewed. Environmental beliefs that were common among interviewees are presented in the results section, whereas beliefs and arguments that were used by only a handful of interviewees are not described.

To answer the second research question of this study (RQ 4 of this thesis), I used matrix queries and cross-tab analyses in NVivo to assess the prevalence of environmental beliefs and arguments associated with participants' predominant environmental ethic (e.g., anthropocentrist, biocentrist, ecocentrist) and overall attitude toward forest biotechnology (i.e., completely supportive to completely opposed). Specifically, these cross-tab queries focused on the following environmental beliefs within the dataset: transgenic organisms have more risk; breeding is more natural; forest biotechnology shouldn't be used to address native threats; humans have an ethical responsibility to protect the environment from threats that we are responsible for introducing; and we shouldn't use forest biotechnology because we cannot fix environmental problems and, therefore, we should not try to intervene. The results of these queries (Appendix H) helped identify differences that might be associated with ethical positions.

It is important to note that many interviewees explicitly used the word *natural* in their descriptions and explanations within the interview, making it clear and straightforward to identify their beliefs about whether something is (not) natural. However, many interviewees did not use that particular word to describe their beliefs, requiring me to infer whether their statements about forest biotechnology were rooted in their environmental beliefs about what is natural. When interviewees supported their statements about biotechnology with comments about natural systems or processes, I inferred that they were referring to their beliefs about whether forest biotechnology is natural. Additionally, many interviewees discussed their attitudes toward forest biotechnology by comparing forest biotechnology with other forest management strategies with which they are familiar– a conversational frame that often included references and allusions to beliefs about naturalness and ethical appropriateness.

## Sample Variation

To answer the research questions, I prioritized obtaining variation in interviewees' attitudes toward forest biotechnology and predominant environmental ethic. As explained in the methods section of Chapter 2, we classified each interviewee's attitude toward forest biotechnology as completely opposed, mostly opposed, ambivalent, mostly supportive, or completely supportive based on their answers to questions throughout the interview (Table 7).

In addition to assessing sample variation in terms of attitudes toward forest biotechnology, for this chapter, I also assessed variation in interviewees' predominant environmental ethic. I reviewed interviewees' responses regarding their perceptions of nature and naturalness, as well as their descriptions of the types of relationship humans should have with nature, primary values of nature, and beliefs about whether humans are more valuable than nature. The content of these responses was used to categorize interviewees as exhibiting primarily anthropocentric, biocentric, or ecocentric environmental ethics (Table 6). It is important to note that many interviewees made statements that aligned with multiple ethics throughout this portion of the interview. For example, an interviewee might describe the primary value of nature as sustaining societies while also describing the need to protect species because they have intrinsic value and a right to exist. In these situations, I assigned the interviewee to the environmental ethic that they most predominantly exhibited throughout the interview as a whole – the ethic to which most of their responses seemed to relate. Therefore, each interviewee was assigned to only one of the environmental ethic categories. It is important to note that we did not conduct a formal inter-rater reliability check on these categorizations. Nevertheless, this categorization was fairly straightforward given that many of the interviewees described their beliefs about how and why lands should be managed in similar ways. This included comments along the lines of: land should be managed to enhance ecosystem services and continuity of resources (anthropocentric), we have a responsibility to protect organisms from harm no matter what (biocentric), or describing nature as a series of systems and processes as opposed to individual organisms (ecocentric). However, as described above, many interviewees expressed beliefs that aligned with multiple categories and it was at times difficult to identify what the overarching ethics were. In some ways, an anthro/non-

anthro categorization scheme may have been more straightforward for this type of categorization considering that most of the difficulty I experienced in coding was whether someone was truly ecocentric or biocentric.

**Table 6:** Description of the types of statements that were used to categorize each interviewee's overall environmental ethic.

| Environmental Ethic | Description | Count of Interviewees (n=33) |
|---|---|---|
| Anthropocentric | • Describes the value of nature in predominantly utilitarian terms (e.g., resources, aesthetics, recreation, ecosystem services)<br>• Believes that nearly anything humans do to manage the natural environment in order to sustain resources for humans is appropriate<br>• Management should be focused on sustaining resources and services for humans and society | 9 |
| Biocentric | • Describes the value of nature in the context of individual living organisms (e.g., plants and animals) and considers humans as another living organism on par with other organisms<br>• Management should allow for each living individual organism to continue living, adapting, and evolving in its natural habitat without experiencing harm | 11 |
| Ecocentric | • Describes nature as ecosystems, interactions between organisms, and environmental processes (e.g., habitat, vegetative communities)<br>• Believes that earth as a whole and environmental collections of living organisms (e.g., species, entire ecosystems) have the right to live and flourish without experiencing harm<br>• Management should be in the context of the entire ecosystem and protecting ecological integrity and function | 13 |

## Results

### Sample Description

Chapter 2 described characteristics of the sample, including gender, age, childhood residence, organizational affiliation, and educational attainment. Attitudes toward forest

biotechnology were variable and ranged from completely opposed to completely supportive (Table 7).

Most of the participants exhibited predominantly non-anthropocentric environmental ethics (i.e., ecocentrism or biocentrism), whereas only one quarter of the sample were anthropocentrists. This spread aligns with recent literature investigating environmental ethics and worldviews, which report that a majority of respondents from studies in the U.S. exhibit non-anthropocentric environmental ethics (Batavia et al., 2018; Bruskotter et al., 2019; Lute et al., 2016). Ecocentrists most commonly opposed forest biotechnology to some degree and anthropocentrists were more supportive of forest biotechnology, whereas biocentrists had a more even distribution across the attitudinal classification (Table 7). Given the small and non-representative nature of the sample, these results should not be considered indicative of the distribution of perspectives in any population.

**Table 7:** The number of participants within each attitudinal classification and environmental ethics category (n=33)

| | 100% Oppose | Mostly Opposed | Ambivalent | Mostly Supportive | 100% Support | Total |
|---|---|---|---|---|---|---|
| **Ecocentric** | 3 | 5 | 3 | 1 | 1 | 13 |
| **Biocentric** | 2 | 3 | 2 | 3 | 1 | 11 |
| **Anthropocentric** | 1 | 1 | 2 | 2 | 3 | 9 |
| **Total** | 6 | 9 | 6 | 8 | 4 | 33 |

## RQ1: Interviewees Commonly Invoked Perceptions of Naturalness When Discussing Forest Biotechnology

Interviewees most commonly invoked perceptions of naturalness when discussing forest biotechnology in two distinct ways: 1) whether genetic modification as a technology is natural, and 2) how forest biotechnology might influence natural ecosystem functions. These perceptions were often rooted in environmental ethics and beliefs about whether humans should intervene to protect nature from threats.

*Perceptions of whether genetic modification is natural informed the types of justifications participants used to support their attitudes toward forest biotechnology.*

## Forest biotechnology is less natural than breeding.

The belief that GM technology is unnatural was widespread among interviewees, based on the way they described forest biotechnology in comparison to other options to protect forest health. Although interviewees didn't always explicitly describe GM technology as unnatural, almost half of the interviewees justified their preference for using breeding to address forest health threats with direct or indirect assertions that forest biotechnology is unnatural. This belief that breeding is more natural was substantially more common among ecocentrist interviewees and interviewees who were completely or mostly opposed to forest biotechnology. For example, one ecocentrist interviewee who was mostly opposed to forest biotechnology (F2) described her preference for breeding by saying,

> *Let's take Dutch elm disease… There were diseases that hit these hard and killed, almost all of the trees in the east. A few didn't get killed so those have something genetically different about them, and trying to incorporate, you know -- doing some breeding that helps incorporate that natural resistance into other trees -- would be a step I would take before actual genetic modification. It's more of a natural approach without really as many potential unintended consequences. (F2; ecocentrist)*

Commonly, interviewees justified their preference for breeding with arguments that it is a more natural and appropriate solution because breeding does not require as much direct manipulation of the plants' genome or natural processes, unlike forest biotechnology. For example, one ecocentrist interviewee (F10) described her complete opposition to forest biotechnology by stating, "*I guess I am a lot more comfortable with breeding because you have not gone and made some alteration."* Similarly, many interviewees suggested the genetic changes that result from breeding could have happened naturally, without human intervention, further supporting their perception that breeding is a more natural solution than forest biotechnology. They viewed breeding-based genetic changes as humans simply accelerating natural evolutionary processes. For example, one anthropocentric interviewee (M15) who was

completely opposed to forest biotechnology justified his preference for breeding using this type of argument:

> *I think it's less harmful for us to accelerate natural selection than to take, you know, a jellyfish gene and stick it into a whatever and do it in a lab, because we're taking things that were never part of that genetic structure, inserting them, and creating a new organism that wasn't tested by 10,000 years of evolution. It was tested in four or five years in a lab and released into the wild. So, I've got no problem with accelerating evolution, but I do have a problem with creating something. (M15; anthropocentric)*

Lastly, many interviewees justified their preference for pursuing breeding-based solutions with a belief that there are fewer environmental risks than with forest biotechnology. For example, one ecocentrist interviewee (M18) who was mostly opposed to forest biotechnology said, *"if there's other options, like I support exploring those other options because for me, they feel less risky, but not knowing for sure."* Some of these interviewees believed that -- because people have been using breeding processes for a very long time -- we are more familiar with how to minimize any potential negative environmental impacts, as one ecocentric interviewee (F10) who was opposed to forest biotechnology stated,

> *There's been a lot of breeding being done for various treatments, right, to show resistance and trying to breed various trees for resistance, I think, including whitebark pine. That kind of thing. And I guess I am a lot more comfortable with breeding*. (F10; ecocentric)

For these participants, the products of forest biotechnology aren't as natural or accepted as products that derive from breeding, and they preferred to investigate other options either concurrently to, or instead of forest biotechnology.

### Transgenesis isn't as natural as cisgenesis.

One of the primary ways interviewees expressed their perception that GM technology is unnatural was through their attitudes about where scientists should source genetic material for genetic modifications. Transgenesis was considered less natural than cisgenesis by approximately half of participants, regardless of their environmental ethic or attitude toward forest biotechnology. Consequently, almost half of the interviewees preferred sourcing DNA

that is as close to the species they are trying to save as possible. This position was much more commonly expressed by interviewees who were opposed to using forest biotechnology and those who expressed predominantly biocentric ethics. Many interviewees described transgenic approaches as "unnatural," "weird," "wrong," or "invasive." For example, one biocentrist interviewee (M5) who mostly opposed forest biotechnology described his perceptions of transgenesis this way: "*It just seems wrong. Like, this isn't something that would occur naturally. It's so far removed."*

Interviewees often justified their perception that transgenesis is unnatural with their belief that the outcome of cisgenic approaches are more natural because they could have occurred through natural environmental processes, like gene flow or reproductive processes, considering that cisgenic approaches source DNA from related species. For example, one biocentrist interviewee (M21) who mostly supported forest biotechnology described his perception that transgenesis is unnatural:

> *There shouldn't be an intrinsic problem with the gene coming from a distant organism. But I still feel more comfortable… when we would have to do some modification, use a related organism. It just feels more natural, you're keeping it, that tree or that organism stays in a more natural setting. Maybe you could have accomplished that with traditional breeding, maybe with crossing between similar sister species… which happens naturally throughout time anyways. So that just feels like a more natural modification and, you know, I'm a lot more comfortable with it. (M21; biocentric)*

Another ecocentric interviewee (M13) who was mostly opposed to forest biotechnology described his preference for cisgensis similarly: "*I lean much more strongly to sort of the classical genetic interference mode where you're using a closely related species or another subspecies to help modify it."* Because these interviewees believed that transgenesis results in an outcome that wouldn't occur naturally, it was perceived as more of a human intervention than cisgenesis. For example, one biocentric interviewee (M5) who was mostly opposed to forest biotechnology described his apprehension toward transgenesis: "*This isn't something that is likely to occur without these tools and this kind of an intervention."* Perhaps because transgenesis was perceived as more of a human intervention than cisgensis, interviewees

perceived it to be riskier than cisgenic approaches. One could argue that this is indirect evidence that they perceived transgenesis as a less natural approach in comparison with cisgensis.

Conversely, approximately half of the interviewees were not concerned about whether scientists used transgenic or cisgenic approaches to source DNA, suggesting the naturalness of forest biotechnology products is not exclusively assessed using substance-based arguments about whether the GM tree was engineered using a cisgenic or transgenic approach. Instead, many of these interviewees argued that it does not matter where the DNA comes from because DNA is DNA. These interviewees were not concerned about sourcing DNA from far away species and did not describe transgenic approaches as unnatural in comparison to cisgenic approaches. For example, one anthropocentric interviewee (M20) who mostly supported forest biotechnology described it succinctly: *"I mean DNA is DNA, I don't care [where they source it from]."* Interviewees commonly justified their positive attitude toward transgenic approaches with their belief that the introduced trait and final GM product will meet the objective scientists and managers are trying to address; and therefore, it doesn't matter which approach is used to meet that objective. For example, one ecocentrist interviewee (F11) who mostly supported forest biotechnology said she would support transgenensis

> *if the genetic trait is still serving the role and it's being expressed the way that we need it to solve the underlying issue. I think it's a little freaky, but I think it certainly is worth exploring and it is ok to apply. (F11; ecocentrist)*

### *Perceptions of what is natural within the ecosystem influenced the types of justifications participants used to support their attitude toward forest biotechnology.*

Many interviewees referenced how ecosystems function and adapt to disturbances and pests as justifications for their attitudes about whether or not to use forest biotechnology to address forest health threats. This was especially prevalent when interviewees described their attitudes and beliefs about using forest biotechnology to address forest health threats that are native, as opposed to non-native threats like SOD. More than half of the interviewees, regardless of their attitude toward forest biotechnology, were vocal about not supporting forest biotechnology to address native pests or pathogens that threaten forest health. Some

interviewees who mostly supported FB were opposed to using it to address native pests and pathogens. Interviewees explained this opposition with a variety of arguments, including references to nature's adaptive capabilities to address threats, natural processes that might influence the long-term viability of the GM tree, potential ways ecosystem function could change as a result of climate change, and the appropriate settings in which to use forest biotechnology. These four arguments are described below.

