Spatial Analysis of Human Activities and Wildfires in the Willamette National Forest

by

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A Thesis Presented to the
Faculty of the USC Graduate School
University of Southern California
In Partial Fulfillment of the
Requirements for the Degree
Master of Science
(Geographic Information Science and Technology)

December 2018

To my wife Sarah, and the Twigglers; Zion and Asher

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Acknowledgements

I am thankful for my wife Sarah, my mother-in-law Vicky, and my entire family for their patience and understanding while I wrote this thesis. I would like to say thank you to my advisor Professor Kemp for her patience and assistance. A large thank you to the U.S. Forest Service employees Matthew Wilson, Glynis Bauer, Matt Peterson, and Don English for their help and data they provided for this thesis. Last, but not least, a thank you to all my fellow students who I had the honor of meeting and exploring Catalina Island with.

List of Abbreviations

ASCII	American Standard Code for Information Interchange
ATV	All-Terrain Vehicle
AUC	Area Under Curve
BRT	Boosted Regression Tree
CSV	Comma-Separated Value
GPS	Global Positioning System
INFRA	Infrastructure
NAD	North American Datum
NW	North West
ResPVT	Residential/private
ROC	Receiver Operating Characteristics
SOPA	Schedule Of Proposed Actions
USDA	United States Department of Agriculture
USFS	United States Forest Service
WNF	Willamette National Forest
WUI	Wildland Urban Interface

Abstract

Across the nation wildfires in national forests and parks annually affect millions of acres of public lands, destroying recreational sites, historical areas, and scenic wilderness, and costing taxpayers hundreds of millions of dollars every year in suppression costs and lost resources. This research examined the spatial correlation between human activities and human caused wildfire occurrences within the Willamette National Forest to explore whether these activities might be responsible for many wildfire ignitions. Between 1995 to 2008, 493 human caused fires occurred. The density of these fires was investigated to identify clustering near recreational sites and human infrastructures. Maxent was used to model the probability of wildfire occurrences in relation to the recreational sites and human infrastructure areas located throughout the Forest.

It was initially hypothesized that more wildfires occur near specific kinds of recreational sites than elsewhere. Preliminary data exploration showed high densities of wildfire occurrences near the towns, human infrastructures, and major highways although these were also areas of clusters of recreational sites. Thus, it was not possible to identify visually which particular activities were most strongly related to wildfire ignitions. Maxent results revealed that areas of high population densities and recreation site clusters were more likely to correspond to areas of more human caused wildfire ignitions.

Chapter 1 Introduction

Since 1944, a lone bear has been reminding people to be careful about forest fires. Today after 70 years of propaganda, wildfires are still a threat to property, lives, wildlife, and resources. Carelessness, accidents, and arson account for a vast majority of human caused wildfires (Chas-Amil et al. 2015; Fox et al. 2015; Pew 2001). These events cost hundreds of millions of dollars in man hours and equipment to suppress and in lost revenue for resource companies and tourism organizations. Research has shown that when rates of human activity within national forests and parks increase, the opportunity for wildfire ignitions that are associated with those activities will rise (Manning 2001). Thus, it is imperative to understand that human actions and wildfires are related.

This research investigates the spatial relationship between human activity and wildfire ignitions to assess the human caused ignition risk of wildfires within the Willamette National Forest (WNF) in Oregon. Figure 1 shows the location of the main settlements and roads in and around it. Given that the WNF is within a few hours' drive from six of Oregon's larger cities—Salem, Albany, Corvallis, Eugene, Redmond, and Bend—the WNF attracts a large number of visitors who partake in recreational activities available throughout the Forest. Industrial activities such as logging are common throughout the WNF and traffic from five major highways are also potential human causes of wildfire ignitions. With the abundant spatial data available from the Forest Service and Data.Gov, the WNF is an excellent case study area with which to explore the spatial relationship between human activity and wildfires.

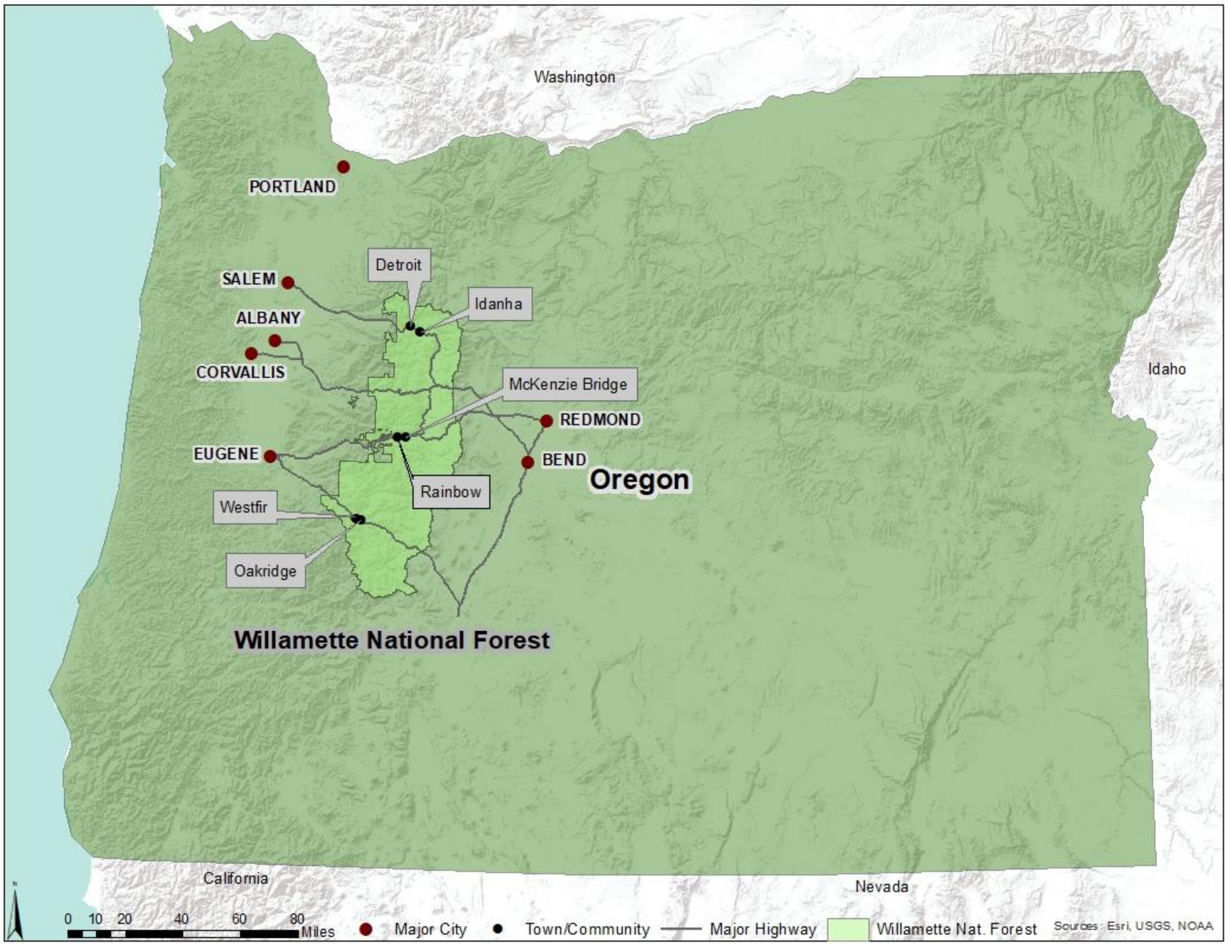

Figure 1. The Study Area: The Willamette National Forest, major roads, towns and communities, and nearby major cities.

Lightning caused wildfires were removed from the study in order to focus on human activities and their relationships with wildfires that may occur due to those activities. Though lightning is a major cause of wildfires, environmental factors (e.g. humidity and fuel load) that may lead to wildfires were not considered for this study, as it was hoped that by investigating the sources of the human caused wildfires, a better assessment of human caused wildfire ignition risk would be reached. Figure 2 shows the human caused wildfire ignition distribution in relation to lightning caused wildfire ignition locations. The two distributions of wildfire ignitions are sufficiently different between lightning and human causes to see there is no relationship between the two. This suggests a different mechanism driving the human caused ignitions and supports the decision to focus only on those fires and the location of human activities in this study.

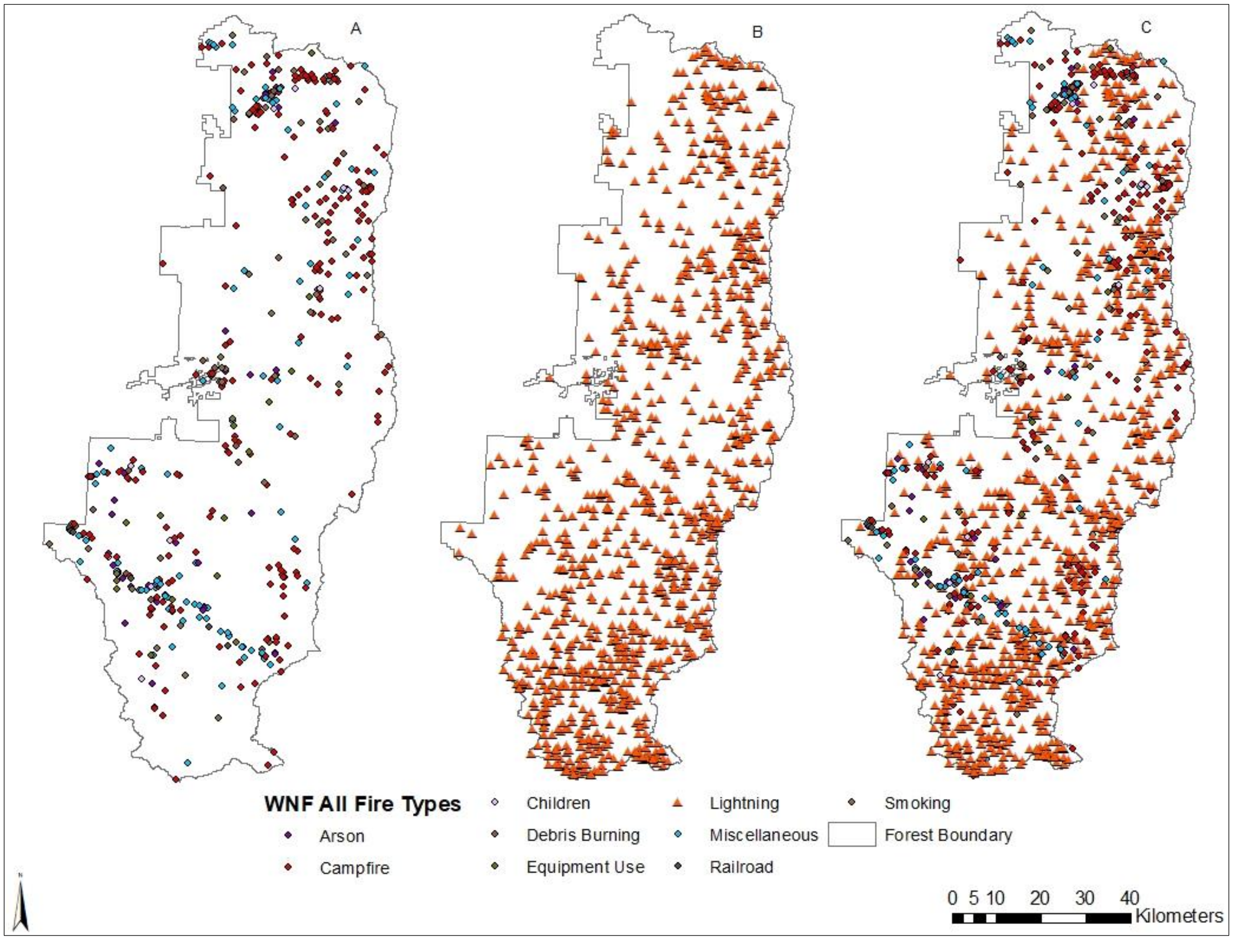

Figure 2. (A) Locations of human caused wildfire ignitions, (B) locations of lightning caused wildfire ignitions, and (C) combined human and lightning caused wildfire ignitions.

1.1. Wildfires and the Willamette National Forest

Like many national forests across the United States, the Willamette National Forest has often dealt with the adverse effects of wildfires. Throughout time, wildfires of varying sizes have altered the landscape and changed the way humans utilize the Forest.

1.1.1. History of Wildfires in the Willamette National Forest

The original Native American settlers of the Willamette Valley and the Western Cascades used fire to maintain harvesting areas and hunting grounds throughout the entire Willamette

Valley and surrounding foothills (Burke 1979; LeQuire 2010). The wildfires suppressed undergrowth that allowed fire-hearty trees and shrubs to thrive. As Burke (1979) has pointed out, the Native American method of using fire as a form of forest management helped to reduce any naturally occurring wildfires.

The issue of human caused wildfires within the Western Cascades actually began in the late 1800s when sheep farmers were blamed for starting fires to increase their grazing areas (Rakestraw 1991). Combating the idea of purposely starting a fire on public domain lands was addressed in 1896 with The Act of February 24, 1897 (29 Stat., 594) which

> provided penalties for willfully or maliciously setting on fire any timber, underbrush, or grass on the public domain; carelessly or negligently leaving fire to burn unattended near any timber or other inflammable material; or failing to totally extinguish any campfire or other fire in or near any forest, timber, or other inflammable material before leaving it (Rakestraw 1991, 21-22).

