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# Invasive Plant Occurrence Across Agency Boundaries: Two Case Studies from California

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# INVASIVE PLANT OCCURRENCE ACROSS AGENCY BOUNDARIES: TWO CASE STUDIES FROM CALIFORNIA

by

Natalie Otto

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

In

Ecology

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# ABSTRACT

## Invasive Plant Occurrence Across Agency
## Boundaries: Two Case Studies
## from California

by

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Non-native invasive species (NNIS) are a major concern confronting land managers in protected area-centered ecosystems (PACEs), which encompass protected areas such as national parks, and their surrounding lands. Due to the large scale of a PACE, these areas include a variety of different public and private jurisdictions. These entities all have different mandates, management priorities, and resources that are allocated to invasive species management. These differences among entities in a PACE can result in ecological divergences at land boundary areas and create barriers to cooperative management of NNIS across jurisdictions. Through interviews and ecological data collection, this research explores the role of two key components related to the movement of NNIS across landscapes in ecologically valuable areas. These include 1. The relationships between the ecology of invasive plants and disturbance events linked to differing land use practices and 2. The extent of, and barriers to collaborative management of NNIS in a politically divided landscape. Coordination and communication were the dominant forms of cooperative management, while formal collaboration was scarce. Data analysis did not find significant differences in occurrence of weeds or disturbances across jurisdictions, nor did it find a significant difference in the correlation between weeds and disturbances when controlling for site in this particular PACE. Based on these findings, I provide recommendations on how to address collaboration challenges, while considering the effects of management-related disturbances on NNIS.

(166 pages)

# PUBLIC ABSTRACT

## Invasive Plant Occurrence Across Agency Boundaries:
## Two Case Studies from California

Natalie K. Otto

Non-native invasive species (NNIS) are a major concern confronting land managers in and surrounding protected areas such as national parks. These areas are managed by a variety of entities, all of which have different mandates, management priorities, and resources that are allocated to NNIS programs. These differences can result in ecological divergences at land boundaries and can create barriers to cooperative management. Through interviews and ecological data collection, this research addresses three topics; 1. It identifies disparities in NNIS and disturbance occurrence between jurisdictions and tests the strength of correlations between these variables; 2. It seeks to determine what role elevation plays in occurrence of NNIS, and; 3. It identifies the current challenges and extent of cooperative interactions among entities. Coordination and communication were the dominant forms of cooperative management, while true collaboration was scarce. Ecological data and analysis did not find significant differences in occurrence of weeds or disturbances across jurisdictions, nor did it find a significant difference in the correlation between weeds and disturbances when controlling for site. Based on these findings, I provide recommendations on how to address collaboration challenges, while considering the effects of management related disturbances on NNIS.

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# CHAPTER 1

# INTRODUCTION

Ecosystems interact over wide temporal and spatial scales and are organized by various processes and feedbacks. These include human influences, which arise from the interactions that organisms have with their environment. If this environment is altered by human activities, ecosystem processes will consequently be altered (Cumming et al., 2006). Regrettably, many protected areas and managed systems were not designated by considering their ecological completeness or function at a landscape level. Rather, they are more often defined by characteristics such as scenic value, land use, political and economic constraints (Dale et al., 2000). Therefore, protected areas may not effectively protect the very species and processes they were created to preserve (Hansen et al., 2011). Ecological processes and human activities that occur in surrounding lands can influence characteristics of protected areas in ways that negatively affect the native species and natural conditions the areas were designed to protect. One such process of particular interest to protected area managers in invasion by non-native species.

Non-native invasive species (NNIS) are defined as species that have been introduced outside their native ranges and which have the ability to reproduce and spread over substantial distances from introduction sites (Bacher et al., 2011), with far reaching and cascading ecological consequences. Many case studies have detailed the ability of NNIS to alter the composition and ecology of long-established biological communities (Simberloff 1995), reduce biodiversity and habitat quality (Mcdougall et al., 2011; Shackleton et al., 2015; Wilcove et al., 1998) alter disturbance regimes (such as fire cycles) (Abella et al., 2015; D'Antonio et al., 2004), and result in negative impacts on the economy and the quality of outdoor recreation (Aukema et al., 2011; Eiswerth et al., 2005). Alien invasive species incur economic damages upwards of $120 billion in the US, and weeds in agriculture alone are responsible for $33 billion in lost crop production annually (Pimentel et al., 2005). Invasive weeds spread and invade U.S. wildlife habitat at a rate of approximately 700,000 ha/year (Babbitt, 1998), incurring widespread ecological damage. Many NNIS that have established in the wild are having profound impacts on U.S. national parks and the surrounding landscapes. Control efforts of NNIS has become one of the most urgent and expensive tasks of managers of these parks (Hobbs & Huenneke, 1992a). For example, in Great Smoky Mountains National Park in North Carolina and Tennessee, about 27% (400 out of 1500) of vascular plant species are exotic (Hiebert & Stubbendieck, 1993). In California, 10% (>3,000 species) of all plants growing spontaneously are exotic; this figure is closer to 90% for California grasslands (Dowell & Krass, 1992). Many of the emerging threats related to NNIS invasions within managed natural systems originate and extend across political land boundaries (Todd et al., 2012). Preventing invasive plant species from infesting new areas is known to be more cost-effective and efficient for management of NNIS compared to trying to restore a system after it is infested (Davies & Sheley, 2007). In order to resolve invasive species challenges in these complex landscapes, we must attempt to understand the effect of jurisdictional boundaries on plant ecology, and explore the importance of regional cooperative ecosystem management (Schwartz et al., 2019), especially in areas that are currently still fairly pristine and weed-free in order to help them remain that way.

# LITERATURE REVIEW

## Factors Influencing NNIS Occurrence

A number of well-supported theories have emerged that explain increased community invasibility. These variables include habitat disturbance (Lozon & Macisaac, 1997; Macdougall et al., 2013), diversity of resident communities and available resources (Loiola et al., 2018), propagule pressure (Lockwood et al., 2005, 2009; Simberloff, 2009; Von Holle & Simberloff, 2005), and biological characteristics of the introduced species (Crawley et al., 1986).

One of the most cited qualities of communities thought to be more vulnerable to invasion is that they are frequently disturbed (Allen et al., 2008; Lockwood et al., 2009; Von Holle & Simberloff, 2005). While many native plant communities rely on some level of natural disturbance regimes for regeneration and successional recovery (Hobbs & Huenneke, 1992a), frequent and intense human, as well as natural disturbances can alter the stability and diversity of ecological systems, effectively weakening beneficial functional attributes such as invasion resistance (Macdougall et al., 2013).

Nature reserves and protected areas, in addition to the ecologically significant lands that surround them often display complex patterns of land ownership (Bergmann & Bliss, 2004). Due to these complexities, disturbances related to land-use activities and recreation are plentiful, thereby increasing the opportunities for the introduction and establishment of NNIS populations. Recreation and tourism-related activities in parks, wilderness, and protected areas show trends of increasing participation (Cordell, 2008). An increase in visitation leads to an increase in anthropogenic disturbances and environmental degradation (Monz et al., 2013). which can result in widespread ecological impacts on natural ecosystems (Green, 1998). Since non-native plants benefit from disturbance events, where native vegetation is damaged by activities related to recreational tourism and development, non-native plants have increased access to the resources needed to flourish (Pauchard & Alaback, 2004), in addition to having more opportunities for introduction (Pickering & Mount, 2010). Protected areas are experiencing increasing numbers of non-native plant species in their flora worldwide (Allen et al., 2008), suggesting a need for cross-boundary stewardship and cooperative management of NNIS.

Propagule pressure may be one of the most important factors in successful establishment of NNIS (of various taxa) in a variety of ecosystems worldwide (Lonsdale, 1999). Put simply, propagule pressure is the number of introduction events (propagule size), as well as the number of individual invasive species released during an event (propagule number) (Cassey et al., 2018). In addition to creating ground disturbances and conditions that are favorable for NNIS, visitors, vehicles, roads, pack animals, cattle, fire crews, logging, mining and construction equipment are all sources of propagule pressure both within and around protected areas (Pauchard & Alaback, 2004; Pickering & Mount, 2010; Tyser et al., 1992). These activities serve as a constant source pool of individuals, giving NNIS many chances to establish and spread, even if the initial propagule pressure was insufficient (Lockwood et al., 2005). In the areas outside national parks, important ecological processes still occur, albeit with less protection, and higher levels of disturbance as a result of development, multiple land uses, and roads (Pauchard & Alaback, 2004; Pickering & Mount, 2010).

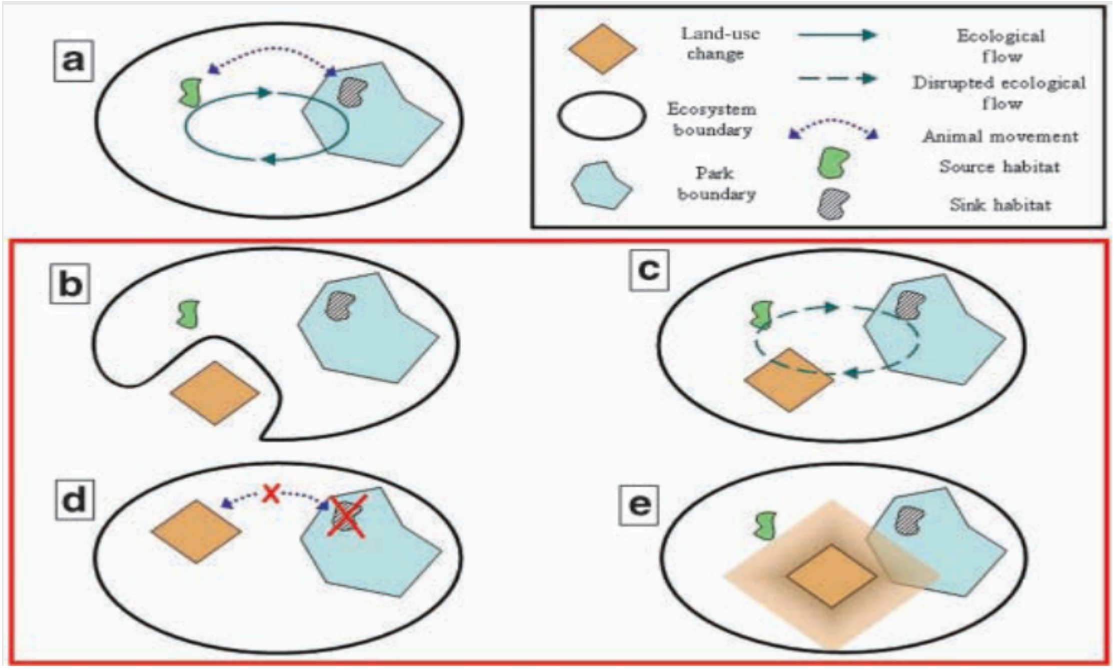
Susceptibility to invasion events can depend on numerous different biotic and abiotic factors (Lonsdale & Lane, 1994; Von Holle & Simberloff, 2005). Elevation, however, is possibly one of the strongest biotic constraints on invasions (Alexander et al., 2010). Historically, montane and alpine environments have experienced fewer NNIS invasions comparative to lowland ecosystems (Alexander et al., 2010; D'Antonio et al., 2004; Pauchard & Alaback, 2004). Although there are some exceptions, resistance to invasion at higher altitudes is because generally, few NNIS are able to adapt to steep climate gradients, short growing seasons, and extreme temperatures in these high elevation ecosystems (Alexander et al., 2010), in addition to less intensive land use and reduced human activity at high elevations (Petitpierre et al., 2016).

If propagule pressure and habitat disturbance increases in mountainous regions due to economic development and human visitation, and if climate change begins to warm these areas thereby reducing the climatic limitation of current non- native species distributions, NNIS may be able to expand into these regions (Pauchard et al., 2009; Petitpierre et al., 2016). These changes may create challenges for land management due to rough terrain, and the isolated and inaccessible nature of higher elevation ecosystems. Therefore, rapid response and prevention from land managers in these areas should be motivated by a desire to protect critical habitat that is essential for the preservation of the unique and endemic biota that can be found in mountainous habitats.

Because protected areas are usually surrounded by lands that experience different uses and impacts but are ecologically similar, it can be useful to understand ecological and social processes that occur within protected area-centered ecosystems (PACEs). PACEs are the larger zones around protected areas, wherein important ecological processes still occur but may be altered by human activity in ways that may be detrimental to the health of native organisms and processes both within and outside of the protected area. Hansen et al (2011) illustrates the concept of PACE and the ecosystem flows that occur both within, and outside of park boundaries, as well as how land use changes affects these processes (Figure 1). The designation of a PACE should help managers, scientists, and the public better conceptualize the importance of PAs in connection with their surrounding land parcels (Hansen et al., 2011).

**Figure 1**

*Effects of Land Use Changes in a Protected Area-Centered Ecosystem. a: Protected areas are strongly connected to the larger landscape. b: Human activities and land-use changes may destroy habitat or cause fragmentation, thereby hindering or negatively altering ecological flows, biodiversity and movements of animals. c: Land use may alter ecological flows through the protected area. d: Land use may eliminate or isolate important habitats which support source populations. e: Land use may increase human activity along park borders and result in the introduction of invasive species, increased hunting and poaching, and higher incidence of wildlife disturbance (Hansen et al., 2011) adapted from (DeFries et al., 2007).*



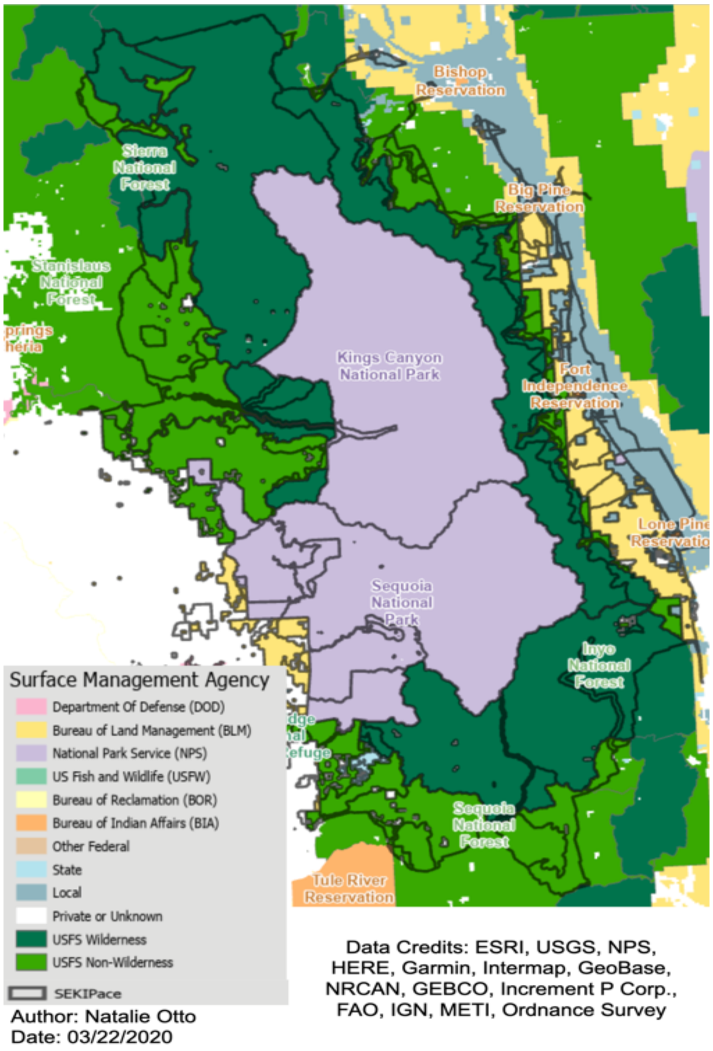
Many of the most pressing and complex environmental issues function at regional or even global scales. As a result, effective cooperative interaction between land managers is one of the best options to address environmental problems at these scales (Young & Kettenring, 2020). This is a problem that confronts PACEs; due to their size and scope, PACEs are often divided into complex management mosaics. The term *management mosaic* refers to landscapes that are comprised of many individually managed properties, all of which have a variety of different uses, as well as management priorities. In a management mosaic, a manager's decision in each land parcel on how to treat (or not treat) NNIS can directly influence his/her neighbors' land and their management decisions by affecting the spread of species across boundaries (Epanchin-Niell et al., 2010).

## Landscape Management

Oftentimes entities within a PACE are confronted with ecological situations such as NNIS invasions, in which they do not have the necessary knowledge to address the problem, or lack the resources needed to achieve the scale of management that is required. A potential solution to this problem would be to increase the scope of management to be able to address broad-scale ecological processes. This, however, is not likely, and so the only other option available is to communicate, coordinate, or collaborate with administrative neighbors throughout a management mosaic in a PACE (Cumming et al., 2006).

**Figure 2**

*Management Mosaic in the SEKI PACE. PACE boundary shown by outer most grey line, land is divided into NPS, BLM, USFS Wilderness and USFS Non-wilderness, as well as local land.*



Author: Natalie Otto
Date: 03/22/2020

Data Credits: ESRI, USGS, NPS, HERE, Garmin, Intermap, GeoBase, NRCAN, GEBCO, Increment P Corp., FAO, IGN, METI, Ordnance Survey

It can be very time and resource-consuming for multiple different agencies and private land-owners with different backgrounds and interests to overcome barriers to cooperative interaction, as well as to continue those interactions and information sharing indefinitely (Raab et al., 2013). However, the challenge of NNIS management is greater than any single method or discipline can tackle alone (Shackleton et al., 2019) because of their movements across landscapes. Reasons for failure to control invasion events include insufficient policy, inadequate funding, gaps in scientific knowledge (Von Holle & Simberloff, 2005), and differing opinions regarding optimal management approaches (Young & Kettenring, 2020).

Due to the large scale, management mosaic, and important ecosystem processes that occur in PACEs, it may be advisable that various stakeholders engage in some degree of cooperative interaction, in order to restore and maintain the health of beneficial ecosystem processes, as well as attempt to limit disruptions. Within a PACE, there can be significant complications because long-term management will require coordinated invasion control action of many agents, across time and space (Epanchin-Niell & Wilen, 2014). Management practices between parcels will also vary to reflect public values and political pressures, which determine primary goals of land use and use of natural resources. Control of NNIS on one parcel increases the incentives for control on other parcels by reducing costs from reinvasion for both parties (Fenichel et al., 2014).

Aside from governmental organizations that manage land within a PACE (e.g., USFS, BLM, NPS, USFWS), private landowners also make up part of the land parcel mosaic. Therefore, federal agencies must not only work with each other to control the spread of NNIS but must also collaborate with private parties. It is important to consider the role that private landowners play in controlling NNIS within the complex social landscapes that make up a PACE. Public awareness regarding the cost and threats of NNIS can serve as an important tool to engage the public in the management process (Pimentel et al., 2005).

Private landowners often make management decisions based on personal values, knowledge, experiences, and other economic constraints (Cocklin et al., 2007), which likely differ from federal agencies whose land borders their properties. Therefore, the effective management of NNIS in a PACE where private landowners play a role requires increasing knowledge about NNIS and the important ecological processes they threaten, creating engagement opportunities, building trust, and incentivizing control efforts. The effort to reduce the spread of NNIS is a collective action problem, requiring all stakeholders to cooperate and agree on management actions and target species (Epanchin-Niell et al., 2010).

## Thesis Purpose

The purpose of this thesis is to assess whether NNIS occurrence within two PACEs, the Sequoia & Kings Canyon PACE (SEKI) and the Lassen Volcanic National Park PACE (LAVO), can be related to jurisdictional differences in impacts and/or uses, as well as the social challenges that environmental managers encounter with cooperative interaction regarding NNIS management at a landscape scale. A mixed-methods approach was used to triangulate data sources and seek a convergence across both qualitative and quantitative measures, which gives a more in-depth depiction of a social-ecological-system (Venkatesh et al., 2013). Collaboration in managing landscape level processes is recommended but not easy, especially for the introduction and spread of NNIS. Many barriers prevent a truly collaborative approach for successfully managing NNIS.

This study included collection of quantitative data about NNIS occurrence and associated environmental factors, and qualitative interviews of key personnel regarding barriers and opportunities for collaboration. The purpose of our quantitative data collection and analysis was threefold: (1) To observe and compare how the presence of disturbances and weeds differ across jurisdictions. (2) To discern whether jurisdictions with higher occurrences of disturbances are positively correlated with a greater occurrence of weeds, and if that correlation is significantly different between jurisdictions at a contrast site, (3) and to ascertain how elevation gradients affect the occurrence of NNIS and therefore, may influence NNIS treatment priorities. These questions were addressed by collecting ecological data on human and natural disturbances and invasive plant occurrence in plots under different management, and by using ArcGIS to extract elevation data. Understanding how ecological patterns change near jurisdictional boundaries is fundamental for assimilating landscape level dynamics and being able to make appropriate large-scale conservation and management decisions (Ries et al., 2004).

The qualitative data were used to (1) describe the current levels of cooperative interactions among entities in two PACEs in California, and recognize which agencies are successful historically, as well as currently, for participating in cooperative management and why; (2) identify the barriers to cooperative management voiced by land managers who have experience in land and invasive species management, a finding which may help us determine how entities within a PACE can overcome these barriers and better align their priorities in the face of NNIS invasions, biodiversity protection and habitat restoration; (3) understand the major concerns regarding NNIS impacts at all elevations in these PACEs; and (4) ascertain management divergencies between jurisdictions and how these divergencies influence neighboring jurisdictions in a PACE.

The aim of this study is to describe and investigate how land use and its associated disturbances differ across jurisdictional land boundaries, and how those discrepancies influence plant ecology and ecological flows across a landscape. These data, paired with interview data from land managers regarding cooperative interactions, will help us understand a broader story about how land use and management decisions in PACEs shape complex ecosystem and social processes.

## Research Questions

### *Ecological Research Questions:*

What are the relationships, if any, between environmental factors and the occurrence, density, and diversity of non-native invasive species (NNIS) within the SEKI and LAVO PACE?

1. *At an ecologically similar site (along a jurisdictional land boundary), are weed occurrence and/or disturbance events likely to be significantly greater in one jurisdiction than another?*
2. *Is there a correlation between weeds and human disturbances, or weeds and natural disturbances in a jurisdiction when controlling by site, and does the correlation differ significantly among those jurisdictions?*
3. *How is elevation related to the occurrence of NNIS?*

### *Interview Research Questions:*

What are the lived experiences of people in land management positions within a PACE, in regard to NNIS ecology and management, specifically cooperative interactions?

1. *Do direct observations from interview participants corroborate current scientific theories about NNIS?*
2. *What are the observed differences in management between jurisdictions and how do these discrepancies influence management between neighbors?*
3. *What are the different and most common levels of cooperative interaction (communication, coordination, collaboration) identified through land manager interviews?*
4. *What are the barriers to collaborative management between jurisdictions*? *How might the barriers be addressed?*
5. *What is the perceived importance of collaborative management among different agencies?*

## Thesis Organization

This thesis is broken down further into three subsequent chapters, chapter one being this introductory chapter. Chapter 2 outlines our ecological data collection from the SEKI and LAVO PACEs in the summer of 2019. This chapter gives further insight on weed ecology, data collection methods, findings, conclusions, study limitations and recommendations.

Following a discussion of weed findings, we introduce management insights in chapter 3. Data was collected through semi-structured interviews and was used to explore the challenges of NNIS management and experiences of cooperative interactions across jurisdictions, as expressed by land managers from these PACEs. In addition, we present options for remediating these challenges.

The fourth and final chapter ties together the findings from chapters 2 & 3 with thoughts concerning the implications about the management of NNIS within PACEs. We discuss how the findings from our ecological data collection support and diverge from phenomena gleaned from our interview data.

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## CHAPTER 2

# NON-NATIVE INVASIVE PLANT SPECIES RESPONSE TO DISTURBANCE DIFFERENCES ACROSS JURISDICTIONS IN PROTECTED AREA-CENTERED ECOSYSTEMS

### Abstract

Invasions by non-native species are a global problem with serious consequences for ecological, economic and social processes. Many circumstances allow for increased invasion success. Here, I explore the role of divergent land management practices and related ground disturbances on invasive plant communities in ecosystems surrounding U.S. national parks. I aim to see if weed occurrence is greater on certain jurisdictions within these ecosystems, and whether it is correlated with human and natural disturbance events. Elevation is explored to see whether weed presence decreases as elevation increases, which may influence priority management areas. The study areas were centered on Lassen Volcanic and Sequoia & Kings Canyon National Parks in California, including lands managed by the National Park Service, Bureau of Land Management (BLM), and US Forest Service. When compared across jurisdiction boundaries, neither total weed occurrence nor disturbance events were significantly greater in any one jurisdiction than another. In some jurisdictions, when controlling for site, the strength of the correlation between weed abundance and natural disturbances was significant. However, analysis of the strength of correlations across jurisdictions did not find that any jurisdiction was more likely than others to experience disturbance-driven weed invasion.

Contrary to prediction, in all jurisdictions, the correlation between weeds and human disturbances was either non-existent or negative; however, human disturbances were decidedly low. In both study areas, non-native invasive plants rarely occurred above 2,000 meters in elevation, giving protected area managers an advantage in battling weeds, as large portions of those areas are situated above 2,000m.