### Nature is adaptive and capable of developing its own solution.

Interviewees commonly revealed their perceptions of naturalness in statements about nature's capacity to develop its own solution to threats. When considering using forest biotechnology to address native pests, interviewees often exhibited a preference to "leave it alone" and allow the system to go through its own process to establish resistance. Many interviewees who relied on these types of arguments were opposed to using forest biotechnology. For example, one ecocentrist interviewee (M1) who was completely opposed to forest biotechnology said,

> *Leave it alone. And eventually, you know, it will come back. You know, all the tanoaks might die off for now. Maybe there won't ever even be tanoaks on the world again. But there's probably thousands of species of plants and creatures that have come and gone. (M1; ecocentrist)*

Another biocentrist interviewee (M14) who was mostly supportive of forest biotechnology said using biotechnology "*is sort of fighting nature a little bit."* He felt it is *"up to tanoak to resist the problem,"* and he *"would have more faith in nature than in humans wasting a whole bunch of money trying to save tanoak,"* because *"nature's been doing that kind of stuff for billions of years."* Some interviewees asserted that nature has been adapting to disturbances for millenia through systems and cycles that we as humans don't fully understand. Consequently, many interviewees believed that there is a natural resistance mechanism for native pests and pathogens within ecosystems, unlike for non-native threats that spread into new ecosystems. One biocentric interviewee (F8) who was completely opposed to forest biotechnology argued that

> *nature finds solutions to problems. And it can be slow. And it can mean a lot of sacrifice along the way. But typically, the solution is a very permanent lasting solution that has, if anything, positive effects on other, you know, the ripples go out in a positive direction. Whereas any attempt made by humans to improve things is primarily driven, motivated by a selfish concern that is very myopic and short lived. And so, as much as I would love to see the oak forests thrive and continue to thrive, I would not trust genetic engineering to be able to find a long-term solution that would be beneficial across the board. (F8; biocentrist)*

Multiple interviewees used natural succession as a justification for their opposition to forest biotechnology -- if the tanoak tree can't establish its own resistance to the non-native sudden oak death, another tree will move into its niche, and humans need to accept that change in the system. For example, one ecocentrist interviewee (F6) who mostly opposed forest biotechnology stated,

> *It may be that… if it [tanoak] disappears from its range, there will be something… to replace it. But that will change everything, habitats, microclimate, all those things. And so, everything will shift, but is that really a bad thing?* (F6; ecocentrist)

### Climate change is changing what interviewees perceive as "natural."

Another type of environmental belief that commonly emerged during interviews was related to climate change. Interviewees frequently described how climate change is affecting naturalness when discussing their attitudes toward using forest biotechnology to address forest health threats. Most commonly, interviewees believed that climate change is increasing the severity of pests and pathogens, encouraging these threats to move into new areas, and changing the behavior of native pests. One ecocentrist interviewee (F2) who was mostly opposed to forest biotechnology said she might be willing to consider using forest biotechnology to protect forests from threats that are more severe in the context of climate change:

> *Ordinarily I'd say let it [the native pest] do its thing, it's natural. You know, there's not a lot of things that are so completely natural anymore, and with the threat of climate*

> *change, which is already happening, we may need to be proactive in order to save species. (F2; ecocentrist)*

This environmental belief also influenced the types of arguments interviewees used to support their attitudes about pursuing forest biotechnology. For example, interviewees argued that scientists need to consider how ecosystems and their processes are projected to change due to climate change when developing a GM tree to ensure it remains viable. These interviewees urged that the resistance traits and mechanisms engineered into a GM tree should be suitable under projected future climatic conditions so the GM tree will be viable in the long-term. For example, one ecocentric interviewee (F2) who was mostly opposed to forest biotechnology said that if she *"was doing the studies,"* she would

> *be thinking hard about climate change and whether it [the trait] would be persistent in the future. You know, make it [the tree] more suitable for what we think the future conditions would be. (F2; ecocentrist)*

Some interviewees interpreted this environmental belief into arguments that climate change is a more systemic issue, and the problems that it is causing cannot be adequately addressed using forest biotechnology. In this context, the environmental belief that climate change is causing pests and pathogens to have increased impacts seemed to promote opposition toward using forest biotechnology to establish a GM tree that is resistant to SOD. Commonly, these interviewees argued that forest biotechnology is not a holistic solution; it does not address the cause of the outbreak – climate change. In other words, instead of simply addressing the symptom climate change is causing, we need to address climate change itself. One ecocentric interviewee (F11) who was mostly supportive of forest biotechnology said that forest biotechnology

> *can short-cut looking at the real underlying reasons for that pest having an outbreak, or a population boom so to speak, or becoming more recognized on the landscape. I think that it's important that we try and solve the underlying issues that might be causing that pest to be damaging on a scale that we think is not good for the economy and ecology. (F11; ecocentrist)*

Instead of investing substantial resources into forest biotechnology as a potential solution to forest health issues, these participants felt we should be focusing efforts on addressing climate change, overpopulation, or large-scale land use changes, which are ultimately responsible for causing these forest health problems. For example, one ecocentric interviewee (F10) asserted that "*climate change is changing the behavior of things, so called pathogens and insects and all that kind of stuff. But to genetically modify as a short-term response, I think would be nuts."* Another ecocentrist interviewee who was completely opposed to forest biotechnology (M1) took an even stronger stance, claiming the real threat to forests is overpopulation: "*You got to figure out where is the real problem? And the real problem isn't tanoak disease. You know, tanoak disease doesn't need to be fixed. The problem is human beings…7 billion [people]… that's the problem."*

### A genetically modified tree won't be viable in the long-term.

Another way interviewees referenced the adaptive nature of ecosystems during these interviews was in the context of the long-term viability of the GM tree or trait developed to address SOD. Commonly, interviewees expressed concern that the pathogen will naturally adapt to overcome the modified trait and its associated resistance mechanism through natural selection, reducing the viability of the GM tree as a long-term solution to the pathogen. One ecocentrist interviewee (M9) who was ambivalent toward forest biotechnology questioned,

> *How fast is this fungus going to mutate and overcome the resistance? Do you think you can build a resistance the fungus won't overcome? And again, we're talking about natural selection now. If it [the fungus] can overcome it, it will. (M9; ecocentrist).*

Another ecocentrist interviewee (M1) who was completely opposed to forest biotechnology related the viability of GM trees to issues with antibiotic resistance, stating,

> *It's like the antibiotics of 20 years ago -- most of them don't even barely work anymore because the germs have evolved to work, or you know, diseases and viruses evolve to work around them. The same thing will happen and they [the GM trees] will just have to become more genetically modified. (M1; ecocentrist)*

Interviewees also expressed concern about the modified trait within the GM tree mutating through natural selection and reproductive processes. One ecocentric interviewee

(M9) who was ambivalent toward forest biotechnology was concerned that *"Whatever we put the genes into is evolving,"* and the GM tree is *"going to evolve for its own benefit. Not ours."* He believed that*, "when you stick a gene into an organism, that may work great for a while, but it might mutate*." Consequently, multiple interviewees discussed how there would need to be multiple forms of resistance in the GM trees to ensure long-term viability. For example, one anthropocentric interviewee (M20) who mostly supported forest biotechnology stated,

> *You either win big or you lose big if you only have one form [of resistance]. So, we need biodiversity [individual GM trees with different forms of resistance] there for the species to live when we plant it and also for it to stay resistant to the disease once we plant it. (M20; anthropocentrist)*

Similarly, another anthropocentric interviewee (M3) with an ambivalent attitude toward forest biotechnology questioned,

> *Are you just putting out a clonal population? I would be worried about that. I'd be interested in the mechanism of resistance in terms of whether it was breakable or not. Is this going to be another treadmill that we're on? (M3; anthropocentrist)*

### Forest biotechnology is more appropriate to use in tree farms than natural settings.

Another way interviewees revealed their perceptions of naturalness was in talking about the types of settings where they would support planting GM trees. Predominantly, interviewees expressed more support for using forest biotechnology in tree farms because they are perceived more as agricultural areas than natural forests. For example, one anthropocentric interviewee (M12) who was mostly opposed to forest biotechnology described his opposition toward planting GM trees outside of confined, farm-like areas:

> *If these trees were, you know, in a confined area, you could genetically modify them, you could breed them just like we do with crops and it's no big deal. But it's just when it gets out in nature it's a problem. (M12; anthropocentrist)*

One biocentric interview (M21) supported exploring and using forest biotechnology in most contexts that arose throughout the interview, although he did draw the line at planting trees where GM is used to enhance commercial traits such as growth and yield in contiguous and natural forests:

> *I can see a role of the genetically modified organisms increasing yield in certain types of land settings where, you know… it's been maintained by man forever. It's never going back in any political situation you could imagine. So, the example might be like, you know, a cottonwood plantation that's on the edge of a forest in a field, you know, that's purely there just for wood production and they're treating it like a crop, like a wheat crop really. But when you asked the question, I was thinking mostly for the settings of having GMOs put into a more contiguous natural landscape for the purpose of growth and yield -- I'm opposed to that. (M21; biocentrist)*

### RQ2: The environmental ethic of minimizing harm to nature informed the type of arguments interviewees used to justify their attitude toward forest biotechnology.

Almost all of the interviewees relied on some version of the environmental ethic that humans should minimize harm to nature to justify their attitude toward forest biotechnology (Figure 4). Minimizing harm to the environment and protecting nature from threats will ensure that nature can continue providing resources and/or sustain ecological function and integrity. Interestingly, this conviction was used both as a reason to use forest biotechnology and to avoid using forest biotechnology. On one hand, forest biotechnology can be used to protect nature from potentially devastating and severe forest health threats. On the other hand, because forest biotechnology is a potentially risky technology that might have unintended consequences, the best way to minimize harm to nature is by not intervening. One biocentrist interviewee (F4) with an ambivalent attitude toward forest biotechnology described this moral dilemma succinctly:

> *I just feel like this is really going back to every other question you've asked me about like what nature is and what is human. Like there are the extremes that people can take of answering this kind of question. It's either like we have to do everything and protect it or like nature is going to take its course. (F4; biocentrist)*


***Figure 4:*** *Arguments interviewees used to justify their attitudes toward forest biotechnology commonly related to a conviction that humans should minimize harm to nature.*

Almost half of interviewees (~40%) used ethical arguments on both ends of this ethical spectrum (Figure 4), by supporting intervention to protect nature in some situations but saying nature should be left alone in others. These contradictory sentiments often highlighted the types of contexts and situations in which they would (not) be supportive of using forest biotechnology. For example, one interviewee (F2) was mostly opposed toward using forest biotechnology given that we do not know all of the potential consequences it might have on the environment; she generally felt that we should not intervene using forest biotechnology because it will likely cause more environmental harm than it will solve. However, she was clearly interested in protecting nature from harm and stated multiple times that she would be willing to use forest biotechnology to protect nature from threats if we were scientifically certain that there wouldn't be any unintended consequences arising from its use. She further qualified her attitude by stating that she would be willing to use forest biotechnology without that level of certainty if necessary to protect nature from severe and catastrophic threats, especially those that are being exacerbated by climate change.

Another way interviewees used arguments from both sides of this moral continuum was in their willingness to explore forest biotechnology as a last resort – some interviewees who were mostly opposed to forest biotechnology given its potential for causing environmental harm (via unintended consequences) were willing to use forest biotechnology if other options to address the threat were not effective.

Lastly, another interviewee (M2) used arguments on both sides of this moral dilemma when he described his opposition toward transgenesis with his worldview that we shouldn't be creating life. He would rather leave nature alone than "play God" by creating transgenic lifeforms. However, his broader attitude toward forest biotechnology was positive – he felt that humans should use forest biotechnology as a tool to address severe threats that are affecting forest health.

In contrast to people who used arguments from both positions (i.e., either intervene to protect nature or don't intervene and leave it alone), just over half of interviewees (~60%) relied on arguments from only one of the two ethical positions. Among these interviewees, it was more common to prefer that humans simply leave nature alone than to support intervening to protect nature from a specific threat. These arguments are described in more detail in the following sections.