Then in 1897, The Sundry Civil Appropriations Act of June 4 (30 Stat. 11, 34) granted the Secretary of the Interior the authorization to make rules that would protect the Forest Reserves against destruction by fire (Rakestraw 1991). Various additional laws since that time have been imposed to try to improve the safety and protection of the forests, but wildfires persist. During the 13-year time span the data for this study cover, a total of 1,584 wildfires, both natural and human caused, were recorded within the WNF. Data from the Willamette National Forest lists nine different wildfire causes which include lightning, equipment use, smoking, campfires, debris burning, railroad, arson, children, and miscellaneous.

1.2. Common Activities Found in the Willamette National Forest

Every year the Willamette National Forest receives numerous visitors seeking some type of recreation or engaging in some sort of occupation. There are many different types of recreation and industrial activities within the WNF. All of these activities are a necessary part of what creates the uniqueness of the WNF.

1.2.1. Recreational Activities in the Willamette National Forest

Recreational areas within the Willamette National Forest encompass a large variety of activities. Camping, hiking, fishing, boating, hunting, skiing, horseback riding, and off-road vehicle use are some of the most common activities in which visitors engage. Trails of varying difficulty and length allow people to explore the multiple attractions the WNF has to offer. Some trails, such as the Pacific Crest Trail, test hiker's endurance with a variety of difficulties and long travel times. Hunting and fishing bring visitors to the WNF, allowing them a chance to hunt a variety of different game animals or fish the multiple lakes and rivers for several different types of trout, steelhead, and salmon. Camping allows the visitors a chance to relax and enjoy the outdoors. Some trails and gravel roads are accessible to off-road vehicles, such as motorcycles, ATVs (all-terrain vehicles), and other specialized vehicles. Horseback riding is allowed on certain trails, and some campsites are designed to accommodate horses and their owners. All Forest Service maintained campgrounds and day use areas have some type of fire pit, fireplace, or barbeque station (U.S. Forest Service n.d.).

1.2.2. Industrial Activities in the Willamette National Forest

The Willamette National Forest is no stranger to industrial activities. Industrial activities found throughout the WNF include logging, construction, hydroelectric dams, high voltage power line and cell phone tower repairs, fish hatcheries, trail repair, and railroads. Each quarter, the Willamette National Forest releases a Schedule of Proposed Actions (SOPA) that details projects planned for the WNF. These projects range from repairing trails and fixing winter road damage to upgrading campsites and rehabilitating huckleberry habitats. Manmade structures such as hydroelectric dams, cell phone towers, and ski lifts often need to be upgraded or repaired due to normal wear and tear. These activities often require a significant amount of manpower and can take weeks, even months to complete. The U.S. Forest Service and the Oregon Department of Fish and Wildlife each maintain a fish hatchery within the Willamette National Forest. Each of these fish hatcheries has abundant human and vehicle traffic entering and exiting the facility due to the activities of volunteers, employees, visitors, and fish hauling tankers.

Some less common harvesting and collecting activities can be classified as either recreational or industrial depending on whether resources are collected for income. In Willamette National Forest, these activities include collecting moss, harvesting camas or wild berries, gathering mushrooms or truffles, or picking wildflowers or other types of decorative foliage. Such activities are usually undertaken by single individuals or small groups who have acquired the proper permits and have been given suggestions about the location of appropriate collection areas within the WNF.

1.3. Wildfire Impacts on Economic Factors

Historically, wildfires have been described as both a tool for and a disaster to human communities (Rakestraw 1991). Wildfire before the European settlers was a natural cycle of the forest. Native Americans would follow a wildfire after a few days and harvest seeds and insects. European settlers then used fire to clear land for harvesting and to remove remaining stubble after harvest. It was not until the great forests of the New World were finally deemed a resource instead of a nuisance that wildfires became an issue.

Wildfire suppression costs have increased dramatically due to human infrastructure within the forest (Donovan 2008; Pew 2001; Gebert 2007). The National Interagency Fire Center releases details on the cost of fighting wildfires every year. Table 1 displays the total firefighting costs for the entire United States for the years 1995 and 2008, the first and final years examined in this study. Note that although the number of fires declined, spending and acreage affected increased. Costs of manpower, small equipment (personal equipment, chain saws, hoes, etc.), heavy equipment (bulldozers, fire trucks), air support, and logistics make up the majority of the necessary expenditures for every wildfire (National Interagency Fire Center 2016). Furthermore, the table does not show the costs of lost resources, homes, wildlife, domestic animals, revenue, and scenic beauty.

Table 1. National Interagency Fire Center costs for the years 1995 and 2008 for wildfire suppression. Source: National Interagency Fire Center 2016.

Year	**# of Fires**	**# of Acres**	**Dollars spent (in million $)**		
			Forest Service	**DOI Agencies**	**Total**
1995	82,591	2,896,147	161.5	78.4	239.9
2008	78,979	5,292,468	1,193.1	392.8	1,585.9

Wildfire damage reduces the availability of resources such as paper, pulp, and lumber to wood industries (Flannigan, Stocks, and Wotton 2000). Damage to hiking trails, campgrounds, and other recreational sites or surrounding areas prevent visitors from entering the areas until they have time to recover. Income can be lost from fees associated with permits, dues, and programs that are dependent on the availability of activities in or around recreational areas. Wildfires also impact local businesses: loss of tourism income due to visitors avoiding the effects of the fires or unable to enter fire-affected areas also impact local economies.

1.4. Project Objectives

Wildfires caused by human actions are a serious threat to private property, national parks, and forests. The goal of this study was to examine the relationship between the location of human activities and the location of wildfire ignitions in order to gain some insight about the potential locations of future wildfires. This study focused specifically on recreational sites and other human infrastructures and their relationship with human caused wildfire ignitions within the Willamette National Forest. The main objectives of this study were to validate three hypotheses:

(1) campfire caused fires would cluster near campgrounds,

(2) smoking related fire ignitions would be more abundant near day use areas, towns, and residential areas, and

(3) wildfires would be more frequent near areas with multiple numbers of recreational sites or human infrastructures.

1.5. Organization of this Document

This remainder of this thesis is composed of five chapters. Chapter 2 reviews related work about wildfires and their relationships to human activities and human infrastructures. This chapter also introduces previous research on the modeling of wildfire probability. Chapter 3 discusses the data pertinent to the study as well as the preliminary data exploration that was completed. Chapter 4 explains the Maxent software used to model the relationship between activities and wildfire ignitions. It also explains how the data were converted for use in Maxent and the necessary processes for entering the data within the modeling software. Chapter 5 provides the results of the Maxent software modeling processes and discusses the probability of occurrence of wildfires given different variables related to human infrastructure or recreational activities within the WNF. Chapter 6 offers discussion about the findings of this thesis and possible future work.

Chapter 2 Related Research

A great deal of research has gone into investigating the causes of wildfires. Previous studies have shown that human activities in areas like the WNF are often responsible for wildfire ignitions (Pew 2001). This chapter takes a look at prior research that explored factors that influence wildfire occurrences, including recreational activities, human infrastructure, industrial activities, forest management, and weather conditions. It also introduces Maxent, a machine learning tool, that has been used to model relationships between various environmental variables and species locations using presence only data.

There has been extensive research on how human infrastructure encroachment on wilderness areas affects wildfire probability (Chas-Amil et al. 2015; McLemore 2017). Much of the previous work deals with the Wildland Urban Interface (WUI). Wildfire occurrences that are spatially related to recreational activities within the WNF are the focus of this study, so it is important to understand that WUI deals strictly with areas of urbanization and some, but not all, forms of human infrastructure. Urbanization is associated with growth or expansion of cities or areas of large population densities, whereas human infrastructure for the purpose of this study, refers to those areas related to highways, roads, railroads, resorts, private residency, towns or communities, and administrative areas.

2.1. Human Activities Related to Wildfire Occurrences

Forests provide numerous opportunities for humans to enjoy and use the resources within them. Some activities are industrial, such as logging, road building, and forest management. Other reasons for people to trek into the WNF are recreational, including activities such as camping, hiking, fishing, cross-country skiing, or off-road vehicle usage. According to Parisien et al. (2012), human activities need to be included in all estimates of wildfire probabilities because human activities as potential factors in wildfire occurrences are often ignored. Whatever the reason for humans to be in the WNF, there is always a possibility of wildfires.

2.1.1. Relationship of Recreational Activities to Wildfire Occurrences

With a vast number of recreational opportunities, the Willamette National Forest receives a considerable number of visitors each year. Annually, the number of visitors to national forests continues to increase (U.S. Forest Service 2014). The results of several studies suggest that as the popularity of outdoor recreation grows, and the rate of yearly visitors increases, so does the risk of wildfire ignitions from human related activities. Camp and Krawchuk (2017) showed that recreational activities are positively associated with wildfire ignitions. Other research has shown that areas associated with activities such as camping and hiking, particularly those involving campfires, create situations that increase the possibility of wildfire ignitions (Chas-Amil et al. 2015; Cole 1981). Romero-Calcerrada (2008) showed that distance from recreational areas is an important factor when predicting wildfire ignitions. Pew (2001) discovered that recreational activities on Vancouver Island in Canada contributed to a high percentage of wildfire ignitions, though most of the fires were small.

Recreational destinations such as the Willamette National Forest allow human recreational activities into back country areas where fire suppression response may be inhibited due to inaccessible terrain. These types of situations, where a wildfire ignition happens in remote areas, may increase the acres affected due to the time it takes to report the wildfire. Hiking and horseback riding are examples of activities that allows people access to areas of the WNF where a wildfire may go unnoticed. Camp and Krawchuk (2017) note that campfires that are built while hiking pose a high risk of wildfire probability. Romero-Calcerrada (2008) showed that trails used for hiking or horseback riding increase the risk of wildfires by increasing accessibility to areas inside forests.

Additionally, areas with high levels of hiking and horseback riding are subjected to changes in vegetation composition, which allows non-native plant species to invade the areas (Cole 1981). According to Stein et al. (2013), replacement of native vegetation by highly flammable non-native vegetation increases the potential for wildfires.

2.1.2. Relationship of Human Infrastructure to Wildfire Ignitions

There has been extensive research on how human infrastructure encroachment on wilderness areas affect wildfire probability by increasing the frequency of human activities in surrounding forested areas (Chas-Amil et al. 2015; McLemore 2017). Human infrastructure in this research was defined earlier as highways, roads, railroads, resorts, private residences, towns or communities, and administrative areas.

Camp and Krawchuk (2017) have shown that greater densities of infrastructure increases human activities in forested areas. Such human infrastructure can be found throughout the Willamette National Forest, except where the area is designated as a Wilderness Area. The next sections discuss the impact of different kinds of human infrastructure individually.

2.1.2.1. Roads

Originally, roads were built to gain access to those resources (timber, ore, coal) that a growing nation required. Today, roads into the forest have multiple uses such as hunting, logging, and forest management and they are used by a variety of people. Yang et al. (2007) have shown that human caused wildfire occurrences are more likely to be spatially clustered near human infrastructures such as roads and agricultural areas. Findings have also shown that the rate of wildfire occurrence per unit area is higher near roads and decreases with distance from the road (Pew 2001; Romero-Calcerrada 2008). This correlates with a study by Young (2015) that showed higher frequency of wildfire occurrences along major freeways across the Western United States. Roads, according to Camp and Krawchuk (2017), contribute to wildfire ignitions through discarded cigarettes, sparks from accidents, or even a bad muffler.

2.1.2.2. The Wildland Urban Interface and Wildfires

The Wildland Urban Interface (WUI), as defined by Stein et al. (2013), comprises areas in or around forests, grasslands, shrub lands, and other natural areas into which some type of urban expansion is occurring. In a report for the U.S. Forest Service, Stein et al. state that approximately 32 percent of U.S. housing units (homes, apartment buildings, and other human dwellings) are within the WUI. Stein et al. also note that as many as one million homes were built within the WUI in Oregon, California, and Washington between 1990 and 2000. For the purpose of this study in the Willamette National Forest, the WUI includes all areas surrounding towns, communities, areas of summer homes, lodges, resorts, and hotels.

Population expansion into forests and rural areas has been shown to be related to an increase in wildfire ignition counts by as much as double the number of natural fires (Calef, McGuire, and Chapin 2008). Proximity to population centers was also associated with higher counts of arson related wildfires (Yang 2007). Additionally, Hawbaker et al. (2013) discovered a positive relationship between urban density and increases in wildfires in the Mediterranean California climate zone.

2.1.3. Relationship of Industrial Activities to Wildfire Occurrences

There are many reasons for humans to enter the forest, but one of the oldest reasons would be to collect resources. Timber harvesting practices and replanting methods create denser stands of smaller tree sizes allowing for fire to crown (reach the upper levels of the trees) and spread faster than in a forest that had seen fires previously (Stephens et al. 2009; Lenart 2006; Pew 2001). With advances in logging techniques, it was anticipated that as a bonus, logging could reduce potential wildfire occurrences and severity by reducing fuel loads. Yet, research has shown that logging causes reoccurrence and greater severity of wildfires due to an unintended effect of increasing fuel loads (Camp and Krawchuk 2017; Lenart 2006; Pew 2001; Westerling et al. 2006). McKenzie et al. (2004) explain that increasing temperatures within a region due to current logging practices will speed up the drying of fuel loads which will increase the severity and frequency of wildfires.

In a study done on Vancouver Island, Pew (2001) discovered that logging between 1950-1992 was responsible for the greatest proportion of the increase in large acreage fires. In a study done by Miller et al. (2009) on fire severity in the Sierra Nevada Mountains, they found that fire severity increased overall across their period of research. Their data showed that increases in fire severity was due to fragmentation of forests (the patchwork like results of logging sections of a forest and leaving other sections either uncut or in different phases of growth) (Miller, Safford, and Crimmins 2009).