## Introduction

A non-native plant species is defined as a plant found outside of its native home range, directly or indirectly due to human agency (Henderson et al., 2006). Non-native plants are not always invasive: once established, non-native plants may be benign additions to native communities. A non-native plant becomes a non-native invasive species (NNIS) when the introduced species is able to establish and expand its range from the site of original arrival into surrounding ecosystems and is able to dominate those vegetation communities (Bacher et al., 2011; Henderson et al., 2006). NNIS can outcompete native plants, degrade habitat, and form monocultures that have little to no ecological benefit (Pejchar & Mooney, 2009).

The introduction of invasive plants into native plant communities, and their subsequent establishment and spread, constitutes one of the main threats to biodiversity, habitat quality, and ecosystem function, a threat second only to land use change and habitat fragmentation (Wilcove et al., 1998). An estimated 5,000 introduced plant species are now established in natural ecosystems where they are displacing native plant species and altering ecosystems (Morse et al., 1995), and inflicting significant damage to natural and managed ecosystems (Pejchar & Mooney, 2009).

Due to their ability to rapidly transform ecosystems and cause severe declines in biodiversity, invasive plants and animals have attracted the attention of many ecologists and have been a major focus of conservation related research. A number of factors and theories have been identified as contributing to the likelihood that an established species will spread and become invasive (Davis et al., 2000; Henderson et al., 2006; Lockwood et al., 2005; Lonsdale, 1999). This study expands upon this work by incorporating these theories into a complex social-ecological-management system. Differences in land management across natural landscapes can create disturbances and impose variation in ecological flows and plant community structures. Over time, these anthropogenic and natural factors may result in sharp changes in vegetation communities.

Protected areas (PAs) and their surrounding landscapes are prime examples of ecologically important areas threatened by the invasion of NNIS due to varied and divergent land use activities (Trakhtenbrot et al., 2005). Many PAs are parts of larger protected area-centered ecosystems (PACEs), wherein interactions with surrounding lands are critical for the continued health of these areas (Davis & Hansen, 2011). They include lands that are not subject to the same set of stringent regulations and management objectives as the PAs they surround, but may be altered by human activities in ways that are detrimental to the health of the larger ecosystem (Hansen et al., 2011). PACEs, due to their scale, represent landscapes comprised of numerous individually managed properties, many of which have different land uses, as well as management objectives and priorities (Epanchin-niell et al., 2010). Management discrepancies over time can lead to ecological contrasts across landscapes and hinder ecological function (Kerby et al. 2007).

Divergent management trajectories can create edge effects, habitat patchiness and fragmentation, and increase disturbances that may encourage the introduction, establishment, and spread of NNIS. This raises a few questions: To what extent are divergent management trajectories influencing disturbances and effecting the movement and introduction of NNIS? At ecologically similar sites, are weed occurrence and disturbance events likely to be greater in one jurisdiction than another? Is there a correlation between weeds and disturbances in a certain jurisdiction, when controlling for location? And what role does elevation play in these areas in regard to management? Understanding how dissimilar environmental management creates differences in disturbance and plant community structure is fundamental for discerning how the variability of habitat quality influences the movement of invasive species across multi-jurisdictional landscapes.

For this chapter, I collected data from two PACEs in California, USA, with the goal of observing and comparing different jurisdictions to determine if human and natural disturbances associated with disparate land uses had any effect on the presence of NNIS. I hypothesized that, based on different land use activities ground disturbances would be a positive predictor for weed presence.

## Theoretical Framework

Disturbances, in the context of invasive plant species, are regarded as events or mechanisms that reduce biological resistance in an invaded community, and permit exotic species to better utilize available resources and avoid competition from the native plant community (Lozon & Macisaac, 1997). Human populations and intensifying land use have increased rapidly in PACEs in the United States (Davis & Hansen, 2011). Humans have surpassed many natural forces as primary global plant dispersers (Mack & Lonsdale, 2001), and disturbances associated with land use have been known to alter the stability and diversity of ecological systems, effectively weakening beneficial functional attributes such as invasion resistance (Macdougall et al., 2013). Control efforts of NNIS have become one of the most urgent and expensive tasks of managers of U.S. National Parks (Hobbs & Huenneke, 1992a), and the land use activities outside the borders of these PAs adds to the challenge in successfully managing weeds.

Environmental disturbances, particularly ground-disturbing events, are thought to be one of the most common qualities of invaded communities (Allen et al., 2008; D'Antonio et al., 2001; Barros & Pickering, 2014; Bazzaz et al., 2000; Lockwood et al., 2009; Lonsdale & Lane, 1994; Von Holle & Simberloff, 2005). Some examples of human disturbances that influence the spread of NNIS include housing and road developments, land use practices such as logging, grazing, fire suppression activities (Hobbs & Huenneke, 1992a), hiking trails, and other activities related to tourism (Pauchard & Alaback, 2004; Pickering & Hill, 2007).

Grazing by domesticated animals can facilitate the introduction and spread of NNIS (Aplet et al., 1991; Lozon & Macisaac, 1997). Grazing is common on federal land within PACEs, but only in certain jurisdictions; In the U.S., the USFS leases 49% of their land for grazing, and BLM leases 63%, while grazing is not permitted on NPS land (fs.fed.us, blm.gov). Increasing recreation and tourism activities are known to cause an increase in anthropogenic disturbances and environmental degradation (Monz et al., 2013). Many studies have concluded that an increase in the number of human visitors to an area leads to an increase in the number of exotic species due to humans acting as agents of disturbance, as well as vectors for transportation of NNIS (Allen et al., 2008; Lozon & Macisaac, 1997; Macdonald & Debenedetti, 1988; Pauchard et al., 2009; Pickering & Hill, 2007).

Humans, however, are not the only sources of disturbances; natural disturbances, such as those caused by hydrologic processes, wild animals (Hobbs & Huenneke, 1992a), fire cycles and insects also influence the spread of NNIS (D'Antonio & Vitousek, 1992).

Propagule pressure is another important component of plant community invasibility (Lockwood et al., 2005; Lockwood et al., 2009; Lonsdale, 1999; Von Holle & Simberloff, 2005). Both disturbance as well as sustained propagule pressure exist in and around popular natural areas such as National Parks. Propagule pressure has two components: propagule size, and number (Cassey et al., 2018; Simberloff, 2009). The size is the number of individuals released during any one event, and the number is the amount of discrete release events, or the rate at which propagules arrive per unit time (Lockwood et al., 2005, 2009). For establishment to occur, one or more propagules of a species must enter a transportation pathway, survive the voyage, exit the vector, then establish a population (Simberloff, 2009). Once established, a population may or may not spread to invasion levels.

Human activity and movement, as well as disturbance rates are constant and high in protected areas and surrounding land, providing sustained transportation pathways and introduction events, and making management and prevention of NNIS a constant challenge. Visitors, vehicles, roads, pack animals, fire crews, and construction equipment serve as vectors; coming from geographically diverse areas and providing a regular, repeated supply of NNIS propagules (Barros & Pickering, 2014; Pickering & Mount, 2010). NNIS richness has been positively correlated with visitors, backcountry trails and roads (Barros & Pickering, 2017). Bazzaz et al. (2000), found that invasions occur most rapidly with numerous, small and repeated introductions. He also noted that the more disturbed the location, the lower the propagule pressure needed to establish a population.

Recreation and multiple land use activities such as logging, grazing and fire suppression act as both forms of habitat disturbance (Pickering & Hill, 2007), as well as sources of propagule pressure, potentially facilitating NNIS invasion events. Once NNIS seeds reach a site through different pathways, trampling, grazing, logging, fire, and mining activities may further facilitate their establishment and spread. Trampling off trail by tourists, pack animals, and for fire suppression activities can favor the establishment of some non-native species by creating an increase in resource availability (Barros & Pickering, 2014; Burke & Grime, 1996; Pimentel et al., 2005).

One of the strongest abiotic constraints on invasions include severe climatic conditions and effects of elevation such as those that occur in deserts, high montane and alpine/sub-alpine habitats. Historically, montane and alpine environments have seen fewer NNIS invasions comparative to lowland ecosystems (Alexander et al., 2010; D' Antonio et al., 2004; Pauchard & Alaback, 2004). Resistance to invasion at higher altitudes is because few NNIS are able to adapt to steep climate gradients, short growing seasons, and extreme temperatures in these high elevation ecosystems (Alexander et al., 2010). Within these PACEs, elevation ranges dramatically, with the protected areas generally at a higher elevation than the rest of the PACE. This variance in elevation may give the protected areas an advantage for NNIS management, or influence management priority areas.

While the risk of invasion remains lower in mountains compared to lowland ecosystems, it is not unheard of for them to occur. As a consequence of climate change and increasing rates of tourism to mountain areas, plant invasions are likely to increase, potentially affecting endemic populations, biodiversity, and the cultural and ecosystem services that mountainous regions provide (Pauchard et al., 2009; Petitpierre et al., 2016). If this does occur, NNIS can become unmanageable quite rapidly due to the rugged terrain, safety considerations, and inaccessibility of many of these mountain landscapes (Barbero et al., 2015; Collins et al., 2013). Mountains exhibit sharp ecotones and transitions due to their rapid changes in elevation, and as a result are hotspots for biodiversity as well as endemic plant and animal communities, due to their isolated nature (Beniston, 2003). Aside from preserving the biodiversity of these unique ecosystems, intensive management of NNIS will also be important for cultural and aesthetic values, as many mountainous areas are treasured landscapes for tourism, recreation, and spirituality (Mcdougall et al., 2011).

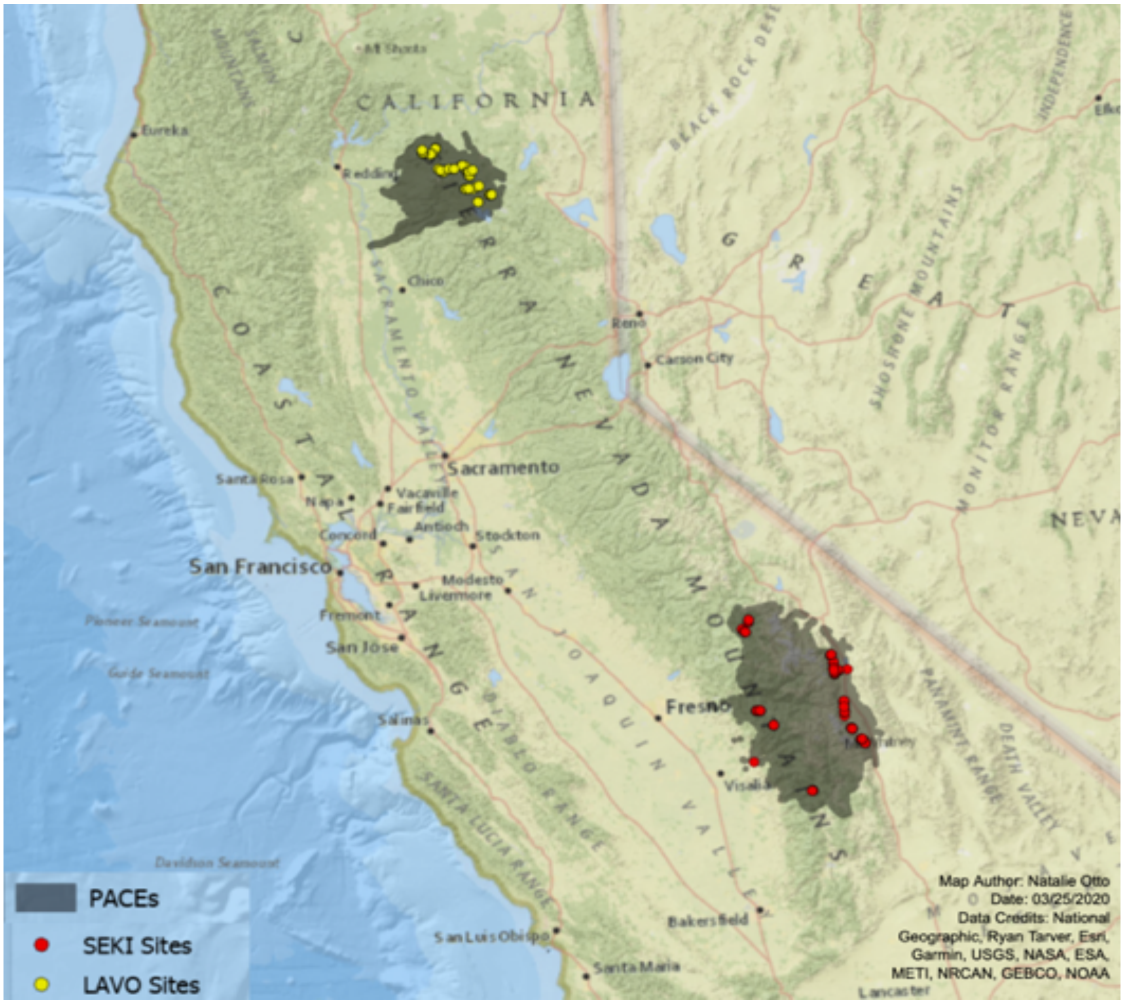
## Study Areas

The scope of data collection included two national parks in California: Sequoia and Kings Canyon National Park, and Lassen Volcanic National Park (Figure 3), as well as the jurisdictions surrounding these parks that delineate their PACE, referred to as the SEKI and the LAVO PACE. These PACEs include land managed by the National Park

Service (NPS) United States Forest Service Wilderness and Non-Wilderness land (USFS (W), USFS (NW)), and the Bureau of Land Management (BLM).

**Figure 3**

*PACE Locations. Grey areas depict the size and location of the LAVO (near Redding), and SEKI PACE (near Fresno), and locations of data collection sites within each PACE.*



***Sequoia Kings Canyon Protected Area-Centered Ecosystem***

Sequoia and Kings Canyon (SEKI) are two contiguous parks that are jointly administrated and have a combined area of 3,504 km2. About 96% of the park is designated or managed as wilderness, which is accessible to visitors only on foot and horseback via a network of over 1,300 km of trails. SEKI is located in the southern Sierra Nevada range, approximately 100 km east of Fresno, California. The SEKI PACE spans three different counties; Tulare, Fresno, and Inyo County, and three Forest Service jurisdictions: The Sierra, Sequoia, and Inyo National Forests. Sequoia and Kings Canyon, along with the John Muir Wilderness, represent the three protected areas within this PACE. In addition to National Park Service and Forest Service land, SEKI is also broken into a management mosaic consisting of private landowners and companies, the Bureau of Indian Affairs, Bureau of Land Management, city and county lands, U.S. Fish and Wildlife Service, and NGO managed land. Those making up the largest portion of the PACE include NPS, USFS and BLM land. In total, the PACE encompasses about 4.7 million ac.

The regional climate is Mediterranean, exhibiting warm dry summers and cool wet winters (Vankat & Major, 1978). According to the NPS website, elevation in the park ranges from 418 m in the foothills, up to 4,418 m at the summit of Mount Whitney; the 4,000 m gradient allows for a wide variety of habitats, and therefore plants, animals, and other organisms as well. While the vegetation communities in the PACE can be quite complex, they are categorized into four different zones: (1) The foothills, characterized by oak woodland and chaparral shrubland, (2) montane forests where conifer trees grow, (3) the subalpine zone, which marks the tree line, and (4) alpine ecosystems where only the hardy perennial plants grow (NPS.gov). Few exotics are reported to establish above 1,800 meters of elevation in the Sierra, and historically, a very limited number of these are known to invade habitats above 2,600 meters (D'Antonio et al., 2004), however, some

NNIS are widespread in the Sierra, and can rapidly invade many high elevation meadows (D'Antonio et al., 2002), making monitoring and preventative management essential. Both Sequoia and Kings Canyon are recognized as International Biosphere Reserves for their role in biodiversity conservation.

While the park supports many native organisms, its varying ecosystems also support NNIS. Out of the nearly 1,500 plant species in Sequoia Kings Canyon, 183 are non-native, with new species being identified each year. Some of these may be innocuous, but others are highly invasive. Even the former is a source of concern since non-native innocuous species can suddenly become invasive after years or even decades of reproduction (nps.gov/seki). For example, cheatgrass (*Bromus tectorum),* has been observed at elevations up to 2,800 meters on eastern slopes of the Sierra range and has invaded the understory of ponderosa pine (*Pinus ponderosa*) forests in SEKI (McGinnis et al., 2002). Cheatgrass is considered highly invasive and capable of triggering environmental changes that alter ecosystems in the Western United States (Peeler & Smithwick, 2018).

Vegetation communities in SEKI reflect a history of livestock grazing, and changing fire management and fire frequencies, in addition to increasing tourism activities (Vankat & Major, 1978). Grazing, logging, resource extraction, fire management, tourism and development continue across the PACE today. Urban and suburban development, livestock, roads, and agriculture have been cited as the principal causes of native plant population declines. The introduction and spread of non-native plants by anthropogenic activities have also been implicated in the decline of special status plant species (State of California, 1992).

### *Lassen Volcanic National Park Protected Area-Centered Ecosystem*

Lassen Volcanic National Park (LAVO), located in Northern California, encompasses 106,240 acres of volcanic features, boasting the most thermal features in the Cascade Range. Within the park, 79,062 ac, or 74% of the park is designated wilderness. The LAVO PACE is smaller than SEKI, at approximately 930,000 ac, encompassing parts of Tehema, Plumas, Lassen, and Shasta counties. This PACE includes three protected areas: Lassen Volcanic National Park, Thousand Lakes Wilderness, and the Caribou Wilderness. The PACE is split into National Park Service, BLM, state, county and Forest Service land. Only one Forest Service jurisdiction is included, the Lassen National Forest, and includes three ranger districts: Almanor, Hat Creek, and Eagle Lake ranger districts.

The terrain is mountainous, with flat plateaus produced by lava flows. The climate is upland, sub-tropical Mediterranean type, and has never been heavily logged (Pinder et al., 1997). However, vegetation communities may have been altered by regional variations in fire history, grazing, and climate change (Hurteau et al., 2014). Below 6,500 feet of elevation, LAVO is comprised of conifer forest. White Fir, along with Ponderosa, Jeffrey, and Sugar Pine make up the forest canopy at these lower elevations, as well as Manzanita, Gooseberry, Ceanothus, and a variety of wildflowers. From 6,500 to 8,500 feet, the park transitions to a Red Fir forest. At this elevation, the predominant vegetation includes stands of Mountain Hemlock with Red Fir and Lodgepole Pine. In the subalpine zone (8,000 to 10,000 ft), there is very sparse to no vegetation. Plants that can survive this rugged terrain include Rock Spirea, Lupine, Indian Paintbrush and Penstemon, in addition to small holdouts of White Bark Pine and Mountain Hemlock. According to the

National Park Service, the greatest threats to LAVO's native flora and fauna include climate change, competition with invasive plants, and historical fire suppression (NPS.gov).

## Methodology

Quantitative data collection took place during ten-day field campaigns May 21-Aug. 3, 2019. Objectives of this study were to see whether numbers of disturbances and/or weed occurrence were significantly different between jurisdictions within contrast sites, and to identify whether a correlation existed between weed presence and disturbances in certain jurisdictions when controlling by site, in addition to seeing if the correlation differed significantly among those jurisdictions.

It is important to note that this study was part of a much larger, pre-existing National Science Foundation-funded project focused on the study of cross-boundary ecological processes within PACEs and the effects of jurisdictional missions and boundaries on those processes. These included Grand Canyon , Great Smoky Mountains, and Rocky Mountain national parks as well as LAVO and SEKI. These PACEs were chosen to represent a range of climatic regions and geologic, land-use, and management histories, and were also places where PACE boundaries had already been delineated and where park officials were willing to issue research permits.

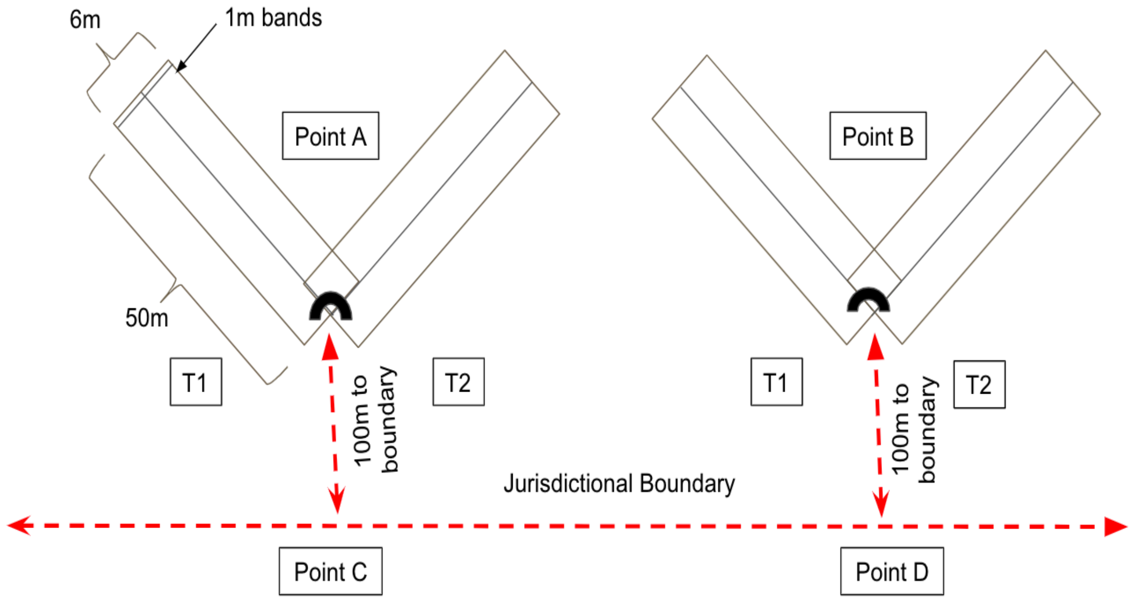
Therefore, the sampling protocol was designed to identify differences in ecological parameters – including but not limited to native vs. non-native plant composition within communities - that could be directly attributable to the existence of a socially determined boundary between jurisdictions with differing management missions and goals. Sites were located close to the boundary to maximize the likelihood of similar geographic settings (e.g., slope and aspect), soils, and plant community conditions on either side of the boundary and were randomly selected within each jurisdiction pair (unit contrast) along the entire length of boundaries but were not chosen to reflect any prior knowledge about presence/absence of invasive plants.

### *Study Design*

My design is hierarchical, with sites, units (2) within sites, points (2) within units, transects (2) within points, and 1-m “bands” (50) within transects, as shown in Figure 4. A site is the area surveyed that contains a comparison of two units, one on either side of a jurisdictional boundary to be compared. Two points were placed in each unit (A, B in one unit and C, D in another). Two 50m transects were measured from each point (Transect 1 and 2), forming a 90° V shape facing away from the boundary; four different transects were positioned within a unit (Transect 1 and 2 for each point), and 8 total transects for one site. Various presence/absence (binary) metrics were observed on fifty 1m bands focused around a transect tape. I tallied the number of times weeds and human and natural disturbances were present along a total of 200m for each unit.

**Figure 4**

*Study Design. Diagram shows hierarchical study sites; point A and B are in a unit on one side of a boundary in the site, 100m away. Point C and D are on the opposing side in another unit in the site, also 100m away. Each point has two 50m transects and fifty 1m bands per transect.*



I focused on top-priority NNIS as identified by the National Park Service for these PACEs to ensure relevance to management goals. These included: cheatgrass (*Bromus tectorum*), common mullein (*Verbascum thapsus*), bull thistle (*Cirsium vulgare*), Canada thistle (*Cirsium arvense*), and oxeye daisy (*Leucanthemum vulgare*) for LAVO. For SEKI these included: bull thistle (*Cirsium vulgare*), cheatgrass (*Bromus tectorum*), foxglove (*Digitalis purpurea*), Himalayan blackberry (*Rubus armeniacus*), greater periwinkle (*Vinca major*), Italian thistle (*Carduus pycnocephalus*), reed canarygrass (*Phalaris arundinacea*), and velvet grass (*Holcus lanatus*).

The sources of disturbance I used as they related to NNIS included: cattle (specify print, scat, bones, live), animal digging, animal scat, roads, trail/human footpath, game trail, chainsaw, and fire footprint. I also looked for signs of active building or construction and mine exploration/activities, but these disturbances were never found in my sites. I further aggregated disturbances into two categories: human disturbances and natural disturbances. Human disturbances included any caused by cattle, trails, roads, or chainsaw activity (evidence of felled trees). Natural disturbances included animal digging and scat (game/bear scat is distinguishable from cattle), game trails, and evidence of a fire footprint.

Data collection locations were chosen by using a randomization process in ArcGIS. Points were generated under the requirements that they should be located 100 m from boundaries between jurisdictional units, with a distance of ≥200m between each point. To maximize data collection efficiency and technician safety, some of the selected points were subsequently dropped due to inaccessibility. For each selected point, we used random selection again to choose sampling sites for management unit comparisons. The intention was to generate 15 sites per contrast (e.g., NPS vs USFSnw, BLM vs USFSw, etc.) to achieve a balanced incomplete block design.