### *Humans should intervene to minimize harm to nature and protect nature from threats.*

Some interviewees expressed a moral conviction that humans should intervene to protect nature from threats, especially threats that are considered to be catastrophic or that were introduced or caused by humans (e.g., climate change impacts, non-native or invasive pest/pathogen introductions). Although this moral responsibility to protect nature was exhibited by individuals regardless of their attitude towards forest biotechnology, it was most common among interviewees who were either ambivalent or oppositional toward forest biotechnology. These interviewees felt that there was an obvious need to intervene and protect nature from threats but were opposed to using forest biotechnology as the tool to do so. The belief that humans need to intervene to protect nature more broadly (i.e., from any type of threat regardless of whether it was introduced or caused by humans) was generally more common among anthropocentric interviewees. For example, one anthropocentric interviewee (M2) described his broad support for using forest biotechnology to protect nature:

> *It doesn't matter to me whether the pest was here, was brought, came on its own or was inadvertently or intentionally transported by people… The result is the same. And if that's [the result] deemed to be not good from either a use point of view… or… if the goal is to protect that species, we should if we can. (M2; anthropocentrist)*

Another anthropocentric interviewee (M6) described his broad support for forest biotechnology as a tool to protect nature:

> *I feel as with genetic modification, there's a lot of benefits… it's good and like the scientific community just doesn't get it out that this is actually helpful. People just fear it so much. But, I think that's the way we're going to have to do a lot of things in the future is with GMOs because of climate issues, human population issues… I think that it's a key tool going forward. (M6; anthropocentrist)*

Biocentrists and ecocentrists were more likely to say that humans should only intervene to protect nature using forest biotechnology when humans are responsible for introducing the specific threat that is causing harm. One biocentric interviewee (M19) with an ambivalent attitude toward forest biotechnology illustrated this particularly well:

> *If humans caused the problem, then we have the responsibility to try and sort it out. But if it's part of a natural process [i.e., a native pest], I don't know how much responsibility we have to sort it out. (M19; biocentrist)*

Another biocentric interviewee (F4) with an ambivalent attitude toward forest biotechnology described her belief that humans need to protect nature from threats we have introduced: *"There's another part of me that is like oh… we need to save the forests. And especially if we're the ones who are transporting these fungi all over, like it's us who are doing it" (F4; biocentrist).*

The prevalence of this moral responsibility to protect nature was also revealed by the type of intents and goals interviewees were willing to use forest biotechnology to address. Most interviewees were more accepting of using forest biotechnology to address a threat (e.g., resistance traits or overall resilience mechanisms) than using forest biotechnology to enhance commercial traits (e.g., growth or yield). For example, one ecocentrist interviewee (F11) said she "*definitely"* valued *"the restorative goal more than the commercial harvest goal,"* because it would promote *"building a more resilient landscape to climate change."* When it comes to *"increasing the growth rate of trees for harvest,"* she said, *"I guess in general I just don't find that as incredibly important to be spending a lot of time researching that."* Although she could *"see there's definitely values for both,"* she said she preferred *"that [forest biotechnology] be*

*applied for building a more resilient landscape first."* An anthropocentric interviewee (M10) with an ambivalent attitude toward forest biotechnology described his support toward using it to protect tanoak given the species' role in the ecosystem:

> *My reaction, I guess, is not like "oh my gosh, no way. You know, don't do it, like, this is silly," or something. It's like, I think that because tanoak does have a key ecosystem function in the forests in that area that it's worth trying to figure out how to protect them and kind of put all options on the table I guess. (M10; anthropocentrist)*

Conversely, another anthropocentric interviewee (M22) who completely supported forest biotechnology described his willingness to use forest biotechnology to protect any species, regardless of the intent: "*I don't care about whether it's a timber value crop or not… Should we do something to support this plant? My answer would be yes… I don't care whether it's a valuable timber commodity or not."*

### *Humans should not intervene to protect nature; humans should leave nature alone.*

A majority of interviewees who only relied on arguments from one side of the moral continuum of minimizing harm to nature felt that not using forest biotechnology was the appropriate way to protect nature. Although these beliefs were expressed by interviewees regardless of their attitudes toward forest biotechnology, they were most common among ecocentric interviewees and people who had ambivalent or oppositional attitudes. Frequently, these interviewees expressed concern about misplaced human desires to intervene in environmental systems and attempts to solve problems. Instead of meddling in nature or trying to control nature to ensure a socially desirable outcome, humans should leave nature alone. This position was supported by assertions that humans cause more problems when they intervene or humans shouldn't be "playing God."

Participants described how prior interventions have ended up causing more environmental problems, often due to our lack of knowledge about the complex interactions within natural systems. For example, one ecocentrist interviewee (M1) described his opposition toward forest biotechnology:

> *That's the darn problem with doing things like this again and again. "Well we got it wrong last time, but we're going to get it right this time." Well, that's what we've been*

> *saying for the last many thousands of years and it just hasn't turned out to be true ever. You know they don't ever say, "why don't we just leave this forest alone now and not do anything?" Like, "oh we're just going to do a little bit, this will help us along faster." We need to leave it alone. (M1; ecocentrist)*

Another ecocentrist interviewee (F10) used a similar argument to describe her complete opposition to forest biotechnology: *"People are still going to do what people do. But it's the colossal arrogance to me to go and think 'Oh you're going to gene edit this stuff and it's going to be great' as if there isn't something we haven't thought of… We know so little."* Another ecocentric interviewee (M11) with an ambivalent attitude toward forest biotechnology articulated this concern:

> *Like we do that a lot… always looking for that next fix. And so, you know, lots of great ecological examples of like, well, we introduced this to control this, whoops. These things got out of control. We introduced this to control this, turns out that didn't work either. It's like we love to tinker, we just don't like to always step back and then blame ourselves for what happened. (M11; ecocentrist)*

Lastly, one ecocentric interviewee (F6) who was mostly opposed to forest biotechnology stated:

> *Humans think they can fix things without knowing enough. And that's just been proven again and again and again to be not the best approach. I mean, we have to basically switch from the Judeo-Christian way of looking at the world to something a little bit more, I don't know, Buddhist or something. (F6; ecocentrist)*

Interviewees also expressed concern about humans arbitrarily choosing which species have value and need to be protected from threats when discussing why we should not use forest biotechnology. For example, one ecocentrist interviewee (F6) who was mostly opposed to forest biotechnology questioned society's preference for protecting species from impacts: "*We always think, 'OK well it's getting wiped out. We can't let that happen.' Well why? Why can't we let that happen?"* Another ecocentrist interviewee (F3) with an ambivalent attitude toward forest biotechnology questioned why humans feel that native pests and pathogens are threats that need to be addressed: "*It's a sense that it's native. It belongs there. Who are we to*

*be interfering and intervening? Why do we feel it's a threat? What is it threatening?"* Interviewees were especially concerned about choosing to protect one species, such as the tanoak tree, at the expense of another, such as the SOD fungus. This sentiment is captured in the words of one ecocentrist interviewee (M13) who was mostly opposed to using forest biotechnology:

> *Pathogens are part of ecosystems. They provide mortality, which is important… whether you're looking at carbon sequestration or ecosystem dynamics, mortality is part of natural systems. And pathogen induced mortality is one of them. So, we can't rid ourselves of those sources. (M13; ecocentrist)*

Another biocentrist interviewee (M5) who was mostly opposed to forest biotechnology had similar concerns: "*I do feel like pathogens are natural, right? I mean they exist. They have that same kind of right to exist. They need hosts too."*

Lastly, interviewees referred pejoratively to humans "playing God" to support and justify their belief that humans shouldn't use forest biotechnology to intervene and protect nature from threats. Often, these comments were accompanied by concerns about creating new lifeforms or choosing which species are worth protecting. Interviewees expressed these types of ethical concerns about forest biotechnology regardless of their environmental ethics, although these comments were more common among anthropocentrists and interviewees who were completely opposed to forest biotechnology. For example, one anthropocentrist interviewee (M15) described his opposition toward using forest biotechnology by stating, "*I'm tempted to use an expression that I don't really believe but it would come out something like 'God didn't put it there. Man did.' And that worries me."* Another anthropocentric interviewee (M2) who was completely supportive of forest biotechnology described his apprehension about using forest biotechnology to create life that couldn't otherwise have existed:

> *Ethically or spiritually I'm not opposed to that [using forest biotechnology], but I am opposed to the concept of creating artificial life, creating a creature, taking genes from every different source and combining them and creating an animal that never existed and probably never would exist. That I think crosses my line of ethics. (M2; anthropocentrist)*

## Discussion

This study aimed to understand how conservation professionals and volunteers invoke their environmental beliefs, perceptions of naturalness, and ethics-based arguments when discussing the acceptability of using biotechnology to address forest health threats. Specifically, this study investigated how these environmental beliefs and perceptions of naturalness influenced attitudes toward forest biotechnology (research question 1) and how environmental ethics influenced the types of arguments and justifications conservation professionals and volunteers used to support their attitudes (research question 2).

### Perceptions of Naturalness Influenced the Types of Arguments Interviewees Used to Explain their Attitudes toward Forest Biotechnology

Interviewees revealed their environmental beliefs and perceptions of naturalness in a variety of ways when discussing the potential to use biotechnology to address forest health threats. Primarily, these beliefs emerged when interviewees described the reasons for their attitudes toward forest biotechnology. These reasons closely aligned with arguments and considerations about naturalness that have been highlighted in other related studies investigating biotechnology (Bearth & Siegrist, 2016; A. Buijs et al., 2012; Ditlevsen, Glerup, Sandøe, & Lassen, 2020; Kronberger et al., 2013; Roman, Sanchez-Siles, & Siegrist, 2017; Rozin, 2005; Rozin et al., 2012). These studies provide the foundation of the various beliefs and perceptions about the characteristics of naturalness that are associated with different applications of biotechnology, including which process was used, what DNA was sourced, and the modification that was made.

Many of the considerations of naturalness presented in these studies were succinctly synthesized and described in five different arguments about the naturalness of biotechnology that emerged from a qualitative study investigating attitudes and acceptability of cisgenic and transgenic GM approaches in agriculture (Mielby et al., 2013). In that study, focus group participants used these arguments to describe whether they considered a transgenic GM crop to be “natural.” These arguments about whether something is considered natural included beliefs about the following: the process used to make it (history-based argument), what materials the product came in contact with while it was being developed (substance-based

argument), whether the product is perceived to have negative impacts on the environment (harmony-based argument), whether it was created using a process that is familiar and commonly used (acquaintance-based argument), and whether the product has features different than what occurs naturally (feature-based argument). Because Mielby et al.'s (2013) work largely encapsulates findings from related studies, which clearly emerged in my study, I organize much of the following discussion around them.

- ***History-based arguments*** – these are arguments that an entity is unnatural because it results from processes other than those that have occurred historically. For example, participants in Mielby et al.'s (2013) study described their beliefs that transgenic crops are unnatural by arguing that these products would not exist in historical contexts -- they depend on innovative scientific technologies that allow humans to move DNA among species that are not sexually compatible. Thus, these transgenic or GM products would not occur if left to natural processes and cycles that have historically guided reproduction and evolutionary adaptation. This is similar to the results reported in Rozin (2005) in which the history of processing involved in creating the product was more important than the contents of the product when assessing the naturalness of a GM product.
- ***Substance-based arguments –*** these are arguments that an entity is unnatural because it has come in contact with an unnatural substance. For example, participants in Mielby et al.'s (2013) study described their beliefs that transgenic approaches are unnatural because transgenic products have exotic DNA within them. Often, introducing exotic DNA from another species is perceived as contamination, causing people to see the transgenic product as less natural than a cisgenic product. Similarly, Rozin (2005) reported that GM products experienced the largest reduction in their perceived naturalness when they were believed to be transgenic and use exotic DNA.
- ***Harmony-based arguments –*** these are arguments that an entity is unnatural if it is not in harmony with nature (e.g., products that pose increased environmental risks). For example, interviewees in this study used this argument when they described GM trees as unnatural, insofar as they would disrupt the natural balance and harmony that exists in nature, such as impacting how organisms interact with the GM tree. This argument also

aligns with recent studies reporting that perceptions of naturalness are important in how lay people assess and describe the risks associated with GM products, such as vaccines (Ditlevsen et al., 2020), GM trees (Peterson St-Laurent et al., 2018), and GM crops (Bearth & Siegrist, 2016). In other words, because respondents perceived GM products as unnatural, they also perceived greater risk associated with them – risks that could potentially disrupt the harmony of the natural world. Studies have also reported that respondents believe that products and processes that are considered natural are inherently good for the environment (Rozin, 2005; Scott et al., 2018).

- ***Acquaintance-based arguments*** – these are arguments that an entity is unnatural if it is not well known or familiar. One study investigating attitudes toward synthetic vaccines for livestock described this argument as a belief that biotechnology is unnatural because it is new and, consequently, there is a need to be particularly cautious with its use (Ditlevsen et al., 2020). This argument was especially common among interviewees in my study who described their preference for breeding because it is a more familiar and common process to improve the genetics of species than forest biotechnology. Consequently, interviewees perceived breeding as a more natural endeavor than forest biotechnology.
- ***Feature-based arguments –*** these are arguments that an entity is unnatural because it has physical features that are abnormal or substantially different from the wild-type, non-GM versions of the species. This is similar to the results reported in Rozin (2005) in which respondents in the U.S. felt that GM processes that result in chemical changes to a plant are substantially less natural than physical changes that arise through traditional processes, such as breeding. Although many of the interviewees in this sample were highly educated conservation professionals and volunteers with some level of familiarity with forest biotechnology, this argument was not as common as the other four arguments about naturalness within my data and therefore is not discussed throughout the remainder of this discussion.

Aside from the feature-based argument, the other naturalness arguments described by Mielby et al. (2013) capture the data of this study and the characteristics of naturalness that have been described in the related literature. Throughout this portion of the discussion section,

I highlight how these arguments about naturalness were used in different ways to describe environmental beliefs and justify attitudes toward forest biotechnology, as well as what types of interviewees used these arguments, and the types of claims they used these naturalness arguments to support.

### *Some Interviewees Used Naturalness-based Arguments to Explain their Opposition toward Forest Biotechnology.*

Similar to the results of other studies (Bennett et al., 2013; Kronberger et al., 2013; Lassen et al., 2002; Mielby et al., 2013; Scott et al., 2018; Weale, 2010), many interviewees in this study perceived GM as unnatural in comparison to other options, such as breeding. Interviewees perceived transgenic approaches using DNA from unrelated organisms as less natural than cisgenic approaches using DNA from related species. Interviewees used four of the naturalness arguments described above to justify their beliefs that forest biotechnology and transgenic approaches are unnatural (history-based, substance-based, harmony-based, and acquaintance-based arguments). However, it is important to note that it is uncertain if individuals' beliefs promoted opposition toward forest biotechnology or if their opposition toward forest biotechnology led them to develop arguments that it is an unnatural endeavor. Either way, it makes sense that individuals who believed that forest biotechnology and transgenesis are unnatural would express oppositional attitudes towards its use.

Beliefs that forest biotechnology and transgenesis are unnatural were more common among ecocentric and biocentric interviewees than anthropocentric interviews. Ecocentrists and biocentrists commonly relied on ***history-based arguments*** to explain their opposition toward forest biotechnology -- because these products require human intervention and processing that is different from what has been used historically, they are less natural and less acceptable. Interviewees also used this argument when they described their preference for using forest biotechnology to make changes that could have arisen naturally, either through natural reproduction or evolutionary adaptation. For example, some interviewees explicitly described their preference to use forest biotechnology in ways where it is speeding up natural adaptation and evolutionary processes to bring about a solution more quickly.