Wildfire occurrences have been attributed to timber harvesting which leaves unwanted material (commonly referred to as slash) that dries and increases potential ignitions (Camp and Krawchuk 2017). Pew (2001) confirmed that slash burns, the burning of unwanted material after harvesting operations, were directly related to 29 percent of all logging related fires on Vancouver Island in British Columbia, Canada.

2.2. Wildfire Prevention Through Forest Management

Maintaining a healthy forest ecosystem is imperative to reducing wildfire potential and severity, aiding suppression, and insuring safety of human visitors in case of wildfires. After the devastating wildfires of 1910, where 3 million acres were destroyed, and 78 firefighters lost their lives, state and federal agencies made it a high priority to suppress all wildfires (Stein et al. 2013). Later in the early 20th century, wildfire occurrences were lessened by different types of forest management, including techniques such as grazing that were used to reduce grasses, small shrubbery, and leaf litter thereby limiting fuels on which a fire could burn (Lenart 2006; Westerling et al. 2006). During the 1960's and 1970's, the importance of wildfires' role in forests and wildland ecosystems was beginning to be understood (Stein et al. 2013). Since that time, controlled burns have been carefully reintroduced to restore fire-adapted vegetation and reduce fuel loads.

As of 2009, within the Western U.S. over ten million hectares of forests are considered a medium to high risk for wildfires and the potential for wildfire ignitions is a significant issue for forest management (Stephens et al. 2009). According to Lenart (2006), one of main goals of current forest management practices is to reduce wildfire dangers. Hirsch et al. (2001) explain that "Fire-Smart Forest Management" uses methods such as thinning existing stands of timber, harvest scheduling, and harvest designs to reduce potential wildfire severity.

2.3. The Role of Weather in Wildfire Occurrence

Weather in the Willamette Valley and the neighboring foothills and mountains is ever-changing. There are many contributing factors to the sometimes-erratic nature of the weather. Terrain, vegetation, ocean currents, and even inland waterbodies influence different attributes of weather. Terrain is influential in forcing winds and clouds, vegetation can increase humidity, lakes and streams create areas of cooler temperatures, and ocean currents contribute to all types of weather, especially yearly weather patterns. Weather changes due to yearly cycles of El Niño and La Niña create abnormalities such as drought, unusual precipitation patterns, early spring temperatures, longer wildfire seasons, and increased wildfire severity (Dale et al. 2000; Westerling et al. 2006). According to Stein et al. (2013), forests and other wildland areas with low humidity and higher seasonal temperature patterns have a higher susceptibility to wildfires.

2.3.1. Fair Weather Activities and Impact on Fire Frequency

Wildfires in the western United States are a seasonal occurrence, with 94 percent of wildfires occurring between May and October (Westerling et al. 2003). Seasonally, the Cascade Mountain Range has the highest number of wildfires between July and August. Recreational activities are often most prominent during the warmer seasons of the year, which coincides with fire season. It is this combination of warm, dry weather which brings people to the forests, but it is also a combination for wildfires. Romero-Calcerrada (2008) also found that wildfire occurrences increased near recreational areas during the summer holiday months, July and August. Pew (2001) observed that monthly percentages of the annual count of human caused wildfires on Vancouver Island began to increase in May, peaked in August, and then dropped substantially in October. According to Young (2014), peaks in wildfire occurrences were recorded during certain times of the year, including the beginning of hunting season in the late Summer or early Fall, the Fourth of July, Memorial Day, and Veteran’s Day.

Weather often determines the intensity of human activities in the WNF. With warmer weather, people look forward to hiking their favorite trails, camping, or undertaking other recreational activities and may make plans to engage in their favorite activity as early as possible. For example, Monahan (2016) concluded that warmer than normal early spring temperatures increases the number of visitors and extends the visitation seasons within National Parks.

2.4. Modeling Wildfires using Maximum Entropy Techniques

Maximum entropy is a machine learning technique that is used to model presence only data against environmental conditions to predict the probability of presence for the purpose of species distribution and environmental niche modeling (Merow 2013). This method has been used extensively to model the relationship between the environment and the occurrence of animals, plants, and fish, as well as archaeological sites and other kinds of sites (Elith et al. 2011; Oyarzun 2016).

There has been some research on the use of maximum entropy to model wildfire probability. Wildfire ignition distribution modeling is similar to species distribution modeling because the basic approach is to analyze locations in relation to environmental variables said to influence the spatial distributions of wildfire ignitions.

According to Massada et al. (2013), human and natural wildfires display distinctive spatial patterns that can be determined by using human and environmental variables. Using 340 human caused ignition points and three types of environmental data (landcover, topography and human), Massada et al. created three different models of wildfire ignition probabilities within the Huron-Manistee National Forest. They found that in areas where human population density is high, and the number of human caused wildfires is greater than the number of naturally occurring wildfires, accessibility and density contribute more to the wildfire probability. Areas near roads also showed higher probabilities of human caused wildfires than naturally occurring wildfires.

In a study conducted by Parisien et al. (2009), they attempted to quantify the influence of environmental variables on the prediction of wildfire distributions for three separate spatial scales: the conterminous United States, the state of California, and five fire-prone ecoregions of California. To model their hypothesis, they used both Maxent and boosted regression trees

(BRT) and compared the models. Fire data for their research dated from 1950-2003 and omitted prescribed burns and wildfires that measured under 300 acres. For their environmental variables, Parisien et al. included climate data, elevation, vegetation, and areas with sparse vegetation. To compare the models, they evaluated the receiver operating characteristics (ROC) and the area under the curve (AUC) for the highest score. The higher the AUC score is, the better the model fits real world applications. The results indicated that Maxent and the BRT showed similar results across all models. The California model results produced the highest AUC score across all models, and the five ecoregions had mixed results, with scores varying between high desert and coastline regions.

The use of machine learning software to model wildfire probabilities for evaluating relationships of fire presence against environmental variable backgrounds has been shown to produce probability maps that capture complex relationships (Parisien et al. 2012). Massada et al. (2013) question the fact that comparing continuous probability maps is not a simple task and suggests comparing both values and patterns. Maxent has been used to predict wildfire probabilities in both large areas and in smaller, localized areas. In both situations, research has shown that Maxent is capable of modeling wildfire ignition points with relative accuracy.

2.5. Summary

Understanding that there are many different factors that contribute to wildfires is important. The previous research discussed in this chapter provides information about how different activities, practices, and natural conditions affect how wildfires begin and how they react to those factors. In all, the main cause that was referred to the most was some sort of human activity.

Chapter 3 Data and Preliminary Data Exploration

This chapter provides a description of the study area, gives an overview of the data sources, and explains the preliminary data exploration used in this study. The purpose of the preliminary data exploration was to examine the data for any spatial correlation between wildfire occurrences and recreational sites, administrative locations, and/or human infrastructure. The results of the preliminary analysis indicated the direction to be taken in the full analysis described in Chapter 4.

3.1. Study Area: Willamette National Forest

The Willamette National Forest is the area of focus for this study. The WNF is the fourth largest national forest in the state of Oregon (U.S. Forest Service n.d.). The WNF is centrally located along the western slopes and foothills of the Cascade Mountain Range bordering the eastern side of the Willamette Valley. With four major cities to the west of the WNF and two major cities to the east of the WNF, traffic and visitors are abundant, as are recreational activities.

3.1.1. Geographical Features of The Willamette National Forest

The Willamette National Forest is 110 miles long and is spread across six Oregon counties (U.S. Forest Service n.d.). Approximately 1,675,400 acres are designated as National Forest under the supervision of the U.S. Forest Service. Under the Wilderness Act of 1964, 380,805 acres of the WNF were designated as wilderness area, which forbids human residency, motorized vehicles, and requires no disruption of natural ecology. Figure 3 shows the main roads and communities in and surrounding the WNF.

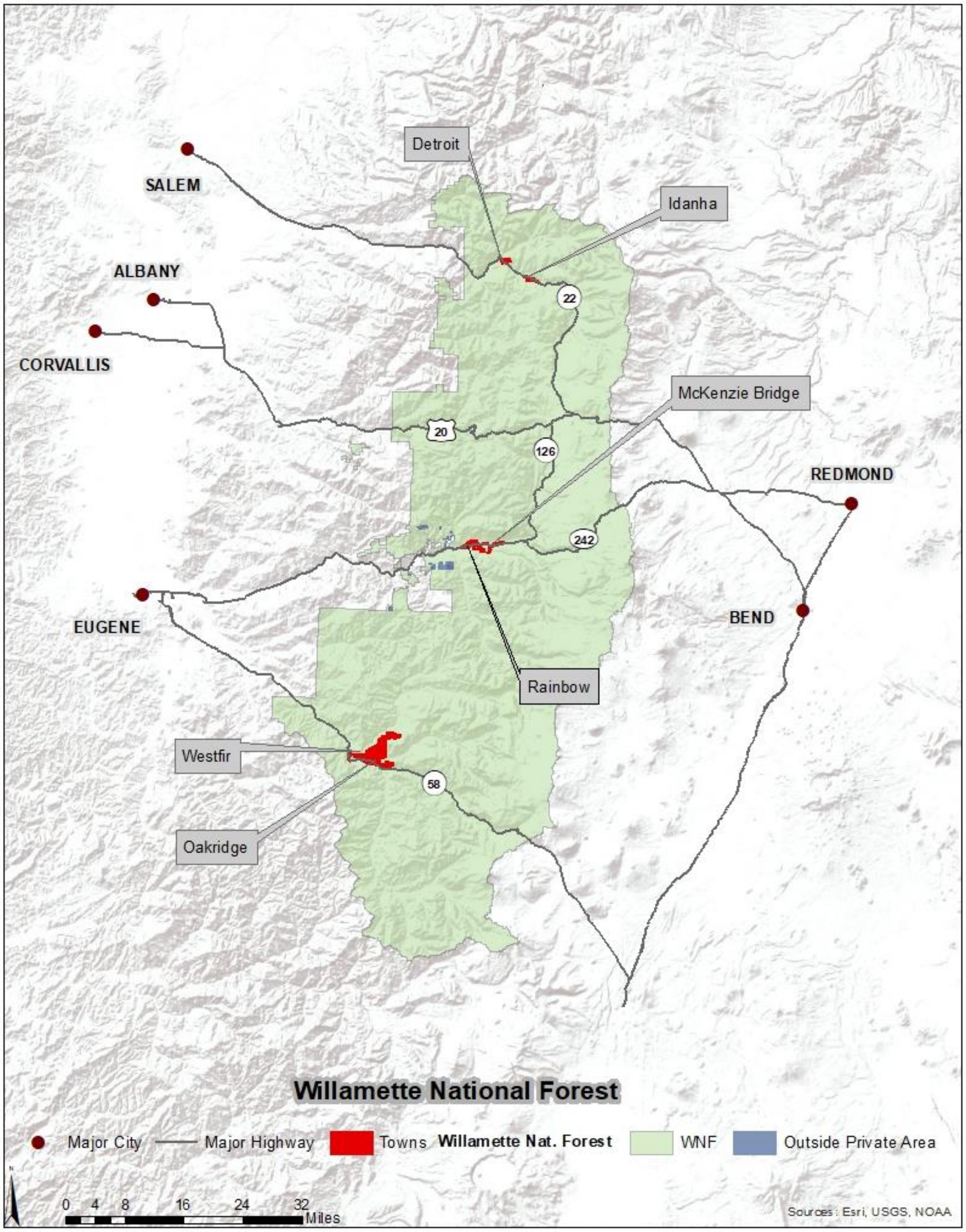

Figure 3. The Willamette National Forest with town, community, highway locations, and privately owned areas outside of the WNF.

Four towns and two unincorporated communities are located within the boundaries of the Willamette National Forest. The towns of Detroit and Idanha are located near the northern boundary along Highway 22. The unincorporated towns of McKenzie Bridge and Rainbow are found near the western boundary on Highway 20. The towns of Oakridge and Westfir are located along Highway 58 which runs through the southern quarter of the WNF. The towns of Detroit, Idanha, and Westfir have populations of less than 260, and Oakridge maintains a population of 3205 (U.S. Census Bureau 2010). Population counts for Rainbow and McKenzie Bridge were not available. All towns and communities inside the boundary of the WNF, while containing a combination of privately owned lands and areas governed by local, county and state agencies, are considered part of the WNF for this analysis.

An additional 123,000 acres of small inholdings are scattered throughout the WNF. These areas fall under the supervision of private ownership or other government agencies but are considered part of the WNF for the purposes of this study. Some of these privately held lands are used for forestry purposes only. The areas were considered part of the WNF for this study based on the fact that often there is no marked boundary or other evidence to differentiate the WNF from private lands. Another factor in the decision was that U.S. Forest Service roads pass through private lands, making these privately held lands accessible to the public. Other types of privately held lands are discussed later in this chapter.

A few small, isolated areas of the WNF fall outside of the main forest boundary; these small islands of national forest are visible on the west side in Figure 3. While these islands are part of the national forest, they do not contain any form of recreational site or human infrastructure, nor do any wildfire ignition points fall within them. These islands were cut from analysis, but they are displayed in maps presented in this thesis.

As well, there are some larger privately-owned areas that are holes inside the main forest boundary near the western mid-section of the WNF (shown in blue in Figure 3). These areas were removed from the data set used in this study by the U.S. Forest Service prior to distribution. As a result, these areas are not considered part of the privately-owned areas that were included in the analysis.