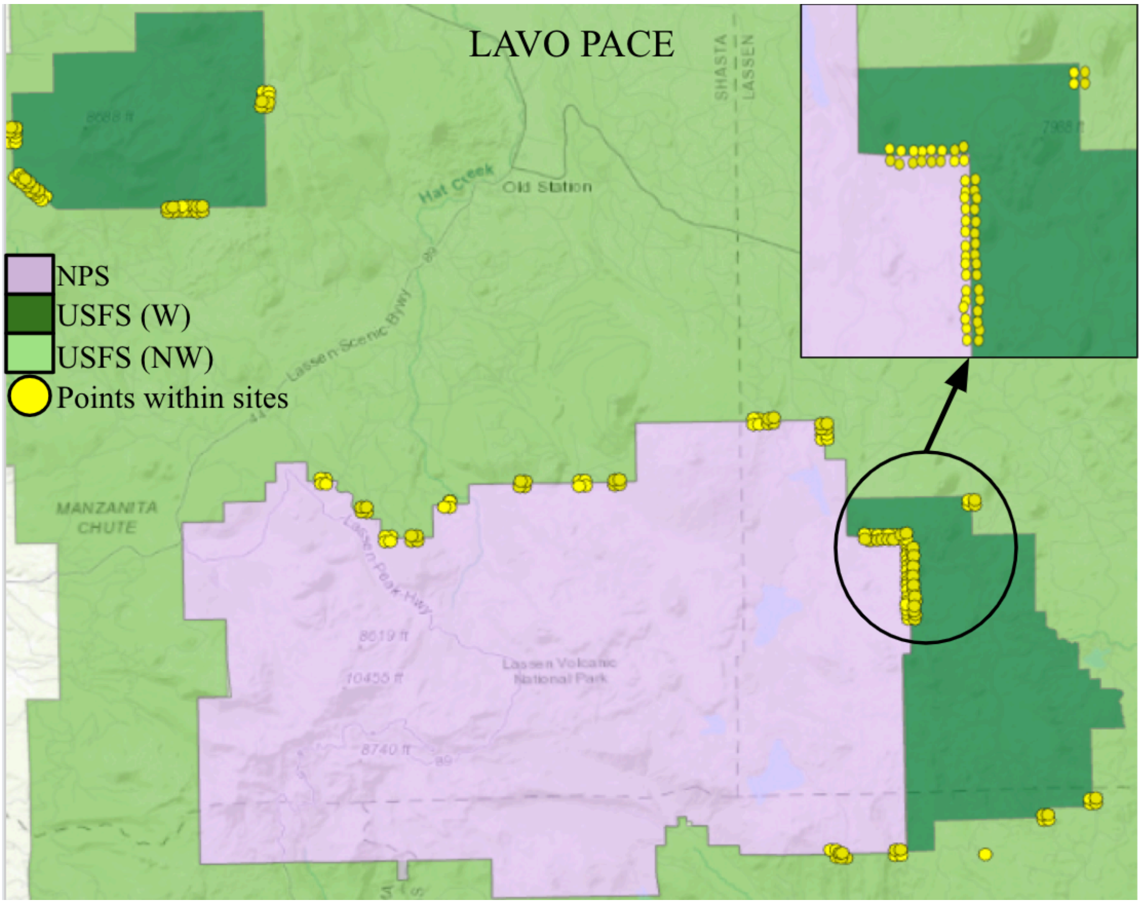
Each site is a block containing two units which are associated with two of the four jurisdictions in this study. The blocks are incomplete because each block does not contain units for all four jurisdictions. There were no physical barriers (such as fences) separating the jurisdictions in these PACEs.

One of the randomly generated GIS points served as the first of four sampling locations per blocked site; each site had four points: points A and B were on one side of a jurisdictional land boundary, and plots C and D on the other side of this boundary. Figure

5 depicts the location of points within a site. Four points make up a site; points are placed along a jurisdictional boundary to form a 200 x 200m square.

**Figure 5**

*LAVO PACE. Yellow circles depict 2019 data collection points within our sampling units. Our points formed squares with two points on either side of a jurisdiction, 100m from the boundary, and 200m from other points.*



Using GPS, and the Avenza phone application showing locations of jurisdictional boundaries, I navigated to the number corresponding to the destination site. Once I was ~100 meters from the jurisdictional boundary I determined which direction faced directly away from the boundary and marked this as the points' central bearing (the plot area is a half-circle with a 50 m radius, bisected by this bearing). From the bearing, transect 1 = Plot Center - 45°, transect 2 = Plot Center + 45°. Two transect tapes were connected to the “candy cane” at a 90-degree angle from one another, extending away from the boundary. The transect tapes measured 50 x 6 meters, and these were walked for each jurisdictional unit (A, B, C & D), summing to a total of 200 m of data collection for each unit (4 transects x 50 meters each), and 400 m per site (200m x 2 units).

### *Data Collection*

Walking the length of the 50 m transect tape, I identified and recorded human (cattle, trails, roads, or chainsaw activity) and natural (animal digging and scat, game trails, and fire footprints) disturbances and NNIS as observed in one-meter intervals as they occurred along the transect to enable calculation of proportional occurrence of each disturbance and weed type across the 50 intervals of each transect. All metrics were quantified as “percent cover” based on presence or absence in contiguous quadrats along transects. Our data was collected as counts, in order to answer questions about proportions; the counts were the number of “hits” (weeds or disturbances present) out of a fixed number of “trials” (meters on a transect). At the transect level, counts could range from 0 to 50 - but notably, no larger than 50; the counts are bounded on both ends. 0 was entered if there were no weeds or specific disturbances, and a 1 was entered if any number of weeds or specific disturbances were present per meter.

This recording process was repeated for plots B, C, and D. B was located 200 m away on the same side of the boundary, while C and D were on the other side of the boundary. To get from plot B to plot C, we travelled perpendicular to the boundary and crossed it. The four plots at a site formed a 200 x 200 m square, bisected by the boundary. This design allowed for comparison of disturbances and weeds by jurisdictions to determine whether locations on one side of the boundary displayed differences or similarities in disturbances and vegetation community type. The design also clustered the data collection in an attempt to reduce discrepancies in elevation, and variances in vegetation type and topography.

## Data Analysis

Weeds in LAVO sites were too rarely observed to permit any inferential statistical analysis. According to NPS employees, weeds were one of the top management priorities, therefore it is possible that the survey methods used in this study weren't the most effective in detecting weeds. However, since this was part of a larger study with a defined protocol, data collection methods could not be altered. Weeds were observed in only 5 of the 100 sampling units (50 sites x 2 jurisdictional units), and in only 3 sites. Due to the lack of weeds in this PACE, I present descriptive statistics only, whereas I could further analyze data for the SEKI PACE.

In SEKI, some disturbance metrics did not have enough variability/occurrence for statistically based explanation, which influenced my decision to aggregate disturbances into total human and total natural disturbances. For example, out of 104 (52 sites x 2 jurisdictional units) sampling units, 99 had zero percent cover for trails, 95 had zero percent cover for roads, 89 had zero percent cover for chainsaw activity, and 76 had zero percent cover for cattle. To attempt to understand if any trends are visible with the given data, I used descriptive statistics, tables and figures generated with the R statistical software, along with a few parsimonious statistical tests.

I created descriptive statistic tables, clustered column graphs, and paired scatterplots to help display apparent differences in the amount of human disturbance, natural disturbance, and weed occurrences between paired jurisdictions. I then used the Wilcoxon Signed Rank test to determine whether the number of recorded weed occurrences, human disturbances, or natural disturbances was significantly greater in one unit (jurisdiction) within a site than in the contrasting unit. This test was chosen as an alternative to the paired t-test, as it is the non-parametric equivalent.

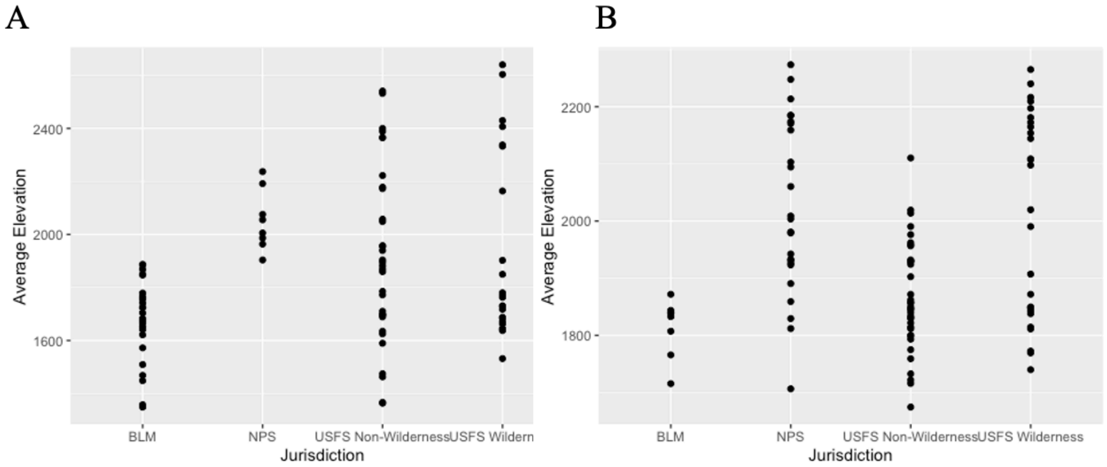
To determine whether a correlation existed between weeds and disturbances in a jurisdiction when controlling by site, and if that correlation differed significantly among jurisdictions, I used a linear mixed model; regressing ranked and standardized weed abundance on ranked and standardized human and natural disturbance abundance, blocking by site to estimate Spearman's correlation by jurisdiction. By regressing my Y variable on my X variable, I used the values of variable X to predict those of Y. This approach allowed me to compare the strength of correlations and differences among correlations between weeds and disturbances among jurisdictions, while controlling for the clustering of observations within sites. By scaling the data, the slopes of the regressions represent correlations, and because I ranked the data, the slopes estimate the Spearman's correlation for each jurisdiction. Each slope represents the predicted value of the occurrence of the dependent variable (total weed occurrence) as the occurrence of the independent variable increased. The independent variable, or X, was always disturbances and Y was always NNIS occurrence. I ran this regression three different times, with total disturbances, total human disturbances, and total natural disturbances as three different independent variables.

The general linear mixed-model followed this notation: $Y_{ij} = \gamma_{00} + \gamma_{0i} + \gamma_{10}X_{ij} + \gamma_{2i}X_{ij} + u_{0j} + \varepsilon_{ij}$ where $Y_{ij}$ is the response for the $i^{\text{th}}$ jurisdiction at the $j^{\text{th}}$ site, $X_{ij}$ is the total number of disturbances (ranked and scaled) for the $i^{\text{th}}$ jurisdiction at the $j^{\text{th}}$ site, $\gamma_{00}$ is the intercept, $\gamma_{0i}$ is the adjustment to the intercept for the $i^{\text{th}}$ jurisdiction, $\gamma_{10}$ is the slope of the regression of $Y$ on $X$, $\gamma_{2i}$ is the adjustment to the slope for the $\text{i}^{\text{th}}$ jurisdiction, $u_{0j}$ is the random intercept for the $j^{\text{th}}$ site, and $\varepsilon_{ij}$ is the residual for the $i^{\text{th}}$ (1,4) jurisdiction at the $j^{\text{th}}$ (1,52) site.

To understand what effect elevation had on weed occurrence, and whether or not that may have been influencing management, I used ArcGIS to extract the elevation data from each of the two plots within a treatment unit, then found the average elevation of each treatment within a site. I used this data to create scatterplots showing elevation data for the SEKI (Figure 6A) and LAVO PACE (Figure 6B). These plots showed that in both PACEs, BLM sites had the lowest average distribution of elevations. In the SEKI PACE USFS jurisdictions had the higher average elevations, while in LAVO, NPS and USFS (W) had the highest average distributions of elevation.

**Figure 6**

*Average Elevations by PACE. Average elevation of sampling units in the SEKI (A) and LAVO (B) PACEs, by jurisdiction. Average elevations obtained by adding extracted elevation data for paired plots within each unit and dividing by two.*



## Results

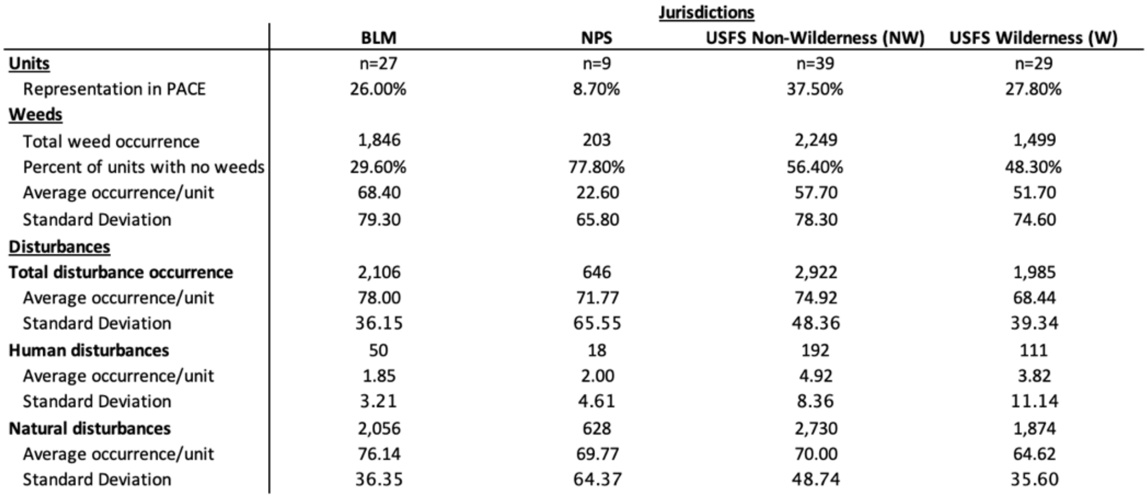
### *Descriptive statistics*

The SEKI PACE consisted of 104 treatment units (Table 1). The combinations we were able to attain in the SEKI PACE allowed for 52 sites consisting of the following comparisons: 14 BLM-USFS (NW); 16 USFS (NW)-USFS (W); 9 NPS-USFS (NW); and 13 BLM-USFS (W). In the LAVO PACE, we had 100 treatment units (Table 2), and 50 sites: 8 BLM-USFS(NW); 15 USFS (NW)-USFS (W); 15 NPS-USFS (NW); and 12 NPS-USFS (W). BLM land in the LAVO PACE was less extensive and only abutted USFS (NW) areas, resulting in less opportunity for comparisons with BLM jurisdictions. As noted previously, weed occurrences in the LAVO PACE were too rare to allow for analysis using inferential statistics. No weeds were found in 100% of BLM units, 92.6% of NPS units, 94.7% of USFS (NW) units, and 96.3% of USFS (W) units. However, as previously mentioned, the lack of detections is likely due to study design and should not be interpreted as an indication that weeds may be more common in other locations within these jurisdictions.

In SEKI, NPS jurisdictions are under-represented, meaning that the design for comparison of jurisdictions across boundaries is unbalanced. Some contrasts are also under-represented, such as BLM/USFS (W) contrasts and NPS/USFS (NW). For these contrasts, under-representation reflects the unequal availability of jurisdictions within the PACE available to survey based on survey methods and protocols. A qualitative assessment based on arithmetic means shown in Table 1 suggests that BLM jurisdictions had highest average occurrence of weeds per unit, highest average occurrence of total disturbances per unit, and highest average occurrence of natural disturbances per unit when taking into account the number of units surveyed. Total weed and disturbance occurrences were consistently highest in USFS (NW) when not considering the number of units per jurisdiction. USFS (NW) jurisdiction had the highest average occurrence of human disturbances per unit (Table 1).

**Table 1**

*Descriptive summary statistics (SEKI PACE). Representation of jurisdictions in the PACE as well as totals and averages for weed, human, and natural disturbances.*



| | Jurisdictions | | | |
|---|---|---|---|---|
| | **BLM** | **NPS** | **USFS Non-Wilderness (NW)** | **USFS Wilderness (W)** |
| **Units** | n=27 | n=9 | n=39 | n=29 |
| Representation in PACE | 26.00% | 8.70% | 37.50% | 27.80% |
| **Weeds** | | | | |
| Total weed occurrence | 1,846 | 203 | 2,249 | 1,499 |
| Percent of units with no weeds | 29.60% | 77.80% | 56.40% | 48.30% |
| Average occurrence/unit | 68.40 | 22.60 | 57.70 | 51.70 |
| Standard Deviation | 79.30 | 65.80 | 78.30 | 74.60 |
| **Disturbances** | | | | |
| **Total disturbance occurrence** | 2,106 | 646 | 2,922 | 1,985 |
| Average occurrence/unit | 78.00 | 71.77 | 74.92 | 68.44 |
| Standard Deviation | 36.15 | 65.55 | 48.36 | 39.34 |
| **Human disturbances** | 50 | 18 | 192 | 111 |
| Average occurrence/unit | 1.85 | 2.00 | 4.92 | 3.82 |
| Standard Deviation | 3.21 | 4.61 | 8.36 | 11.14 |
| **Natural disturbances** | 2,056 | 628 | 2,730 | 1,874 |
| Average occurrence/unit | 76.14 | 69.77 | 70.00 | 64.62 |
| Standard Deviation | 36.35 | 64.37 | 48.74 | 35.60 |

In the LAVO PACE, non-wilderness Forest Service lands had the highest totals and averages per unit for weed occurrence and human disturbances. NPS jurisdictions had the highest totals and averages for total disturbances and natural disturbances (Table 2).

**Table 2**

*Descriptive summary statistics (LAVO PACE). Representation of jurisdictions in the PACE as well as totals and averages for weed, human and natural disturbances.*

| | Jurisdictions | | | |
|---|---|---|---|---|
| | **BLM** | **NPS** | **USFS Non-Wilderness (NW)** | **USFS Wilderness (W)** |
| **Units** | n=8 | n=27 | n=38 | n=27 |
| Representation in PACE | 8.00% | 27.00% | 38.00% | 27.00% |
| **Weeds** | | | | |
| Total weed occurrence | 0 | 6 | 84 | 1 |
| Percent of units with no weeds | 100.00% | 92.60% | 94.70% | 96.30% |
| Average occurrence/unit | 0.00 | 0.22 | 2.21 | 0.03 |
| Standard Deviation | 0.00 | 0.80 | 12.80 | 0.20 |
| **Disturbances** | | | | |
| **Total disturbance occurrence** | 310 | 2,432 | 2,464 | 820 |
| Average occurrence/unit | 38.75 | 90.07 | 64.84 | 30.37 |
| Standard Deviation | 30.66 | 75.17 | 75.60 | 27.51 |
| **Human disturbances** | 110 | 17 | 511 | 4 |
| Average occurrence/unit | 13.75 | 0.62 | 13.44 | 0.14 |
| Standard Deviation | 24.39 | 2.90 | 17.00 | 0.77 |
| **Natural disturbances** | 200 | 2,415 | 1,953 | 816 |
| Average occurrence/unit | 25.00 | 89.44 | 51.39 | 30.22 |
| Standard Deviation | 13.29 | 75.23 | 68.19 | 27.34 |

Scatterplots of the distributions of human disturbances, natural disturbances, and weeds by site and jurisdictions in SEKI are depicted in Figure 7A, B & C. Although a few Forest Service plots had relatively high levels of human disturbance compared to NPS and BLM plots, differences across jurisdiction did not appear to be substantial. No noticeable differences were found in the number of natural disturbances or of units with weed occurrences. In LAVO (Figure 8A), USFS (NW) appears to have more human disturbances compared to other jurisdictions. NPS and USFS (NW) had more sites with greater evidence of natural disturbances (Figure 8B). Weeds were very sparse in LAVO; one USFS (NW) unit had 79 weed occurrences, while the other four units with weeds had no more than 5 occurrences each (Figure 8C).

**Figure 7**

*Scatterplots of weeds and disturbances (SEKI). (A) total human disturbances, (B), total natural disturbances, (C) total weed occurrences within each jurisdiction sampled across the PACE. Points represent individual units within a site. Fewer points for NPS are attributed to the same value being measured more than once; 0 was most commonly recorded for NPS units for human disturbances and weed occurrence.*

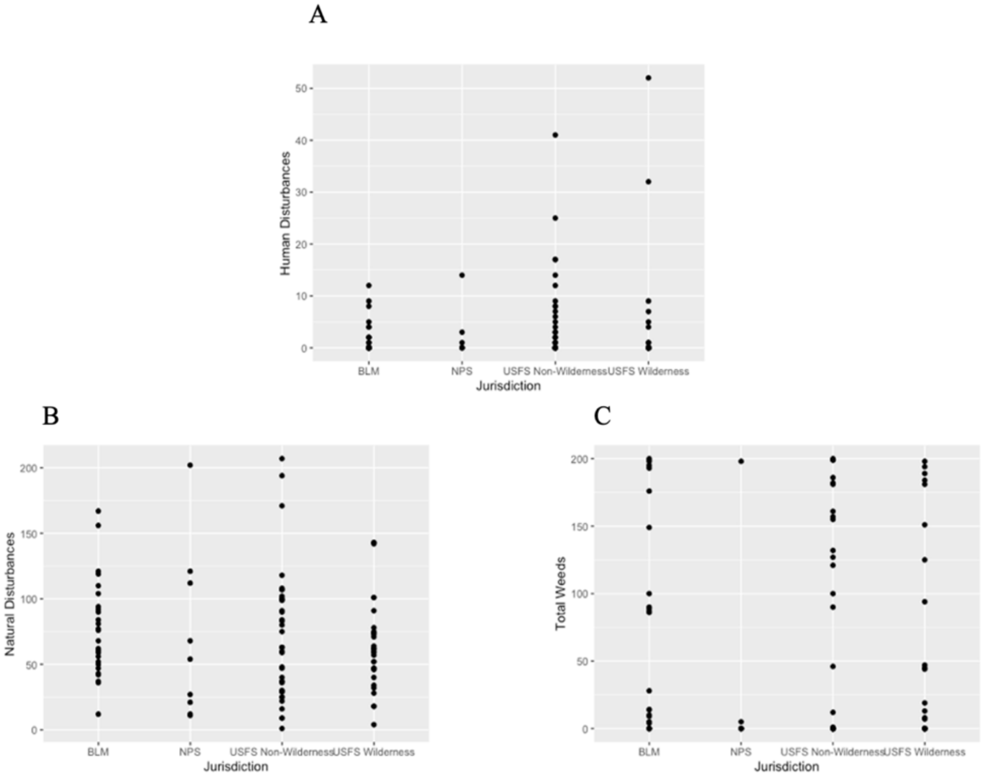
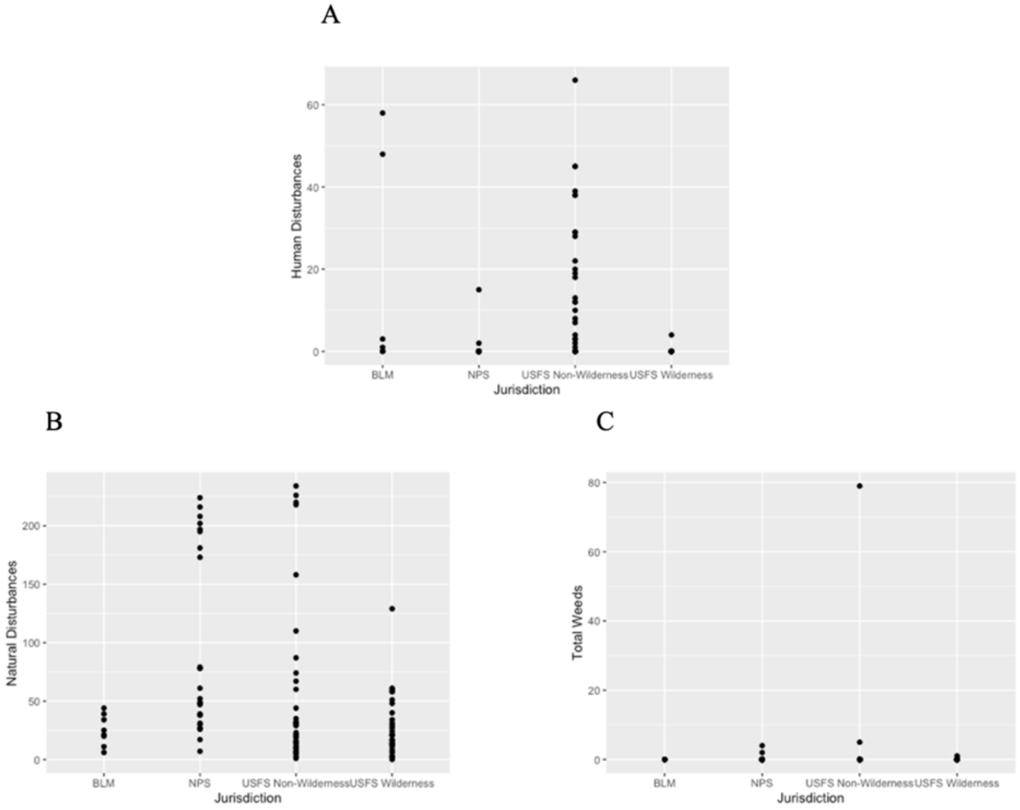


**Figure 8**

*Scatterplots of weeds and disturbances (LAVO). (A) total human disturbances, (B), total natural disturbances, (C) total weed occurrences within each jurisdiction sampled across the PACE. Points represent individual units within a site. Fewer points for NPS are attributed to the same value being measured more than once; 0 was most commonly recorded for NPS units for human disturbances and weed occurrence.*



The most common situation in LAVO units was the absence of both weeds and evidence of human disturbance. The second most common finding was units (within sites) that had evidence of human disturbance but had no weeds (Table 3). Therefore, areas with no human disturbances are also less likely to have NNIS present. Units within contrast sites that had human disturbances, but no weeds contradict these theories, and suggests that other ecological factors such as elevation, or a resilient native plant community restricted the ability of NNIS to establish and invade, despite the opportunities associated with disturbances. Another contributing factor to these findings may have been the experimental design, which was developed to maximize the likelihood of similar geographic settings along jurisdictional boundaries, but were not chosen to reflect any prior knowledge about presence/absence of invasive plants in these areas

**Table 3**

*LAVO Relationships (jurisdiction, weed occurrence, and human disturbances grouped by contrast site)*.

| | Unit Contrast Sites | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BLM-USFS Non-Wilderness (NW) | | NPS-USFS Non-Wilderness (NW) | | NPS-USFS Wilderness (W) | | USFS Non-Wilderness (NW)-USFS Wilderness (W) | |
| Sites | n=8 | | n=15 | | n=12 | | n=15 | |
| Jurisdictions | BLM | USFS (NW) | NPS | USFS (NW) | NPS | USFS (W) | USFS (NW) | USFS (W) |
| Units out of total with human disturbances and no weeds | 4/8 | 4/8 | 1/15 | 11/15 | 1/12 | 0/12 | 7/15 | 1/15 |
| Units out of total with weeds and no human disturbances | 0/8 | 0/8 | 2/15 | 0/15 | 0/12 | 1/12 | 0/15 | 0/15 |
| Units out of total with no human disturbances nor weeds | 4/8 | 4/8 | 12/15 | 2/15 | 11/12 | 11/12 | 8/15 | 14/15 |
| Units out of total with both human disturbances and weeds | 0/8 | 0/8 | 0/15 | 2/15 | 0/12 | 0/12 | 0/15 | 0/15 |

### *Differences Among Jurisdictions*

The primary purpose of this research is to understand whether the social process of jurisdictional partitioning leads to ecologically relevant differences in non-native species invasion between jurisdictions within PACEs. To answer this question, I used data collected from the SEKI PACE. The descriptive tables (Table 1, Table 2, and Table 4) and clustered column graphs (Figure 9) suggest some nuanced differences in weeds and human/natural occurrences between jurisdictions in a contrast. However, analysis using the Wilcoxon matched pairs signed rank test among jurisdiction contrasts found no significant statistical differences in weed and human/natural disturbance occurrences between jurisdictions (Table 4).