Similar to the history-based argument described above, ***substance-based arguments*** were used by half of the interviewees in this study. These people argued that transgenesis is unnatural because it introduces DNA from an unrelated species into the species of interest. Consequently, these interviewees argued that forest biotechnology should source DNA from as close to the species of interest as possible. In this context, the perceived naturalness of the resulting GM product is dependent on whether it comprises foreign materials, such as DNA from an unrelated species (Mielby et al., 2013; Rozin, 2005). In terms of GM crops, we have seen this argument in beliefs that GM will corrupt or contaminate the perceived purity of the natural organism (Lassen et al., 2002). This substance-based argument has also been reported in investigations into how the public describes the unnaturalness of vaccines developed using synthetic biology (Ditlevsen et al., 2020) and other agricultural biotechnologies (Weale, 2010), suggesting that this is a common argument used to describe the unnaturalness of not only the products that arise from biotechnology, but also to biotechnology as a process.

Additionally, many oppositional interviewees used ***acquaintance-based arguments*** to support their belief that breeding is more natural than forest biotechnology. In this context, interviewees argued that breeding is more natural because it was a familiar process to them. Breeding has been widely used for decades and many are introduced to the concept of cross-breeding and domestication through education, making it a more comfortable and familiar approach. Interviewees' beliefs that breeding has been used to address environmental issues in forestry and land management for decades made them believe it was more acceptable because it is well studied and documented. Despite the reality that every breeding project is different, interviewees in this sample did not perceive breeding as a novel technology or process. This type of argument for breeding and other less-interventionist strategies has been highlighted in studies investigating attitudes toward GM food (Rozin, 2005) and may be underlying the preference for using breeding-based solutions to address forest threats that has been reported in other studies (Hajjar & Kozak, 2015; Hajjar et al., 2014; Needham et al., 2015; Peterson St-Laurent et al., 2018; Strauss et al., 2017).

These acquaintance-based arguments were often used in conjunction with ***harmony-based arguments*** that described forest biotechnology and its products as inherently risky.

Many interviewees believed that forest biotechnology, and transgenesis more specifically, is riskier than more familiar options, such as breeding. Similar to the results reported in other studies, interviewees argued that forest biotechnology might cause unintended consequences or ecological impacts that will disrupt the natural harmony of the environment to justify their opposition or apprehension toward using forest biotechnology (Lassen et al., 2002; Weale, 2010). Consequently, many interviewees used harmony-based arguments when describing their preference for using options they believed would not disrupt the natural order, function, or integrity of the environment. Implicit in this argument is the belief that the GM tree or plant is artificial in some way and that its introduction poses some immediate risk to other organisms -- a belief that has also been reported for agricultural biotechnology (Weale, 2010). Although this sample included highly educated conservation professionals and volunteers – participants who are arguably more knowledgeable about environmental processes and strategies to address environmental issues than the general public – these interviewees still commonly perceived forest biotechnology as potentially having some sort of catastrophic impact on the natural harmony of the ecosystem; the belief that biotechnology might cause severe and potentially catastrophic environmental impacts doesn't not dissipate with environmental knowledge or familiarity. Therefore, I would expect that this belief and argument would be even more prevalent among audiences that are not highly knowledgeable about environmental processes (i.e., the general public).

Overall, the results of this study suggest that interviewees used different naturalness-based arguments to describe their beliefs about why using forest biotechnology to address forest health threats is unacceptable. This suggests that perceptions of naturalness may be one of the major considerations that influence overall attitudes toward forest biotechnology, in addition to their risk and benefit perceptions (as discussed in Chapter 2). Further, these various environmental beliefs and perceptions of naturalness were influenced by multiple contextual factors about the specific application of forest biotechnology, for instance, where the DNA was sourced from and what types of impacts it could have. This suggests that, although some interviewees who opposed forest biotechnology widely perceived it as an unnatural process, they clearly perceived some FB products as being more natural than others (i.e., transgenesis).

More work is needed to understand these various contextual factors and how they influence environmental beliefs and perceptions of naturalness within specific scenarios.

### *Some Interviewees Used Naturalness-based Arguments to Explain Their Support for Forest Biotechnology*

Interestingly, versions of these same naturalness arguments were also used by interviewees to justify their support of forest biotechnology. These interviewees used these naturalness arguments to describe the various contexts in which they supported using forest biotechnology and to compare forest biotechnology to other options that might be available. These arguments were much more common among anthropocentric interviewees than ecocentrist or biocentrists.

Many interviewees who were familiar with GM and forest biotechnology used the antithesis of the ***substance-based argument*** to describe their support for forest biotechnology and transgenesis. Instead of expressing concerns about transgenic products being contaminated by the unrelated DNA, these interviewees commonly perceived DNA from different species as similar entities, regardless of the source. These interviewees generally exhibited a lack of concern about the source of the DNA used to develop a GM tree. Other studies have shown this response as well – experts working in genetics and biotechnologies do not tend to exhibit strong concerns about whether GM approaches are cisgenic or transgenic because they consider DNA a universal language across all species. In a sense, experts do not express an intuitive concern about crossing species boundaries (Ditlevsen et al., 2020; Mielby et al., 2013; Rozin, 2005).

Supportive interviewees also used the ***history-based, harmony-based,*** and ***acquaintance-based arguments*** as reasons to support forest biotechnology. For example, some interviewees argued that forest biotechnology is a scientific advancement of other commonly used strategies to address forest health, such as scientific breeding – an argument that includes elements of both history-based and acquaintance-based arguments about naturalness. Forest biotechnology simply allows scientists to make desired changes to species more efficiently and quickly than breeding can accomplish. Accordingly, products of forest biotechnology are not

inherently riskier and will not disrupt the natural harmony of the environment (harmony-based argument).

This study provides insight about the arguments individuals use to describe their beliefs that forest biotechnology is natural and acceptable. Most of the existing literature focuses on the use of such arguments to explain the unnaturalness of GM products, and it is important to understand how people who support biotechnology construct arguments differing from that common rhetoric. Our recruitment strategy focused on conservation organizations in an environmentally oriented region, potentially allowing us to obtain more insight into these pro-naturalness arguments in this study. However, there is substantially more work needed to identify the types of pro-naturalness arguments individuals use to describe their support for forest biotechnology, as well as the other cognitions and characteristics of people who use these arguments.

## Environmental Ethics Informed Attitudes and Arguments toward Forest Biotechnology

In addition to environmental beliefs and perceptions of naturalness, these interviews also revealed the ways environmental ethics shaped attitudes toward forest biotechnology. Ecocentric interviewees tended to be more opposed to using forest biotechnology to protect nature from environmental threats than anthropocentric interviewees were. This opposition was supported by a variety of beliefs related to the ecocentric environmental ethic, which grants moral standing to ecological collections and systems. Interviewees used arguments related to their beliefs about our lack of scientific understanding about how these systems function; they were especially concerned that lack of understanding will result in negative, and potentially catastrophic impacts to the ecological collective (i.e., biodiversity) they don't want to harm (i.e., through ecological impacts from forest biotechnology). Their ecocentric ethic is thus underpinning their opposition toward using biotechnology to address a forest health threat. Ecocentrists were essentially the only interviewees who argued that forest biotechnology is not appropriate to use because humans should not be choosing which species have the right to live and be protected by technological interventions, an argument that clearly aligns with the ecocentric belief that all organisms and ecological systems have moral rights and standing. Lastly, ecocentrists more commonly argued that we should not use forest

biotechnology to address environmental threats that are native to the ecosystem, an attitude that was often supported with arguments that there may be a natural process of resistance in the ecosystem for that pest or pathogen. Because it is native threat, as opposed to a non-native threat, people reasoned that the ecosystem will have a natural process to ameliorate or adapt to the impacts without requiring humans to intervene using forest biotechnology (and potentially cause unintended consequences to the ecological integrity). Overall, it is interesting that ecocentrists in this sample were willing to let an entire species go extinct from sudden oak death – an impact that would reduce the overall biodiversity of the ecosystem -- but they were so frequently opposed toward intervening and using forest biotechnology to address the disease and maintain tanoak in the ecosystem. I speculate this may be because ecocentrists are more prone to believe that natural systems are dynamic and always changing. Potentially, ecocentrists are more accepting of losing tanoak because they believe a new species will move into its place.

Anthropocentric interviewees tended to be more supportive of using forest biotechnology to protect forests from environmental threats like sudden oak death – a result that has been reported by at least one other study (Peterson St-Laurent et al., 2018). The result that anthropocentric interviewees were more supportive of this type of technological intervention seems intuitive and logical, given that the anthropocentric environmental ethic promotes human intervention and management activities that ensure forest resources and services are sustained. These interviewees generally explained their support for forest biotechnology with their beliefs that it is a scientific advancement of breeding that could provide substantial benefits, and therefore should be a tool that is available in situations that require it. Further, compared to ecocentrists and biocentrists, anthropocentrists more commonly based their support for forest biotechnology on the argument that humans need to protect nature from threats. They clearly exhibited a strong conviction that humans have an important responsibility in protecting nature and intervening when necessary.

While anthropocentrists were more supportive of using forest biotechnology broadly to protect tree species from threats, biocentrists and ecocentrists more commonly argued that it is most appropriate to use forest biotechnology to address environmental threats *that humans*

*are responsible for causing*. Anthropocentrists didn't explicitly argue this consideration of responsibility, potentially because anthropocentrists commonly believe that humans are legitimate users of environmental resources and their actions to protect and sustain resources aren't inherently bad. The argument among eco- and biocentrists that we have a responsibility to intervene to protect nature from threats we have caused aligns with existing research related to invasive species -- participants tend to perceive invasive and introduced species as more problematic and requiring action than species that naturally moved into the area (Buijs et al., 2012).

Unlike ecocentrist and anthropocentrist interviewees, there was no clear pattern among biocentrists' attitudes toward forest biotechnology. Biocentrists exhibited attitudes across the entire attitudinal spectrum, ranging from completely opposed to completely supportive. Other studies investigating public perceptions of forest biotechnology have published contradictory results about biocentrists' attitudes, with some studies suggesting that biocentrists tend to be more accepting of some forest biotechnology applications (Needham et al., 2015), while others report that biocentrists are less accepting (Hajjar et al., 2014). In this study, biocentrists who were opposed to forest biotechnology relied on many of the same arguments that ecocentrists did to justify their opposition, including the argument that nature is adaptive and capable of developing its own solution to address environmental issues such as SOD. Further, biocentrists and ecocentrists argued that humans shouldn't intervene to address forest health threats with forest biotechnology because these interventions only cause additional environmental problems – an argument that was rare among anthropocentrist interviewees. Lastly, ecocentrists and biocentrists made arguments that we do not know enough about how these ecosystems function or what the potential impacts of forest biotechnology might be, leading these interviewees to prefer a more cautious approach toward using forest biotechnology.

## Implications of the Study for Communication Strategies

The results of this study suggest that attitudes toward forest biotechnology are complex and supported by a variety of environmental beliefs and environmental ethics. Further, this study highlights that conservation professionals and volunteers assess multiple characteristics of naturalness about forest biotechnology and GM trees, considerations that seem to influence

their attitudes toward using this technology. This suggests that individuals will interpret and respond to messages about forest biotechnology through the lens of multiple beliefs, potentially influencing how effective these messages can be. Consequently, assuming that it is the goal of communication strategies to promote acceptance of forest biotechnology, it is important that these messages are framed in ways that align with the these various, and sometimes disparate, existing environmental beliefs. Aligning messages with existing beliefs may prevent them from being rejected out of hand by the audience and promote open-ended reasoning and potential elaboration on the merits of the message. For example, one way to potentially reduce concerns about substance-based naturalness for a cisgenic plant would be to clearly describe the DNA source. On the other hand, if one were messaging to promote a transgenic tree, it might be advisable to avoid messages about the DNA source, because these would likely promote substance-based arguments about the unnaturalness of the product. Instead, in such cases, there may be opportunity to develop messages that emphasize the substantial research involved in minimizing risks to reduce harmony-based concerns about the transgenic product. It would be interesting for future research to investigate the factors that influence motivated reasoning and expanded elaboration associated with forest biotechnology messages to provide more context to these results.

While communication strategies might be able to alleviate substance-based and harmony-based concerns about naturalness with these types of approaches, it will likely be more difficult to use messages to influence audiences with beliefs that forest biotechnology is inherently unnatural because it is a novel, and therefore unfamiliar process (history-based and acquaintance-based arguments). There may be opportunity to alleviate these types of concerns for specific applications of forest biotechnology, such as those that are trying to speed up evolutionary processes that could be achieved through breeding. For example, developing communication materials to explain how forest biotechnology is being used to speed outcomes that would take much longer to achieve through breeding might help some people perceive forest biotechnology more favorably because it is being compared to familiar processes that are considered appropriate.

## Implications of this Study for the Acceptability of Biotechnology Research

As in the prior section, the results of this study suggest that individuals assess a variety of different considerations when determining the naturalness of forest biotechnology and its products. In addition to having substantial implications for communication strategies, this also has a variety of implications for conducting biotechnology research. First, the variety of arguments that individuals used to describe why forest biotechnology is (not) natural suggests that biotechnologists' efforts to quell public opposition to forest biotechnology and genetic modification as technologies by requiring that GM products use only cisgenic approaches will not be successful. Substance-based arguments are not the only arguments that influence people to perceive forest biotechnology as unnatural (Mielby et al., 2013; Rozin, 2005; Scott et al., 2018). Instead, if biotechnologists want to enhance the perception that forest biotechnology products are natural in an effort to improve public attitudes toward them, they should limit the use of this technology to applications that either remove or reduce the expression of specific traits or ways that the technology is speeding up natural adaptation and evolutionary processes to achieve a desired result more efficiently and quickly.

## Study Limitations

One major limitation of this study is the limited and non-representative purposive convenience sample; the results and conclusions are not generalizable to any other population. As is common in qualitative research, this study did not aim to acquire a representative sample of the general public. Instead, this study aimed to identify and describe the ways environmental beliefs, perceptions of naturalness, and environmental ethics inform attitudes toward forest biotechnology among a small convenience sample of conservation professionals and volunteers in the Pacific Northwest, USA. Because these results are not generalizable, it is important for future research to investigate whether my findings are prevalent in other communities and groups, especially people who are not directly benefited by conservation initiatives, given that they may have different environmental beliefs and ethics than this sample exhibited.