A variety of terrains are found within the WNF, from narrow canyons, cascading streams, and wooded foothills to a tall stratovolcano at the eastern forest boundary (U.S. Forest Service n.d.). The WNF elevation ranges from approximately 900 feet above sea level to 10,495 feet atop Mt. Jefferson and the Three Sisters.

3.1.2. Recreation in the Willamette National Forest

Recreational areas within the Willamette National Forest encompass a large variety of activities. Camping, hiking, fishing, boating, hunting, skiing, horseback riding, and off-road vehicle usage are some of the most common activities visitors engage in. Within the WNF there are 90 campgrounds (82 Forest Service, 8 private or other agency), and 22 picnic or day-use areas. All Forest Service maintained campgrounds and day use areas have some type of fire pit, fireplace, or barbeque station (U.S. Forest Service n.d.). There are 1360 miles of hiking trails give access to a large amount of the WNF (U. S. Forest Service n.d. A). There are 400 named lakes, 4101 secondary waterbodies equaling approximately 26,000 acres of surface water, and 2700 miles of rivers and streams for boating, fishing, and rafting (U.S. Forest Service n.d.). There are two developed ski areas, Hoodoo Ski Area and Willamette Ski Area, both operating under special permits within the Willamette National Forest. There are certain areas within the WNF that allow for ATV recreation where ATVs can be used on specific trails with the proper permits.

Wildfire safety warnings and information are common propaganda throughout designated recreational areas. Despite these warnings, wildfires do occur.

3.1.3. Vegetation

The WNF is positioned along the Western Cascade foothills and contains some of the most productive forest land within the U.S (U.S. Forest Service n.d.). The forest vegetation consists mainly of Douglas Fir, but also contains 15 different conifer species and other broad-leaf hard and softwoods. Old-growth stands of Douglas Fir are common throughout the WNF with tree diameters ranging from 3-8 feet (U.S. Forest Service n.d.). Douglas Fir and other types of timber are an important resource for local economies that depend on the lumber and wood fiber industry. Other forest resources such as moss, mushrooms, camas, and Christmas trees are also commonly sought-after commodities within the WNF by Native American tribespeople and others in small groups or individually.

The Willamette National Forest is more than just a stand of timber. Throughout the WNF there are meadows of grasses, shrubbery (underbrush), a wide variety of wildflowers, different types of berry plants, and lichens. All of the different plant life makes up a well-established ecosystem that depends on seasonal climate fluctuations.

3.1.4. Climate

The Willamette National Forest is located at a geographic location and latitude that gives it the classification of a sub-tropical rainforest. This means it receives between 40 to 150 inches of rainfall, some of which falls as snow in the upper elevations (U.S. Forest Service n.d.). With its location against the western side of Cascade Mountain Range, and being approximately 85 miles inland from the Pacific Ocean, a number of different climates affect the WNF. Depending on location, elevation, and season, the temperatures of the WNF can vary quite dramatically, with temperatures ranging from single digit winter temperatures to summer temperatures into the mid 80's Fahrenheit.

Cyclical climate patterns such as El Niño and La Niña are common occurrences that affect the climate within the WNF. Depending on the cycle, a variety of weather patterns from drought to intense rain/snow storms are possible. Droughts brought on by the El Niño cycle reduce precipitation and available snowpack in the mountains. La Niña denotes a cycle where precipitation levels are higher than normal, which helps to increase snowpack in the higher elevations and to maintain lower temperatures during the spring and summer seasons.

3.1.5. The Role of the Forest Service and Other Agencies

The Willamette National Forest falls under the federal authority of the U.S. Department of Agriculture (USDA). The USDA manages national forests throughout the United States through the U.S. Forest Service (USFS). The USFS in its mission as managers of the Willamette National Forest has laid two principles as foundations for maintaining the WNF

> -*Land Stewardship*: The Willamette National Forest is managed to conserve natural resources, promote long-term productivity and sustained yield, and enhance environmental quality. Commitment to long-term stewardship must be demonstrated by strong and visible sensitivity to the land in on-the-ground management activities. (U.S. Forest Service 1990, IV-2)

> -*Public Trust*: Managers of the Willamette National Forest are public servants and are charged to listen and to provide for the public needs to the best of their ability. They will be open and forthright with the public in all manners. Regardless of the potential conflict and controversy, public interest in National Forest management is best served by active and informed public participation. (U.S. Forest Service 1990, IV-2)

The USFS oversees an assortment of resource management programs that pertain to the WNF. Wildfire management, hydrological concerns, invasive plants, timber management, and recreational management are a few issues that are discussed on the Willamette National Forests Project page https://www.fs.usda.gov/projects/willamette/landmanagement/projects. The USFS is charged with maintaining all federally owned recreational sites within the WNF: this means upkeep of all camping sites, boating areas, trails, roads, and permits for ski areas. Hydrological or aquatic programs target the rehabilitation of streams, rivers, and neighboring banks and vegetation for the improvement of aquatic species. Wildfire management within the WNF consists of assessment of wilderness areas, monitoring vegetation and timber, as well as

> understanding and modeling fundamental fire processes, interactions of fire with ecosystems and the environment, social and economic aspects of fire, evaluating integrated management strategies and disturbance interactions… [and] prioritizing and implementing fuel hazard reduction projects, in smoke forecasting, in rehabilitating and restoring land after severe wildfire, and in providing information to home owners in the wildland-urban interface (U.S. Forest Service 2016b, n.p.).

The State of Oregon maintains the five major highways that run through the WNF and polices the highways and urban areas found within the WNF. The State of Oregon operates maintenance yards near the highways to accommodate highway maintenance year-round. The Oregon Department of Fish and Wildlife is responsible for overseeing all hunting and fishing regulations, licensing, monitoring wildlife and aquatic species populations, as well as enforcement of hunting and fishing rules and regulations within the WNF.

3.2. Data Overview

The main objective of this study was to determine if there exists a spatial relationship between wildfire ignitions and recreational sites and human infrastructures in the WNF. This study focused solely on wildfires that have been determined to have been started by human related activity, removing natural occurring fire ignitions from the equation.

Data were collected from one or all of the following data libraries: the Willamette National Forest Data Library, USDA Forest Service FSGeodata Clearinghouse, and Data.gov. All data for this study was converted to NAD 1983 USFS R6 Albers, a version of the Albers Conical Equal Area system. This is the coordinate system the Forest Service uses in Region 6 of the USDA. Each data type and how it was used is explained in further detail in the next sections.

3.2.1. Forest Boundary Data

The Willamette National Forest boundary data is a polygon layer that defines the forest boundary and other ownerships found within the forest boundary, as well as depicts the individual ranger districts that make up the complete national forest. The Willamette National Forest Headquarters in Eugene, OR created the data for the purpose of management of natural resources. The data attributes used in this study are the DIST (ranger district) and PROCLAIMNF (this indicates whether polygons contain land inside or outside of the WNF, as explained earlier in the study area description). This data set was created February 2, 2001 and was last updated September 13, 2007. Although this boundary was more than 10 years old at the time of this study, the wildfire data covers the years up to 2008 so it is current with respect to the other data.

3.2.2. Wildfire Data

The USFS recorded 493 human caused fires between 1995-2008 in the WNF. The time range for this study was chosen based upon the time span of the original data found within the Willamette National Forest Data Library. The wildfire data set from the Willamette National Forest Data Library was incomplete since data between the years 1999 to 2003 were missing; thus, that data set was discarded. It was necessary to use data found in the FSGeodata Clearinghouse and the Data.gov Fire Program Analysis - Fire Occurrence Database which included data from all 50 states, Guam, and Puerto Rico. Figure 4 displays the locations of the all human caused wildfire ignitions within the Willamette National Forest between the years 1995 to 2008, with many overlapping symbols where fire ignition points are superimposed. Table 2 summarizes the wildfires during 1995-2008 in the WNF by category.

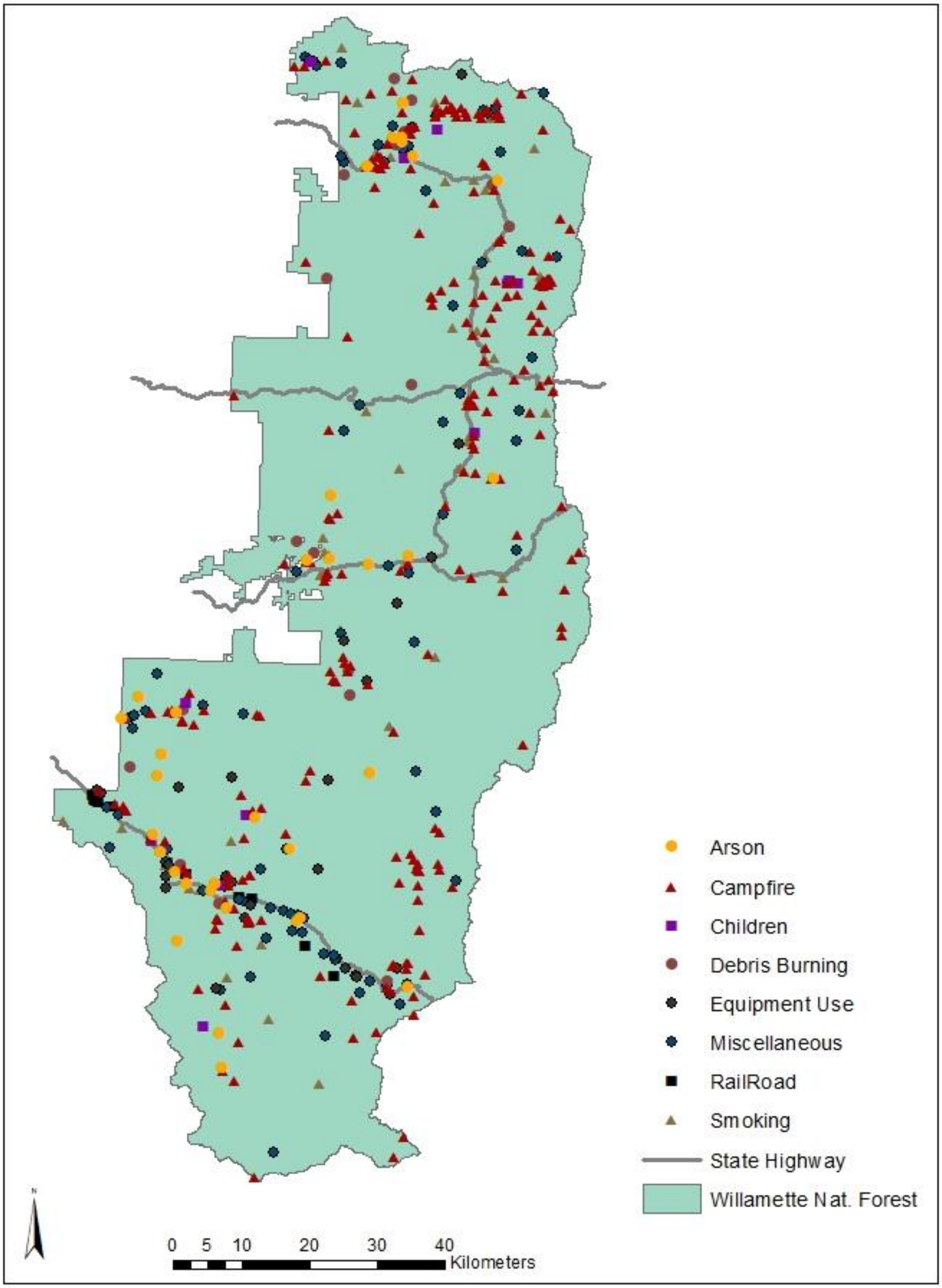

Figure 4. Location of the 493 human caused wildfires in the WNF between 1995 and 2008.

Table 2. Number of human caused wildfire occurrences by category, 1995-2008

Wildfire Type	Number of Occurrences
Arson	34
Campfire	256
Children	13
Debris Burning	17
Equipment Use	20
Smoking	50
Miscellaneous	93
Railroad	10
Grand Total	**493**

The wildfire data selected for this study were obtained in point format. A point format was chosen because the idea of this study was to find a relationship between the original point of ignition to whatever human activity might be responsible for the cause. The USFS collects and stores fire occurrence data in a database called the Fire Statistical System (FIRESTAT) (U.S. Forest Service 2016a). The data for each individual wildfire occurrence is recorded using a form called the Individual Wildland Fire Report. Current methods utilize GPS technology to record the wildfire ignition locations, but prior to 2014, the locations were input using either lat/long coordinates taken at the occurrence site (small fires) or using a map to determine the location of the fire ignition using the Township, Range, Subsection, and Principal Meridian of that location to identify and plot the coordinates.

The U.S. Public Lands Survey System uses Township, Range, Subsection, and Principal Meridians to subdivide the United States. Townships are measured as 6-mile by 6-mile squares. Townships are surveyed north, south, east, and west from an initial point. There are 37 Principal Meridians running parallel, north to south across the United States. A baseline runs perpendicular to the meridians and is used to designate Township locations north or south of the baseline. A range number indicates the number of townships east or west of the Principal Meridian. Townships are further subdivided into 36 Sections, which are a 1-mile by 1-mile square. These Sections, too, can be subdivided into Subsections which are measured ¼-mile by ¼-mile and contain 40 acres. Assuming the center points of Subsections were used to get the coordinates of fire ignition locations, the precision of these locations recorded in this database should be considered +/- 0.125 mile, 660 feet or approximately 200 m.