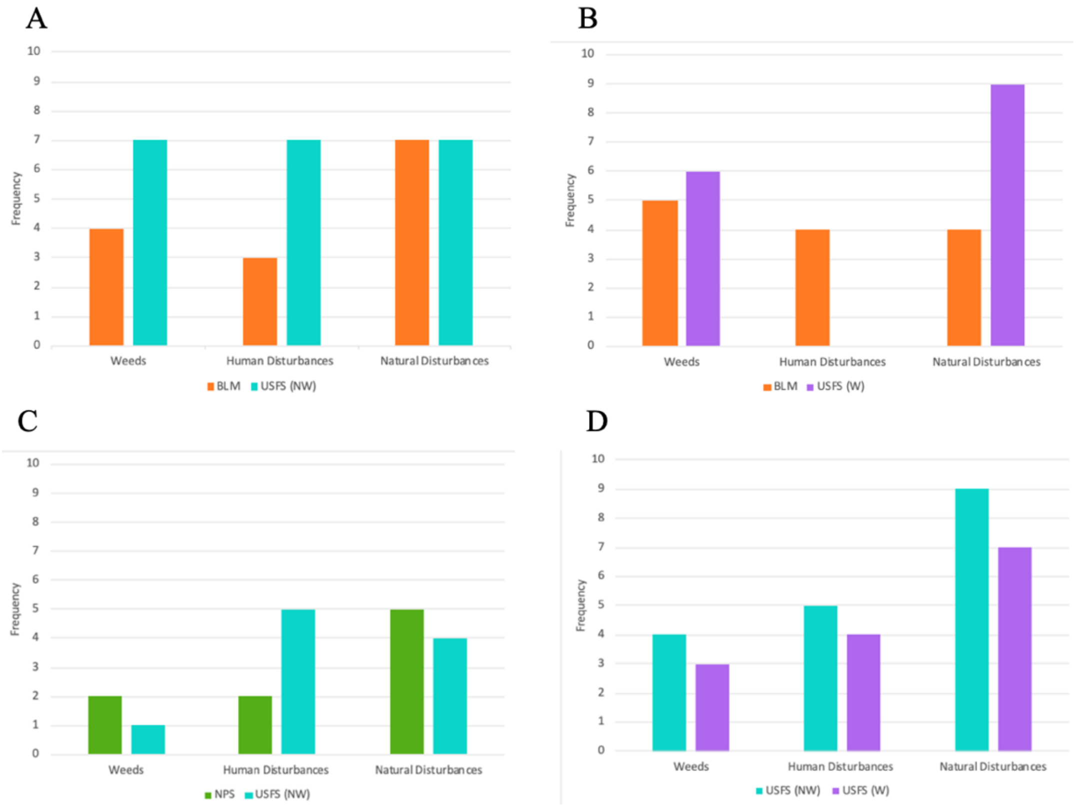
Clustered column graphs help us visualize subtle differences between weed occurrence and different disturbance occurrences between jurisdiction contrasts. Although there was only one more recorded occurrence of human disturbances in USFS (NW) along all of the meters surveyed for this contrast (14 sites) compared to BLM units (Table 4: BLM – USFS nw under "Human Disturbances"), Figure 9A shows that USFS (NW) units 7/14 times had a greater proportion of the transects with evidence of human disturbance than BLM. BLM units only 3/14 times had a greater proportion of the transects with evidence of human disturbance. This is because the occurrence of human disturbances was high in a few BLM units while other BLM units had very few, whereas USFS (NW) units had moderately high numbers of human disturbances that were more evenly distributed across units.

Figure 9B depicts BLM – USFS (W) contrasts. Here, I found more transects on USFS wilderness units with evidence of weeds (6/13) and natural disturbance (9/13) than on BLM land (5 units with weeds, 4 units with natural disturbance). However, there were no unit contrasts where USFS (W) units had more human disturbances than on BLM land, but 4 BLM units had more human disturbances than the corresponding USFS (W) unit.

NPS – USFS (NW) contrasts are shown in figure 9C. This graph reveals that NPS units had more transects with weeds and natural disturbances occurrences than its USFS (NW) contrast, but fewer units with a greater proportion of human disturbances along its transects. In USFS (NW) – USFS (W) contrasts, USFS (NW) units were more likely to have a higher occurrence of weeds, evidence of human disturbance, and evidence of natural disturbances compared to USFS (W) (Figure 9D).

**Figure 9**

*Clustered column graphs (SEKI). Graphs show the number of times one jurisdiction in a site had a greater proportion of its transects with weed, human, and natural disturbance occurrence per unit compared to its contrasting jurisdiction. BLM-USFS (NW) (A), BLM-USFS (W) (B), NPS-USFS (NW) (C), USFS (NW)-USFS (W) (D). Not included are the number of times the jurisdictions within a contrast site had the same, or no weeds, nor human or natural disturbances.*



While there may be some subtle differences in total weed and disturbance proportions counted along transects between jurisdictions, statistical analysis using the Wilcoxon matched pairs signed rank test did not find a significant result: that is, the variance in results from site to site within all four different contrasts was such that I could not reject the hypothesis that the implied differences as seen in the graphs are a result of random chance (Table 4). The Wilcoxon matched-pairs signed rank test (Wilcoxon 1945) is the nonparametric equivalent of a paired t-test, which tests for statistical evidence that a mean difference between paired observations on a particular outcome is significantly different from zero (Reimann et al., 2008). Here, we aim to see whether there is a significant statistical difference in observations of weeds, human and natural disturbance occurrence between pairs of differing jurisdictions. This test is preferred when data do not follow a normal distribution, as is the case here (Bellera et al., 2010). The null hypothesis is that the median of the differences of the pairs of samples is zero. The alternative hypothesis therefore, is that the median of the differences of the pairs of samples is different from zero (Reimann et al., 2008).

A p-value <.05 never occurred in this test, so we cannot reject the null hypothesis. I can therefore conclude that this study found no differences between jurisdictions within a contrast. The test statistic V corresponds to the value of the signed rank statistic when performing the paired test. The V statistic, as reported in R statistical software, is the sum of the positive ranks of the difference between observed value and the null value of the median.

**Table 4**

*Wilcoxon test statistic (V) for matched pairs of jurisdictions (SEKI). Total number of weeds and disturbances occurrence along the transects for each jurisdiction within a contrast and Wilcoxon test statistic. Significant p-values based on alpha = 0.05 and symbolized with an asterisk.*

| | Contrasts | | | |
|---|---|---|---|---|
| | **BLM - USFS Non-Wilderness** | **BLM - USFS Wilderness** | **NPS - USFS Non-Wilderness** | **USFS Non-Wilderness - USFS Wilderness** |
| **Weeds** | | | | |
| Total Weeds | 1,202 - 1,285 | 644 - 532 | 203 - 121 | 843 - 967 |
| Test Statistic (V) | 37.00 | 59.50 | 4.00 | 10.00 |
| **Disturbances** | | | | |
| Total (human and natural) | 1,198 - 1,132 | 908 - 1,053 | 646 - 637 | 1,153 - 932 |
| Test Statistic (V) | 48.00 | 92.00 | 19.00 | 84.00 |
| **Human Disturbances** | | | | |
| Total | 36 - 37 | 14 - 1 | 18 - 76 | 79 - 110 |
| Test Statistic (V) | 33.00 | 30.00 | 6.50 | 23.50 |
| **Natural Disturbances** | | | | |
| Total | 1,162 - 1,095 | 894 - 1,052 | 628 - 561 | 1,074 - 822 |
| Test Statistic (V) | 49.00 | 98.00 | 22.00 | 83.00 |

Note. * $p < .05$. ** $p < .01$. *** $p < .001$.

### *Correlations Between Weeds and Disturbances by Jurisdiction*

To test for the strength of association between weed abundance and disturbance types I used Spearman’s rank correlation coefficient, a nonparametric statistical measure of the strength of the association between two variables (Shepherd et al., 2018). It is used when the distribution of data makes the outcome of the Pearson’s correlation co-efficient disingenuous or misleading. The Spearman’s coefficient is not a measure of the linear relationship between two variables, rather, it determines how well an arbitrary monotonic function can describe the relationship between two variables, without making any assumptions about the frequency distribution of the variables (Hauke & Kossowski, 2011). The Spearman correlation ranges between -1.00 and +1.00, and as noted in the “Rule of Thumb” from Hinkle et. al., (2003), as the coefficient moves closer to -1 or +1, the strength of the correlation increases.

However, confidence intervals can often be more telling than the correlation coefficient; when a 95% CI does not include a zero-treatment difference, this demonstrates that the results are statistically significant. When the upper and lower confidence intervals do not pass through zero, this is equivalent to a *P* value less than .05. Therefore, the presence or absence of a zero-treatment difference in a 95% CI gives the same information as a statement that *P* is greater or less than .05 (K. D. Young & Lewis, 1997). Using this metric, the only significant correlations detected in the SEKI PACE were between weeds and total disturbances and weeds and natural disturbances in USFS (NW) jurisdictions (Table 5).

**Table 5**

*Spearman's correlation coefficient (ρ) (SEKI). Measured between weed abundance and total disturbance, human disturbance, and natural disturbance abundance by jurisdiction, standard error, and upper and lower confidence intervals (CI) controlling for site in SEKI.*

| | Spearman's ρ | Standard Error | Lower CI | Upper CI |
|---|---|---|---|---|
| **Weeds x Total Disturbances** | | | | |
| BLM | 0.07 | 0.16 | -0.25 | 0.39 |
| NPS | 0.07 | 0.29 | -0.50 | 0.65 |
| USFS Non-Wilderness | 0.30 | 0.13 | 0.04 | 0.57 |
| USFS Wilderness | 0.27 | 0.16 | -0.05 | 0.58 |
| **Weeds x Human Disturbances** | | | | |
| BLM | 0.09 | 0.16 | -0.24 | 0.42 |
| NPS | -0.29 | 0.29 | -0.87 | 0.29 |
| USFS Non-Wilderness | 0.02 | 0.14 | -0.25 | 0.30 |
| USFS Wilderness | 0.00 | 0.16 | -0.33 | 0.32 |
| **Weeds x Natural Disturbances** | | | | |
| BLM | 0.04 | 0.16 | -0.28 | 0.36 |
| NPS | 0.24 | 0.29 | -0.33 | 0.82 |
| USFS Non-Wilderness | 0.34 | 0.13 | 0.08 | 0.61 |
| USFS Wilderness | 0.28 | 0.16 | -0.03 | 0.60 |

*** Confidence level used: 0.95**

### ***Correlation Differences Between Weeds and Disturbances by Jurisdiction Contrasts***

Using the same linear mixed-model used to test for the strength of the association between weeds and various disturbances by jurisdiction, I compared these correlations among jurisdiction contrasts to determine whether the strength of these correlations was significantly greater in one jurisdiction than another. This analysis yielded no evidence of differences among slopes between jurisdictions. A small p-value corresponds to a large difference that would have provided evidence that the two slopes were not equal. Here, a $P<.05$ did not occur. Therefore, while moderate and low correlations did exist between weeds and total and natural disturbances within jurisdictions when controlling for site, the slopes of these correlations when compared to each jurisdiction's contrast was not significantly different, suggesting that in this PACE, differences in management practices are not currently impacting plant ecology or disturbances at jurisdictional boundaries (Table 6).

**Table 6**

*Spearman's correlations (ρ) difference between jurisdictions (SEKI). Standard error of the regression of ranked and standardized weed abundance on ranked and standardized total disturbance, human disturbance, and natural disturbance abundance among pairs of jurisdiction contrasts. P-values adjusted using the Tukey method to control for family-wise Type I error.*

| | **Contrasts** | | | |
|---|---|---|---|---|
| | BLM - USFS Non-Wilderness | BLM - USFS Wilderness | NPS - USFS Non-Wilderness | USFS Non-Wilderness - USFS Wilderness |
| **Weeds x Total Disturbances** | | | | |
| Spearman's ρ | -0.24 | -0.20 | -0.23 | 0.04 |
| Standard Error | (0.21) | (0.22) | (0.31) | (0.20) |
| **Weeds x Human Disturbances** | | | | |
| Spearman's ρ | 0.07 | 0.09 | -0.32 | 0.03 |
| Standard Error | (0.20) | (0.22) | (0.33) | (0.19) |
| **Weeds x Natural Disturbances** | | | | |
| Spearman's ρ | -0.30 | -0.24 | -0.10 | 0.06 |
| Standard Error | (0.20) | (0.22) | (0.30) | (0.20) |

Note. * p < .05. ** p < .01. *** p < .001.

### *Elevation and Weeds*

Scatterplots of data points and extracted elevation values show no linear trend between total weeds and elevation gradients. Due to this observation no further analysis was performed. Figure 10 shows that in SEKI, in sites above 2,000 meters in elevation, non-native invasive weed species occurred very rarely. Below 2,000 meters, no elevation-related pattern of weed occurrence was found. Figure 11 illustrates similar patterns for LAVO.

**Figure 10**

*Mean elevation and total weeds by jurisdiction in the SEKI PACE. Each point represents a site and corresponds to a jurisdiction.*

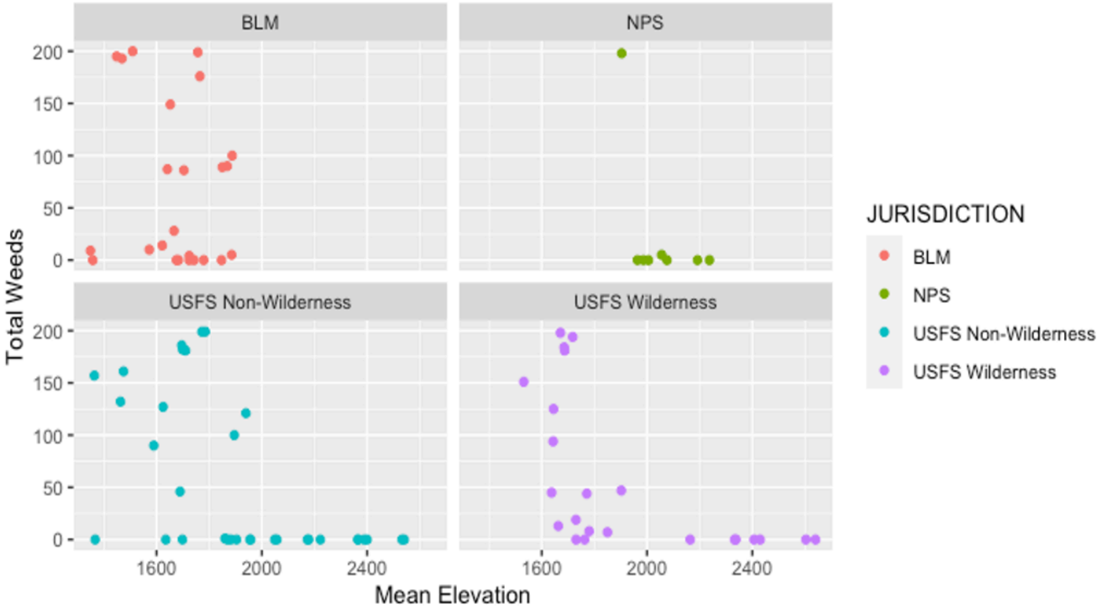
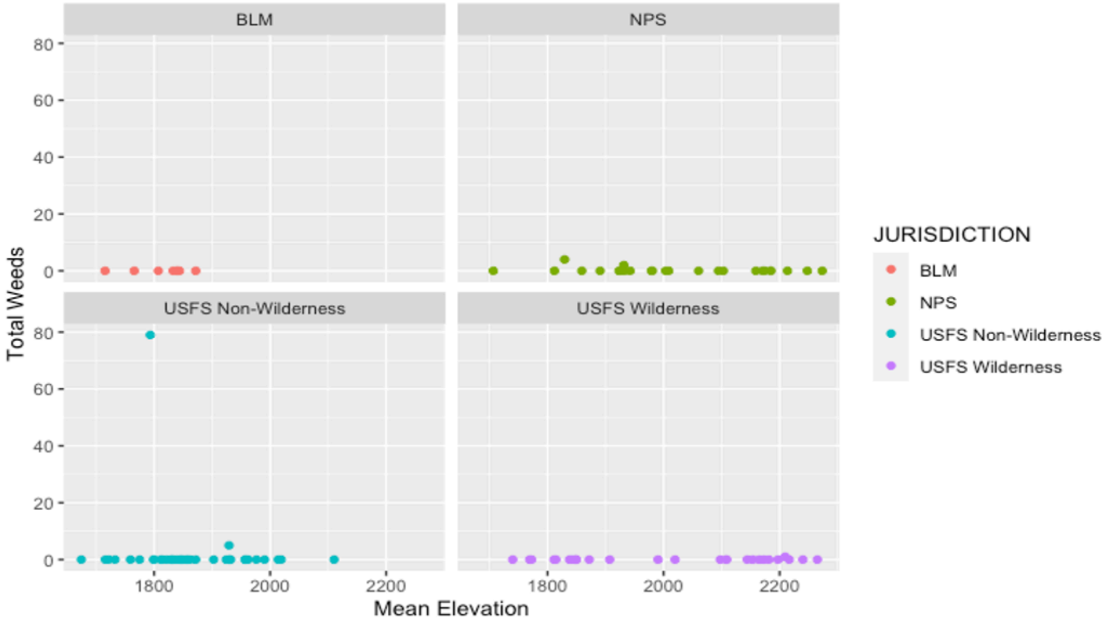


**Figure 11**

*Mean elevation and total weeds by jurisdiction in the LAVO PACE. Each point represents a site and corresponds to a jurisdiction.*



## Discussion

Protected areas are subsets of larger ecosystems and are vulnerable to changes and management related disturbances in the unprotected portions of these PACEs (Hansen et al., 2011). Divergent trajectories of habitats and ecological flows can occur at political land boundary areas when managers from neighboring jurisdictions apply different objectives and activities over time (Aslan et al., 2020; Holcomb et al., 2011). Understanding how divergent management practices can influence native and invasive plant communities, as well as other landscape scale ecological processes across multi-jurisdictional landscapes is fundamental to predicting how ecosystems respond and how habitat connectivity varies in these landscapes (Aslan et al., 2020). Once we have this information, we will be better able to discern the most appropriate course of action to protect our natural resources in these ecologically valuable, and socially complex areas.

From this research, it is still unclear if weed occurrence and/or disturbance events were likely to be significantly greater in one jurisdiction than another. At first glance, descriptive statistics, bar graphs, and total raw counts of weed and disturbance presence as recorded along transects suggested some subtle differences among jurisdictions. Preliminary observations of the data in the SEKI PACE indicated that BLM jurisdictions had the highest average occurrence of weeds, total disturbances and natural disturbances per unit, while USFS (NW) jurisdiction had the highest average occurrence of human disturbances. This is perhaps unsurprising, as the NPS was established to manage for combined conservation and recreation, whereas the BLM and USFS manage their lands for multiple uses, including recreation, grazing and timber (Aslan et al., 2020; Mcclaran, 1990). However, under scrutiny of the Wilcoxon matched pairs signed rank test, no significant statistical differences in weed and human/natural disturbance occurrences were found between jurisdictions. This means that in this PACE, differences in land management between jurisdictions has not yet led to a significant difference in disturbance or weed presence, or that the scope of this study or study design was not able to detect differences that might exist in this PACE.

While I found very few units with weeds in LAVO, some units did have evidence of natural or human disturbance. The lack of invasion of those disturbed sites suggests low propagule pressure, likely because the sites were generally far from trails, roads, or other sources of weed transmission (Lockwood et al., 2009; Yeates et al., 2012)

To delve deeper into the strength of the relationship between disturbance events and weed presence, I examined whether a correlation existed between weeds and disturbances in a jurisdiction when controlling by site, and if the correlations found in jurisdictions differed significantly *among* jurisdictions. In SEKI, some significant positive correlations were found between total disturbances and weeds, and natural disturbances and weeds in three out of four jurisdictions. These findings were strongest in USFS (NW) jurisdictions.

Contrary to my expectations, no significant positive correlations were found in any jurisdiction between weeds and human disturbances. This is likely because human disturbances were decidedly low in the sites I surveyed. It’s also possible that the areas where human disturbances were found, represented ecologically valuable areas, or recreation destinations that are more highly visited, but also more highly managed. For example, in national parks and other protected areas, some research shows that the number of NNIS is often seen as decreasing as the distance from a boundary increases

(Foxcroft et al., 2019). These areas can also be home to more endemic or sensitive species, of which are often formally protected (Gaston et al., 2008). The popularity of these areas for recreation activities can also help finance conservation-related activities (Barros & Pickering, 2017). The correlations found in jurisdictions between weeds and disturbances did not however, differ significantly *among* jurisdictions. That is, the relationship between presence of weeds and disturbances was not significantly different in any one jurisdiction. Based on this study, we cannot say that the disturbances caused by management practices of one entity is having a stronger impact on the presence of NNIS than another. This suggests that jurisdictional boundaries in this PACE do not track hard, consistent divergencies in disturbances and weed presence, instead, the plot-scale differences across boundaries between jurisdictions were more subtle (Aslan et al., 2020).

To determine whether elevation played a role in the occurrence of invasive species, a qualitative assessment using scatterplots of the relationships between elevation and weed occurrence were made. This assessment showed no evidence for an elevation gradient except that NNIS were rarely found above 2,000 m elevation. This finding supports existing literature (Alexander et al., 2010; D'Antonio et al., 2004; Pauchard et al., 2009) asserting that invasive plants do not grow well at higher elevations. However, 2,000 m appears to represent a threshold in these ecosystems, as I found no evidence of a gradient whereby weed occurrence decreases as elevation increases. Elevation may have played a role in the low occurrence of weeds, particularly at NPS sites as NPS land is situated at a higher elevation than most of the surrounding land in both PACEs.

### ***Study Limitations***

Studying vegetation patterns along jurisdictional land boundaries can give insight as to how divergent land management practices influence plant community structures and ecological flows in these areas, and also about how to appropriately manage discrepancies. My sampling strategy, which focused on cross-boundary comparisons, did not detect large numbers of disturbances and weeds, and was appreciably unbalanced in terms of number of jurisdictional units surveyed. The study was set up to be an incomplete block design; the best incomplete block designs are balanced such that each treatment (here, jurisdiction) occurs the same number of times with every other treatment. This study was not able to meet that goal. In each park, the design includes data from only four of the possible six combinations of four jurisdictions.

Findings of non-significance in this study between jurisdictions can be attributed to a variety of unforeseen variables. The spatial scale and design of sampling (50 m belt transects) may not have been commensurate with spatial scale of weeds and disturbances. If weeds are known to be at LAVO, which they are, according to NPS and USFS employees, the near-total absence of weeds and a plethora of zero percent cover for some disturbances on transects might suggest that a different sampling protocol would have been better. Alternatively, these findings might simply mean that the weeds present in LAVO aren't found along boundaries in the backcountry but are concentrated in locations that are more heavily traveled. This would be consistent with invasion theory (Anderson et al., 2015; Barros & Pickering, 2014; Potito & Beatty, 2005; Tyser et al.,1992). Based on this low occurrence of weeds and disturbances, I would recommend that similar studies in the future either sample many more sites using a similar method or explore other sampling methods such as adaptive or opportunistic sampling.