Another important limitation of this study is the qualitative categorization of interviewees as either anthropocentric, biocentric, or ecocentric. Although this categorization had clearly defined coding rules based on robust descriptions of these ethics in scientific

literature, there are many reliable scales that are commonly used to assess environmental ethics and beliefs (Dunlap et al., 2000). Using qualitative methods to categorize an individual's predominant environmental ethic is substantially less common in scientific studies, and arguably less reliable than using a standardized scale. This is especially notable in this study given that these ethical categorizations were not confirmed with another researcher. Further, the dichotomous framing of the interview question investigating environmental ethics framed anthropocentrism in contrast with ecocentrism, prompting a vast majority of interviewees to initially describe themselves as "somewhere in the middle" of the spectrum. Consequently, I had to ask a number of probing questions to obtain the type of data necessary to assign them as either anthro-, bio-, or ecocentric. Although I believed that some of my interviewees were truly in the middle of this continuum between ecocentric and anthropocentric, I wanted to confirm that they weren't simply trying to avoid the apparently extreme classifications of the dichotomous framing. The probing questions allowed me to ensure whether people were truly biocentric or whether they expressed anthropocentric or ecocentric ethics. However, some interviewees' discussion of their environmental ethics and descriptions of the types of relationship they believe humans should have with nature was quite shallow, affecting my ability to reliably categorize them as either predominantly anthro-, bio-, or ecocentric. It would be useful for future investigations within this arena to use a mixed methods approach that incorporates a reliable scale for assessing environmental ethics into the data collection protocol to increase the trustworthiness and reliability of the conclusions.

Lastly, using SOD as the scenario for the interview was another important limitation of this study. My review of existing literature suggested that attitudes toward forest biotechnology would be context dependent. Therefore, it was important to use a scenario that would be relevant and complex enough to highlight different dimensions of the topic. I chose to use sudden oak death because it is a serious concern in southern Oregon and causes high mortality to tanoak trees. Given that this pathogen receives considerable attention in conservation and land management networks within Oregon, we thought it would be a familiar forest health threat to study participants. However, there are a few limitations related to this decision. First, I used only one scenario to reduce demands on respondents, but other scenarios

might have revealed different results, especially if the scenario was focused on a more commonly known forest health threat or a commercial tree species. Many interviewees either weren't familiar with SOD or repeatedly referred to other forest health pests/pathogens to answer questions throughout the interview (e.g., emerald ash borer, Dutch elm disease, chestnut blight). A few studies have investigated public perceptions toward using GE in the context of chestnut blight (Needham et al., 2015; Petit, 2019), but it would be interesting for additional investigations using pests or pathogens that are more widely known among the general public given how complex and contextual attitudes toward forest biotechnology are.

## Conclusion

This study used semi-structured interviews to investigate how a small group of conservation professionals and volunteers in the Pacific Northwest, USA, invoked perceptions of naturalness and ethics-based arguments when discussing the potential to use forest biotechnology to genetically engineer trees to be resistant to a specific forest health threat – sudden oak death. Overall, interviewees invoked naturalness in two different ways. First, they considered whether forest biotechnology as a technology is natural in comparison to other options to address the forest health threat. Interviewees used a variety of arguments (history-based, acquaintance-based, harmony-based, substance-based arguments) to describe their beliefs about whether forest biotechnology is unnatural in comparison to other options or whether transgenesis is less natural than cisgenesis. Forest biotechnology was widely considered less natural than breeding, and within that, transgenesis was considered less natural than cisgensis. Second, interviewees also considered whether forest biotechnology would disrupt the natural environment. For example, some interviewees believed nature is capable of developing its own solution to address catastrophic threats as a reason to oppose forest biotechnology. Others reasoned about whether the GM tree would be viable in the long-term given natural adaptation and evolutionary processes. These results build on our existing understanding of how people conceptualize forest biotechnology as natural or unnatural. Although interviewees widely believed that forest biotechnology was unnatural and used a variety of arguments to support that attitude, there was also a variety of considerations

associated with assessing the naturalness of GM products. This suggests that the naturalness of GM plants need to be assessed on a case-by-case basis.

This study also investigated how conservation professionals invoked ethics-based arguments related to the need to minimize harm to nature when describing and justifying their attitudes toward forest biotechnology. Interestingly, some interviewees believed that forest biotechnology could minimize harm to nature by protecting species from threats while also believing that forest biotechnology could cause harm to nature through unintended consequences. Consequently, a variety of conditions and contexts emerged in which interviewees believed that forest biotechnology was appropriate to use because it would minimize harm to nature (e.g., to address catastrophic and severe threats that were introduced by humans). This builds on our existing understanding of the ethical considerations of forest biotechnology by providing types of contexts and conditions in which individuals might be willing to explore trade-offs. For example, although many interviewees considered forest biotechnology unnatural and believed that we should not use it because it will cause more harm to nature, they were willing to consider using it to address catastrophic threats that could not be solved in other ways. More work is needed to explore the ethical contexts that influence attitudes toward forest biotechnology and the perceived acceptability of this technology in natural forests.

# Chapter 4: Overall Conclusion

This thesis used semi-structured interviews with a purposive sample of 33 conservation professionals and volunteers located in the Northwest (primarily western Oregon) to investigate a variety of social psychological constructs that influence perceptions and attitudes toward using forest biotechnology to address forest health threats, in this case, sudden oak death. Chapter 2 investigated how participants' familiarity with forest biotechnology influenced the risks and benefits they believed forest biotechnology would provide. Further, the study presented in Chapter 2 described how those risk and benefit perceptions shaped the arguments interviewees used to justify their attitudes toward forest biotechnology. Overall the results of Chapter 2 suggest:

1. ***Interviewees, regardless of their familiarity with forest biotechnology or their attitude toward it, were very concerned about the potential unintended consequences that might arise from its use***. This concern was influenced by variety of environmental beliefs, such as potential scientific uncertainty regarding how ecosystems might adapt and respond to a GM tree. Further, this concern was prevalent in the arguments interviewees used to describe their attitudes toward using forest biotechnology, especially in arguments that forest biotechnology should be used only as a last resort and in cautious ways that reduce the potential for unintended consequences. These concerns were referenced in some way by every participant, suggesting that unintended consequences were a substantial risk perception about forest biotechnology among the conservation professionals who participated in this study. This finding could imply that concerns about unintended consequences do not dissipate as people become more knowledgeable about forest biotechnology. Nevertheless, many individuals in this sample were at least partially supportive of forest biotechnology, suggesting that there is a threshold of risk related to uncertainty that individuals are willing to tolerate. It would be interesting for future research to investigate that threshold of acceptability and how it might change among different groups.

2. ***Familiarity with forest biotechnology appears to have an impact on the types of risks and benefits interviewees perceived about using forest biotechnology to address forest health threats.*** Although concerns about potential ecological risks and unintended consequences were referenced by all of the interviewees, these concerns were especially salient for individuals who were not familiar with biotechnology. I speculate that this was due to the prevalence of oppositional media coverage containing messages about gene flow and concerns about contamination in agricultural applications. Although these participants were unfamiliar with forest biotechnology, seemingly relevant components of these oppositional messages (i.e., concerns about gene flow and contamination) were likely translated into this new context: forestry. These are very common messages that may have led some individuals to perceive biotechnology products as potentially having unintended consequences in any ecosystem. More work is needed to understand the social representations of forest biotechnology and how these products are being socially constructed by different groups of people. This understanding can contributing to our understanding of risk perception about these using forest biotechnology.

   Conversely, interviewees who were familiar with forest biotechnology perceived more risks related to potentially wasting money and resources on a solution that might not be viable in the long-term. I speculate this is because these individuals were more familiar with the processes involved with trying to improve plants as well as the ways ecological systems adapt over time – knowledge that influenced them to believe that forest biotechnology is not a simple and immediate genetic change that provides results like common opposition media about biotechnology seem to suggest.

3. ***Interviewees were able to describe the potential risks associated with using forest biotechnology to address sudden oak death in much more depth than they were able to describe benefits.*** Not only did interviewees describe more types of risks than benefits, they also explained their beliefs about why these risks might occur with more detail, often using examples from negative outcomes that have resulted from agricultural biotechnology or other forest management strategies, such as escaped GM

crops or failed biocontrol measures. This suggests that many of the risks interviewees perceived about forest biotechnology were informed by their beliefs about agricultural biotechnology.

Conversely, interviewees did not describe many different types of benefits and, often, the benefits they did describe were focused on protecting the species from threats more broadly. Interviewees often described the broad ecosystem benefits that protecting tanoak would provide, as opposed to the benefits of using forest biotechnology as the specific tool to protect that species. This may be due to the nature of the interview, where questions about benefits were only explicitly asked in the context of addressing sudden oak death.

I find it interesting that while benefits were focused on ecological outcomes of protecting the species, interviewees did not tend to focus as strongly on the risks of not protecting this species – the risks of letting tanoak succumb to sudden oak death. When describing their risk perceptions, interviewees focused on the potential adverse consequences of acting, rather than the potential adverse consequences of *not* acting. Even though they were given a scenario suggesting an entire ecosystem could be lost, many people didn't think about the consequences of letting that ecosystem be lost if we don't take action to address SOD.

Chapter 3 of this thesis used the same interviews to investigate how participants invoked their environmental beliefs, perceptions of naturalness, and ethics when describing and justifying their attitudes toward using forest biotechnology to address forest health threats, including sudden oak death. Overall, the results of Chapter 3 suggest:

1. ***Interviewees considered multiple aspects of naturalness to determine whether GM trees are natural,*** including the process used to make them, where the DNA was sourced, whether a genetically modified tree would disrupt the natural harmony of the ecosystem, and the type of trait that is being engineered into the tree. Because the perception that forest biotechnology is unnatural was supported by multiple beliefs, it will likely be more difficult to change the perception that forest biotechnology is unnatural. When attitudes are supported by multiple beliefs, they tend to be stronger

and less malleable through persuasive communication efforts, as opposed to when they are only supported with a few beliefs that haven't been supported with evidence (Krosnik & Petty, 1995).

Interestingly, although many interviews considered forest biotechnology as an unnatural process, the different dimensions of naturalness suggest that there may be a continuum of naturalness associated with GM trees. For example, GM trees that have genetic material removed instead of introduced, or those that have been modified in ways that simply speed up natural evolutionary processes, were perceived by interviewees as more natural than other types of GM trees. Even more interesting, these same consideration and arguments about why forest biotechnology is unnatural were also used by supportive interviewees to describe why forest biotechnology is natural. For example, some people said that, because DNA is a universal entity, it doesn't matter whether DNA is introduced or removed. There is surely more work needed to understand the various contextual factors that influence perceptions about whether GM trees are natural and the magnitude of effect these perceptions have on attitudes toward forest biotechnology. Although my sample is arguably more educated and familiar with biotechnology, and has a strong interest in conserving natural resources, there was wide variety in the way they described and perceived naturalness, suggesting that the "expert" group that is commonly pitted against "lay groups" needs more differentiation in future studies – a claim supported by other studies in this field (Ditlevsen et al., 2020; Mielby et al., 2013). Further, more information is needed about how perceptions about what is "natural" are translated into arguments about forest biotechnology and how their use might differ based on familiarity or knowledge about GM and/or forest biotechnology.

2. ***Interviewees sometimes simultaneously expressed support for using forest biotechnology to minimize the harm to nature caused by a pest or pathogen, while also being concerned about using forest biotechnology because it may result in additional harm to nature through unintended consequences.*** Considering whether to use forest biotechnology as a solution to address forest health threats can involve

navigating trade-offs among competing ethical convictions about if and when humans should intervene to protect nature, in the context of their ethical stance toward minimizing harm to nature. This suggests that many interviewees would prefer to assess the ethical appropriateness of whether to intervene to protect a species with forest biotechnology on a case-by-case basis, as opposed to unilaterally. Thus, there is a need for additional scientific investigation to identify what other environmental ethics or beliefs might be associated with considering the use of forest biotechnology to address forest health threats in natural forests. This will help inform what other trade-offs people are having to navigate when considering this issue, in addition to providing insight about what other cognitive dimensions might be underpinning whether people think we should intervene using forest biotechnology. This type of research will start building the scientific foundation for what an ethical analysis for forest biotechnology would require.

## Implications of the Study

This study builds on our limited existing scientific knowledge about the various contextual factors, environmental beliefs, and ethical considerations that influence conservation professionals' and volunteers' attitudes toward using forest biotechnology to address forest health threats. The results of this study have a variety of implications for human decision making and communication strategies.

### Acceptability of Using Forest Biotechnology to Address Forest Health Threats.

This study contributes to existing scientific knowledge about public perceptions and decision making about forest biotechnology. It provides insight about various factors (i.e., environmental beliefs, perceptions of naturalness, and environmental ethics) that underpin and influence attitudes toward forest biotechnology, such as the species being genetically modified, the source of the DNA for the genetic modification, whether there are other options available to address the threat, and various factors about the threat being addressed (e.g., nativity, severity, or history). The results presented in this thesis suggest that people tend to consider forest biotechnology as unnatural and associate it with considerable potential risk, suggesting

that using forest biotechnology to address forest health threats could be ripe for public debate and potential controversy.

These contextual factors have a variety of implications about the acceptability of using forest biotechnology to address forest health threats. If forest biotechnology researchers want the public to consider forest biotechnology as an acceptable tool to address forest health threats, they should restrict its use to situations in which individuals are more supportive of its use, such as when a threat is very severe, non-native or introduced by humans in some way. Further, biotechnology researchers should be cautious in how they use this technology – instead of using it as the first tool in the tool box, it will potentially be more acceptable to the public if it is only used in situations in which there is not another viable option that can meaningfully address the threat.

### Communication Strategies.

My research also has implications for how biotechnology researchers and land managers communicate about this topic. If land managers and researchers are aiming to promote acceptance of using forest biotechnology in specific applications, they can use the results of my studies to proactively develop messages that directly align with the considerations that shaped interviewees' attitudes toward forest biotechnology. For example, given that many interviewees felt a need to minimize harm to nature and protect nature from threats caused by humans (e.g., non-native pests and pathogens), it might be useful to develop messages about the history of the threat and why forest biotechnology is the only specific tool that can be used to address the threat. These types of communication strategies may help land managers and scientists reduce potential public controversy surrounding forest biotechnology and pave the way for a more successful (and acceptable) roll-out of this type of management strategy, although these would have to be tested with additional study and beta testing.