The original data were filtered to extract only data found in the Willamette National Forest. Further editing included clipping the data to remove any outliers outside of the forest boundary as described in the previous section and selecting only the data from 1995-2008. All non-human caused wildfires were removed. The attributes used for this study were the FIRE_NAME, STAT_CAUSE (a value given to identify the wildfire cause: for example, Campfire = 4), STAT_CAUSE_1 (a written description of the wildfire cause), X_COORD, Y_COORD. Eight different categories are found in the STAT_CAUSE (wildfire cause) attribute data: Arson, Campfire, Children, Debris Burning, Equipment Use, Smoking, Railroad, and Miscellaneous.

Only the wildfire causes of Smoking (50 fires) and Campfires (256 fires) were deemed to have sufficient occurrences to permit detailed individual examination of these causes. These data were extracted into two separate data layers for individual analysis. Data in the Miscellaneous causes category (93 fires) while numerous, were not examined as a separate category due to uncertainty of what “miscellaneous” was categorizing—did these include fires in other categories? Finally, the full set of all 493 wildfires were included in analyses that considered the entire collection of fires collectively. Maps showing the locations of each type of wildfire ignition are included in Appendix A.

3.2.3. Recreational Site and Human Infrastructures Data

Creation of the recreational site and human infrastructures data layers required the combination of data from several sources. These are shown in Table 3 and discussed below.

Table 3. Sources used to create the recreational site and human infrastructures data layers

Layer	**Source**	**Type**	**Description**
Recsite Point	Willamette National Forest Data Library	Point	Locations of recreational sites recorded at points
Recsite Poly	Willamette National Forest Data Library	Polygon	Locations of recreational sites large enough to be represented by area features
Management Areas	Willamette National Forest Data Library	Polygon	Categories of administrative areas as defined by the 1990 Willamette National Forest Plan
Private Campgrounds	Google Earth, Accompanying websites	Point	Locations of private campgrounds not included in any of the previous data layers, included in the analysis.

Two key data sets were used for the purpose of identifying areas that had frequent human activity within the Willamette National Forest. One data set had all site types as points, and the second had recreational sites as polygons. These data were available through the Willamette National Forest Data Library. The USFS Geospatial Service and Technology Center created the original data set. These data were created June 18, 2001 and were last updated June 28, 2010 so this data is relatively concurrent with the fire data. The data were produced using one of two of the following methods: 1) scanning a map or 2) manually digitizing a map by using a digitizing table to capture the data. Point data depict developed recreational sites too small to be depicted at 1:24,000, polygon data depict sites large enough to be represented as polygons. The Data Resource Management Division of the USFS Pacific Northwest Region later edited the data to adjust certain locales within the Detroit Ranger District and divided the original data set into separate point and polygon data sets for the purpose of spatial display and analysis.

Attribute data for both the point and polygon data used in this study consisted of SITE_TYPE (type of site), NAME, DESCRIPTION, and OWNER. For the purpose of complete and accurate coverage of all recreational sites within the Willamette National Forest, it was decided that both point and polygon data would be used. It should be noted that more than one recreational site type may be present within a single location, but each unique site type is considered to be a single feature.

More recreational site data were found in the Management Area data set from the Willamette National Forest Data Library. This data set was created April 13, 1994 and was last updated January 22, 2010. This data set contains polygons of all classes of management areas within the Willamette National Forest as described by the 1990 Forest Plan, later amended by the 1994 NW Forest Plan. For the purpose of complete data sets, all polygons within the Management Areas data set with a category similar to other site type categories in the previously discussed data sets were added to the other recreational site data. The Willamette National Forest Supervisors Office created this data set for the purpose of managing natural resources. No information was available on how the data set was created, thus its spatial uncertainty is unknown.

Three private campgrounds that were not part of the original data were discovered during the editing process of the recreational site data. Information about the campgrounds was obtained via word of mouth. The campgrounds' locations were investigated using Google Earth in order to attain their lat/long coordinates so that points could be added to the layer. Attribute data for these campgrounds were added manually.

3.2.3.1. Creation of the recreational site and human infrastructures data layers

The creation of the recreation site and human infrastructures data layers used in the analyses involved recategorizing the site types, separating the data into separate layers and combining features from several sources. Figure 5 shows the workflows, discussed in detail below, that were used in the preliminary editing process on the different data sets.

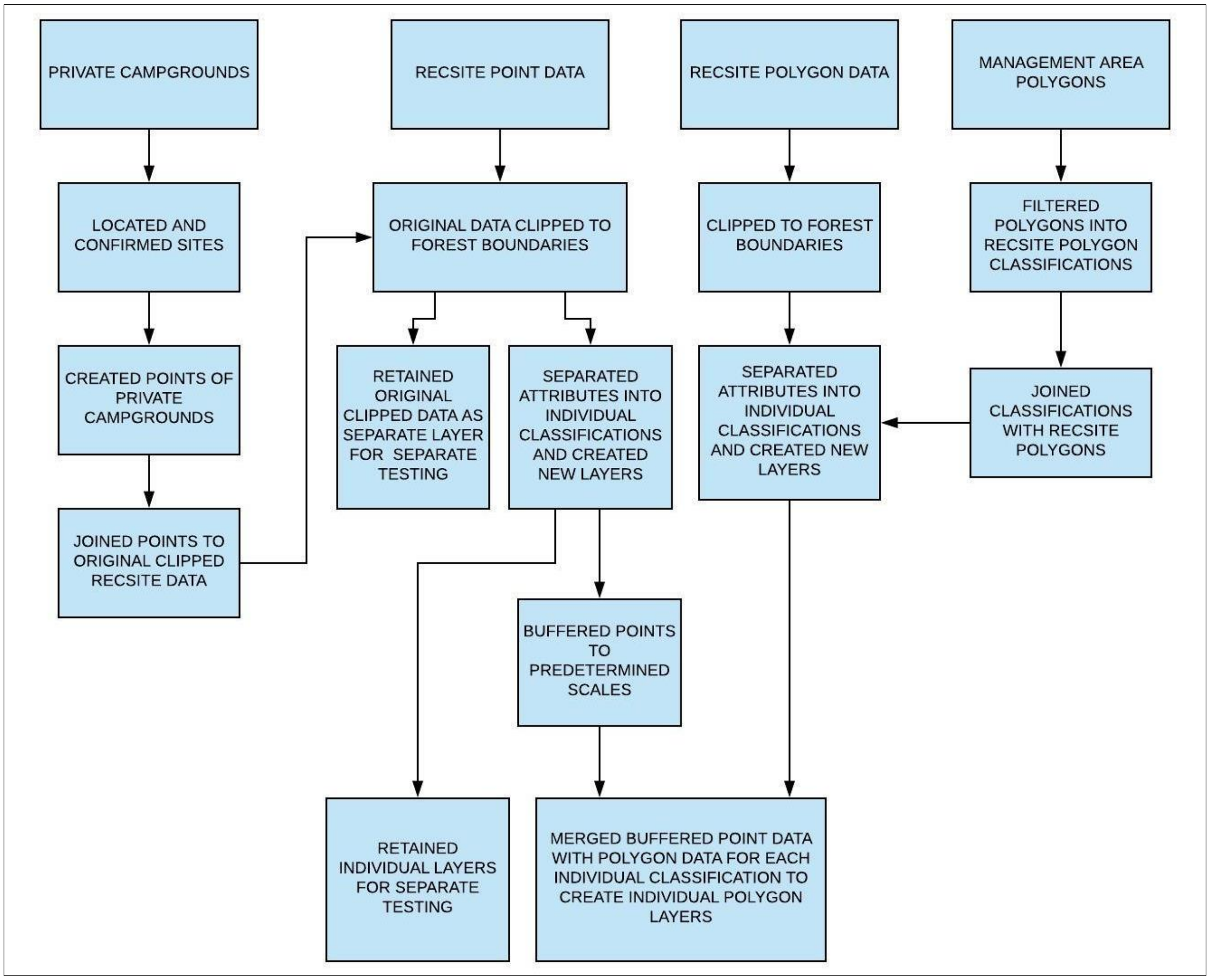

Figure 5. Flowchart showing the Recsite and human infrastructures data preparation

In the point recreational site data (called Recsite point in Table 4), there were 18 different types of recreational sites and administrative sites described in the site_type column of the attribute table. With 171-point recreational sites (not counting administrative sites, resorts, or summer homes), it was necessary to sort and consolidate the categories. Initial editing grouped the types into nine different categories: campgrounds, day use areas, lookouts, snow parks, boating, trail shelters, resorts, Forest Service Administrative areas, and ski areas. Categories for sites that had a blank entry for SITE_TYPE attribute field were determined by reading the DESCRIPTION attribute. The private campgrounds were added to the point layer.

Due to low counts of site locations in some categories, it was necessary to further consolidate categories having few locations with similar categories. Separate layers were then created for each of the different categories. Town, Community, Administrative site, Hotel, Lodge, Resort, and residential/private features were removed from the Recsite classification and were converted into three separate data sets henceforth referred to as human infrastructures. Table 4 shows the consolidation and final naming of the five Recsite and two human infrastructures layers. The same reclassification process was then followed for the Recsite polygon data and those data were likewise separated into the same seven layers.

Table 4. Consolidation of Categories and Naming of Data Layers for Recreational Sites and Human Infrastructures

<table>
<tr><th>Original Category</th><th>Revised Category</th><th>Final Layer Name</th><th># of features</th><th>Dataset Collection</th></tr>
<tr><td>Boating Site</td><td>Boating Site</td><td>Boating Site</td><td>14</td><td rowspan="16">Recreational sites</td></tr>
<tr><td>Campground</td><td>Campground</td><td rowspan="3">Campground</td><td rowspan="3">256</td></tr>
<tr><td>Group Campground</td><td>Campground</td></tr>
<tr><td>Horse Camp</td><td>Campground</td></tr>
<tr><td>Lookout/Cabin</td><td>Lookout</td><td rowspan="5">Trail Shelter</td><td rowspan="5">30</td></tr>
<tr><td>Observation Site</td><td>Lookout</td></tr>
<tr><td>Trail Shelter</td><td>Trail Shelter</td></tr>
<tr><td>Blank (trail shelter)</td><td>Trail Shelter</td></tr>
<tr><td>Blank (lookout)</td><td>Lookout</td></tr>
<tr><td>Picnic Site</td><td>Day Use Area</td><td rowspan="5">Day Use Area</td><td rowspan="5">22</td></tr>
<tr><td>Day Use Area</td><td>Day Use Area</td></tr>
<tr><td>Blank (Picnic Area)</td><td>Day Use Area</td></tr>
<tr><td>Other Rec. Concession</td><td>Day Use Area</td></tr>
<tr><td>Skiing, Down Hill</td><td>Skiing Area</td></tr>
<tr><td>Snowpark</td><td>Snowpark</td><td rowspan="2">Snowpark</td><td rowspan="2">13</td></tr>
<tr><td>Trailhead</td><td>Snowpark</td></tr>
<tr><td>Hotel, Lodge, Resort</td><td>Lodge/Resort</td><td rowspan="2">Private/ Residential</td><td rowspan="2">31</td><td rowspan="6">Human infrastructures</td></tr>
<tr><td>Private Summer Homes</td><td>Private Summer Homes</td></tr>
<tr><td>Forest Service Facility</td><td>F.S. Facility</td><td rowspan="2">Administration Area</td><td rowspan="2">13</td></tr>
<tr><td>Other Agency site</td><td>Administrative Area</td></tr>
<tr><td>Towns</td><td>Town</td><td rowspan="2">Town</td><td rowspan="2">6</td></tr>
<tr><td>Community</td><td>Town</td></tr>
<tr><td></td><td></td><td>Total</td><td>385</td><td></td></tr>
</table>

Once the point data was cleaned up and separated into seven-point layers, it was necessary to merge those with the polygon data in the original Recsite polygons. This was accomplished first by buffering all points to create polygons. The point buffer size was determined by calculating the average of size measurements of randomly selected recreational sites taken from imagery from Google Earth. The sites that were measured included three to four of each of the different categories of recreational sites. The measurements are intended to express the average footprint size of each type of recreational site. This is used to account for the recognition that the spatial influence of these sites on the landscape is spread over an area, not just at a one-dimensional point. Buffer sizing that was used for the recreational sites is listed in Table 5. The buffered points were then merged with the appropriate layer from the Recsite polygon data and any buffered point features that matched with a polygon of the same category were removed.

Table 5. Type Buffer Size

Type	**Buffer Radius**
Boating Site	100m
Campground	250m
Trail Shelter	75m
Day Use	125m
Snowpark	100m

Finally, the Management Areas data set additionally provided administrative areas, community, and private summer homes polygons. As a result, any administrative sites in this data source were added to the administrative site layer, the private summer homes were added to the residential/private layer and towns and communities were added to the towns layer. These additional data layers are described further below.

3.2.4. Road Data

The Willamette National Forest offers access to many areas through a vast network of roads. Different categories of roads, from paved highway, county, and agency access roads to seasonal gravel maintenance and logging roads, allow vehicles of the appropriate type to navigate areas where permissible within the WNF. These roads give people access to many of the different recreational sites found throughout the WNF.

The road data were obtained in a polyline vector format. The USFS originally designed the road data to show specific types of roads, their designated use, seasons of use, types of vehicles allowed, and whether they are intended for the purpose of fire protection or administrative use. The data were collected using one or both of two different methods: 1) on-screen digitizing from a georeferenced topographic map, or image background, or 2) GPS field collected positions. The data set was acquired from the FSGeodata Clearinghouse. The data was last updated February 27, 2015. The Metadata gave no indication of updates for new roads had been added to the data set since it was originally created. Initial editing of the data required clipping the road layer to match the forest boundaries.