Adaptive sampling refers to sampling designs in which the procedure for selecting sites or units to be included in the sample may depend on values of the variable of interest observed during the survey. This approach may take more time and resources but would likely result in more precise estimates of weed and disturbance occurrence (Thompson, 2013). Opportunistic sampling involves observers to record chance observations of a phenomenon in their general study area. Opportunistic sampling is not probability-based nor is it guided by a model-assisted design. This kind of design is substantively different from sampling based on randomization, or purposive sampling based on assumed environmental features (Williams & Brown, 2019). These types of sampling are not without flaws; both are subject to selection bias, non-detection, observer bias, recording errors, and other factors (Isaac et al., 2014). Sampling locations would have to be restricted to areas with jurisdictional boundaries nearby; I would suggest if a disturbance or population of NNIS is found in one jurisdiction, the researcher should then cross the boundary to the other side and survey that area as well.

The lack of a physical barrier between jurisdictions throughout the PACE allows animals and humans to use the site as if it was a single unit. Given this unexpected scenario, there is little reason to think that a significant distinction between jurisdictions would exist in this particular PACE. We might expect that in PACEs with physical barriers and higher levels of disturbances such as grazing by domestic livestock, divergences in plant community composition would be more pronounced. Absence of fences may well have heavily influenced these findings. Future studies focused on ecological differences between management units should scout and try to select locations that have a physical barrier separating jurisdictions so that differences in disturbances and management practices might be more pronounced. Additionally, studies comparing PACEs whose boundaries have barriers compared to those that do not could be an interesting topic to pursue to see to what extent physical barriers reduce the movement and dispersal of NNIS and disturbances.

Other contributing factors to findings of non-significance may include the locations of my treatments. It's possible that the effects of these differences don't fully manifest themselves right at these border areas, or differences in land use and management of adjacent jurisdictions were not as important as other effects in this PACE. Differences in plant community structures and disturbances may be more apparent if pairs were farther apart. For example, some activities such as logging are generally not occurring right up against a park boundary, so there might be a transition zone. However, where there's livestock grazing and fences, you might expect to see a sharper contrast in soils or plant community composition. In the LAVO and SEKI PACE, recordings of cattle presence were low; in LAVO, cattle presence was not observed at all. In SEKI, even in sites with cattle presence recorded, we would not expect to see sharp edges due to the lack of a barrier between jurisdictions.

## Conclusions and Implications

Although no significant differences were observed in weed or disturbance occurrence between jurisdictions in this PACE, this work still helps to elucidate what is occurring in plant community structures at political land boundaries as a result of management. This enables us to better understand how management mosaics influence ecological flows and processes across various different landscapes, as well as how they may differ from PACE to PACE based on terrain, elevation, land use history, and barriers. For example, in PACEs with fences and jurisdictions with differing levels of human visitation and recreation, history of heavy grazing and varied management interventions with regards to fire, we might see a much different outcome.

Over time, variations in natural resource management may create divergent plant communities, soils, or disturbance regimes, possibly leading to negative effects on biodiversity. This kind of ecological fragmentation is therefore often a result of social fragmentation in areas where many different management units exist (Aslan et al., 2020). Due to the lack of barriers present in this particular PACE from one jurisdiction to another, disturbances and NNIS on adjacent lands may have a greater likelihood of affecting protected areas in the future. Given this, the SEKI PACE and its land stewards are faced with two different options in controlling the spread of NNIS across ecologically valuable areas. 1) Erect fences to slow the spread of NNIS and other ground disturbances that are easily crossing from one jurisdiction to another or, 2) Embrace the lack of fences and use it as an incentive to increase collaborative management at these areas while NNIS occurrence is still fairly low. No system can remain immune from disturbances and NNIS in the future as climates warm and ranges for NNIS expand, but adaptive, cooperative management and an understanding of how disturbances influence NNIS may be a way to effectively fight the war against weeds in these ecologically valuable areas.

Biological invasions are complex problems to address due to their movement across landscapes and ownerships, and can be difficult to rally support for because of uncertainty regarding the timing and extent of consequences (Lien et al., 2019). Changing climatic conditions will likely make the challenge of forecasting the severity of consequences of NNIS even more challenging (Brenner & Franklin, 2017). Ecosystem management, in which management goals are directed at sustaining healthy ecosystem functions over time and space, and across administrative and ownership boundaries (Landres et al., 1998), becomes possible only when managers of adjacent jurisdictions jointly undertake management to achieve common goals.

In this study, high concentrations of weed and disturbance occurrences were found together very rarely. Divergent management by differing jurisdictions has the potential to play a role in ecosystem composition, however the type and intensity of disturbance may be a major driver. This work suggests that some sort of threshold of disturbance might a factor worth pursuing in future analysis of similar research be the next level in this analysis. Lastly, I would recommend an alternative sampling strategy be used, either through purposive sampling of areas along borders known to support NNIS or using a design that allowed detection of weeds farther from jurisdictional boundaries.

Managing the movement of NNIS and protecting native plant communities and wildlife habitat is fundamentally a social-ecological-system challenge. Addressing this challenge will require further research and different research methods to understand what kinds and levels of disturbances are related to different land-use practices, and the influence these practices are having on ecological flows and processes concerning plant and animal communities.

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# CHAPTER 3

# UNDERSTANDING COOPERATIVE INTERACTION AND BARRIERS TO COLLABORATION ACROSS JURISDICTIONAL LAND BOUNDARIES

## Abstract

Conservation plans and invasive species management are generally executed at the scale of independent jurisdictions. However, the important ecological processes and biodiversity we aim to protect from invasions are often spread over large spatial scales and across multiple jurisdictions. Jurisdictional land boundaries influence the flows and dynamics of ecological systems, as well as the social systems that exist in these complex landscapes. Regrettably, a majority of scientific research in the field of conservation science has disregarded how agencies are actually addressing particular cross-boundary management challenges, and what variables allows for success or failure. I interviewed federal, county and state agencies, research organizations, nonprofits and local stakeholder groups in two national parks and their surrounding lands in California, USA, in order to identify barriers and opportunities for cross-boundary stewardship and cooperative interactions with respect to invasive species management. Interviews revealed that some entities communicate, others practice forms of coordinated management, and very few are involved in collaborative management plans regarding invasive plant species. All participants agreed that working together with neighbors is a beneficial action to halt the movement of damaging weeds. However, they also reported

having mis-matching priorities, different geography, too little resources, too many job responsibilities, and not enough support from management to be able to engage in collaborative projects.

## Introduction

Protected areas (PAs) are designated to conserve and maintain biodiversity and ecosystems; to protect these areas from land use activities that occur outside their borders (Margules & Pressey, 2000). However, PAs are just one part of much larger ecosystems. To the detriment of many organisms, most PAs and the land they encompass are not designated by considering ecological completeness or function (Sacre et al., 2019), but rather by characteristics such as land use, scenic value, or ease of management (Pressey, 1994). Due to this lack of a holistic view, PAs may not effectively protect the very species and processes they were originally created to preserve (Davis & Hansen, 2011).

As disturbance regimes change, climate patterns shift, and human activities expand, interest in ecological flows and processes between national parks and their surrounding lands has increased (Hansen et al., 2011). When these ecologically invaluable environments are altered by human activities, the processes that occur within them will consequently be altered as well (Cumming et al., 2006). Due to the complexities of these ecosystems and their multiple interactions across landscapes, as well as between social and ecological systems, cooperative interaction between resource managers may be vital for the continued resilience and biodiversity within and around protected areas (Mayer & Rietkerk, 2004). The challenge land managers are confronted with, is how to effectively participate in cross boundary stewardship to manage for healthy ecosystems and the threats these ecosystems face; the most pressing among these threats being the movement of non-native invasive species (NNIS) (Fenichel et al., 2014; Shackleton et al., 2019).

NNIS are a recurrent environmental problem, causing hundreds of billions of dollars in damages annually, in addition to seriously harming the environment (Pimentel et al., 2005), and shifting fire regimes (Peeler & Smithwick, 2018). PAs, and the managed lands abutting them, may be more susceptible to invasions by weeds because of the extent and nature of disturbance in surrounding lands (Macdonald & Debenedetti, 1988). This is especially relevant to protected areas that are in close proximity to urban and agricultural settings.

Historically, broadscale management of NNIS has been a cause of conflict in the field of biodiversity conservation because of the difficulty of cooperative interaction (Stokes et al., 2006). Costs to each agency or private entity are evaluated differently according to stakeholder positions and priorities. Most stakeholders in natural resource management understand that NNIS have the potential to incur damage to economic interests, degradation to native habitats and damage to native species. However, they also acknowledge the substantial costs and time associated with prevention, control, and eradication of NNIS. Many private landowners and land management agencies lack adequate resources to dedicate towards NNIS when they have a host of other issues to worry about as well (Simberloff, 2003).

A key issue that hinders the possibility of cooperative interactions among different agencies in a complex natural landscape is the justification of resource allocation towards NNIS (Stokes et al., 2006). Stakeholders and managers or supervisors may express polarized viewpoints depending on how they are differently affected, or how they perceive the effect of NNIS in the context of other looming issues, such as fire and fuel management. Agencies in different sectors may view the significance of NNIS management differently. For example, the mission of the National Park Service is to "preserve, unimpaired, the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations (NPS.gov)." Controlling NNIS to preserve natural resources may be a higher priority for the Park Service compared to the Bureau of Land Management or Forest Service, whose goals are to manage lands to sustain multiple uses including grazing, hunting and fishing, recreation, timber harvesting, and energy development in addition to wilderness protection.

Regardless of the level of resources dedicated to NNIS management among agencies, one thing can be certain: invasive weeds and other disturbances pay no mind to property boundaries. They spread across the landscape, and if they are not controlled on one jurisdiction, they will continue to be a problem for the neighboring jurisdiction; a concept called "neighbor to neighbor spillover" (Fenichel et al., 2014). The concept of spillover is an important one in and around protected areas, which form management mosaics (Epanchin-Niell et al., 2010), in which numerous agencies and independent landowners exist. In these settings, control of NNIS is a complex problem because the success of control will require cooperative actions of all parties included in the management mosaic (Epanchin-Niell & Wilen, 2014).

In an era when globalization, growth in tourism, travel, trade, and transportation of goods and people are ever increasing, many barriers to the spread of NNIS have been undermined, allowing for more opportunities for introduction (IUCN, 2000). To mount a productive response to biological invasions in the face of these changes, in addition to mismatched management goals, resource managers could strive to create active partnerships with neighbors where common goals can be aligned (Simpson et al., 2009). Understanding how land managers adopt and use cooperative management relationships, and why, can help agencies and private landowners within and around protected areas establish plans to increase momentum for collaborative NNIS management across jurisdictions.

I present a case study focused on the ecosystems surrounding Sequoia- Kings Canyon and Lassen Volcanic national parks in California, in which challenges and successes of collaborative NNIS management are identified. I explore how neighbors' actions influence management, provide an overview of the challenges to NNIS cooperative management, describe various types of cooperative interactions among stakeholders involved in land management, and discuss the benefits of cooperative management that emerged from this research. Furthermore, based on findings from this study, recommendations are provided that may help agencies and private landowners overcome the barriers to collaborative management of invasive species, while taking into consideration differences in available resources and land-use priorities.

## Theoretical Framework

The delineation of what is called a protected area-centered ecosystem (PACE) helps conceptualize the span of ecological processes that occur both within and outside of PAs. PACEs are the larger zones around PAs, wherein ecological flows occur on a landscape scale (DeFries et al., 2007), and are the areas in which our research was conducted. Residents and managers who understand the important ecosystem services that originate from PACEs will have better incentive to support cooperative interaction strategies outside PAs. Recognizing that these processes occur on a large scale may be a catalyst for action from landholders in both the public and private sectors in order to maintain a healthy ecosystem in the face of increasing anthropogenic pressure.

While the concept of a PACE may address the span of ecological activity, what it doesn't consider is how to effectively manage these large areas, which are comprised of many individually managed properties, all of which have a variety of different uses, as well as management priorities. How each jurisdiction uses its land may determine presence and diversity of NNIS, and how these agencies decide to manage NNIS over time may create starkly different ecological communities or ecosystem types. This ecological contrast has the potential to inhibit or alter important biotic flows and functions across PACEs (Fenichel et al., 2014). As it is not uncommon for conservation features and ecological processes to be distributed across landscapes (whether at a watershed, county, state or even national level), conservation outcomes will therefore be conditional on interactions that are made across multiple jurisdictions (Kark et al., 2014).

Scant literature in the field of natural resources has addressed the empirical differences between the terms, 'cooperation, communication, coordination, and collaboration', despite their frequency of use (Keast et al., 2007; McNamara, 2012). For the purposes of this thesis, 'cooperative interaction' will serve as an umbrella term, wherein communication, coordination and collaboration reside (Yaffee, 1998). Keast et al., (2007, p.17), utilizing qualitative research findings, defines cooperation as "getting along with others so that you can both achieve your own goals” and, “taking each other’s goals into account and trying to accommodate those goals.” In essence, cooperation reflects various behaviors and interactions that encourage a mutually beneficial relationship with one or more people from different organizations (Yaffee, 1998).

Under the umbrella of cooperation, communication is at the beginning of the continuum, requiring the least amount of effort. Communication involves recognizing and being aware of others’ priorities, and goals, sharing knowledge, and talking about others’ activities and current projects. In the context of NNIS, communication may include annual meetings with other natural resource managers from geographically similar areas and sharing successes and failures for weed treatments. Communication however, unlike coordination and collaboration, often doesn’t lead to any kind of collective or mutually beneficial action.

While communication has very little sustained involvement and doesn’t lead to actions or partnerships performed by two parties to achieve similar goals, there is a value in talking to others. Communication creates knowledge-sharing opportunities which may help individuals more effectively treat weeds, and keeps doors open so that more involved forms of cooperative interaction may be possible in the future.

Coordination requires a higher degree of effort, and establishes a higher level of integration between entities (Keast et al., 2007). Coordination often involves an interaction with another agency in which information sharing or participation is advantageous in achieving independent goals, while also not conflicting with the goals of the other entity involved (Yaffee, 1998). Generally, coordination occurs when there is a need to align, to more effectively address priorities (Litterer, 1973). Organizations remain autonomous (Cigler, 1992), but contribute to specific, coordinated actions which do not harm, and generally benefit the partners they're coordinating with, if only indirectly.

Even farther along the cooperative interaction continuum exist collaboration. In simple terms, collaboration is defined as "active partnerships with resources being shared or work being done by multiple partners (Yaffee, 1998, p. 301)." However, collaboration is much more involved than that. In collaborative interactions, participants work together to address complex problems and collective interests which cannot be accomplished independently (Mattessich et al., 2001). The partnerships and relationships that exist in collaboration entail trust, taking risks, sharing resources, planning together to an extent where at times, "a blurring of the boundaries between organizations" occurs (Keast et al., 2007, p.19). Collaboration may be desirable, and sometimes even necessary, to tackle a problem no one organization can accomplish alone, but the research evidence indicates that it is hardly easy (Bryson et al., 2006). However, if achievable, ecosystems benefit, as well as the organizations that are involved.

Collaborative advantage is a theory put forward by Huxham & Vangen (2005) that posits that collaboration fosters creativity, prolonged and meaningful partnerships, and the ability of multiple organizations to achieve its objectives better than it ever could alone. These relationships are essential in a PACE with multiple land ownership because each stakeholder control decisions can directly and dramatically impact their neighbors' decisions and management activities by affecting the spread of species across boundaries (Epanchin-Niell et al., 2010).

When problems arise that are deemed of high importance, and that cannot be satisfactorily managed by a single organization, the likelihood of collaboration is predicted to increase (Gray, 1985). When agencies recognize that a new approach to working together is needed to address problems where and coordination have not been sufficient, collaboration may be the answer. Agencies that acknowledge the importance of collaborative action begin to not only share resources and work jointly, but they also begin to work towards collective action and changes on a systems scale; while they still represent independent organizations and missions, their perspectives represent a holistic one, where the need for landscape scale management is realized (Keast et al., 2007; Keast et al., 2004).

## Study Areas

Hansen et al. (2011), developed a framework to identify the zone around each PA wherein human activities and development may have a negative impact on ecological processes and their flows across the landscape. The PACE boundaries and their respective polygons are determined by six criteria: Hydrologic flows, atmospheric flows, disturbances, crucial habitats, effective size, and human impacts. Once delineated, the relevance of a PACE is to help land managers, policy makers and researchers focus on this area as the site and appropriate scale of monitoring, research, and collaborative management that is needed to maintain protected area function and condition (Hansen et al., 2011).

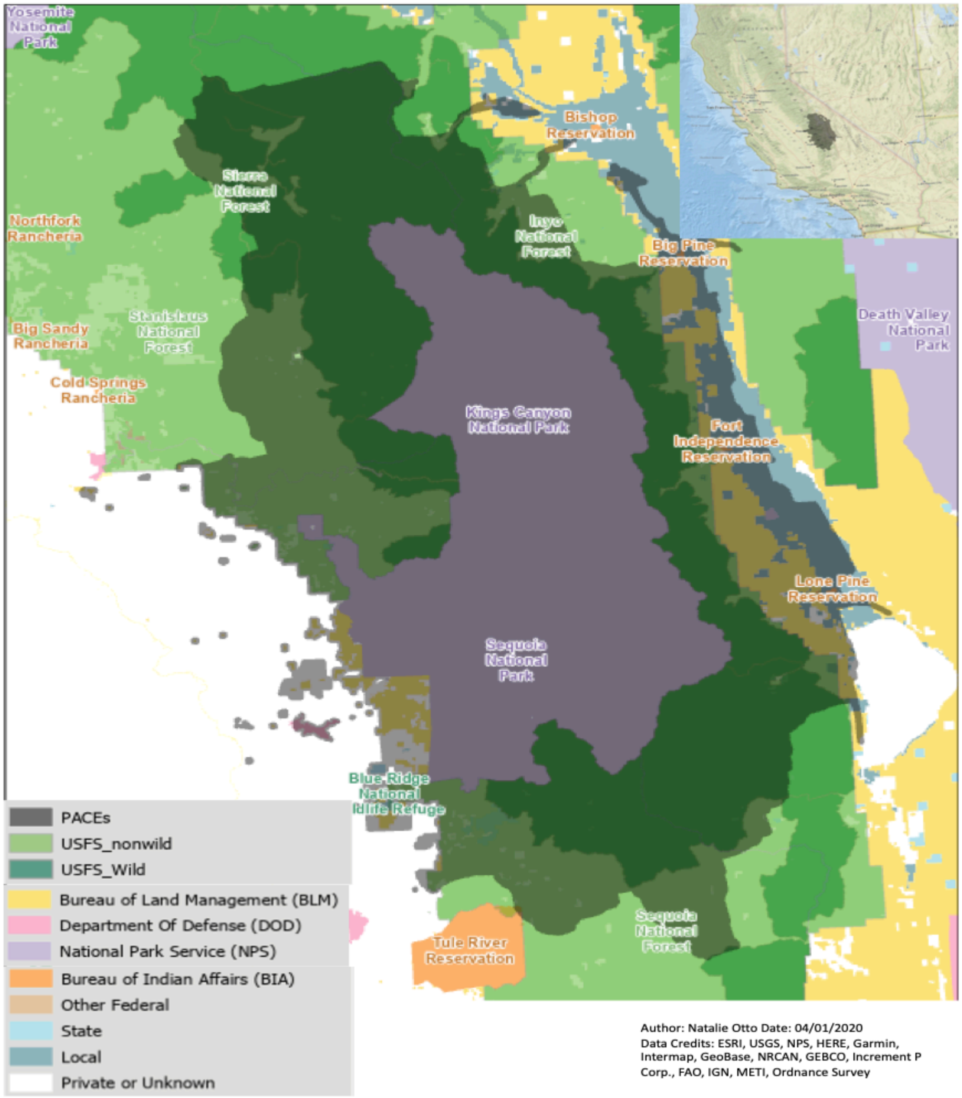
### *Sequoia Kings Canyon (SEKI) National Park PACE*

Sequoia and Kings Canyon National Parks (designated as SEKI in the National Park Service four-letter unit code system), are jointly administered, with a combined area of 865,857 ac. The parks are located in the southern Sierra Nevada range, approximately 100 km east of Fresno, California (NPS.gov). The Sierra Nevada constitutes a very topographically and biologically diverse region, not just in California, but in the whole of the western United States. This mountain range contains half of all the native plant species that occur in the state and provide habitat for over 400 endemic plant species (Shevock, 1996).

The SEKI PACE spans three different counties; Tulare, Fresno, and Inyo County, and three different Forest Service districts: The Sierra, Sequoia, and Inyo National Forests. Sequoia and Kings Canyon, along with the John Muir Wilderness represent the three protected areas within this PACE. In addition to National Park Service and Forest Service land, SEKI is also broken into a management mosaic consisting of private landowners and companies, the Bureau of Indian Affairs, Bureau of Land Management, city and county land, U.S. Fish and Wildlife Service, and NGO managed land. Those making up the largest portion of the PACE include NPS, USFS and BLM land. Figure 12 shows the SEKI PACE. In total, the PACE circumscribes approximately 4,700,000 acres of land.

**Figure 12**

*The greater SEKI PACE ecosystem. The PACE is a mosaic of multiple landowners, wherein NNIS and ecological processes flow across the landscape.*



Author: Natalie Otto Date: 04/01/2020
Data Credits: ESRI, USGS, NPS, HERE, Garmin, Intermap, GeoBase, NRCAN, GEBCO, Increment P Corp., FAO, IGN, METI, Ordnance Survey

According to the NPS, the number of visits to Sequoia National Park in 2018 was 1,229,594, while Kings Canyon received 699,023. Approximately 96% of the park is designated or managed as wilderness, which is accessible to visitors only on foot and horseback via a network of over 1,300 km of trails. Elevation at SEKI ranges from 1,370 ft in the foothills, up to 14,494 ft at the summit of Mount Whitney, a gradient of over

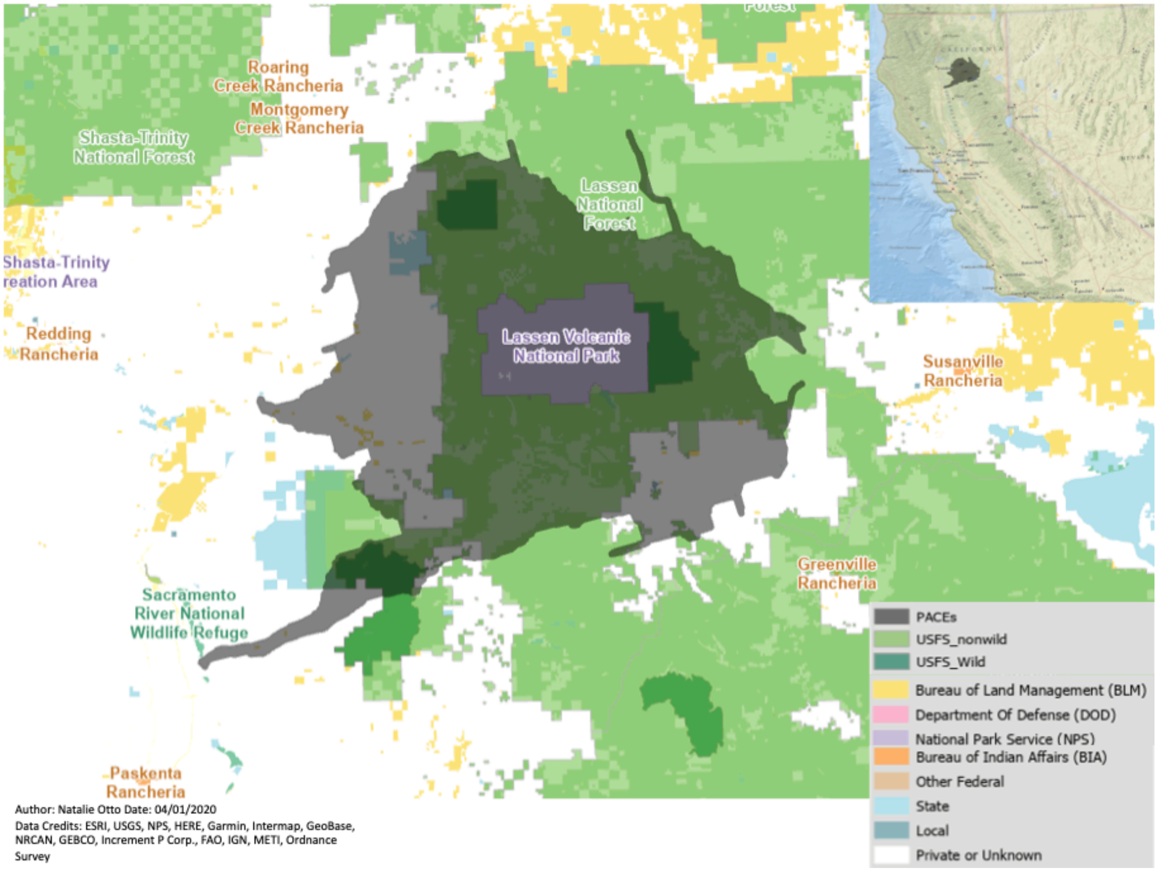
13,000 ft (Vizgirdas & Rey-Vizgirdas, 2006), allowing for a wide variety of habitats, and therefore plants, animals, and other organisms. Both parks are recognized as International Biosphere Reserves for their role in biodiversity conservation. SEKI is home to 1,300-1,500 native species of vascular plants and nearly 300 native animal species. However, even in protected areas, and despite best efforts by park employees, NNIS are present; out of the nearly 1,500 plant species in SEKI, 183 are non-native, with new species being identified each year. (Wrench, 2019).