## Study Limitations

There are a variety of limitations of this thesis, which were discussed in detail in the conclusions of each individual chapter. However, in reflecting on the overall approach to my study, there are two primary ways that I would change the design if I were to conduct this study

again. First, I would use a different scenario that is more familiar and salient to interviewees. Fewer than half of the interviewees were familiar with sudden oak death and many interviewees referenced other forest health threats and species frequently throughout the interview. Using a pest/pathogen such as white pine blister rust or emerald ash borer – threats that seemed to be more salient to participants -- might have yielded different results because people might have felt more urgency to act in ways that protect the species or they might have been more knowledgeable about other strategies that can or have been used to address the threat. However, it is interesting in that as we experience more new, unknown, and unfamiliar environmental problems (e.g., invasive weeds, new pests), people may approach reasoning about those new issues based on their understanding of things that already know about or have experience with. Further, given how contextual attitudes were, it would be interesting to design a study in which interviewees explicitly compare and contrast their attitudes toward different scenarios: especially one that is a forest health application and one that is commercial in nature (e.g., increased yield of Douglas-fir trees). This would provide opportunities for interviewees to verbally elaborate on the contextual considerations that distinguish these two applications, as opposed to the researcher inferring some of these details. This would also provide insight into what types of trade-offs and considerations are important to include in any type of ethical analysis of these products.

Additionally, if I were to redesign this study, I would use a mixed methods approach in which participants completed a survey to reliably determine their environmental value orientation. Further, this would have allowed for these results of this study to better align with existing studies, since public perception studies in natural resource disciplines so commonly use the New Environmental Paradigm to categorize participants and analyze results.

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# Appendices

## Appendix A: Letter of Initial Recruitment

[NOTE: this is the email I sent to potential study participants to try to recruit them to participate in the study. I also attached the informed consent document to this email.]

Hello [name],

My name is Elizabeth Emery. I am a graduate student in the Forest Ecosystems and Society Program at Oregon State University. I am emailing to invite you to participate in my Master of Science research study about people's attitudes about genetically modifying trees to address forest health threats. I am especially interested in interviewing people that might have different perspectives about this issue based on how they think about natural landscapes.

Forests in Oregon are currently facing pressure from insects and disease. Consequently, scientists and land managers are interested in pursuing possible solutions to address these insects and diseases. One possibility is genetically modifying trees to resist them. My study explores whether people support or oppose this approach, and why. I'm especially interested in how people think about this issue and what influences their attitudes about it.

If you choose to participate, you will be asked to complete an individual interview with questions about hypothetical scenarios where genetic modification could be used. This interview will last approximately 30-45 minutes. Your participation will be completely confidential.

Please contact me if you are interested in participating. I will be conducting interviews over the next few months. I would appreciate an opportunity to meet you and discuss your thoughts about this topic. You can contact me at elizabeth.emery@oregonstate.edu with any questions or to set up a time to meet.

Thank you for considering this request.

Sincerely,

Elizabeth Emery
Graduate Research Assistant
Department of Forest Ecosystems and Society
College of Forestry
Oregon State University

## Appendix B: Letter of Informed Consent

[NOTE: The informed consent document was attached to the recruitment email and provided to interviewees again in advance of the actual interview.]

**What Do People Think about Planting Genetically Engineered Trees?**
**A Qualitative Inquiry to Understand How People Reason about Forest Biotechnology to Address Forest Health Threats**

You are being asked to take part in a research study about people's attitudes about genetically modifying trees to address forest health threats. We are interested in understanding the various perspectives people might have about this issue.

I'm required by university policy to provide the following information. Please read this form carefully and ask any questions you may have before agreeing to take part in the study.

**What the study is about:** This study explores how people think about the use of genetic modification to address specific forest health threats. We are interested in the different ways people think about this issue and what influences their attitudes about it.

**What we will ask you to do:** If you choose to participate, you will be asked to complete an individual interview (approximately 30-45 minutes) with questions about hypothetical scenarios where genetic modification could be used. Your participation will be completely confidential. With your permission, we would also like to audio-record the interview.

**Risks, compensation, and benefits:** We do not anticipate any risks to you participating in this study other than those encountered within your day-to-day life. You will not receive any compensation or benefits in exchange for your participation. However, your participation would benefit science and society by informing land managers and decision makers about whether the public would support this type of action.

**Your responses will be confidential.** Your identity will be kept confidential to the extent permitted by law. To protect your identity, your responses (survey and interview) will be saved with a pseudonym. We will use that pseudonym in any reports or publications associated with this research project.

If you choose to disclose identifiable information in your responses to interview questions (for example, your institutional affiliation, workplace, or names of people) there is a chance we could disclose information that may identify you.

Research records will be kept in a locked file accessible only to the researchers involved in this project.

The security and confidentiality of information shared online cannot be guaranteed (e.g., email correspondence). Confidentiality will be kept to the extent permitted by the technology being used. Information collected online can be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

**Taking part is voluntary:** Taking part in this study is completely voluntary. You may skip any questions that you do not want to answer. If you decide not to take part or to skip some of the questions, it will not affect your current or future relationship with Oregon State University or the College of Forestry. If you decide to take part, you are free to withdraw at any time.

**Future studies**: The information that you give us will only be used for this study. We will not share information about you with others or use it in future studies without your consent. However, it is possible that some or all data from your interview could be shared with other researchers or in publications about this project, although any information that could be used to identify you will be removed.

**If you have questions:** The researchers conducting this study are Elizabeth Emery and Professor Troy Hall. If you have any questions and concerns, please do not hesitate contact Elizabeth at Elizabeth.Emery@oregonstate.edu or Troy at Troy.Hall@oregonstate.edu.

If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Oregon State University's Institutional Review Board at (541)737-3467 or access their website at https://research.oregonstate.edu/irb.

## Appendix C: Interview Guide

***Introduction:***

*[provide informed consent document for their review and as a reminder]*

*Thank you for agreeing to participate in this research project. This interview is completely voluntary and confidential. You can decide to opt out of participating at any time. It will take approximately 45 minutes to an hour to complete.*

*Today we will be discussing two topics: your personal ideas about nature and your thoughts about genetically modifying trees to resist insects and diseases. I will start with some general questions, then I'll ask you to read a short description about a forest health threat and ask you some specific questions about it. Then we will wrap up the interview.*

*It's ok if you're unsure or don't know about any of the questions I ask – feel free to ask for clarification or elaboration.*

1. Do you mind if I audio record this conversation for future reference? Your identity will remain confidential. [if no, "no problem. I'll just take written notes"]
2. Before we get started, do you have any questions for me?

*Great. The first set of questions ask about your views on nature and natural environments.*

***Nature/Naturalness Questions:***

1. People have different ways of viewing the natural world. Some say that humans are more important than nature, while others say that nature is still important even if it doesn't provide things for humans to use. How do you feel about these statements? [Potential follow-up probing questions:]
    - Do you think society/people and nature are of equal value, or do you think one is more important?
    - Do you ever feel connected to nature? How so?
2. Does nature have a spatial component for you? Does it have to be a certain size to really feel like you're in nature?
3. Would you describe nature as more resilient or fragile?
4. What kinds of landscapes do you use the word "nature" to describe?
5. What would you describe as the ideal relationship humans should have with nature?
6. What does "natural" mean to you in the context of forests? [Potential follow-up probing questions:]
    - What is the difference between natural and unnatural areas? What types of characteristics do natural landscapes have?
    - In your mind, are City parks natural or considered part of "nature"?

***Genetic Modification (Broad) Questions:***
*Okay, now we will move on to the second set of questions that are focused on what you think about genetic modification.*

*To make sure we are both on the same page, when I say "genetic modification," I'm talking about adding, removing, or editing an organism's genetic material or DNA so the organism has new characteristics or traits. I'm interested in your thoughts about potentially genetically modifying trees to make them more resistant to insects and diseases. As we talk, feel free to "think aloud" so I can be sure to understand why you feel the way you do.*

7. Do you have any opinions about genetic modification in general?
    - If so, what are they?
8. Have you ever heard about the possibility of genetically modifying trees?
    - If yes, do you remember what you heard about it and where?
9. Do you think differently about using GM on trees as opposed to crops where it has traditionally been applied?
10. What are your thoughts about using GM for commercial applications in forests, like making trees grow faster or improving the qualities of wood, versus more restoration or resiliency-based applications, like resistance to pest and pathogens?

***Scenario-Specific Questions:***

*Great, thank you. Now we will move into talking about a specific scenario. I'll ask you to read a short description about a threat that is affecting Oregon's forests. Then, I'll ask you some questions this situation.*

*It's important to note that although this scenario is a description of an actual forest health threat, there is not currently an effort to genetically modify these trees to be resistant. Genetically modified trees cannot be planted outside of lab settings, although research focused on genetically modifying trees is occurring in labs.*

*Here is the scenario.* [*provide respondent with the Sudden Oak Death scenario to read and reference throughout interview*]

11. What is your general reaction to the scenario?
    - [Probe:] Did anything surprise/bother you about it?
12. Had you ever heard of this forest health threat prior to today?
    - [If yes:] what kinds of things have you heard about it and where have you heard this information?
    - [Probe:] Based on what you know or what you read in the scenario, how much of a problem do you think this threat is?
13. Do you have any thoughts about genetically engineering this tree to be resistant to this threat?
    - [Probe:] Do you have any emotional responses to the idea of genetically modifying tanoak?
    - [Probe:] Do you think it is a good thing? A bad thing?

14. Do you see any advantages or benefits to genetically engineering this tree to be resistant?
15. Do you see any disadvantages or risks to genetically engineering this tree to be resistant?
16. Would it make any difference to you if they used DNA from another tree species?
    - [Probe:] What if they used DNA from a completely unrelated species, like a fish?
17. Would it matter to you if this threat was native to the ecosystem or non-native?
18. How do you feel about scientists investing time and money into researching how to genetically engineer this tree to exhibit resistance to this threat?
19. What if there were other options available to establish resistance that didn't require genetic modification? Would that influence your opinion?
20. If scientists and land managers decided they wanted to pursue planting genetically engineered trees - what type of information or "evidence" would you want to have to form an opinion?

*Great, thank you for sharing your opinions about this topic with me.*

21. Is there anything else you'd like to share with me about any of the topics we've discussed today?

*I have a few demographic questions to wrap up. These are meant to help me understand what types of variation I am getting in the people I interview. Would you be willing to answer these? [if yes:]*

22. What year were you born?
23. What is the highest level of education you have completed?
    - For those who have obtained degrees: what was your major?
24. Would you say you grew up in a more urban or rural area?
25. What is your job title/profession?
26. What is your ethnicity?

***Wrap Up:*** *I really appreciate you taking the time to participate in this interview. As a reminder, your participation in this project is completely confidential. Any reports or publications about this project will not include your identity. I will be sure to share any of those reports or publications with you if you are interested in seeing them. I'd be happy to answer any questions you might have about the project.*

## Appendix D: Sudden Oak Death Interview Scenario

Sudden Oak Death (SOD) is a disease caused by a fungus that is not native to the western U.S. SOD kills specific oak species, including tanoak, which is especially vulnerable and of particular concern, because it is native only to southwest Oregon and northern California.

Although the SOD is prolific in northern California, it was first discovered in southwest Oregon in 2001. Oregon government officials quickly formed a program to attempt to remove the fungus from the area. Between 2001 and 2009, any infected trees on state, private, or federal lands were required to be treated by cutting, piling, and burning all plant material within 300 feet surrounding the infected plant or tree. Even though these treatments were effective in removing the disease from areas that were previously infected, the fungus continues to spread approximately 4 miles each year.

Primarily, the fungus spreads during rainy periods when it can be transported by wind or water more easily. It can survive for months or even years in soil or plants, making it hard to know where it is located when plants aren't showing symptoms. Consequently, in 2010, the interagency program's goal shifted from removing the disease to slowing its spread. This effort has been effective; as of 2019, the disease remains confined to Curry County due to vigilant monitoring and treatments that cost approximately $800,000/year.

Although tanoak is not a valuable timber species, infection and subsequent required removal can have negative impacts. Tanoak is a primary tree species of some forests, so when these trees are infected or killed, it can dramatically change the forest structure. Additionally, treatments can potentially reduce the scenic beauty and property values of the area of infection. Additionally, towns that have experienced extensive tree mortality have concerns about increased fire risk. Loss of native tanoaks can also have impacts on wildlife that rely on these trees for food and habitat, as well as native Americans who rely on them for food-gathering traditions.

However, scientists may be able to genetically modify tanoak to be resistant to the sudden oak death, potentially protecting it from this threat.

## Appendix E: Final Codebook

***Environmental Ethics:***
Interviewee responses to questions about how they describe nature and naturalness, beliefs about whether nature is resilient or fragile, and primary values of nature were used to categorize interviewees as either exhibiting predominantly anthropocentric, biocentric, or ecocentric environmental ethics. Each interviewee was placed into the category that most strongly aligned with the tone of their responses in the first section of the interview. This categorization was used to highlight variation within the sample and investigate analytical dimensions within the data for the third chapter of this thesis.

| **Category:** | **Description:** |
|---|---|
| Anthropocentric | • Describes the value of nature in predominantly utilitarian terms (e.g., resources, aesthetics, recreation, ecosystem services)<br>• Belief that anything humans do to the natural environment is natural and appropriate<br>• Management should be focused on sustaining resources and services for humans and society to continue |
| Biocentric | • Describes nature as living organisms (e.g., plants and animals) and considers humans as another living organism<br>• Management should allow for all living things to continue living, adapting, and evolving in their natural habitat |
| Ecocentric | • Describes nature as ecosystems, interactions between organisms, and environmental processes (e.g., habitat, vegetative communities)<br>• Belief that earth and living organisms have the right to live<br>• Management should be in the context of the entire ecosystem and how it impacts ecological integrity and function |

***Attitudes Toward Forest Biotechnology:***
This coding is based on interviewee responses to questions about their baseline attitude toward forest biotechnology (prior to reading Sudden Oak Death (SOD) scenario) as well as their responses to the potential of genetically modifying tanoak as a potential solution for SOD. As a whole, their responses were used to categorize the interviewee as either 100% supportive, mostly supportive, ambivalent, mostly opposed, or fully opposed to using forest biotechnology to address forest health threats. Each interviewee was categorized within one of these attitudinal categories.