Road layer data were buffered to an average width determined by using 20 random samples of road widths throughout the WNF. Road widths were measured using Google Earth Ruler at points where both sides of a road section were visible and displayed a definite road edge. The samples were chosen manually by zooming in to visually determine if road sides were visible. Five road sections were chosen from each of the four ranger districts. Road sections where the road was visually wider than normal, such as intersections or turn-outs were excluded. The 20 road widths were averaged resulting in a width of approximately 5m (exact average was 4.75m), this equaled a buffer of approximately 2.5m. Figure 6 shows the editing processes for the road data.

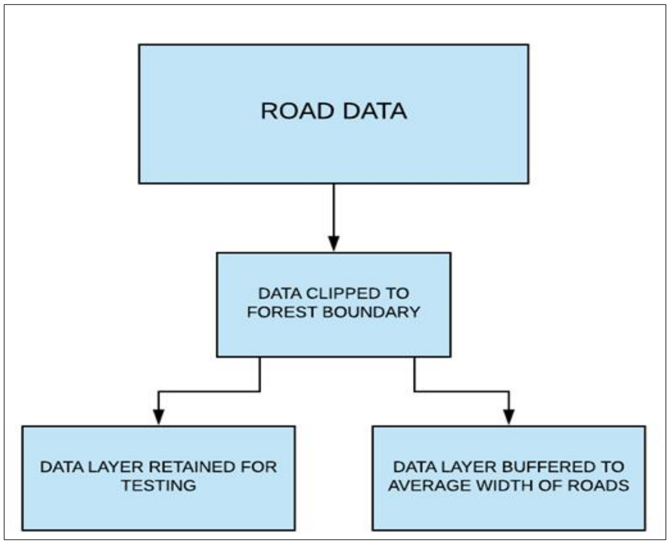

Figure 6. Road data editing process

It was later decided that, for visualization purposes, the state highways needed to extend beyond the forest boundary to show a general direction to the neighboring major cities. Data depicting the state highways for the entire state, created by the Oregon Dept. of Transportation (ODOT), were found at ArcGIS Online. The state highway data were clipped at random distances that extended beyond the forest boundary to show relative direction to major cities. The ODOT highway data were not used for analysis purposes, only for reference and visualization since the Willamette National Forest road layer already contained all WNF roads and highways.

3.2.5. Trail Data

The trail data used for this study was created by the USFS to provide public information about trails, their locations, and characteristics. Trail attribute data used in this study included NAME (when available). Trail data were clipped to the forest boundary. Data for this data set were found in the FSGeodata Clearinghouse. The data set was created February 27, 2015. The Metadata gave no indication of updates that new trails had been added to the data set since it was originally created Individual Forests are responsible for managing road and trail data sets. Trail data was collected in the same manner as road data.

The trail layer was buffered to 0.75 meters which gives total trail width of 1.5 meters wide. This width was estimated from personal experience from hiking Forest Service trails in the area.

3.2.6. Private, Residential, and Lodging Areas

Throughout the Willamette National Forest there are sections of land that are privately owned. Some of these areas are simple forest plots, owned by people or businesses for forestry harvest purposes. There are other areas where people have created small neighborhoods (too small to designate them as towns or unincorporated communities) that are used as summer homes, retreats, or resorts. For the purpose of this study, we focused on the areas of higher density human activity, such as the residences and those areas that are used for retreats or recreational use. Private land that was strictly used for forestry purposes was considered the same as USFS lands that had been designated for forestry purposes. Access to the areas was available using USFS roads and trails. By including the private lands as part of the WNF's extent, it made it possible to examine complete wildfire coverage through the entire WNF.

Private, residential, and lodging data includes any privately-owned lands within the WNF. The residential type includes any form of private ownership of a house, condominium, or place in which a human resides, and the lodging type includes any commercial residence where individuals rent or pay for temporary residency. There were private land areas within the Management Area data set that were homes that are owned privately, but the house resides on Forest Service lands. These types of residence are known as a lease type residency for the purposes of this study, were considered areas of private residences.

As explained above in Section 3.2.3, Private, Residential, and Lodging data were extracted from the Management Areas data set created by the USFS at the Willamette National Forest Headquarters. Polygons that were defined as private land ownership, residency, lodge, or resort were separated out and merged with the same data type that had been extracted from the original Recsite data. Attribute data used for this study included FP_NAME, FP_MGT_ALC (Forest Plan Management Allocation), and MGT_ALC (Management Allocation Consolidation of 1990 Plan and 1994 Plan).

3.2.7. Administrative Areas

Administrative areas were included to ensure all types of human activities found within the WNF were considered. Administrative areas for the purpose of this study are areas that are controlled by a government agency and are off-limits or have limited public access. Forest Service Ranger Stations, Forest Service and Oregon Dept. of Transportation maintenance yards, and fish hatcheries are a few examples. Agencies found within the Willamette National Forest who maintain such areas other than the Forest Service are the Oregon Dept. of Transportation, the Oregon Dept. of Parks and Recreation, Oregon Dept. of Fish and Wildlife, and Oregon Dept. of Forestry.

As explained in Section 3.2.3, these data were found in the Management Areas layer. As with the Private, Residential, and Lodging data, only the FP_NAME, FP_MGT_ALC (Forest Plan Management Allocation), MGT_ALC (Management Allocation Consolidation of 1990 Plan and 1994 Plan) and LABEL attributes were used.

3.2.8. Town Sites

Data for towns and communities was filtered from the Management Areas data set discussed in previous sections of this chapter. The town and community polygons were identified and extracted. Then the polygons were trimmed to the outermost boundary of built-up residential areas visible in Google Earth. Thus, it was possible to confirm the functional extent of the towns and communities and to verify that the included polygons did follow the outskirts of the towns. Issues with the town polygon data were limited to the original polygons' size and shape, which included large private lands next to the towns. These private forestry lands did not contribute to the towns as locations of focused human activity and as such were removed from the polygons to limit the influence of towns or communities to their residential and commercial footprints. Only the FP_NAME, FP_MGT_ALC (Forest Plan Management Allocation), MGT_ALC (Management Allocation Consolidation of 1990 Plan and 1994 Plan) and LABEL attributes were used from the data set. All towns and communities are positioned well within the forest boundaries, but the data were clipped to the forest boundary extent to eliminate any possible problems.

Within this layer are four polygons representing the towns of Detroit, Idanha, Westfir, and Oakridge. There are also 2 polygons representing the unincorporated communities of Rainbow and McKenzie Bridge. Originally, town and community data were not to be included in this analysis given the decision initially to disregard the influence on wildfires of population expansion into the Wildland Urban Interface discussed earlier. It was later decided that towns and communities do not influence wildfires strictly through population expansion. Tourism and major highways bring a large number of people through the towns and communities to recreational areas nearby. These towns and communities contain businesses that attract tourists, such as stores, restaurants, and gas stations. As well, these denser population areas may be expected to have a small impact on the wildfire probability as human activities within a residential setting do include a number of possible wildfire ignition types, such as barbeques, fireworks, and backyard burning.

3.2.9. Summary of Data Layers Used in the Analyses

As a result of this data preparation, a total of 385 sites were included for further analysis. Edge effects caused by clipping to the WNF boundary are assumed to be minimal due to the size of the WNF and the small number of recreational sites and administrative areas near the edges of the WNF. Figure 7 shows the locations of all the sites used in this study. Also, Appendix B includes individual maps of all the different site types.

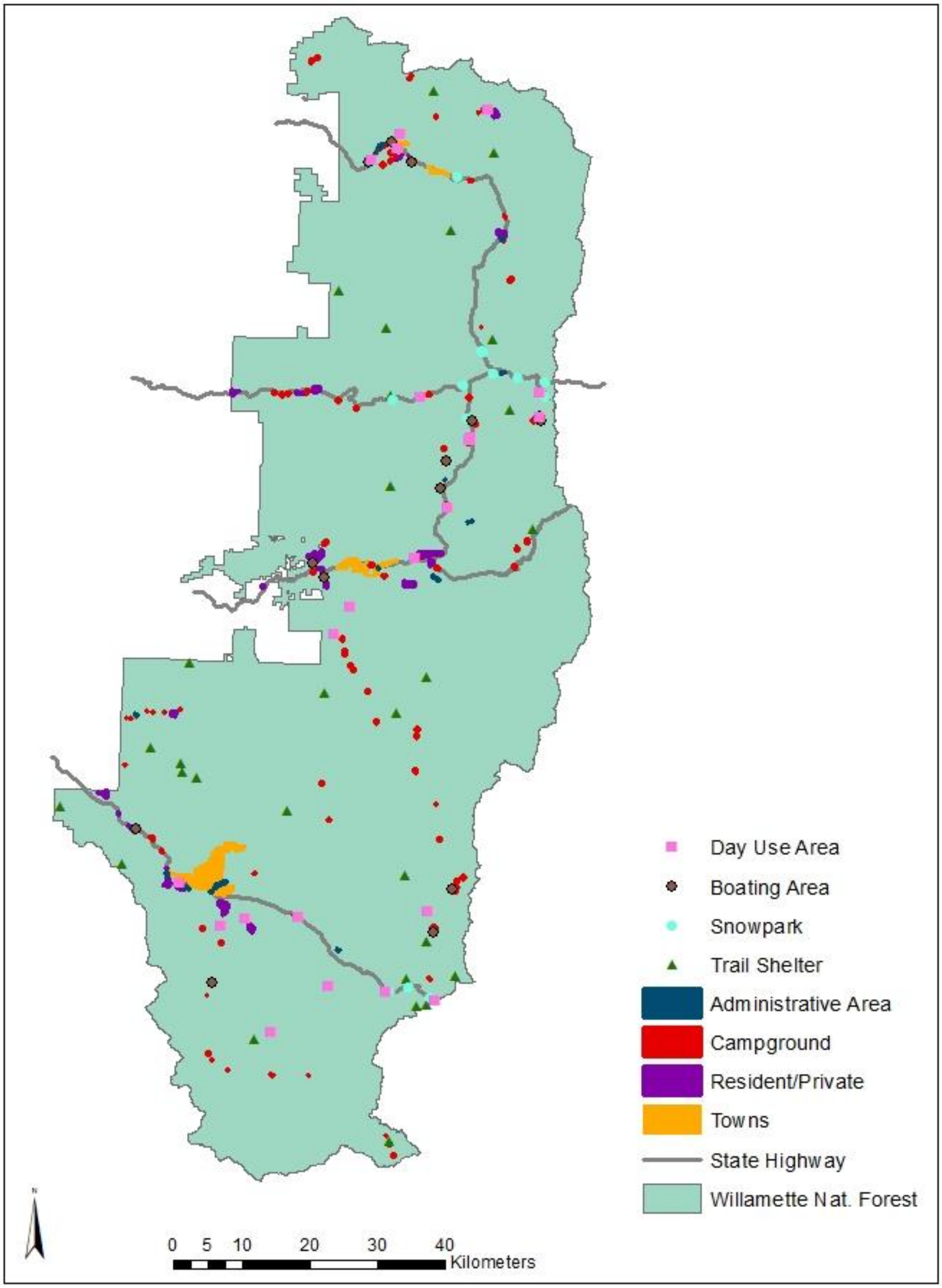

Figure 7. Locations of all recreational sites and human infrastructures included in this study. Points were used to show polygon sites too small to see on this map. Their colors match the relevant polygon colors shown in the legend.

Other features that may influence wildfire occurrences exist within the Willamette National Forest. Lakes and streams, for example, are usually accessible by roads or trails and are often located near a campground, day use area, a lodge or resort, private residence, or one of the other types of features explored in this study. Thus, water features were not included in this study since it was assumed that any human caused wildfire that occurred near a water feature would also be associated with the presence other features previously described. Similar decisions were made about many other possible features that could be included in this study.

3.3. Preliminary Data Exploration

Once the data layers were prepared, preliminary data exploration could begin. To start exploring the relationship between wildfire occurrences and the recreational sites (campgrounds, day use areas, trail shelters, snowparks, and boating areas) and human infrastructures (administrative areas, residential/private, and towns), it was necessary to visualize the data together. Initial data exploration used the Kernel Density tool to explore the spatial relationships between wildfire ignitions and all recreational sites, roads, trails, administrative areas, and towns/communities. This section describes how this tool was used and discusses the results of this preliminary data exploration in preparation for the main analysis described in Chapter 4.

3.3.1. Kernel Density

Kernel density calculates the number of features or events per unit area within a region defined by a search radius (O'Sullivan and Unwin 2014). Cell values decrease with distance from locations with high numbers of features, until the cell value is zero where no features are found within the search radius.

Kernel density was used to assess visually if any type(s) of wildfire occurrence appeared to be more related to a particular type of site. It was assumed, for example, that wildfires caused by campfires would occur more frequently near campgrounds. The density assessment compared wildfires caused by Smoking and Campfires individually and all fires collectively against all site types.

To insure consistent results, the same input parameters were used for all kernel density analyses. Table 6 shows the input parameters for each field of the kernel density tool.

Table 6. Kernel Density Input Parameters

Input field	**Input Parameter**
Input point or polyline feature	Individual wildfire cause layer (Smoking, Campfire) or the complete fire dataset
Population field	None
Output raster	Name based on cause type
Output cell size	500 meters
Search radius	5 kilometers
Area units	Square kilometers (default when units are metric)
Output values are	Densities
Method	Planar

A 500 meter output cell size was based on an assumed distance a person might casually wander from a site, road, or trail as well as the +/- 200 meter imprecision of fire locations. The Search Radius was set to five kilometers allowing for a focused density result around clusters of occurrences. Area unit input parameter defaulted to square kilometers based on the input feature class linear units on meters. The Out_Cell_Values was set to Densities in order to look for high areas of wildfire occurrences.