### ***Lassen Volcanic (LAVO) National Park PACE***

The LAVO PACE is smaller, at approximately 930,000 acres within Tehema, Plumas, Lassen, and Shasta counties. This PACE includes three protected areas: Lassen Volcanic National Park, Thousand Lakes Wilderness, and Caribou Wilderness. The PACE is split into National Park Service, BLM, state, county and Forest Service land. Only one Forest Service jurisdiction is included, the Lassen National Forest, and includes three ranger districts: Almanor, Hat Creek, and Eagle Lake ranger districts. Figure 13 shows the LAVO PACE boundary and land division.

**Figure 13**

*The Greater LAVO PACE Ecosystem. Located in Northern California. As with the SEKI PACE, LAVO encompasses many different landowners, but with most representation being USFS, NPS, state and BLM.*



Author: Natalie Otto Date: 04/01/2020
Data Credits: ESRI, USGS, NPS, HERE, Garmin, Intermap, GeoBase, NRCAN, GEBCO, Increment P Corp., FAO, IGN, METI, Ordnance Survey

In 2018, the number of visitors to Lassen Volcanic National Park was recorded by NPS as 499,435. The park encompasses 166 square miles of volcanic features, boasting the most thermal features in the Cascade Range. The region is bounded on the west by the Sacramento Valley, on the south by the Sierra Nevada, on the east by the Basin and Range Province, and on the north by Mount Shasta and Medicine Lake volcanoes (Clynne & Muffler, 2017).

Lassen Volcanic National Park ranges from 5,275-feet to 10,457 in elevation. Below 6,500 feet, the park is comprised of conifer forest. From 6,500 to 8,500 feet, the park transitions to a Red Fir forest. In the subalpine zone, 8,000 to 10,000 ft, there is very sparse to no vegetation. According to the National Park Service, the greatest threats to Lassen's native flora and fauna include climate change, competition with invasive plants, and historical fire suppression ("Non-Native Invasives" 2019).

## Methodology

### *Semi-Structured Interviews*

I used a qualitative, phenomenological, case study approach involving semi-structured interviews with various individuals involved in land management in the SEKI and LAVO PACEs in California to address this primary research question: "What are the lived experiences of people in land management positions within a PACE, in regard to NNIS ecology and management, specifically cooperative interactions?" Taking an interview approach provides in-depth information about the participants' lived experiences and viewpoints associated with the particular phenomenon under study.

Semi-structured interviews allow subjects to talk about the topics they deem important and are passionate about, while at the same time allowing researchers to learn more about the topic of study. Questions were developed to focus on various aspects of NNIS but centered on the challenges and opportunities associated with collaborative NNIS control across jurisdictions. I drew on themes found from interview data by the process of coding the interviews, to develop an in-depth case study of NNIS management efforts, or lack of efforts, and used the case to describe themes and mechanisms that might prompt effective collective action by land managers.

The purpose of this research is to analyze and describe a group of people involved in land management and the processes and problems they encounter when faced with cooperative NNIS management decisions. Simons, (2009, p.21), defines a case study as: “An in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in ‘real life”. George and Bennett (2005) identify four benefits to a case study approach: Their potential to achieve conceptual validity of research themes, ability to foster new hypothesis, usefulness for being able to closely examine mechanisms, understand relationships and processes, and their capacity for addressing complex questions.

In a phenomenological study, one is concerned with the lived experiences of the people involved in the phenomenon being researched. In this case, the phenomenon is cooperative NNIS management within a PACE, or, the concept of working together to address landscape scale processes. This phenomenological research aims to focus on what participants have in common as they experience the phenomenon of cooperation; to reduce the experience to a description of the “essence” of the phenomenon (Creswell & Poth, 2018). The ‘essence’ is the culminating aspect; it is the ‘what’ and ‘how’ of the experience. Therefore, phenomenology isn’t simply a description of experiences, but it is also an interpretive process wherein I interpret common lived experiences that are found throughout the conversations with interviewees.

Interviews provided comprehensive information about the ways in which agencies within a PACE deal with NNIS, the challenges they face in management and their participation in cooperative interaction. The interviews shed light on individual perceptions of cooperative partnerships, and themes such as the importance of collective action and management of NNIS across landscapes, as well as the perceived impacts and damages caused by NNIS. In addition, interviews portrayed the emotions individuals felt towards relationships (or lack of relationships) they had with their neighbors, lending depth to this thesis. A semi-structured interview guide was developed, consisting of 26 questions which I expected to take a half hour to an hour to answer (Appendix B). Initial questions focused on their background in natural resource management, then progressed to specific questions about NNIS in the areas they work, followed by questions relating to differences across jurisdictions and cooperative management successes and barriers. Semi-structured interviews involved prepared questions but did not restrict the interviews if the subjects digressed from a direct question. This approach allowed participants to discuss what was important to them, express their values, and communicate ideas as they came up naturally, while also providing insight about the study topic that we may not have gleaned otherwise.

### *Data Collection*

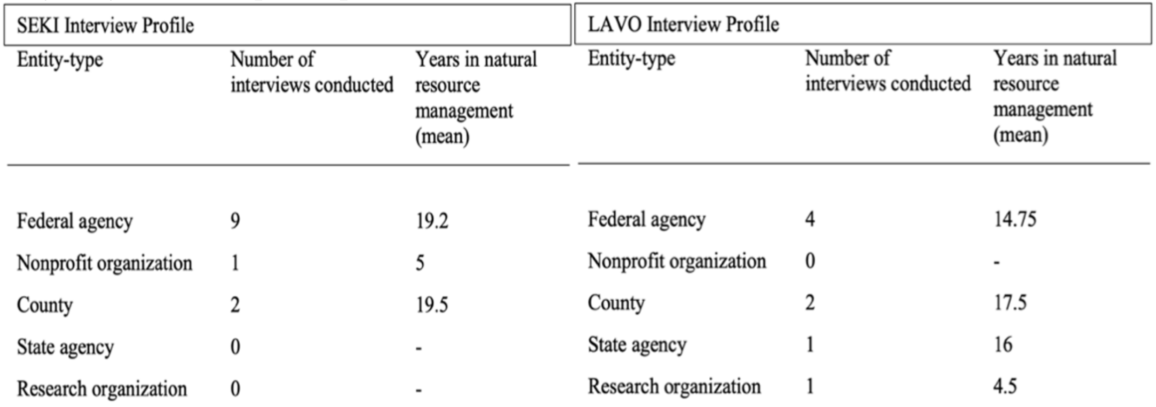
Interviews were conducted in August-November 2019. Interviewees were identified by contacting jurisdiction offices within the PACE to identify persons with direct responsibility for NNIS management. After the initial interviews had been conducted with these primary interviewees, I employed “snowball sampling” (Biernacki & Waldorf, 1981) by asking if they could refer me to other individuals who they thought might have valuable insight. I continued with this method until saturation was reached, i.e., no new information or themes were observed in the interviews (Guest et al., 2006). The numbers recommended to reach saturation vary, but generally fall between 5-25 interviews for a phenomenological study (Creswell, 1998).

Ideal candidates were contacted by email with a letter of invitation to participate. If they did not respond within a few weeks, they were called and invited to participate. If they accepted over the phone, recruitment materials were re-sent to them over email (Appendix B). Once they consented to participate, I scheduled an interview time that was convenient for them. With interviewees' permission, the interview was recorded both on the phone, as well as a recording device for back-up. All but one interview was conducted over the phone.

In total, 20 individuals volunteered to participate, 8 from the LAVO PACE and 12 from the SEKI PACE. Saturation was reached for both PACEs. The interview durations ranged from 22 to 90 minutes. Interviews involved individuals employed by the United States Forest Service, National Park Service, Inventory and Monitoring Program, California Department of Transportation, the UC Cooperative Extension, California Departments of Agriculture, Weed Management Areas, Sequoia Riverland's Trust, and the Natural Resource Conservation Service (Table 7). These agencies represent the PACEs management mosaics wherein federal, public, state, local, and nonprofit organizations co-occur.

**Table 7**

*Profile of interview participants.*



| SEKI Interview Profile | | | LAVO Interview Profile | | |
|---|---|---|---|---|---|
| Entity-type | Number of interviews conducted | Years in natural resource management (mean) | Entity-type | Number of interviews conducted | Years in natural resource management (mean) |
| Federal agency | 9 | 19.2 | Federal agency | 4 | 14.75 |
| Nonprofit organization | 1 | 5 | Nonprofit organization | 0 | - |
| County | 2 | 19.5 | County | 2 | 17.5 |
| State agency | 0 | - | State agency | 1 | 16 |
| Research organization | 0 | - | Research organization | 1 | 4.5 |

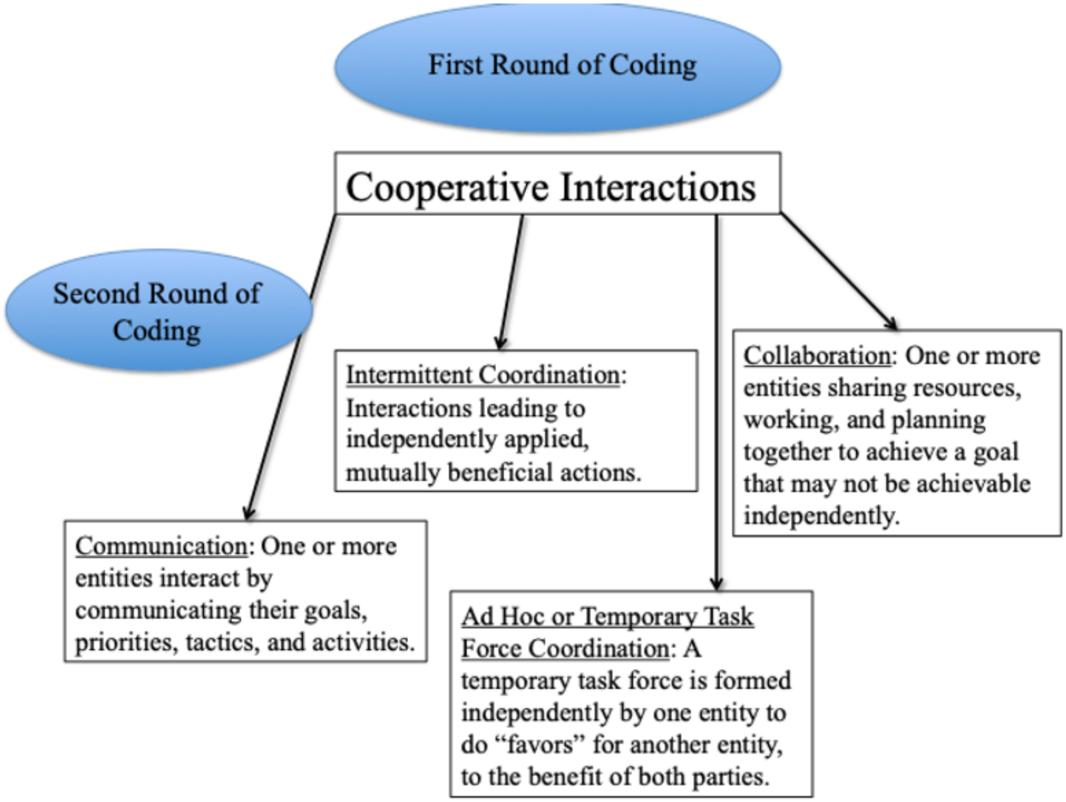
## Analysis

Before analyzing any of the interview data, I completed word-for-word transcriptions of 19 interviews. One interview was muffled, and the interviewee kept cutting out, so I transcribed half of it to the best of my abilities (I had interviewed another employee from this agency, so didn’t feel as though an incomplete interview with this subject would be detrimental to the study). Each interview was studied independently at first, then ATLAS.ti qualitative analysis software was used to code and highlight significant statements, sentences, and quotes that provided a description of how the participants have experienced working together with other agencies or private landowners in their PACE.

I first identified themes in ATLAS.ti by using an inductive, data-driven approach; using detailed readings of raw data to derive recurring concepts through interpretations made from the data (Thomas, 2006). The method was data-driven and exploratory in that I did not try to fit the initial coding into a pre-existing coding framework, as I wanted to follow this specific data and code based on the themes that emerged in the process. I did this by coding the interviews, first broadly, relating to the interview questions, then more succinctly in a second round of coding as pertinent themes began to emerge within these broader codes. Figure 14 shows an example of how this was performed. In doing this, I was able to develop 'clusters of meaning' by identifying the important common experiences of the participants (Creswell & Poth, 2018), which helped us to conceptualize underlying patterns. Once I had coded all relevant quotes, I had a total of 130 codes and 1,053 quotations.

**Figure 14**

*Coding Example. Diagram shows an example of first and second round of coding. The first round was based on interview questions, the second round was based on the common, specific themes to the question that emerged during the interviews.*



## Results

Five themes emerged from the interviews: (1) concerns surrounding NNIS, (2) present management disparities and observed differences between jurisdictions, and the influences those disparities have on management across borders, (3) the challenges of collaborative NNIS management, (4) the level of cooperative interaction that is occurring between different agencies and across jurisdictional lines, and (5) the perceived benefits and importance of collaboration.

### ***NNIS Ecology and Environmental Impacts***

All participants agreed that NNIS have an ecological or economic impact on the lands they manage, with the ecological impacts being reported as the most worrisome. Differences in responses between the two PACEs were negligible. Habitat quality degradation was the most commonly noted ecological consequence of NNIS, followed by impacts on biodiversity, NNIS' ability to alter fire and disturbance regimes, and their cascading ecological effects. These findings all correspond to well-known adverse effects of NNIS invasions in natural ecosystems. One participant describes the effects of NNIS,

> Weeds change fuel models, they push ecological communities over ecological thresholds that they can't get back over again, they change the fire return interval, they crowd out native species, which has a whole cascade of impacts on invertebrates, on birds and wildlife, and they have impacts on recreation as well.

Participants from both SEKI and LAVO specifically mentioned cheatgrass (*Bromus tectorum*) as a big issue, particularly in relation to shifting disturbance and fire regimes. This invasive annual grass has triggered environmental changes that have altered many ecosystems in the western United States (Peeler & Smithwick, 2018). As one SEKI participant voiced her concern, “I feel like there's not a lot we can do with the cheatgrass and the annual grass conversion… And the fire footprint is a big one ecologically, maybe the most extensive.”

### ***Management Disparities***

To better understand the management discrepancies between jurisdictions in a PACE, we asked participants if they noticed any differences between their management and their neighbors’ management of NNIS, and whether those differences impeded, benefitted, or had any influence on their management actions.

The most commonly observed difference was in the amount of resources their neighbors had available for NNIS management. While specific allocations for invasive species are not available for the units within the LAVO and SEKI PACEs, the U.S. Department of Interior (2020) reported that the National Park Service spent $23.2 million controlling invasive species in 2019. Overall, the National Park Service budget of $2.7 billion in FY2020 is greater than either that of the national forest system or Bureau of Land Management, although the NPS manages fewer acres than either of the other agencies (U.S. Department of thr Interior, 2020). USFS and NPS participants from both PACEs acknowledged that the Park Service had more funding and staff to dedicate to NNIS programs. County agriculture commissioners generally reported they had more resources than USFS, but less than NPS. One Park Service subject explained,

> The National Park Service and the funding for them has different priorities. What we find in particular with the national forest is that they share the same concerns that we do but have woefully fewer monetary resources. So, they really have to pick and choose their priorities.

To further portray how vast these differences can be, one USFS participant recalled, “I've seen presentations from park staff about their crews managing dandelions… I just can never imagine getting to that point - taking crews out and pulling dandelions out of meadows.”

The next most common responses were seeing or experiencing a difference in neighbors’ management priorities or land use goals; differences in weeds prioritized for control; and neighbors not managing their invasive weeds at all. Participants noted fire and fuel reduction as taking priority over managing weeds (specifically for USFS), protecting native species and healthy ecosystems as a priority for NPS, and managing for mixed uses as a priority for BLM and USFS. One NPS participant described the influence of fire on USFS priorities:

> I can tell you right now they're much more concerned with burning down somebody's town. You have to look at the prioritization of where we are right now. They don’t care about weeds. They don't. That's just the reality of it, weeds are not their concern.

Another subject describes the differences in priorities between agencies this way: “[BLM & USFS] manage quite differently - they have different mandates than the National Park Service, and the funding for them has different priorities.”

Differences in priority weed species were often a result of funding and having to “pick and choose battles”, as well as a consequence of topography; generally, the land outside of the national parks are lower in elevation and therefore host different, and often more, weed species. About one-fourth of respondents from both PACEs reported their neighbors not managing their weeds at all. Management disparity between neighbors has the potential to influence management of NNIS on one or both sides of a jurisdictional land boundary. These influences are most impactful both ecologically and economically when one jurisdiction is highly managing their weeds, and their neighbors are poorly managing, or not managing their weeds at all.

### *Influence of Disparities on Neighbors*

Generally, interview subjects from both PACEs reported the Park Service as having the most time, money, and financial resources to dedicate to invasive weed programs. Consequently, the Park Service most frequently mentioned having to watch their boundaries and manage those areas more heavily due to neighbor-to-neighbor spillover, and propagule sources from outside their jurisdiction. County agriculture commissioners also reported having to battle invading weeds from outside their jurisdiction. USFS employees were influenced by the Park Service in that, because of the higher control and more pristine land managed by the Park Service, they were often either asked, or felt obligated to prioritize management of NNIS in the areas where their land abutted park land. Regarding vigilance and battling outside weeds, one NPS employee said, “if we decide that say, cheatgrass is unacceptable and Forest Service, which has way too much land than they could feasibly attempt to control cheatgrass on, then it is up to us, because they’re not going to do it.” Another participant noted, “We always know that the spotted knapweed infestation that they (USFS) have could come across, so we are always watching.” While this was a common theme, another influence was how neighbor’s management of NNIS effected priority treatment sites. One participant described this prioritization,

> The patches (of weeds) that I've been treating for the longest time here are close to the park boundary as well as close to our wilderness boundary. So

> that has made it an extra priority, certainly, keeping it from spreading into the park and into our wilderness area is one of the objectives.

This sentiment was repeated by participants, particularly USFS employees who seemed to feel responsible for, and acknowledged the importance of, keeping weeds out of areas that are still fairly pristine, such as park land, designated wilderness, and backcountry areas. Participants identified a variety of cross-boundary influences on management under their jurisdiction. These included: having to be vigilant and fight back weeds spilling over from other jurisdictions, prioritizing certain areas in an attempt to keep weeds from creeping onto their neighbors' land, and a recognition of the need for all players to be on the same page to effectively manage NNIS.

The role for private landowners was identified as well and was mentioned in many different contexts. Some participants said private in-holdings and private landowners made up a very small portion of the land they manage and therefore weren't important players. Others said private landowners were very cooperative and would either treat their weeds or allow an outside entity to come onto their property and treat weeds. In the SEKI PACE, 'moderate involvement' was the most common response when asked about the level of involvement, while for LAVO, 'some involvement' was most common. One participant from SEKI voiced his pride in the working relationship he and his crew have with private landowners, "like anyone else they're up here because they love the land and the area, and I think that's where you try to find that common ground." Others however, said private land allotments were vacant, or owners were very uncooperative, making NNIS management in those areas a challenge. All participants that had substantial private inholdings agreed that their involvement was important for holding back the spread of weeds.

### ***Challenges to Cooperative Interactions and Collaborative Management***

In multi-ownership landscapes, the wide-ranging beliefs, values, and motivations of each stakeholder contribute to a highly complex pattern of landscape conditions (Stanfield et al., 2002), creating many challenges for ecosystem management. The need for cooperation across ownership boundaries has been acknowledged, and voiced for many years (e.g., Brunson, 1998). Agencies, organizations, and private entities alike face many challenges to forming and sustaining cooperative relationships. The main barriers that were reported by participants in this study include (1) limited resources (funding, time, personnel) and too many other job responsibilities, (2) differing management objectives/priorities, including priority weeds, (3) lack of managerial support and education and, (4) paperwork, and policy barriers on Federal land, such as NEPA requirements (environmental assessments and environmental impact assessments).

### ***Limited Resources***

Resource limitation was the most often reported barrier to NNIS control and collaborative management, mentioned by every LAVO participant and 75% of SEKI participants. Funding was frequently cited, as well as too few staff and not enough time. Participants noted that they had many other things to prioritize as well - many of the job titles participants held were not solely dedicated to NNIS control. One participant stated that, "You just don't have the time for it (collaboration) when you have one botanist for the entire forest." Another explained, "I think it's just a question of resources to acres. We have way higher resources for fewer acres whereas the Forest Service has squat for millions of acres." Regarding time management, a participant elucidated: "The time it takes to organize that… We don't have enough time to dedicate to invasive programs in general." Appropriate funding to allocate to NNIS for all entities within a PACE was seen as crucial for being able to cooperate in balanced collaborative partnerships.

### ***Different Management Objectives/Priorities***

The second most common barrier to cooperation was differing management priorities and land use objectives between entities in a PACE. The priorities and mission statements between organizations often differ in focus and scope: county agriculture departments are mandated to manage all Class A noxious weeds as defined by the California Department of Food and Agriculture, the National Park Service has the responsibility to protect natural and cultural resources, and the Forest Service and BLM are directed to manage land for a variety of uses. This dichotomy is described by one participant, "I think it's (collaboration) more driven by the Park Service. Because again, we have the mission to maintain the native-ness if you will. And Forest Service has a mission to graze and create more feet of lumber."

The propensity of the Forest Service to prioritize issues related to fire and fuel reduction above NNIS management, despite the connection of NNIS to increasing fire disturbances, was cited often. One participant reported that, "They're (USFS) so concerned about the fuel issue and fires and managing those aspects, it's a prioritization thing. When towns burn down, nobody cares about invasive species." Another participant stated that there would have to be some serious and obvious repercussions of NNIS before the Forest Service shifted their management priorities, such as extinctions of endangered species and huge spikes in invasive populations. In addition to different management priorities, subjects also reported that their top priority weeds were often different than their neighbors as well.

### *Lack of Managerial Support*

Lack of support from upper-level management was cited as a barrier to NNIS control as well as to NNIS cooperation. Lack of managerial support was a barrier especially relevant to federal agencies and was an obvious source of frustration for select federal participants; federal agencies are responsible for public interests and are susceptible to public influence, a barrier which can help, or hurt NNIS management. Currently, agencies such as the BLM and USFS are much more concerned with fuel and fire issues. Therefore, NNIS management is a much lower priority, despite scientific research that illustrates the role of invasive annual grasses in fire occurrence and intensity. One participant elaborated on the challenge of making upper-level management understand the importance of weed control, “As you move up you have to change the mindset at the federal level, you have to convince CDFA that weeds are important.”

Federal agency interviewees recognized the importance of education as a tool for leverage. One stated, “You've got too many under-educated, miseducated, or non-educated general public and politicians that just don't have a clue. And so, you're never going to get funding until you can raise up the understanding level of everyone.” Public perception can have a great impact on what federal agencies decide to prioritize and pay attention to. If there is no support from the public, priorities for these agencies may not align in a way that will allow for successful cooperative NNIS management programs.

### ***Paperwork and Policy Barriers***

This barrier was recognized by participants from both PACEs. Federal employees expressed frustration at the hoops they have to jump through, the paperwork and restrictions they have to complete, and how policy barriers such as NEPA documents hinder their ability to get anything done in a relatively quick manner, both independently and when working with others. A federal employee explained, “A lot of times bureaucracy for whatever reason impedes us; it takes a lot of work to push paper just to be able to do a simple task.” Participants not working for a federal entity conveyed similar frustration when describing attempts at cooperation. A non-federal employee expressed his frustration, “For as good intentioned as they (USFS) are, they get bogged down with paperwork, and the work doesn't get done because of that.”

Forest Service employees most often reported getting bogged down with paperwork and expressed annoyance at the time it takes to get National Environmental Policy Act paperwork done, especially when it came to the approval of herbicide use. They believed that NNIS management and cooperative partnerships would be more attainable with streamlined herbicide use documents and NEPA approval. Some Forest Service interviewees stated that with all their other job responsibilities to consider, the time and effort required for approval are often not worth it. That leaves no other option but hand pulling and other physical approaches to weed removal, which, at a large scale, and for certain perennial weeds, is far from effective.

### *Elevation*

Elevation was mentioned as a challenge, or a benefit by a majority of participants from both PACEs. Lassen Volcanic National Park ranges in elevation from 5,275 to 10,457 feet, while Sequoia Kings Canyon National Park ranges from 1,370 feet to 14,494 feet. Participants saw Lassen Volcanic National Park as having an elevation advantage, “They have this park that's at high elevation and it just doesn't get these big, high priority weeds. The higher elevations of the forest are relatively weed free.” Subjects in the SEKI PACE noted that the lower elevations and areas around the park have some bad invasions, but at higher altitudes these invasions are notably less, “Luckily for us, because the park goes up in elevation so quickly, most of the invasives are confined to the lower elevation, the foothills, and that’s obviously where a lot of the use is as well.”