These categorizations were used to explore analytical relationships within the overarching arguments and supplemental justifications interviewees relied on when reasoning about using forest biotechnology to address forest health threats.

| **Attitude:** | **Description:** |
|---|---|

| | |
|---|---|
| Completely Supportive | A completely positive attitude toward forest biotechnology and comfortability using it in a variety of contexts and situations without identifying explicit conditions associated with their support |
| Mostly Supportive | A predominantly positive attitude toward forest biotechnology, with limited conditions in which they are opposed to investigating it as a solution |
| Ambivalent | An ambivalent attitude toward forest biotechnology, including references to being able to see both sides of the issue |
| Mostly Opposed | A predominantly negative attitude toward forest biotechnology, with limited conditions in which they would be willing to investigate it as a solution (e.g., only in specific types of settings, in specific contexts, or for specific types of threats) |
| Completely Opposed | A universally negative attitude toward forest biotechnology and opposition toward using it whatsoever in any type of situation |

***Risk Perceptions of GM Trees and Forest Biotechnology:***
Each of the risks or concerns about forest biotechnology that interviewees identified was coded to one of the following categories: control*, severity*, ecological integrity*, who's involved, unintended consequence*, viability, economic, and social risks. Descriptions and examples of these code categories are included below. Those codes marked with an * were included in the codebook *a priori*, whereas the rest emerged from the data.

Interviewees often expressed multiple concerns about forest biotechnology throughout their interview. Codes are presented by order of most frequent use.

| **Risk:** | **Description:** | **Example:** |
|---|---|---|
| Unintended Consequences* | • Concerns about the potential severity of consequences associated with GM<br>• Inability to predict responses/outcomes in the future | "I think it has proven itself to be very useful in many settings. I do worry at times how when lab setting situations are put out in the field for implementation and use it can be challenging to foresee all the expressions or the situations that might arise. Because I feel like in a lab setting it's very controlled. I feel pretty safe about that but once put out into the natural environment or the field there's just so many variables that it could be hard to forecast that I guess I'm more apprehensive about that." (F11) |
| Ecological Integrity* | • Concerns about interactions between the GM tree and other entities in the ecosystem (e.g., bugs, | "Like if you were replacing a fern, I would want to know what happens with the spores. If you're |

| | | |
|---|---|---|
| | animals, plants)<br>• Concerns about maintaining genetic diversity within the species that is being genetically modified<br>• References to other plants being affected by the SOD fungus as a result of GM tanoak not being susceptible<br>• Modified tanoaks having a competitive advantage within the system that isn't natural<br>• Concerns about how the GM trait moves through generations | replacing like, in this case I'm guessing it would be acorns. Like what happens with the acorns. What happens with the flowers, when the tree flowers and releases pollen? Do they do any kind of other kinds of tests about other organisms that might be affected like pollinators? Are there pollinators who come and pollinate the tanoak in a lab which would be very difficult. You'd have to just have a field - contain it. But like what happens with other species interactions. Because to me this is like these are ecosystems these are entire ecosystems with long timeline that you're messing with... (F1) |
| Control* | • Concerns about whether we will be able to control a GM species once it is planted.<br>• References to invasiveness potential.<br>• Concern about the type of setting to plant it in and whether humans will be able to control it from spreading from the planting location<br>• Concerns about the gene spreading into wild populations/gene flow | "You know I mean the whole roundup issue. Roundup Ready crops. You know, they've escaped their confines and now we're having trouble managing, you know, certain kinds of weeds in natural areas because of that spread. I would worry the same about trees that way." (F2) |
| Severity* | • References to irreversibility and permanence of it once it is outplanted<br>• References to GE tree species contaminating other trees in the area where it is planted | |
| Viability | • concerns about whether the modification will work in the long-term<br>• Questions about whether the pathogen will change or evolve and the resistance mechanism will no longer work<br>• References to the long-term nature | "Yeah, I don't think it's gonna be sustainable because people lose. I mean it. I see it all the time in restoration. We gravitate towards one or two species and for a long for a few years it's really just. Lots and lots of energy around it. And then it just seems to dissolve and |

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|---|---|---|
| | of forestry projects like this and the time it would take to develop a solution using GM<br>• References to tanoak not being a viable species for GM because it doesn't have commercial value | go away. And then it's like "whatever happened to that thing?" Yeah and it's still a thing." (M11) |
| Who's Involved | • Concerns about the commodification of living organisms<br>• Concerns about corporations making profits off the technology<br>• Concerns about who/what organization will be implementing the project | "I guess my thought would just be who is doing it. Is it some big corporation that's going to go out and do it? And do they have other…do they have a hidden agenda when they're doing it or is it the good guy who's doing it?" (F7) |
| Economic | • Consequences/unintended outcomes of GM could be a lot more expensive to address than the $800k/year they are spending currently<br>• Risk of wasting money on this project because it isn't effective or successful | "…if we did make a mistake in the genetic modification, the consequences could be a lot more expensive than $800,000 a year" (F2) |
| Social | • GM tanoak causing strife, upsetting anti-GMO groups, creating controversy within the community | "In terms of it being a risk, you know, I mean, so there's strife right. I mean there's clearly groups who are vehemently opposed. And so there is a risk of just fracturing the social fabric, right. It is kind of a flashpoint where people have very strongly held differing opinions so I would think about sort of that social risk as one component of risk." (M5) |

***Benefit Perceptions of GM Trees and forest biotechnology:***

Interviewees were asked to identify benefits that they perceive to be associated with forest biotechnology and/or genetically engineering tanoak to be resistant to SOD. These benefits were coded to larger categories: ecological*, social*, economic*, cultural*, and increased scientific knowledge. Those benefits marked with an * were included in the codebook *a priori*, whereas the other category emerged from the data. Codes are presented in order of most frequent use.

| **Benefit:** | **Description:** | **Example:** |
|---|---|---|

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|---|---|---|
| Ecological* | • References to reducing chemical inputs, such as insecticide, pesticide, or herbicides to manage or address threats (Kazana et al., 2015)<br>• References to GE trees having potential to restore forests and reduce threats overall<br>• Preventing widespread destruction of habitat and potential carbon loss<br>• GE trees using land more efficiently and freeing up land for other uses, potentially less utilitarian uses | "the way I viewed it originally was in terms of primarily pest resistance. That this would give us genetic tools to fight insects and disease, as opposed to chemical tools, which had been problematic in various ways." (M3) |
| Increased Scientific Knowledge | • GM process increasing knowledge and understanding about biology, ecology, etc.<br>• GM tanoak as a case study of what could be possible with the technology | "I guess in some ways I welcome this because it's getting people to think and talk and learn about these things and about biology and so I think that's something that could be a benefit." (M5) |
| Cultural* | • Maintaining native American food collection traditions (seeded in the scenario text) | "But saving the tanoak has multiple benefits. Right. Like it's got Native Americans, this is food gathering traditions, it's also cultural traditions." (F1) |
| Economic* | • GM/GE trees could reduce costs of treating pests/pathogens in the long-term | "Aside from its vulnerability, those plants have a really high ornamental value if we could use them in the urban landscape. They are really nice material, except for their weakness. And we know, phytophera is all over the place. It's on this campus. But it's hit and miss. And I think that if we can add some value to something that is then immune that we could use in the urban environment, great. Cause otherwise, it's adaptable. We're trying it here where we think we can stay away from the disease and it's working. With limited inputs – no water or fertilizer. From our point of view, from a maintenance standpoint, the input is close to zero. Would |

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| | | the nursery industry pick it up if they weren't worried about the threat, would the nursery industry now absorb that more. It's a long haul because you already have all this fear in the system. And somebody has to convince everybody it's okay." (M22) |
| Social* | • Maintain scenic beauty of the area<br>• Psychological benefits of maintaining the tree species in that area and continuing to see them on the landscape | "And it's going to maintain the beauty of that type of forest." (M21) |

***Justifications Used to Support Attitude:***

The justifications and arguments that interviewees used to support their attitude toward forest biotechnology were coded to the following categories: intent matters, GM affects naturalness, thoughtful and cautious approach, nature is adaptive, humans can't fix nature, climate change, regulations/boundaries, humans are responsible, GM is another tool, humans need to protect nature, address the cause, risks vs. benefits, humans have always been GMing, future applications, we shouldn't be creating life, species value judgements, GM is not always practical, we don't know enough, leave it alone, good in theory/bad in practice, and other options. All of these categories are emergent from the data.

Interviewees often supported their attitude with a variety of these supplemental justifications. Each of the justifications were coded, meaning that each interviewee could have exhibited multiple of these codes throughout their interview. Codes are presented approximately in order of most frequent use.

| **Code:** | **Description:** | **Example:** |
|---|---|---|
| The goal or intent of the modification matters | • Building an argument around concern about why we are GMing organisms<br>• Concerns about intent being driven by economic interests or corporate greed<br>• Need a compelling argument about why GE approach is needed/the goal of the project<br>• Understanding the motives associated with GMing the tree at all (e.g., to "save the tree" or to "wipe out the fungus") | "Well why are we doing this? Are we doing this to make more money?" (F1) |
| We don't | • Not forming a clear attitude until they have more information | "I mean, I don't, I think I don't have enough information, but I |

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| know enough | • Need to understand that role the fungus plays in the system and more research about it generally<br>• References to not knowing enough about GM or the environment to be able to do it appropriately<br>• Reasoning based on the belief that humans do not know enough about how the ecosystem functions to try GE<br>• References to slowing down and taking more time to understand these processes and interactions, studying responses, etc. | like to research things a lot before I really, I know very, I don't know a lot about this, and I don't, I wouldn't want to make broad statements." (F4) |
| Climate change | • Climate change might make forest health threats more severe and require GM<br>• Climate change is changing the behavior of pathogens and insects<br>• GM could be a way to protect forests in the context of future conditions and a changing climate<br>• Climate change may require humans to "resort" to using GM | "But on the other hand, we have major change in climate change and all of the human, you know, the growing population, and we may have to resort to such things." (F2) |
| Humans can't fix nature | • Criticism of human's desire to try to "fix", control, or protect nature<br>• Humans always want to try to save species because they are uncomfortable losing things<br>• humans have a history of messing things up when they try to fix things in nature<br>• humans shouldn't be fighting natural processes or trying to control it, it's up to nature to find a solution | "That is to me like so typical of our behavior, is that we have these great ideas quote unquote. We jump on them. We develop them. We make huge leaps in knowledge engineering you know, and we build these fantastic things. And then it takes us half a century to see what the consequences are. And then we want to go back and undo it. But it's been half a century of nature adapting to our changes." (F8) |
| Nature is Adaptive | • a belief that nature can adapt and fix the system the way it needs to or in ways that can benefit the entire ecosystem, as opposed to just one symptom or tree<br>• belief that even if you GM tanoak, the | "If it disappears from its range, there will be something to replace it. But that will change everything. Habitats, microclimate, all those things. And so everything will shift but |

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| | fungus will continue to evolve in the system and therefore the GM might not be an effective solution in the long term. | is that really a bad thing? We resist change. I mean. Just period. You know which on one hand is responsible for me saying no don't do that." (F6) |
| Humans are Responsible | • Humans have negatively impacted the forest and caused these problems (e.g., introduced Sudden Oak Death, bad management to reduce threat potential) and now humans are trying to use GM to fix the problem that they caused. | "The problem isn't really the tanoak fungus or SOD, the problem is human beings and the things that they're doing." (M1) |
| Risk vs. Benefits | • references to the need for risk benefit analyses to determine the best course of action<br>• need for a cost-benefit analysis to decide what option is most useful<br>• references to NEPA process and different types of alternatives. | "But there actually has to be a risk analysis on that, whether you do it with, you know, the risk, balance the risk of climate change with or without the genetic engineering associated with it. That's the answer. That's the end answer." (M8) |
| GM affects naturalness | • GM isn't natural<br>• GM product isn't as natural or pure as non-GM variety<br>• there are more natural options that could be pursued (e.g., breeding, assisted migration, biocontrols) | "I can see a role of the genetically modified organisms increasing yield in certain types of land settings where, you know, it's been maintained by man forever, it's never going back in any political situation you could imagine. So, the example might be like, you know, a cottonwood plantation that's on the edge of a forest in a field, you know, that's purely there just for wood production and they're treating it like a crop, like a wheat crop really. But when you ask the question, I was thinking mostly for the settings of having GMOs put into a more contiguous natural landscape for the purpose of growth and yield I'm opposed to that. hope that makes some sense." (M21) |

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| Thoughtful and cautious approach | • Need to be thoughtful and cautious in how we approach/implement GM and ensure that it is coming from an analytical space and not an emotional/panic/urgent space<br>• Slow down and fully think through potential actions and their potential side effects<br>• Need to think about the system as a whole<br>• GM should be the last resort, instead of the first potential solution | "When I hear throw lots of resources at it, that feels more panicky – we've got to do something now. Versus being more intentional about it." (F3) |
| Species value judgments | • References to making a decision that one species is worth saving at the expense of another, either explicitly about GM or other forest management decisions | "And the only way to prevent it is to shoot the barred owl…I'm troubled, I have a little problem with that. Who has decided the spotted owl is more important, better owl than the barred owl? We're choosing to protect one species at the expense of another…" (M2) |
| Address the cause | • Relates to concerns about the viability of GMing a tree because it is only focused on a symptom of a bigger issue and doesn't address the cause of it (e.g., overpopulation, climate change) | "I just think that it will be used a little more recklessly and it will continue to allow us to move forward on a pretty unsustainable path. It's just a big Band-Aid covering up these really. The trees are showing signs of stress. Okay. Why are they showing signs of stress. You know, like I think we just need to be tackling it from that direction instead of like oh pine Beetle outbreak. Okay well let's just genetically modify all those trees and that won't happen anymore." (F11) |
| GM is another tool | • GM is another tool we have in the tool box to address forest health threats<br>• GM provides a genetic tool to address threats instead of chemical tools<br>• GM is an advancement of existing tools we have used traditionally to address | "Like is there any benefit of this tool over another tool. No, they're just tools." (F1) |