3.3.2. Results of Kernel Density Preliminary Data Exploration

The results of the preliminary data exploration revealed that areas of high fire density did not correlate strongly with what was thought to be the site feature responsible for the occurrence. For example, Figure 8 shows three copies of the same density surface created from fires caused by campfires along with three different sets of the site features. These fires caused by campfires did not show any particular spatial relationship with the locations of campgrounds and day use areas, as hoped (Figure 8A). While there are campgrounds and day use areas in the areas of higher density, there are plenty of campgrounds and day use areas in the areas of 0 density. When compared with the locations of trails (Figure 8B) and roads (Figure 8C), the density results for fires caused by campfires showed some correlation, but the results were not consistent enough to suggest a strong relationship worth exploring statistically.

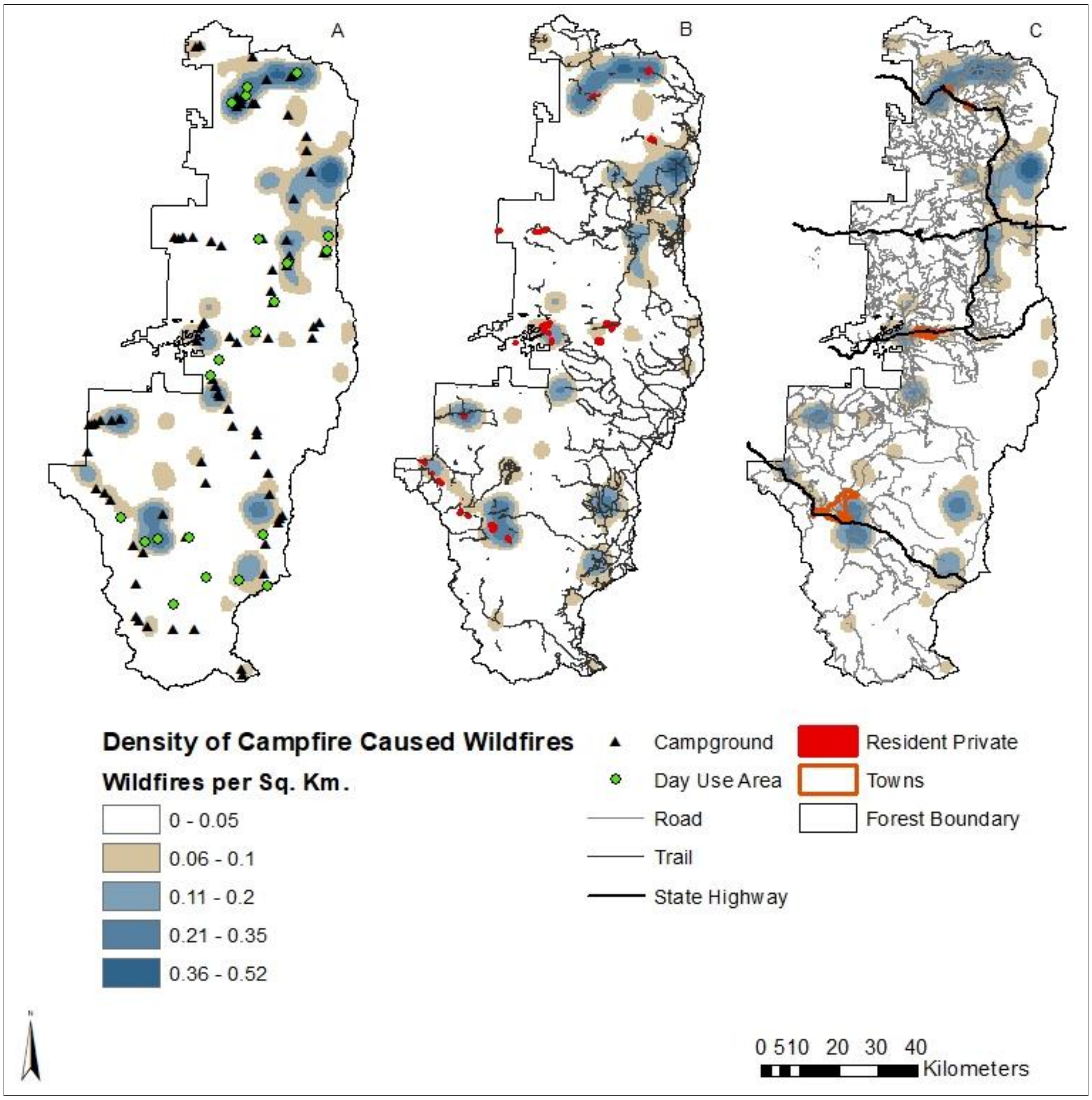

Figure 8. Density of campfire caused wildfires in relation to (A) campgrounds and day use areas, (B) trails and residential/private, and (C) roads and towns

While it was anticipated that smoking caused wildfires would reveal a significant relationship to day use areas, towns, and communities, the density analysis results shown in Figure 9 do not suggest any particular association between areas of high density and any particular site type. Significantly, the areas where high density of smoking related fires occurred are also areas where there are many different types sites.

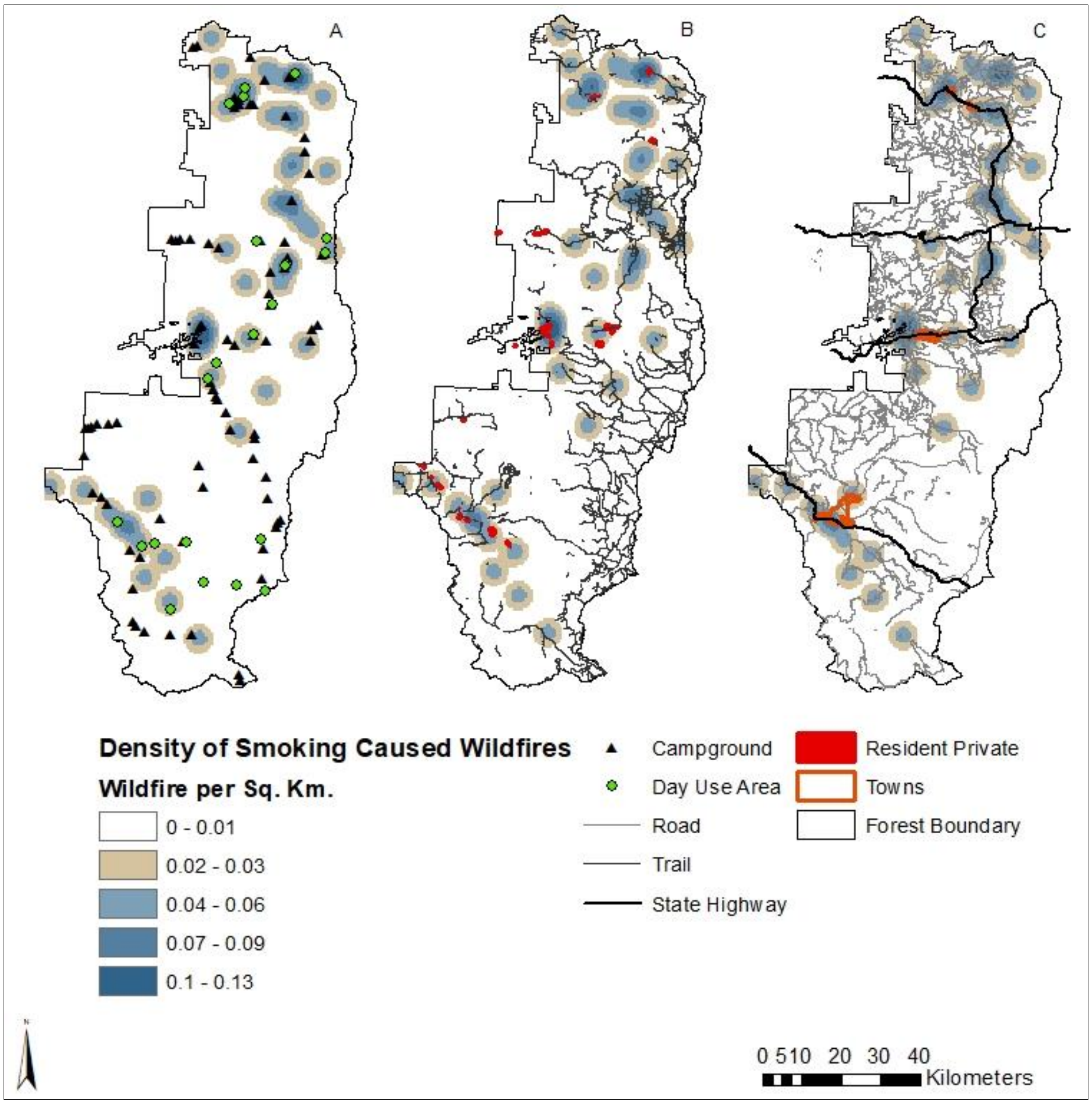

Figure 9. Density of smoking caused wildfires and (A) campgrounds and day use areas, (B) trails and residential/private, and (C) roads and towns

Finally, Figure 10 shows the density surface for the full set of 493 human caused wildfire ignition locations for the study period. As above, there is little evidence of strong spatial relationships here, though there does seem to be some tendency for the densest areas to follow the highway corridors. There is also a higher density in close proximity to the larger towns to the north and the south.

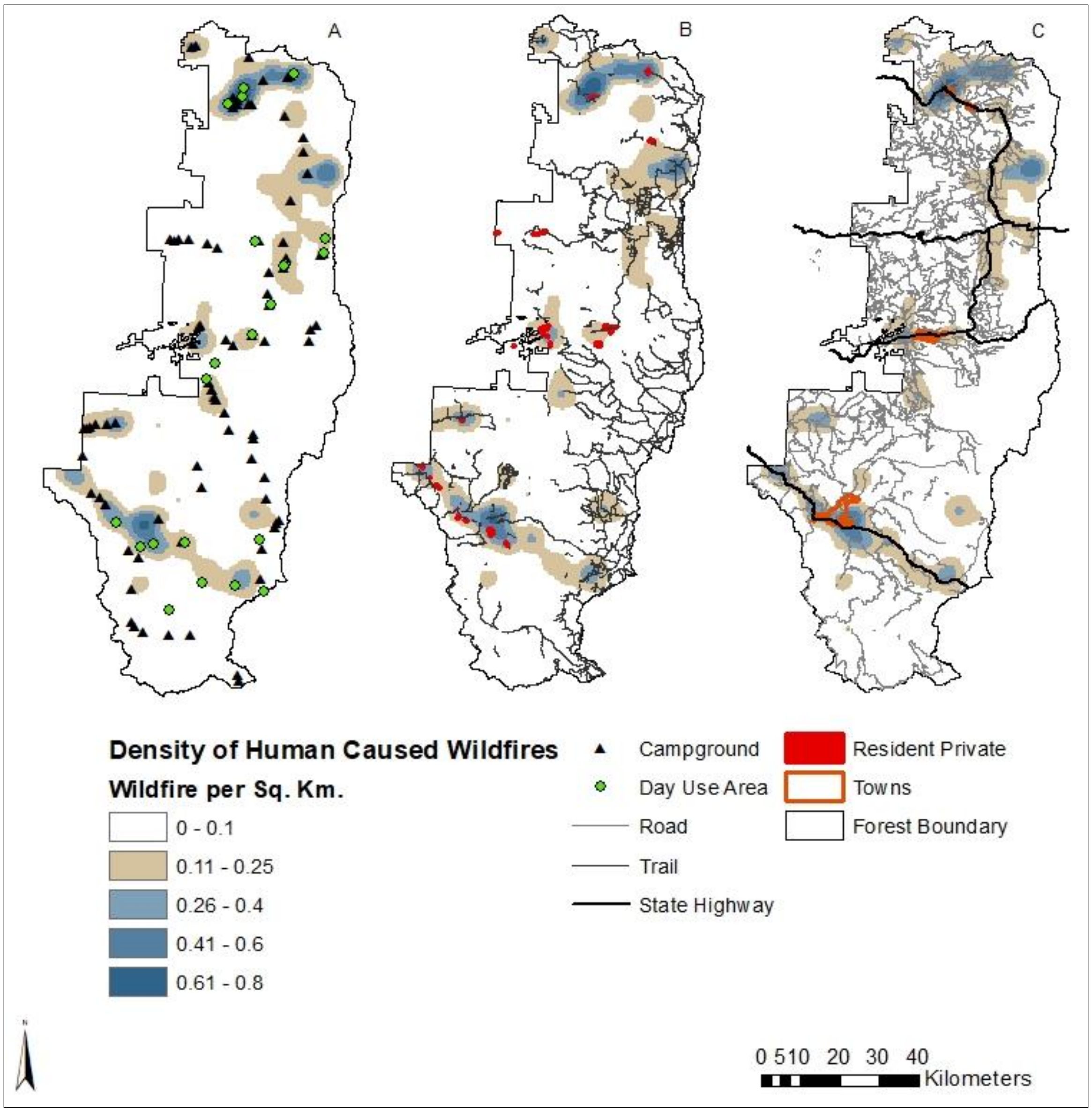

Figure 10. Density of human caused wildfires and (A) campgrounds and day use areas, (B) trails and residential/private, and (C) roads and towns

3.3.3. Overall Observations from Density Analysis

The results of the kernel density analysis revealed that wildfire occurrence frequencies are not consistent with any specific recreation site type. Site types found throughout the WNF may show a relationship to wildfires in certain areas, but not in others. Areas of high population densities occurred in higher total wildfire density, especially near the towns of Detroit and Westfir/Oakridge. Though the kernel densities are higher in these areas, so are the number of people. Also, it must be noted that the areas near towns and communities generally have many types of recreational sites nearby. This crowding of recreational sites, residential/private, and other human infrastructure sites into small areas makes it difficult to find relationships between specific wildfire types and site types. As for sites in less confined areas, the seemingly random nature of wildfire and site relationships is inconclusive. The results of this preliminary exploration are not substantial enough to suggest any type of relationship. Therefore, it was decided to explore these relationships collectively through the use of a maximum entropy technique as described in the next chapter.