Five participants suggested that climate change might shift plant community structures in higher elevation areas. They predicted more occurrences of NNIS at higher altitudes as the climate warms and growing seasons become longer, a trend that would consequently affect land managers’ capability to manage NNIS in more rugged and remote locations of the backcountry, “We know things are changing and invasives are potentially going to have the ability to start moving uphill as the climate warms and as winters change, the snow line heads uphill.” Shifting climate patterns will change disturbance regimes such as fire intervals and will alter the range and spread of NNIS. Existing data shows that climate change is already affecting species distributions and these changes and impacts on ecosystems are predicted to be extensive (Sala et al., 2000). These changes could create a multitude of new management challenges, making cooperative interaction an even more important mechanism to address these changes in ecologically and socially complex landscapes.

### *Cooperative Interactions*

Cooperation is characterized as falling into three sub-categories as described previously: communication, coordination, and collaboration, existing on a continuum spanning from the least amount of involvement and interaction (communication), to the most (collaboration).

### *Communication*

Communication is further defined as: One or more entities that interact through communicating their goals, activities, observation and NNIS treatment outcomes. Within this category of cooperation, knowledge and information was shared, and informal relationships developed, but these conversations did not lead to any kind of planned, mutually beneficial actions between entities; each jurisdiction chose to continue to work independently.

This type of cooperative interaction was reported by more than half of the interviewees in each PACE. Across both PACEs, communication was the second most common form of cooperative interaction mentioned. Communication between entities reportedly occurred generally 1-3 times a year, when different agencies from the region came together for meetings, conferences, or trainings to discuss natural resource related issues. One participant described the benefits of these in-person meetings in terms of networking and contact information: “I learn what person and what agency I have to deal with and who are the contacts, so it's a lot of opening doors and keeping the ball moving on controlling weeds." Another participant mentioned the importance of these meetings for education and knowledge sharing: "We really didn't have to reinvent the wheel, we shared our successes and our failures, and sharing the failures were just as valuable as the successes." Other participants mentioned the value of sharing successful herbicide mixtures, and other treatment methods for specific weeds.

### *Coordination*

Coordination can take various forms, from partnerships that are informal and loosely defined with a limited scope and independent action, to more formal and relationships that focus on tackling issues concerning large-scale systems to accomplish common goals (Mandell & Steelman, 2003). Within this case study, two types of coordination were identified.

The first kind of coordination that was identified was what Mandell & Steelman (2003) define as *intermittent coordination.* Intermittent coordination occurs when policies and procedures of two or more entities are adjusted in order to accomplish a mutual objective. The level of commitment and interaction is low, and resource sharing is minimal. This type of coordination was the most common type of cooperative interaction in this study.

Intermittent coordination occurred when one jurisdiction noticed a patch of weeds adjacent to their boundary. This jurisdiction then contacted their neighboring jurisdiction, told them the exact location of the weeds, and asked them to treat it before it had the chance to cross over the boundary. In most cases, the jurisdiction with the weeds was previously unaware of the weed population, became informed, and treated the site. This cooperative behavior is considered coordination, rather than communication, because two or more different entities consulted one another, planned, and altered their independent activities to achieve a mutual objective. The action carried out by one party was carried out in a manner that supported those of another, but operating procedures of those parties remained independent. A participant describes this interaction:

> Lassen Volcanic National Forest, Lassen Volcanic National Park, and Lassen County we try to coordinate with, as well as with the other agencies on our border. Controlling the spread is important by consulting with all the agencies and saying hey this is on your side, can you take care of it before it gets onto our side?

There were some instances where this process was described as more involved. For example, as one person described a cooperative project: “We discuss with our neighbors, then say ‘hey we have a project that's in your area, we're going to have crews there, do you think that at the same time you can take care of the problem on your side of the fence and control it too?”

The second type of coordination that we identified in this study as defined by Mandell & Steelman (2003), is a *temporary task force* or *ad hoc activity.* This was the third most common type of cooperative interaction reported across participants in both PACEs. A temporary task force is similar to intermittent coordination but is differentiated by the smaller scope of focus, time allotment, and tasks that are to be accomplished. A temporary task force is formed independently by one entity in order to accomplish a specific goal and will disband when that goal is achieved. Resource sharing is limited in scope as well in this form of coordination (Mandell & Steelman, 2003). In this study area, a task force was formed in order to carry out what I will call “favors”, or “hopping the fence." These favors were most commonly carried out by the Park Service for the Forest Service.

These "favors" occurred when weed populations were present at a boundary area, but rather than consulting with their neighbors and asking them to take care of it, the jurisdiction would contact the entity with the weeds and ask permission to cross the boundary in order to treat the weeds for them. One participant reported an informal agreement where they assumed responsibility for a certain amount of land on their neighbor's property, due to an imbalance of resources, and incentive to treat NNIS externally. Favors were always done by the entity with the most resources to allocate to NNIS management. In this case study, that entity was nearly always considered to be the National Park Service. Park officials in both PACEs described "hopping the fence" into their abutting Forest Service land to treat weed populations, to differing degrees. One participant reported a more sporadic type of ad hoc activity, "I've emailed their district Ranger and said 'hey, we found this on your side, do you care if we...?' And she goes 'nope, just go treat it.'" Another Park Service employee describes a more involved form of coordinated activities on Forest Service land:

> We have a cooperative agreement with Sequoia National Forest. They have populations just across our boundary, within 2 miles, and they don't have the resources to go after them, so we've pulled those populations within 2 miles of the boundary and are managing them with our Park Service crews.

### ***Collaboration***

Current and active collaboration was only mentioned by 7 participants out of 20, making it the least practiced form of cooperative interaction. Interviewees reported that historically there had been collaboration when funding was available, and some said they were moving toward collaborative projects. Thus, while collaborative management may not be the most common kind of cooperative interaction between agencies, it is occurring to some degree both historically, currently, and into the future. One subject described an informal type of collaboration,

> They're (USFS) very open, they're very cooperative, they're really open to it, there's no resistance, no lack of follow-through, they offer what they can to help us out including people on the ground. They'll oversee things, commit money to buy equipment where they can. So, they very much show a willingness to work with us.

Aside from this kind of informal, intermittent type of collaboration, only one subject reported more constant relationships and collaboration between entities. This subject described her involvement with the Eastern Sierra Weed Management Area (ESWMA), which is a coalition of all the land management areas, including, but not limited to BLM, the Inyo National Forest, California department of fish and wildlife, California Department of Transportation, California State Parks, and others.

California has many different Weed Management Areas, however, some have remained much more active than others as state funding has waned. ESWMA is an example of a WMA that has stayed active, despite the reduction in state funding for noxious weeds. The Inyo/Mono Counties' Agricultural Commissioner's office administers the ESWMA. The ESWMA views invasive plant issues "without the lens of jurisdictional or other boundaries", a view which "helps managers see the issue of these weeds as it truly is - a regional or watershed issue (Inyocounty.us)." The subject noted that in its incipient stages the WMA was more informal but that, "over the years it's gotten more formal and we are at the point where we have a strategic plan and a

Memorandum of Understanding in place." The participant employed in the ESWMA described her role as follows:

> My role is coordinator and grant writer, so like funding sourcing and coordinating, kind of helping with big picture management and use of resources. It's my job to know where the pools of money are, to know what's going on with the money, and then help our land managers more strategically use their resources.

She further described the ESWMA,

> The Eastern Sierra Weed Management Area is a place for all of the land management agencies to come together and unify our priorities; so much of the and here is government and connected. Weeds don't care about property lines or jurisdiction.

When asked about how this WMA had managed to stay so active over the years where others couldn't when funding dwindled, the subject noted that because of the creation of her position, their WMA was able to dedicate her time to applying for grants. She said, "Most WMAs don't have a dedicated position… It was just the agriculture commissioner applying for grants, or someone in that department that was doing double duty." The participant also noted that in the Eastern Sierra there isn't as much agricultural production compared to the central valley of California, thereby possibly allotting more resources towards range and invasive species management. She also highlighted the importance of planning, "We had a weed management area memorandum of understanding decision plan, so we had this infrastructure going into those years that held it together. Other WMAs may not have had that."

### ***No Cooperative Behavior***

Little to no cooperative interaction was the fourth most common response across jurisdictions when asked about degree of cooperative engagement with neighbors. Here however, there was a bigger difference within PACEs. Within the SEKI PACE, a majority of interviewees reported having little to no interaction with at least one neighboring, but only one LAVO participant mentioned this. Since there are more entities in the SEKI PACE, it may be harder to cooperate with all the bordering entities. Those who reported no interaction also seemed to have negative interactions in the past or preconceived notions about their neighbor.

### *Importance of Collaboration*

All participants agreed that collaborative management for NNIS, as well as landscape scale ecological processes can be difficult, but is a very important tool to help achieve fruitful results. Participants identified three main benefits of collaboration, from least to most frequently cited: (1) Pooling resources when goals align, (2) sharing knowledge and experiences, and (3) enhancing landscape scale management.

The interview subjects chosen for these interviews are in one way or another directly involved with NNIS management. Their lived experiences of working with invasive species and participating in cooperative behaviors with their neighbors inform them of the need for, and the benefits of, working together. Participants recognize that more work can get done through cooperation and the scale of impact on NNIS management can be expanded both in space and time. After identifying the challenges, every participant identified a benefit, and a desire for more cooperation. One participant aptly stated, “Plants don’t know about jurisdictional boundaries, so it makes a lot of sense, for invasive species, to work with our neighbors.” Another participant expanded on the importance of cooperative interactions,

> I think it's fundamental to containing and controlling the problem. I mean, organisms don't see the imaginary lines that we draw in the sand called property boundaries, so if you're not going to work with your neighbor you're never going to get on top of the problem.

Another benefit of cooperative management is sharing knowledge with neighbors. As one participant explained, “If people don't know what's going on and if you don't have open lines of communication it's the blind leading the blind; you don't know who's doing what or where the problems are.”

Cooperative management is an on-going process, a continual building of relationships between different organizations and individuals who are able to identify and strive to address common goals together. A large majority of invasion events occur in these kinds of complex management mosaics that exist within a PACE (Epanchin-niell et al., 2010). While there is no right or wrong way to achieve cooperative management, some form of cooperation between entities will be paramount for successfully managing PACEs in the face of climate change and increasing human pressure.

While the missions and priorities may differ in focus, size or scope between entities in a PACE, organizations in natural resource management tend to have some overlapping goals, and all entities care about managing the harmful effects of NNIS. The objective is to determine what kind of cooperative interaction is best for each entity and their neighbors and foster that relationship so that effective landscape scale management can be achieved, and more involved forms of cooperative behaviors can be attained in the future if and when resources become available, or priorities more closely align. Findings from this research reveal hopes and desires among participants to be involved in more cooperative management with their neighbors. One participant voiced this hope:

> We are always looking for allies wherever they might be, and oftentimes we're looking in places where we thought we would have very antagonistic relationships, but we're actually finding that we have a lot more in common with wanting to protect these areas than we have differences.

## Discussion and Conclusion

Boundary and landscape management that spans jurisdictions is mainly restricted to informal communication and intermittent coordination, while formal processes such as transdisciplinary research, co-production and management, and joint planning and decision making are scarce. Findings from the greater Lassen and Sequoia-Kings Canyon ecosystems show that the entities working in natural resource management in these regions are confronted with four main challenges to NNIS control and cooperation, as identified in the results section. Failure to coordinate in this study was a result of historically poor relationships with, or perceptions of, neighboring entities, in addition to the four main barriers to cooperative management.

This research shows that in these PACEs, communication and two kinds of coordination (intermittent and ad-hoc) are the most common forms of cooperation between entities. The coordination efforts in this study are very intermittent or one-sided in terms of resource sharing but are still considered a kind of coordination: interactions are occurring between two entities that lead to coordinated actions by one party. Actions are being carried out in a manner that supports both entities, and resources are being shared with the jurisdictions that are unable to allocate time, personnel or funding to treat NNIS. While this kind of coordination is more involved, it is not at the level of collaboration because operating procedures of each party still remain independent.

Notably, the one instance where true and constant collaboration is occurring is in an area where a single individual is employed for the sole purpose of identifying funding and facilitating collaboration and strategic use of resources. This is an important finding, as it gives us an idea of what may contribute to more successful collaboration. While collaborative management is one of the least common types of cooperative behaviors in the SEKI and LAVO PACEs, it is occurring both historically and currently, to some extent. From this information, we have gained insight as to how we might increase the occurrence of collaborative partnerships in the future.

The impacts of jurisdictional boundaries on protected areas can have far reaching effects. This case study supports previous research by demonstrating the need for collective action to protect ecosystems against invasion (Epanchin-niell et al., 2010), as well as for managing other landscape scale interactions and processes such as those related to fire, hydrology, migrations and human activity. Participants are concerned with the ecological and economic effects of NNIS on the lands they manage, how climate change will shift vegetation communities, and whether or not they will have the necessary resources to allocate to invasive species management and cooperative interactions with their neighbors.

Findings show that there is an amalgam of barriers to being able to address cross-boundary issues and to developing sustainable collaborative partnerships. However, participants also expressed a desire and a willingness to work with their neighbors. In many cases, participants conceded that the benefits of cooperative interaction would been seen on a much larger scale comparative to the benefits seen as entities continue to work independently of one another.

From this research, we make recommendations for policy makers and land managers to assist entities in overcoming the barriers they identified in developing and maintaining cooperative interactions with their neighbors in a PACE. These recommendations are compatible with suggestions from previous research done on cooperative management (Epanchin-Niell et al., 2010; Novoa et al., 2018, Yaffee, 1998).

### *Hire a Boundary Spanner*

To ensure that cooperative interactions, proper resource allocation, and funding sources are available even during times when federal funding is cut, all entities with the ability to do so, can designate or hire a boundary spanner who is responsible for NNIS management coordination across organizations. A boundary spanner can help address the cooperative barriers associated with limited resources and paperwork/policy barriers. Bednarek et al. (2018) define a boundary spanner as an individual (or organization) that facilitates the process of knowledge exchange between multiple entities in a specific, often complex social setting, whose full-time occupancy is to act as expert intermediary. They cultivate trust, build relationships, determine the different priorities and limitations, and aim to produce multiple options and perspectives that align with the goals of all entities involved. To achieve boundary spanning activities, entities can consider hiring an individual with boundary spanning skills, or if that’s not feasible in a particular situation due to funding limitations, entities should take advantage of boundary spanning organizations – many of which exist at the county level throughout California.

### *Utilize Middle-level Organizations*

A middle-level organization is an example of a boundary spanning organization. Examples include: county weed management programs, regional invasive species control organizations, or other boundary spanning organizations such as local Resource Conservation Districts (RCDs) (Epanchin-Niell et al., 2010). Local weed management programs may take a variety of different forms, based on what works best for a particular region, but the commonality is they all strive to overcome barriers to cooperative management strategies between stakeholders by encouraging participation in weed prevention (Hershdorfer et al., 2007). A middle-level organization can help address the challenges associated with limited resources, differing management objectives, and lack of managerial support and education. In the case of California, Weed Management Areas (WMAs) and RCDs would be considered middle-level organizations, and are already designated throughout the state of California.

Middle-level organizations can be created by top-down, or bottom-up approaches. A bottom-up approach would require the collective action of all stakeholders and land managers in the invaded, or potentially invasible region, whereas the top-down approach would involve the local, state or federal government in the creation of a middle-level organization. The primary role of a middle-level organization is to help foster cooperation across agencies in a management mosaic. They should help facilitate cooperative interactions, identify commonalities, and aim to have support and funding address the constraints on cross-boundary stewardship and NNIS management. Many middle-level organizations are also known as "boundary-spanning organizations," as defined by Bednarek et al. (2018).

In this case study, participants often lamented how active the WMAs used to be when funding was available, and how much more cooperation existed when there was financial support. To address this lack of activity during periods of lower financial support, WMAs should have Memorandums of Understanding in place, to increase entity involvement, as well as their chances of securing funding. Middle-level organizations should encourage or incentivize members to actively apply for grants together and develop a strategic plan which defines goals and objectives, both in times where federal funding is available, and when it's not. For example, what actions can still be done by participating entities at times when funding is not available to middle-level organizations? Can less involved, independent cooperative actions be agreed upon in these times, with a focus on geographically specific areas, such as jurisdictional boundaries?

### *Increase Public Education and Outreach*

Increasing public awareness of the deleterious effects of invasive species may further strengthen weed programs (Hershdorfer et al., 2007). Evidence seems to suggest that bottom-up approaches to natural resource management problems may be as effective as top-down regulatory approaches (Agrawal & Gibson, 1999; Ostrom, 1990). Since many WMAs and other middle-level weed management organizations operate within counties, heightened public awareness and involvement may influence federal support because concern from the general public about weeds will increases pressure to address the issue (Schneider & Ingram, 1990).

When the public and other stakeholders, such as non-profits or community groups, become more educated and involved, their interest in NNIS management is likely to rise, which would also influence the practices of organizations that don't prioritize NNIS management (Henriques & Sadorsky, 1999). Therefore, WMAs or other weed programs or entities concerned with NNIS should attempt to further engage the public and increase support and volunteer opportunities or workshops for weed management activities in the community in order to bolster support. Individuals who are concerned about NNIS, according to Tidwell and Brunson (2008), are more likely to obtain more information about them. Additionally, those who recognize and understand the problems associated with NNIS will aim to reduce the impact of those problems. A volunteer approach could therefore help address the issue of different management priorities, the challenge associated with lack of managerial support and education, and limited resources.

Involving volunteers in weed management can help provide resources to perform a variety of essential tasks. Volunteers tend to volunteer for different reasons, which is why more than one volunteer option should be made available. People may volunteer because they see themselves as doing valued work that can make a difference for the environment, they enjoy developing a sense of community, sharing knowledge and learning new skills, or they simply enjoy spending time outdoors. Whatever the reason, volunteers should have options, and be able to choose among those. Options could include collecting information on locations and scope of infestations, helping with weed control and removal, assisting with education programs, or getting involved in restoration efforts. Over time, it may be possible to develop long-term groups of committed volunteers whose efforts significantly contribute to the management of invasive plants in their communities (Tidwell & Brunson, 2008).

### *Develop Formal Agreements for Cooperative Management*

Due to the complex systems, and varying priorities and pressures put on distinctive entities in a PACE, having a broad understanding of key beliefs, attitudes and restrictions regarding target NNIS may help entities who want to cooperate develop an attainable shared aim for management plan (Novoa et al., 2018). Hiring a facilitator and outside researcher to lead this process, to balance competing interests, and to aid in the initiation of strategic management plans would be beneficial for designing a working relationship and crafting more formal agreements wherein all entities concerns are voiced, and requirements and constraints are acknowledged. Such a facilitator should be able to help those involved to reach consensus on the approaches to be adopted for the cross-boundary management plan (Lampe, 2001).

Once consensus is reached, the cooperative agreement should be revised and updated, to incorporate entities' wants and needs. The plan should be discussed in detail until every entity agrees to the final management plan and its objectives. Management objectives should be documented in writing, and include a communication plan, as well as details on when the agreement will be updated or revisited. The plan should be transparent, and easily accessible to all stakeholders at any time (Novoa et al., 2018). The plan should designate what is going to be done, how, and by whom, as well as which entity or entities will be paying for it, a timeframe for implementation and how the success of the management plan will be determined (Wilson et al., 2017). The development of formal agreements and written plans will help to avoid misunderstanding or confusion, make cooperative management more achievable, ensure the satisfaction of all stakeholders, and hold entities responsible to their commitments.

Resource managers within a PACE, whether they are federal, county, non-profit or research entities, all have an appreciation for the land they steward. They share reliance on the resource system and knowledge of important ecosystem attributes, acknowledge the potential threat of NNIS, and possess the capability of taking action to limit the damage that can be incurred by invasions (Ostrom, 1990).

Many of the emerging threats related to NNIS within PACEs are complex, spanning across landscapes and jurisdictions, and therefore appropriate solutions will need to be similarly complex (Lien et al., 2019). To find resolutions to the issues that are analogous with the challenges, regional cooperative ecosystem management is needed (Schwartz et al., 2019). As land use changes continue to intensify, issues of climate change alter the landscape, and NNIS expand their ranges, cooperative interactions between entities will become even more paramount, and may help shift the balance and reduce costs associated with managing biological invasions (Simpson et al., 2009). While participants identified many challenges to overcome to be able to participate in collaborative partnerships, they also all believed any form of cooperative management with neighbors would be fruitful, and all expressed a desire for more.

This research builds upon existing literature that has investigated cooperative management between different entities in a natural resource context, the challenges of cooperation, and the potential ways to remediate these barriers. I examined protected area-centered ecosystems, and the lived experiences of individuals working with NNIS in these geographically unique areas. While the areas themselves may be unique ecologically, there are many National Parks, and other PACEs across the country. Therefore, one would expect to see similar challenges and levels of cooperative interactions in other landscapes that are broken into similar management mosaics.

Future research on cross-boundary stewardship should investigate other protected areas and their encompassing lands to see if these results are applicable at broader scales. Are similar themes found elsewhere? Comparable challenges identified? Do the challenges differ in dissimilar regions of the country, if so, why? We further recommend an exploration of collaborative NNIS management examine known successes as well as failures to further advance our understanding of cooperative weed management. Lastly, we would encourage research to identify circumstances in which collaboration was attempted, but failed, and why.

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# CHAPTER 4

# AT THE INTERSECTION OF WEED ECOLOGY AND COOPERATIVE MANAGEMENT IN PROTECTED AREA-CENTERED ECOSYSTEMS

## Introduction

Many of the most precarious problems faced by natural resource managers today include processes that occur at large spatial scales. In response to such challenges, scientists and managers must have the capacity to turn their attention to the broader ecological contexts in which they are situated. Biological invasions by non-native invasive species (NNIS) are among one of the biggest threats to ecosystem function and biodiversity, in addition to being one of the more complex problems to tackle due to their ability to move quickly across mixed-ownership landscapes (Epanchin-Niell et al., 2010; Pejchar & Mooney, 2009; Pyšek & Richardson, 2010; Wilcove et al., 1998)

Ecological processes that occur across large swaths of land fall on a patchwork of jurisdictional boundaries and administrative lines, each of which represents distinctly different management objectives and values – values which may not always align (Simberloff, 2003; Stokes et al., 2006). Ecosystem management, in which management goals are directed at sustaining healthy ecosystem functions over time and space and across administrative and ownership boundaries, becomes possible only when managers of adjacent jurisdictions are able to undertake management actions together to achieve common goals (Folke et al., 2005; Mayer & Rietkerk, 2004). Managing the movement of invasive species and protecting native plant communities and wildlife habitat is fundamentally social-ecological-system challenges.

To gain insight as to how land managers can address the challenge of NNIS control across boundaries, I conducted research to see how different management practices may be influencing the ability of invasive species to establish and spread in two geographic areas delineated as protected area-centered ecosystems (PACEs), and across jurisdictions. These included the Sequoia and Kings Canyon (SEKI) PACE, and the Lassen Volcanic (LAVO) PACE in California. I interviewed land managers involved with NNIS management in these areas to determine how different entities might be able to engage in the kinds of cross-boundary cooperation that is essential for attainment of successful conservation efforts. This research helps scientists and land managers identify how divided management in PACEs influence ecological flows and processes across landscapes, and the challenges associated with collaborative management.

Management in mixed-ownership landscapes characterizes what is known as a collective action problem (Olson, 1965); if one manager decides not to control NNIS on their property, they will impose costs on their neighbors by allowing their land to serve as a continuous source of propagules (Epanchin-Niell et al., 2010; Epanchin-Niell & Wilen, 2014). Therefore, understanding the effects management has on plant communities, as well as discerning what barriers entities and private landowners face in cooperative management may help us get closer to collaboration and agreement on control levels from all the parties involved.

## Research Questions and Conclusions

### *NNIS and Disturbances*

My sampling strategy focusing on cross-boundary comparisons was unable to detect enough NNIS in LAVO to permit statistical analysis. To observe whether a significant difference existed in any of the four jurisdictions in the SEKI PACE, I asked whether, at an ecologically similar site, weed occurrence and/or disturbance events were likely to be significantly greater in one jurisdiction than another as a result of divergent management practices. I found no significant differences between jurisdictions (BLM-USFS non-wilderness, BLM-USFS wilderness, NPS-USFS non-wilderness, and USFS non-wilderness-USFS wilderness).

I then explored whether, given the occurrence of disturbances and weeds, the strength of the correlation between weeds and human or natural disturbances differed significantly *among* those jurisdictions when controlling for site. Using a general linear mixed model (GLMM), I found that some significant relationships existed. These relationships were only significant in USFS non-wilderness areas, between total disturbances and NNIS, and between natural disturbances and NNIS. Although a significant relationship existed between weeds and disturbances in USFS non-wilderness lands and not in others, I did not observe that any jurisdiction was more likely than others to experience disturbance-driven weed invasion. The effect of disturbances on NNIS and native plant occurrence may depend more on the intensity of disturbance in the studied system, rather than whether or not it was present along one meter in a transect, a factor future research should consider (Hernández Plaza et al., 2015).

Elevation plays a role in the distribution of weeds (Averett et al., 2016; Beniston, 2003; Mcdougall et al., 2011), as well as management of weeds and priority management areas. By extracting elevation data from ArcGIS, I was able to observe the average elevation of all the study sites. Scatterplots showed that in both PACEs, 2,000 m appeared to represent a threshold for NNIS occurrence, something which could be of benefit to land managers in higher elevations. I found no evidence of a gradient whereby weed occurrence decreased as elevation increased below 2,000 meters.

The sampling strategy used in these PACEs, which focused on cross-boundary comparisons, was unable to detect weeds in the LAVO PACE, but this doesn't mean they weren't there; it means there weren't enough weeds for a fairly intensive level sampling to detect, or that weeds tended not to be at boundaries. Differences in the mission of adjacent jurisdictions did not appear to be as influential as other processes (e.g., disturbance and propagule pressure) in this PACE.