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| | similar problems | |
| Humans need to protect nature from threats | • References to the goal still being the same (protecting the tree, establishing resistance) whether or not the pest/pathogen is native or non-native and therefore it doesn't really matter where the pest came from<br>• We shouldn't sit back and do nothing because we don't want to lose the tree<br>• We shouldn't be eliminating or allowing any species to disappear | "No, because the ultimate goal is to make that species resistant and survive the disease or the pest. I think it doesn't matter to me whether the pest was here, was brought, came on its own…" (M2) |
| Regulations | • Need to put boundaries and regulations on how and when GM is used to ensure that negative impacts and risks are minimized<br>• Need a "stop gap" before the final decision and opportunities to not move forward if results say different things.<br>• References to the need for ongoing monitoring and a monitoring plan | "And so, I would view genetic modification is like, am I all in or all out? No. But you have to put boundaries around how you're going to use it." (F1) |
| Future Applications | • Concerns about how what is considered appropriate or ethical would change as the technology is applied<br>• Concern about scientists using GM as a tool to genetically modify anything for any purpose<br>• References to humans not knowing when to stop and continuously moving forward and applying this technology | "We've lost a moral compass in the secular scientific race for improvement" (M1) |
| Leave it alone | • Leave it alone; we don't need to do anything to address SOD or forest health threats more broadly | "Like why are we trying to regulate anything? Like just don't spend eight hundred thousand dollars a year and just don't try to do anything just totally leave it alone." (F4) |
| Good in theory, bad in practice | • Idea that in theory, GM products and applicaions will be hugely beneficial, but those benefits aren't necessarily seen on the ground. | "I think in principle, it's great. Maybe I'm jumping the gun but I think in practice, it's been broadly a disaster." (M3) |
| Humans have always | • Humans have been modifying crops for thousands of years to improve them | "But I also feel like genetic modification is a practice that |

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|---|---|---|
| been GMing | and this is the next wave of that<br>• GM is the scientific and technological advancement of breeding | humans have been using for a long, long, long time for our benefit. And I think that there's an extremely important value in use for that science." (F11) |
| We shouldn't be creating life | • References to creating life artificially to produce organisms that never existed before and couldn't be established naturally | "…I am opposed to the concept of creating artificial life, creating a creature, taking genes and genes from every different source and combining them and creating an animal that never existed and probably never would exist. That I think crosses my line of ethics" (M2) |
| GM is not practical in all contexts | • Reasoning based on the belief that GM tanoak is not practical for some reason (e.g., cost, acreage required, planting process, no commercial value) | "it's not practical to think of...these are vast areas miles and miles and miles with rugged terrain. It's a... logistically, practically, pragmatically it's an impossible problem, I think. So, I don't think there's much chance of success. That doesn't mean I'm against the concept of genetically modifying an organism to be resistant to sudden oak death, I just don't know how you're going to disperse the genetically resistant trees that have no commercial value. If it was Douglas fir which we use to build houses that might there might be enough incentive. But tanoak has no monetary value." (M2) |

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| Farther away, more risk | • References to transgenic sources of DNA (DNA from another Kingdom) being inherently more risky or unnatural than if they sourced DNA from the same genus or species | "seems like further away you get, the more you might get into unintended consequences, but you could still get them either direct either place. Just sounds weird. We've got this great gene from a frog and we're going to |

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| | | save tanoaks." (F7) |
| Breeding is more natural than GE | • References to breeding being a more natural solution than GM | "They're both a stone fruit. They're kind of family. You know let's have them have sex together. Passive anyway. So up to that point it was cool. I thought that was that was kind of genius. You know. But that was kind of innocent and on a very superficial level, like it could have happened anyways. It could. Maybe it did happen naturally anyway you know human's kind of helped it along." (F8) |
| Don't GM native threats | • Uncomfortability with the idea of genetically modifying trees to be resistant to native pests/pathogens | "I guess I would ask a lot more questions and be a little bit more hesitant to approach a native threat with genetic modification." (F3) |
| GM is fast | • Belief that breeding is slower than GE<br>• References to GE being a very fast, easy process | "So, like this guy is already getting somewhere. Taking a longer period of time and maybe a genetic scientist would be like are you kidding I could just snag that gene over here and splice it in over here and then you'd be done. Give me two years right instead of 20." (F1) |
| GM is riskier than other options | • Concerns about GM being inherently riskier than other potential options to address SOD (e.g., breeding, assisted migration) | "Trying to incorporate you know, doing some breeding that helps incorporate that natural resistance into other trees would be a step I would take before actual genetic modification. It's more of a natural approach without really as many potential unintended consequences." (F2) |
| GM as a last resort | • GM should only be investigated as a last resort when other options aren't feasible | "I'd want it to be, not a first tool in the tool box for a native pest. I'd want to see if the native stuff in the area could take care of the native pest. If that got to the |

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|---|---|---|
| | | point where it looked like it couldn't, yeah I could see how you might have a case for it. But I'd want to be more diligent about that decision. Maybe now that the natural world isn't taking care of it in the longer term. So maybe the natural world was going to take care of that in 10 years anyway." (M22) |
| Playing God | • References to GM/forest biotechnology as a form of humans "playing god" or other explicit references to "playing god" | |

## Appendix F: Risk Perception Crosstab Coding Query Results

**Table 8:** Risk perception coding, by attitude toward forest biotechnology.

| Risk Perception | Completely Supportive (n=5) | Mostly Supportive (n=6) | Ambivalent (n=7) | Mostly Opposed (n=9) | Completely Opposed (n=6) | Total Unique Interviewees (n=33) |
|---|---|---|---|---|---|---|
| Unintended consequence | 2 | 5 | 6 | 9 | 6 | 28 |
| Control | 4 | 6 | 2 | 6 | 3 | 21 |
| Corporate concerns | 3 | 1 | 1 | 3 | 4 | 12 |
| Ecological integrity | 4 | 4 | 7 | 9 | 4 | 28 |
| Economic | 4 | 3 | 2 | 3 | 0 | 12 |
| Social | 0 | 1 | 0 | 1 | 1 | 3 |
| Viability | 5 | 2 | 4 | 5 | 2 | 18 |

**Table 9:** Risk perception argument coding, by attitude toward forest biotechnology

| Risk Perception Argument | Completely Supportive (n=5) | Mostly Support (n=6) | Ambivalent (n=7) | Mostly Oppose (n=9) | Completely Opposed (n=6) | Total Unique Interviewees (n=33) |
|---|---|---|---|---|---|---|
| Conduct a risk benefit analysis | 3 | 2 | 2 | 4 | 1 | 12 |
| Intent of the GM matters | 3 | 6 | 5 | 7 | 3 | 24 |
| We don't know enough | 2 | 1 | 5 | 6 | 6 | 20 |
| Only use GM as a last resort | 1 | 2 | 2 | 3 | 0 | 8 |

**Table 10**: Risk perception, by familiarity with forest biotechnology.

| Risk Perception | Familiar with forest biotechnology (n=14) | Unfamiliar with forest biotechnology (n=19) | Total Unique Interviewees (n=33) |
|---|---|---|---|
| Unintended | 11 | 17 | 28 |

| | | | |
|---|---|---|---|
| consequence | | | |
| Control | 10 | 11 | 21 |
| Corporate concerns | 7 | 5 | 12 |
| Ecological integrity | 11 | 17 | 28 |
| Economic | 6 | 6 | 12 |
| Social | 1 | 2 | 3 |
| Viability | 7 | 11 | 18 |

**Table 11:** Risk perception argument, by familiarity with forest biotechnology.

| **Risk Perception Argument** | **Familiar with forest biotechnology (n=14)** | **Unfamiliar with forest biotechnology (n=19)** | **Total Unique Interviewees (n=33)** |
|---|---|---|---|
| Conduct a risk benefit analysis | 6 | 6 | 12 |
| Intent of the GM matters | 11 | 13 | 24 |
| We don't know enough | 8 | 12 | 20 |
| Only use GM as a last resort | 3 | 5 | 8 |

## Appendix G: Benefit Perception Crosstab Coding Query Results

**Table 12:** Benefit perception coding, by familiarity with forest biotechnology.

| Benefit Perception | Familiar with forest biotechnology (n=14) | Unfamiliar with forest biotechnology (n=19) | Total Unique Interviewees (n=33) |
|---|---|---|---|
| Cultural | 0 | 4 | 4 |
| Ecological | 10 | 12 | 22 |
| Economic | 1 | 3 | 4 |
| Scientific | 7 | 3 | 10 |
| Social | 2 | 2 | 4 |

**Table 13:** Benefit perception coding, by attitude toward forest biotechnology.

| Benefit Perception | Completely Support (n=5) | Completely Opposed (n=6) | Ambivalent (n=7) | Mostly Supportive (n=6) | Mostly Opposed (n=9) | Total Unique Interviewees (n=33) |
|---|---|---|---|---|---|---|
| Cultural | 1 | 0 | 1 | 1 | 1 | 4 |
| Ecological | 5 | 1 | 7 | 4 | 5 | 22 |
| Economic | 2 | 0 | 0 | 1 | 1 | 4 |
| Scientific | 5 | 2 | 1 | 0 | 2 | 10 |
| Social | 1 | 0 | 0 | 3 | 0 | 4 |

## Appendix H: Crosstab Coding Query Results for Chapter 3

Below are cross tab coding queries from raw coding in NVivo. Please note that the numbers in each of the cells refers to the number of interviewees using that argument, not the number of times that argument was used. Additionally, please note that many of the arguments described in the results of this thesis are aggregates of these raw numbers.

**Table 14:** Number of interviewees exhibiting ethics-based arguments, by predominant environmental ethic.

| Argument | Ecocentric (n=13) | Biocentric (n=11) | Anthropocentric (n=9) | Total Interviewees (n=33) |
|---|---|---|---|---|
| Humans are responsible | 4 | 5 | 3 | 12 |
| Humans need to protect nature | 2 | 2 | 5 | 9 |
| Humans shouldn't be Playing God | 2 | 2 | 2 | 6 |
| Humans can't fix nature | 9 | 8 | 1 | 18 |
| Humans should leave nature alone | 3 | 2 | 2 | 7 |
| Human's shouldn't be making species value judgements | 7 | 2 | 1 | 10 |
| Humans shouldn't be creating life | 0 | 1 | 2 | 3 |
| GM is another tool | 4 | 2 | 3 | 9 |
| Humans have always been genetically modifying things | 1 | 2 | 1 | 4 |
| The intent of the forest biotechnology matters | 11 | 8 | 5 | 24 |

**Table 15:** Number of interviewees exhibiting ethics-based arguments, by attitude toward forest

| biotechnology. | | | | | | |
|---|---|---|---|---|---|---|
| **Argument** | **Completely Supportive (n=5)** | **Mostly Supportive (n=6)** | **Ambivalent (n=7)** | **Mostly Opposed (n=9)** | **Completely Opposed (n=6)** | **Total Interviewees (n=33)** |
| Humans are responsible | 1 | 1 | 5 | 3 | 2 | 12 |
| Humans need to protect nature | 3 | 1 | 0 | 2 | 0 | 9 |
| Humans shouldn't be Playing God | 1 | 0 | 0 | 0 | 5 | 6 |
| Humans can't fix nature | 1 | 1 | 4 | 7 | 5 | 18 |
| Humans should leave nature alone | 1 | 1 | 3 | 1 | 1 | 7 |
| Human's shouldn't be making species value judgements | 1 | 1 | 3 | 3 | 2 | 9 |
| Humans shouldn't be creating life | 1 | 0 | 0 | 1 | 1 | 3 |
| GM is another tool | 4 | 1 | 1 | 3 | 0 | 9 |
| Humans have always been genetically modifying things | 2 | 1 | 1 | 0 | 0 | 4 |
| The intent of the forest biotechnology matters | 3 | 6 | 5 | 7 | 3 | 24 |

**Table 16:** Number of interviewees exhibiting arguments based on their perceptions of naturalness, by predominant environmental ethic.

| **Argument** | **Ecocentric (n=13)** | **Biocentric (n=11)** | **Anthropocentric (n=9)** | **Total Interviewees (n=33)** |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Nature is adaptive and capable of developing its own solution | 6 | 6 | 3 | 15 |
| A genetically modified tree won't necessarily be viable | 6 | 4 | 8 | 18 |
| Forest biotechnology isn't as natural as breeding | 6 | 6 | 5 | 17 |
| Transgenesis isn't as natural as cisgenesis | 5 | 7 | 4 | 16 |
| We don't know enough | 8 | 7 | 5 | 20 |
| Don't use forest biotechnology for native threats | 6 | 4 | 3 | 13 |

**Table 17:** Number of interviewees exhibiting arguments based on their perceptions of naturalness, by attitude toward forest biotechnology

| **Argument** | **Completely Supportive (n=5)** | **Mostly Supportive (n=6)** | **Ambivalent (n=7)** | **Mostly Opposed (n=9)** | **Completely Opposed (n=6)** | **Total Interviewees (n=33)** |
|---|---|---|---|---|---|---|
| Nature is adaptive and capable of developing its own solution | 4 | 2 | 4 | 2 | 3 | 15 |
| A genetically modified tree won't necessarily be viable | 5 | 2 | 4 | 5 | 2 | 18 |
| forest biotechnology isn't as natural as | 1 | 5 | 1 | 5 | 5 | 17 |

| | | | | | | |
|---|---|---|---|---|---|---|
| breeding | | | | | | |
| Transgenesis isn't as natural as cisgenesis | 1 | 2 | 4 | 5 | 4 | 16 |
| We don't know enough | 2 | 1 | 5 | 6 | 6 | 20 |
| Don't use forest biotechnology for native threats | 1 | 2 | 5 | 4 | 1 | 13 |