### ***Interviews***

In addition to collecting quantitative data on NNIS and disturbances, I also interviewed employees who worked with invasive plant species in each PACE. In so doing I was able to assess whether NNIS occurrence can be related to jurisdictional differences in impacts and/or uses, as well as to glean information about the perceptions of NNIS from people on the ground, and report on the social challenges that are encountered with cooperative interaction regarding NNIS management at a landscape scale. By using a mixed-methods approach, I was able to seek a convergence across the ecological data and qualitative interviews and present a study that is a representative depiction of a social-ecological-system (Venkatesh et al., 2013).

I asked about people's main concerns regarding NNIS to see if what they had to say corroborated scientific findings. Habitat quality degradation, followed by impacts on biodiversity, changes to fire and disturbance regimes, and cascading ecological effects were the most commonly noted concerns. These findings correspond to well-known adverse effects of NNIS invasions in natural ecosystems (Bazzaz et al., 2000; Kerns et al., 2020; Levine et al., 2003; Pyšek & Richardson, 2010).

My interviews covered on a wide variety of NNIS and management related topics, including observed differences in management between jurisdictions and how these discrepancies influence management between neighbors; participation in cooperative management; barriers to collaborative management between jurisdictions and ways to address them; and the perceived importance of collaborative management among different agencies. All interviewees noted observed differences across jurisdictions, especially that that the National Park Service has more funding and staff to dedicate to NNIS control. This was lamented by USFS, county agriculture commissioners, and park employees alike.

NPS employees acknowledged that weeds often come in from outside their borders, while at the same time recognizing that USFS employees understood the importance of weed control but lacked the resources to be able to focus on controlling them. USFS employees said the same thing; they understood the impact of weeds, but when faced with fire management and a whole host of other problems, NNIS management wasn't at the top of their list. This difference did influence management between neighbors; NPS employees often reported focusing on NNIS at their boundaries to try to keep them from creeping in, and USFS employees used what little funding they had to prioritize management of NNIS in the areas where their land abutted park land.

Four main barriers to cooperative management were identified (1) limited resources (funding, time, personnel) and too many other job responsibilities; (2) paperwork and policy barriers on Federal land, such as NEPA requirements (environmental assessments and environmental impact assessments); (3) differing management priorities and priority weeds between entities; and (4) lack of managerial support and education.

In these PACEs, communication and coordination (intermittent and ad-hoc) were the most common forms of cooperation between entities. Coordination efforts were intermittent or one-sided in terms of resource sharing but were still considered a type of coordination because interactions occurred between two entities that led to coordinated actions by one party. These actions were carried out in a manner that supported the management goals of both entities, and resources were being shared with the jurisdictions that were unable to contribute time, staff or funding. Operating procedures of each party remained independent. True collaboration, where resources were shared and entities worked together to control the spread of NNIS at jurisdictional land boundary areas, was only reported by one interviewee and occurred where a single individual was employed for the sole purpose of identifying funding and facilitating collaboration and strategic use of resources for NNIS projects. This suggests that collaboration may be more attainable in areas where a boundary spanner is utilized. The challenge, however, is finding the money to fund such a position in entities whose budgets are already stretched thin, and whose resources are focused on seemingly more pressing issues such as forest fires.

While the NNIS situation is seemingly less dire in LAVO than in SEKI, I heard similar things from interviewees in both PACEs. People in LAVO reported the same concerns as interviewees from SEKI, the same barriers, and the same challenges they face in being able to cooperatively manage NNIS. One main difference was the role of elevation in LAVO, specifically, the elevation within the park (while some USFS employees mentioned elevation in the SEKI PACE, it came up more frequently in conversations with subjects from LAVO). Within Lassen Volcanic National Park, the elevation ranges from 1,607 to 3,187m. The elevation gradient in Sequoia and Kings Canyon national parks ranges from 414m in the foothills to 4,418m. While the highest point in Sequoia and Kings Canyon is higher, its lowest elevation is much lower – and this low point is at the boundary of the park, meaning the elevation drops lower in the surrounding jurisdictions. Since 2,000 m appeared to represent a threshold for NNIS in both PACEs, only 393m above the lowest elevation in Lassen NP, and since 27 out of 50 sites were located on the NPS boundary, it makes sense that elevation may have played a role in the lack of occurrence of weeds in LAVO.

If the higher elevation, longer winters, and shorter growing seasons in the LAVO PACE plays a role in weed occurrence, land managers here, and in geographically similar areas, can use this advantage as an opportunity to develop and strengthen collaborative relationships with neighbors before climate change creates favorable climate conditions that allow invaders to expand into new ranges (Bradley et al., 2010; Kerns et al., 2020).

In LAVO, one NPS employee described rare and sensitive thermal plant species that are endemic to the higher elevation, volcanically active areas of the park. Due to the heat and the ecology in these locations, this employee noted that cheatgrass was able to grow here at these higher elevations as well. They had therefore been manually treating weeds in these locations habitually, in order to protect the endemic thermal species. If conditions become more favorable for invasive plants at higher elevations as a result of climate change, they may be able to expand and outcompete these native and sensitive plants. Emerging research postulates that with current climate change patterns, even historically pristine alpine areas will be subject to invasion (Mcdougall et al., 2011). But for now, most mountainous regions are among the few areas left in the world that are safe from NNIS invasions, and are where natural resource managers still have the opportunity to respond in time (Aníbal Pauchard et al., 2009).

The lack of evidence I found for jurisdictional differences in NNIS and disturbance occurrence in theses PACEs may be due to the absence of any kind of physical barrier between jurisdictions. Without barriers such as fences, changes in plant communities or human and natural disturbances as a result of divergent management practices would not be as pronounced. However, this also means that activities on lands adjacent to national parks have a greater likelihood of affecting the protected areas. NPS employees consistently mentioned fighting back the spillover from their neighbors. In more extreme cases, they “hop the fence” and treat the weeds just outside of their jurisdiction to keep the weeds at bay, in addition to helping their neighbors. In a sense, this might be another argument for cooperative management. Land managers could either decide to erect fences, a task that is very expensive, time-consuming, and may have negative impacts on wildlife (Jakes et al., 2018), or make the effort to collaborate on

NNIS management and other landscape-scale activities near boundary areas. The occurrence of weeds along jurisdictional boundaries within these landscapes is still relatively low, which provides an opportunity for managers to develop and strengthen collaborative relationships before NNIS issues get out of hand. Both NPS and USFS employees expressed a desire to do this, and understood the importance of working collaboratively, but many entities excluding the NPS lacked the resources and managerial support to do so.

While the ecological data at LAVO was not very telling, we did affirm some positive relationships between weeds and disturbances on USFS non-wilderness areas in the SEKI PACE. This finding corroborates what many USFS employees had to say about their ability to manage NNIS; that they didn't have access to sufficient resources. Interview subjects from both PACEs echoed one another's concerns, challenges, sentiments, hopes, and commitment to land stewardship. They all understood the need for cross-boundary collaboration, but only one subject out of 20 reported true collaboration. This individual had been hired into a position where the specific duties included coordinating weed management activities between agencies in a designated Weed Management Area in California, funding sourcing such as writing grants, and helping land managers more strategically use their resources. A position dedicated to finding funding for NNIS could help pave the way for improved and stable collaborative management efforts within PACEs in the future.

## Next Steps

It is well known that disturbances influence the ability of NNIS to invade an area (Hobbs & Huenneke, 1992; Lozon & Macisaac, 1997; Macdougall et al., 2013). Therefore, I suggest that future research focus on the divergencies in management practices between entities in ecologically valuable areas, such as PACEs. Land management, in addition to differences in elevation, topography, soil, recreation use, and disturbance can impose variation, altering land cover patterns. Habitat characteristics may reflect these natural and human factors and may result in ecological changes and fragmentation along jurisdictional land boundaries (Aslan et al., 2020). Understanding the effects of these divergencies, and the ecological trajectories that result, may predict how to effectively protect these areas going forward. Although this particular study failed to identify many significant NNIS or disturbance differences in or between jurisdictions, I suggest continuing this research, but approaching it with different methods for data collection.

Additionally, this study identified only one participant who described often participating in true land management collaboration. This participant identified themselves as an employee whose role was dedicated solely to applying for grants and allocating resources to NNIS control programs that were conducted in a collaborative manner. The main challenges land managers reported in being able to participate in cooperative management were a lack of time, personnel, finances and support. Future qualitative research could identify other entities who have hired someone to dedicate their time to finding funding, specifically for NNIS, and for coordinating cooperative efforts to see how successful these areas are in engaging in cooperative management.

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# APPENDICES

# APPENDIX A

## ECOLOGICAL DATA: COLLECTION AND METHODS

### Equipment/Protocols

1. Data sheets
    1. General Site Description
    2. Disturbance
    3. LPI
    4. Soil Stability
    5. Trees
2. GPS unit
3. At least one smart phone with the free Avenza maps app
    1. USFS MVUMs/travel maps for applicable ranger districts
    2. NPS or other relevant maps showing geolocated boundaries
4. Compass
5. Clinometer
6. 2x50m transect tapes
7. 2x “candy cane” transect stakes
8. 6 Pin flags
9. Tree identification guides specific to region/park
10. ≥ 1 DBH tape(s)
11. Soil stability kit
    1. 2 white boxes (one with sieves)
    2. Soil tool
    3. Distilled water
12. Soil corer
13. InReach
14. First Aid Kit
15. Bathroom kit

Protocol note: Because it is essential to reach as many sites as possible, efficiency is a priority. If a site cannot be accessed safely, cannot be accessed legally, or would require more than 45 minutes of hiking from the car to reach, moving the site is necessary. The preferred option for moving a site is using GIS with boundary and topographic layers - contact Martha or other office staff to request. If this option is not possible or a feasible alternative is clearly present (e.g., the site as marked on the GPS is on top of a steep rock pile deemed unsafe, but 500 meters along the boundary is a good looking spot with reasonable terrain), the crew leader has discretion to choose to move the site along the same boundary within a one kilometre radius. If a site is moved, record a brief description on the “General Site Description” data sheet.

**Plot Setup**

1. Plot set-up: establishing transects and general site description (General Site Description)
    a. Using the GPS, locate the numbered point corresponding to your destination site. This is ‘Plot A’. Record the coordinates (UTM zone, easting, and northing) and write down the type of jurisdiction the plot is in (USFS non-wilderness, USFS wilderness, NPS, BLM).
        - Mark the plot in the GPS unit and label it using the Site#/Plot letter (e.g., 62A), make sure it’s saved!

    b. Using the Avenza app and a map layer showing the jurisdictional boundary, ensure that you are no more than 100 meters from the boundary, and then place a “candy cane” transect stake in the ground at your feet.

    c. Again, using Avenza, determine which direction (compass bearing) faces directly away from the boundary (point your phone or compass perpendicular to the boundary, with the boundary at your back), and record your plot’s central bearing.
        - Note: Your plot area is a half-circle with a 50 m radius, bisected by this bearing.

    d. Determine the bearings of your two transects and record:
        - Transect 1 = Plot Center - 45°, Transect 2 = Plot Center + 45°

    e. Lay out the transects: attach the ends of the transect tapes to the candy cane. One person will stand at the candy cane and use a compass to guide two people who will walk out the transect tapes in a line that is as straight as possible along each bearing.
        - Note: Keep the tape as close to the ground as possible. If you have the option to take it over or under a shrub, for example, always opt to keep it lower.
        - Note: As much as possible throughout set-up and data collection, walk on the right side of the transect tape, and sample on the left side.

    f. Using a compass, determine the aspect of the plot and record: if your 50 m half circle is on a slope, the aspect is the *downhill* direction you are looking when you stand at the highest point in the plot looking toward the lowest point.

    g. Considering the aspect you just established, and using the clinometer, determine the slope of your plot (in %) and record.
        - Note: You can use the clinometer from either the top or the bottom of a slope, the angle’s measurement will be the same. Remember to point your gaze at something roughly the same height as your eye level when measuring!

   h. Looking around the plot area, record Y/N for evidence of fire management (e.g., piles of branches from thinning, fire breaks), and if yes, describe.
   i. Determine if you can see any roads from the plot, record Y/N, and if yes, describe type of road and estimate distance.

2. Disturbance: Belt Transects
   a. Use a short meter tape to help you visualize/establish a 6 meter wide 'belt' centered on the transect tape. You will only record disturbances observed within this 6 m wide belt along the 50 m transect tape.
      - Note: carry the tape with you as a reference during data collection.
   b. Walking the length of the 50 m transect tape, identify and record disturbances observed and the one meter interval where they are located along the transect.
      - Example: If there is a fallen log that intersects the 6 m wide belt beginning at the 23.4 meter mark of the transect tape, and ending at the 25.9 meter mark, you would record the code "FL" in the boxes next to 23 – 24 m, 24 – 25 m, AND 25 – 26 m.
   c. Repeat protocol on second transect
3. Take down transects, identify next plot
   a. When all data has been collected, remove any remaining pin flags from the tree plot (count to make sure none are missing), pull out the "candy cane," walk to the end of each transect, and roll up the tapes while walking back toward the start.
      - Please respect precious transect tapes and be careful not to pull on them hard if they get snagged during the rolling process. A broken transect tape is a bummer!
      - Check to make sure that all equipment is accounted for BEFORE leaving your plot
   b. The next plot (B) will be located 200 m away on the same side of the boundary (same jurisdiction) as the one you just completed (A).
      - Decide which direction you want to go along the boundary (your bearing will be parallel to the boundary, which you should be able to calculate by adding or subtracting 90 from your previous plot center bearing).
      - Set the GPS to navigate *to* the plot you just marked (yes, it's counterintuitive), have one team member use a compass to make sure you're walking along the right bearing (parallel to the boundary), and one team member watch the GPS until the distance from the previous plot is 200 meters.
      - Note: Plots C and D will be on the other side of the boundary, and to get from plot B to plot C, you will be travelling perpendicular to the boundary and crossing it on your way. The four plots at a site should form a 200 x 200 m square, bisected by the boundary.

4. Complete General Site Description
   a. Once you have finished sampling at all four plots (and have therefore had the chance to cross the jurisdictional boundary at least once), record:
      - Boundary type (e.g., fence, road, unmarked, signs)
      - Boundary condition (e.g., well-maintained fence or signage vs. not)
      - Boundary permeability (to wildlife/seed dispersal/humans/livestock)

**<u>General Site Description Sheets</u>**

Boundary type_________________________ Boundary condition____________________________

Boundary permeability (scale: 1 = permeable to everything; 5 = portions impermeable but portions perfectly permeable; 10= impermeable) _______________________

Boundary notes:_____________________________________________________________________________________________________________________________________

**PLOT A**:
Jurisdiction________________ UTM: Zone ____ Easting ___________ Northing ______________

Slope of plot (clinometer reading): _____________________ Aspect: ________________

Plot center bearing: ______°Transect 1 bearing (-45°): _____° Transect 2 bearing (+45°): _____°

Evidence of fire management? Y / N If yes, describe: ______________________________________________

Roads visible? Y / N If yes, road type__________ & distance to visible road___________________

**PLOT B**:
Jurisdiction________________ UTM: Zone ____ Easting ___________ Northing ______________

Slope of plot (clinometer reading): _____________________ Aspect: ________________

Plot center bearing: ______°Transect 1 bearing (-45°): _____° Transect 2 bearing (+45°): _____°

Evidence of fire management? Y / N If yes, describe: ________________________________________

Roads visible? Y / N If yes, road type__________ & distance to visible road__________________

**PLOT C**:
Jurisdiction_______________ UTM: Zone ____ Easting ___________ Northing ______________

Slope of plot (clinometer reading): ____________________ Aspect: _______________

Plot center bearing: ______°Transect 1 bearing (-45°): _____° Transect 2 bearing (+45°): _____°

Evidence of fire management? Y / N If yes, describe: ________________________________________

Roads visible? Y / N If yes, road type__________ & distance to visible road__________________

**PLOT D**:
Jurisdiction_______________ UTM: Zone ____ Easting ___________ Northing ______________

Slope of plot (clinometer reading): ____________________ Aspect: _______________

Plot center bearing: ______°Transect 1 bearing (-45°): _____° Transect 2 bearing (+45°): _____°

Evidence of fire management? Y / N If yes, describe: ________________________________________

Roads visible? Y / N If yes, road type__________ & distance to visible road__________________

# APPENDIX B

# INTERVIEW DATA: PROTOCOLS, RECRUITMENT, QUESTIONS

## Interview Protocol

Thank you again for agreeing to take part in this interview. We know your time is valuable, so we don't want to take any more of it than absolutely necessary, but we hope you'll be able to help us gain a thorough and nuanced understanding of cross-boundary stewardship and the role it plays in controlling the spread of non-native invasive species.

1. How would you describe your current role with regard to natural resource management in this region?
2. How are you involved with invasive species management, if at all?
3. How long have you been engaged in invasive species management in this region?
4. How long have you been engaged in land management in total (including other areas you may have worked prior to coming to this region)?
5. (If applicable) You've described your own role with regard to land stewardship; now could you please describe the role of the organization you serve? What are the organization's management objectives?
6. Briefly describe your organization's current invasive species management activities. Does your organization have a specific invasive species management plan?

As you know, the purpose of our research is to document the effects of national park boundaries on invasive species management and to understand how presence and diversity of invasive species can be influenced by boundaries, as well as what challenges and opportunities collaborative management presents. To help us do this, we need to learn about the cross-boundary collaborations in this region in regard to invasive species. The next few questions focus on this topic:

7. To what extent are you concerned about weeds? Why?
8. Which weeds are you particularly concerned about?
9. How fast do these weeds spread without control, in your experience?
10. Where are the main areas these weeds are found? Why do you think they are occurring in those areas (if applicable)?
11. Do you see a correlation between occurrence of invasive species and human caused disturbances (high density of tourism, roads, popular trails, timber harvesting, construction activities)? Natural disturbances?
12. Do you think uncontrolled weeds have negative economic and/or ecological impacts on the land you manage?
13. What methods have you tried to control unwanted weeds? Where did you learn about the method?

14. How important is it for you to see someone else implement a particular control method before you try it?
15. If there are weeds you don't currently manage, what would make your agency more likely to undertake control measures (at what point does an invasive plant become a priority species)?
16. For weeds you do control, how did you select which areas to treat?
17. Are you satisfied with the results? Why or why not?
18. What are the main challenges you face in controlling/managing non-native invasive species?
19. Do you believe that it is possible to control or eradicate any of the weeds you mentioned as being concerned about at a landscape level?
20. Do you notice neighboring jurisdictions managing invasive species differently than you do? If so, how?
21. Would you expect non-native invasive species occurrence or diversity to change upon crossing a jurisdictional boundary? Have you seen examples of this? (If applicable) At what jurisdictional boundary is this most pronounced?
22. Do conditions across a boundary from the land you manage ever influence your management objectives or activities on property under *your* jurisdiction? How?
23. In what ways (if at all) does your agency work collaboratively with other agencies to co-manage invasive species at jurisdictional land boundary areas? In what ways are you unable to co-manage these areas?
24. What are the roadblocks you identify (political, ecological, communication, financial, or other) for participating in collaborative management of non-native invasive species? What changes would be needed in order to overcome them?
25. Do you think collaborative invasive species management would be beneficial? In the short or long term?
26. Do you see a role for private landowners in reducing source populations of weeds? How might you involve them?

## Letter of Information

Challenges and Opportunities for Collaborative Invasive Species Management Within Protected Area-Centered Ecosystems

Introduction
You are invited to participate in a research study supervised by Mark Brunson, a Professor in the Department of Environment and Society at Utah State University. The purpose of this research is to study how differing management practices across jurisdictional land boundaries between national parks and adjacent lands influences the occurrence and diversity of non-native invasive species, and to understand the challenges and opportunities for cross-boundary collaborative invasive species management. Your participation is entirely voluntary.

This form includes detailed information on the research to help you decide whether to participate. Please read it carefully and ask any questions you have before you agree to participate.

Procedures

Your participation is completely voluntary, and will involve agreeing to be interviewed by the researcher. The researcher will ask initial questions regarding your own engagement in land management and management of invasive species, and will then ask 8-10 questions that will be more specific to the research question. These interviews will be semi-structured, and will vary in length, however you may decide to end the interview at any time. We expect the interviews to last between 30 minutes - 1 hour. You may skip any questions that make you uncomfortable, or decide not to participate. However, your participation in the interview can help us better understand invasive species management for national parks and their surrounding landscapes. We anticipate that 10 people will participate in these interviews.

Risks

This is a minimal risk research study. That means that the risks of participating are no more likely or serious than those you encounter in everyday activities.

Benefits

Although you may not directly benefit from this study, it has been designed to learn more about managing invasive species, and the role of collaboration across political land boundaries. Participation in this study may benefit you by exposing you to the potential opportunities of managing invasive species collectively across jurisdictions. However, we cannot guarantee that you will directly benefit from this study.

Confidentiality

We will collect your information through audio recordings of interviews, which will then be transcribed. The researchers will make every effort to ensure that the information you provide as part of this study remains confidential. Your identity will not be revealed in any publications, presentations, or reports resulting from this research study. We respect your privacy, and will keep your responses completely confidential. The interview will be assigned an ID number to allow us to keep track of completed interviews. To protect your privacy, the interview file and associated ID number will be kept separate from information about interviewee names and work locations, which are kept in a password-protected computer at USU. All identifying information will be destroyed at the completion of our study, if not before. However, it may be possible for someone to recognize your particular story/situation/response.

This file will be kept for three years after the study is complete, and then it will be destroyed.

It is unlikely, but possible, that others (Utah State University) may require us to share the information you give us from the study to ensure that the research was conducted safely and appropriately. We will only share your information if law or policy requires us to do so.

Voluntary Participation & Withdrawal
Your participation in this research is completely voluntary. If you agree to participate now and change your mind later, you may withdraw at any time by contacting Natalie Otto, or Mark Brunson (contact information listed below). If you choose to withdraw after we have already collected information about you, we will omit your interview responses from the research. If you decide not to participate, you will not be negatively affected in any way. The researchers may choose to terminate your participation in this research study. You will be notified by phone or email if this occurs.

Compensation & Costs
For your participation in this research study, you will receive no compensation.

Study Findings
If the researchers learn anything new during the course of this research study that might affect your willingness to continue participation, you will be contacted about those findings. This might include changes in procedures, changes in the risks or benefits of participation, or any new alternatives to participation that the researchers learn about.

If you wish to know the results of the study, once the research is complete, the researcher will email you the findings of the study, including results relating to your participation.

IRB Review
The Institutional Review Board (IRB) for the protection of human research participants at Utah State University has reviewed and approved this study. If you have questions about the research study itself, please contact the Principal Investigator, Dr. Mark Brunson at mark.brunson@usu.edu. If you have questions about your rights or would simply like to speak with someone other than the research team about questions or concerns, please contact the IRB Director at (435) 797-0567 or irb@usu.edu.

Mark Brunson
(435) 797-2458;
mark.brunson@usu.edu

Natalie Otto
(503) 858-5458;
nataliekotto@aggiemail.usu.edu

Informed Consent
If you are willing to participate in this study, please reply via email or give me (Natalie Otto) a call at the number above so that we can schedule a time for the interview. By agreeing to participate, you indicate that you understand the risks and benefits of

participation, and that you know what you will be asked to do. You also agree that you have asked any questions you might have, and are clear on how to stop your participation in the study if you choose to do so. Please be sure to retain a copy of this form for your records.

| | |
|---|---|
| Participant's Signature Date | Participant's Name, Printed Date |

☐ I do not agree to allow my de-identified information to be used or shared for future research.

**Recruitment Material**

Dear <name of agency land or resource manager>

We are writing to ask for your participation in a research project investigating the effects of disturbance events and differing management protocols between jurisdictional boundaries on presence and diversity of non-native invasive species in national parks and adjacent private or public lands.

The health of national parks and protected areas depends on the quality of the lands surrounding them. Non-native invasive species disrupt important ecological flows, and are capable of spreading rapidly over landscapes and across jurisdictional land boundaries, making them a collective problem; their control often can't be tackled by one entity alone.

Our research team is collecting quantitative data on invasive species and disturbance events, as well as qualitative data about invasive species management. This requires interviewing land and resource managers in the region including and surrounding <<name>> National Park about how they manage non-native invasive species, their interactions with other agencies across political land boundaries in regards to this topic, and how those interactions affect their stewardship of National Parks and valuable surrounding landscapes. This will help managers of national parks and adjacent lands understand the importance of working collaboratively to effectively control the spread of invasive plant species.

If you are willing to participate in this study, please reply via email or give me a call at the number below so that we can schedule a time for the interview. We anticipate that interviews will last 30-60 minutes.

Your participation is completely voluntary. You may skip any questions that make you uncomfortable, or decide not to participate. However, your participation in the interview can help us better understand conservation opportunities for national parks and surrounding landscapes.

We respect your privacy, and will keep your responses completely confidential. The interview will be assigned an ID number to allow us to keep track of completed interviews. To protect your privacy, the interview file and associated ID number will be kept separate from information about interviewee names and work locations, which are kept in a password-protected computer at USU. All identifying information will be destroyed at the completion of our study, if not before.

Thank you for considering this request.
Sincerely,
Natalie Otto
Graduate Student in Environment & Society at Utah State University
nataliekotto@aggiemail.usu.edu
(503) 858-5458