Chapter 4 Data Mining with Maxent

This chapter focuses on the use of Maxent to predict the probabilities of wildfires as related to the various recreational sites and human infrastructures mentioned in the previous chapters. In this study, fire occurrences are the “species” presence data and recreational sites and human infrastructures provide the environmental layers.

Most of the individual wildfire cause occurrences used in this study are small samples. Maxent has the ability to model predictions with species locations that contain small sample quantities (Pearson et al. 2007). Yet, to ensure valid results, for this study only individual wildfire causes with more than 50 occurrences (i.e. Campfire and Smoking) were included in the Maxent modeling. As well, a Maxent model using all wildfire occurrences collectively was developed.

4.1. Using Maxent to Understand Relationships Between Fires and Sites

For each wildfire cause used as an input, a Maxent model was constructed. Maxent provides, for each model calculated, a raster image of the probability surface as well as various model statistics, response curves, analysis of variable contributions, and tables depicting the jackknife testing result of the effect and importance that each environmental variable has on the prediction. More than the probability surface, for the purposes of this study, the response curves and variable contribution outputs are particularly useful in understanding the relationships between recreational sites, human infrastructures and fire occurrences.

Maxent requires specific input formats for both the presence locations and the environmental variables. The presence data input format must be in a Comma Separated Values (CSV) format. The CSV file must contain three columns, the species name (for this study the wildfire cause was used), an X-coordinate, and a Y-coordinate. These data simply give the presence locations within the study area. The environmental data may be either categorical or continuous—a mix of both types in a single model is acceptable—and it must be in ASCII raster format with all layers having the same cell size and extent. Since all of the environmental layers in this study began as vector data, all of it required conversion to raster format.

As noted above, Maxent accepts two different types of environmental data, categorical or continuous. This study used both to 1) analyze the locations of wildfire occurrences with respect to the specific location of various recreational sites (below called the "categorical data analysis"), and 2) examine how distance affected the relationship between wildfire ignitions and recreational sites (the "continuous data analysis"). The next two sections describe how both types of data were prepared for use in Maxent.

4.2. Categorical Data Preparation

Initially, all the data used as environment variables in this study were categorical. All of it needed to be converted to raster format. This section focuses on the methods and preparation for the categorical data.

4.2.1. Wildfire Data

The species location data for the purpose of this study were the wildfire cause data described in Section 3.2.2. The Wildfire Cause attribute table for the vector point file did not contain X or Y coordinate values. To solve this issue, the Add XY Coordinate tool was used to add X and Y Coordinates to the attribute table. The Add XY Coordinate tool simply adds two fields to the attribute table POINT_X and POINT_Y, which are the calculated values of the positions of the wildfire occurrences based on the coordinate system of the dataset. The wildfire cause attribute table was then exported from ArcMap to an Excel file where the wildfire cause, X-coordinate, and Y-coordinate columns were separated out and saved as a CSV file.

4.2.2. Forest Boundary Data

To ensure that all environmental variable layers were the same, the Forest Boundary layer was used to set the extent of all rasters used for the environmental variables. The Forest Boundary layer was converted from a vector format to a raster format. The cell size for the raster was set at 500 meters, the distance a person might casually wander from a site, road, or trail. Values for the raster that indicated the inside of the forest boundary were 1, and any values found outside the forest boundary were No Data. The forest boundary layer was not an environmental variable, but was used only to set the extent of the study area.

4.2.3. Recreational Site Data

Preparation of the recreational site data for use as an environmental variable required that each recreational site type layer be prepared individually. Though each layer was prepared individually, all of the processes were repeated with each layer. Each vector polygon layer (as described in Section 3.2.3) was converted to a raster format with coded values to set the cell values for the raster (e.g. campgrounds = 1, day use area = 2). Any cell that contained any part of an original polygon was coded with the relevant code value. Cells that did not contain a recreational site value were coded as No Data. The raster extent was set within the environments options to that of the Forest Boundary, and the cell size was set at 500 m to match all other raster layers since all Maxent environment layers must have the same extent and cell size. The rasters were then converted to an ASCII file format.

4.2.4. Polyline Data: Road and Trail

The Road and Trail polyline vector data sets were each converted into separate raster layers using the polyline to raster tool. The raster value was set during the raster conversion using 1 = road or trail, and No data = no road or trail. Values for non-polyline raster cells were coded as No Data. The raster extent was set to match that of the forest boundary and the cell size for the raster layers was set at 500 m to match the recreational site raster layers. The Road/Forest Boundary and the Trail/Forest Boundary raster layers were then converted to an ASCII format for Maxent modeling.

4.2.5. Polygon Data: Private/residential, Town, and Administrative Areas

The Private/residential layer, Town layer, and the Administrative Areas layer were each converted to a raster format using the Polygon to Raster tool. The rasters was coded during the rasterization process using the site_value attribute (Towns = 7, Administrative areas = 8, and Residential/Private = 9). Raster cells with no values were coded as No Data. Raster cell size for each layer was set at 500 m to match the Forest Boundary layer. Raster extent was set within the environment options to the forest boundary. Each raster layer was then converted to an ASCII file format to be used in Maxent.

4.3. Continuous Data Preparation

To determine if distance was a factor in the relationships between wildfires, recreational sites and human infrastructures, continuous data were used. The continuous data model used raster layers that contain cell values representing the distances from the cell centers of the nearest feature of interest, such as recreational sites or human infrastructure locations.

The rasters created for the categorical model were used as input into the Euclidean Distance tool to create continuous data rasters for distance analysis in Maxent. Euclidean Distance calculates the distance from cell center to neighboring cell centers by using the Euclidean Distance algorithm, calculated as the length of the hypotenuse of a right triangle. The categorical rasters were used as input because, according to the Euclidean Distance tool description in ArcGIS Help, polygon layers with small polygons should be converted to rasters prior to using Euclidean Distance because the internal raster process of Euclidean Distance uses a cell-centered method. This method may inadvertently remove any polygon that is not located in a cell center. The output cell size was set to 500 m. The extent was set in the environmental options to the forest boundary raster layer described in Section 4.2.2. The rasters were then converted to ASCII format using the ASCII to Raster tool.

4.4. Maxent Data Methods and Procedures

Maxent allows for a variety of input options, depending on the output desired. For this study, it was only required that Maxent create models to show any probabilities of relationships between wildfires and different types of recreational sites and human infrastructures. The parameters chosen for the Maxent model runs are listed in Table 7. To allow easier interpretation of results, the hinge and threshold features were not chosen. The threshold determines the response level at which predicted presences would be indicated. It is not needed for this analysis. Removing the hinge feature, which depends on the threshold setting, smooths out the response curves while increasing uncertainty as variable values (i.e. distance) increase. In this analysis, this is not important as low distance values are the values of interest.

Table 7. Parameter settings used for Maxent model runs

Maxent Parameter	**Input**
Create Responsive Curve	Yes
Do jackknife to measure variable importance	Yes
Output format	Logistic
Random Seed	Yes
Replicates	50
Add all samples to background	Yes

Response curves show how each environmental variable relates to the wildfire cause. Jackknife testing was used to test each variable's importance (Elith et al. 2011). The output format chosen was Logistic, which is used to predict the probability of presence at all sites with typical conditions for the species (or fire in this case) (Elith et al. 2011; Merow, Smith, and Silander 2013). Random Seed was chosen so that a different test partition would be made with each run ensuring that a different random subset of the background was used to test the data. The modeling process was replicated 50 times since each run uses a different random seed and multiple runs are necessary to converge on a stable model.

4.4.1. Presence and Environmental Variables Input Data

The environmental variables used for the Maxent modeling were campgrounds, day use areas, trail shelters, towns, administrative areas, residential/private, roads, and trails. All environmental variables were used in Maxent and the data type chosen (categorical or continuous) depended upon whether an occurrence or a distance model was being run. The wildfire CSV file (presence data) was also input into Maxent and the wildfire type(s) chosen to be run in each model were selected.

The creation of five different models was attempted. Models runs were made for each of campfire and smoking cause types using both the occurrence and distance environmental rasters. The fifth model used all human caused wildfires reported within the Willamette National Forest between 1995 to 2008 and was run using only the distance environmental rasters. Results of the Maxent modeling effort are discussed in the next chapter.

Chapter 5 Maxent Results

Five models were created to explore the difference in the predictive capability of categorical and continuous environmental data. Categorical data were used to model the effect of colocation of recreational sites and human infrastructures with different types of wildfire ignitions. Continuous data were used to explore if distances to features might give more meaningful results. The results of each model are discussed below.

It is important to determine which variables are the most important to model. During each step of the model training, Maxent keeps track of which variable is contributing the most to fitting the model (Phillips 2006). For each iteration of the Maxent training, when a gain is registered, it assigns the gain to the environmental variable that was responsible. This produces a useful measure for assessing which variables are most important in determining presence.

5.1. Categorical Results

In hindsight, as might be expected, producing valid models using the categorical data was not possible. Given that the recreational sites and human infrastructures are sparsely distributed across the WNF, Maxent failed to find enough fire locations that aligned with any type of site feature to produce the intended occurrence models. Only the distance models produced valid results.

5.2. Continuous Data Results

This section explains the results from the distance modeling which can be used to examine how distance from recreational sites and human infrastructures affect the presence of wildfire ignitions. Maxent model results discussed here were gathered from the summary HTML file produced during the modeling runs. These summary reports display the responses curves and the environmental variable contributions resulting from the 50-fold cross-validation models run for Willamette National Forest. Using the logistic output format option, Maxent creates two sets of response curves to show how each environmental variable affects the Maxent output. The first set of curves show that while all other environmental variables are kept at their average value, the predicted probability of presence changes when each environmental variable is varied. The second set of curves uses only the corresponding variable and reflect the dependence of predicted suitability on both the selected variable and dependencies induced by correlations between the selected variable and other variables. According to Phillips (2009), results for environmental variables that are correlated may be misleading as the change in one variable will affect the outcome of other variables. It is for this reason that Maxent creates the second set of response curves as they are easier to interpret when there is correlation between variables.

A Maxent model report also displays an Analysis of Variable Contribution table. This table lists the environmental variable, the percent contribution, and the permutation importance. The percent contribution is the percentage of the gain that each variable contributes to fitting the model (Phillips 2017). Again, when variables are correlated, the percent contribution should be interpreted with caution as altering one variable might change the gain of another. The permutation importance uses the AUC to determine the importance of the variable by measuring increases or decreases in AU. Large decreases indicate that the variable is highly important to the model. All values are normalized to be read as percentages.

As described in the previous chapter, the models discussed here are those for the campfire and smoking caused fires as well as for the entire collection of human caused fires.

5.2.1. Campfire Caused Wildfire Model

There were 259 campfire caused wildfires throughout the Willamette National Forest between 1995 to 2008. Maxent was able to produce a good model showing the predicted probability of wildfire occurrences from the continuous data with an AUC of 0.773.

Most important for this analysis is consideration of how the different variables contributed to the final model. Table 8 shows the percent contribution and permutation importance of the variables in the model. The variables contributing the most to the model are campground at 26.4 percent, residential/private at 17.4 percent, trail at 16.1 percent, and snowpark at 9.2 percent. However, the variables in this study are highly correlated since, as mentioned in Chapter 3, recreational areas often include more than one site type and these contributions are impacted by the correlations between the site types. When considering permutation importance, which shows how important the variable is when all other variables are held constant, trail and snowpark ranked the highest at 15.9 percent, followed by residential/private at 15 percent, and campground at 10 percent. All other variables had little importance in the model.

Table 8. Variable contributions for campfire caused wildfires

Variable	**Percent contribution**	**Permutation importance**
campground	26.4	10
respvt	17.4	15
trail	16.1	15.9
snowpark	9.2	15.9
dayuse	8.2	3.4
boat	5.9	6.5
road	5.8	7.2
admin	5.1	12.9
trailshelter	3.1	6.4
town	2.8	6.9

Figure 11 shows the response curves from the jackknife test. Though the response curves show results as far out as 60 kilometers, it is most important to focus on the results within three kilometers from the source. This is assumed to be the maximum distance to which the risk of ignition from human activities will extend from a given site or feature. The red vertical line in the graphs represents approximately three kilometers. Though these graphs extend out tens of kilometers, the extreme end of these graphs are not relevant as they are far beyond any distance relevant to this study.

As expected, campgrounds (Figure 11A) showed a clear relationship with campfire ignitions where probability of a wildfire ignition is high close to campgrounds and decreases rapidly as the distance from campgrounds increases. Similar results were found with the trail variable in that it showed the probability of an occurrence of a campfire caused fire is high close to trails and decreases quickly with distance from trails. The day use, residential/private, and snowpark area variables also showed a decrease in probability of occurrence with distance,

Figure 12 shows each of the variables in relationship to the model's probability surface. While the individual relationships are not strong, areas of high probability have combinations of site types, such as campgrounds, day use areas, or campgrounds and boating areas.

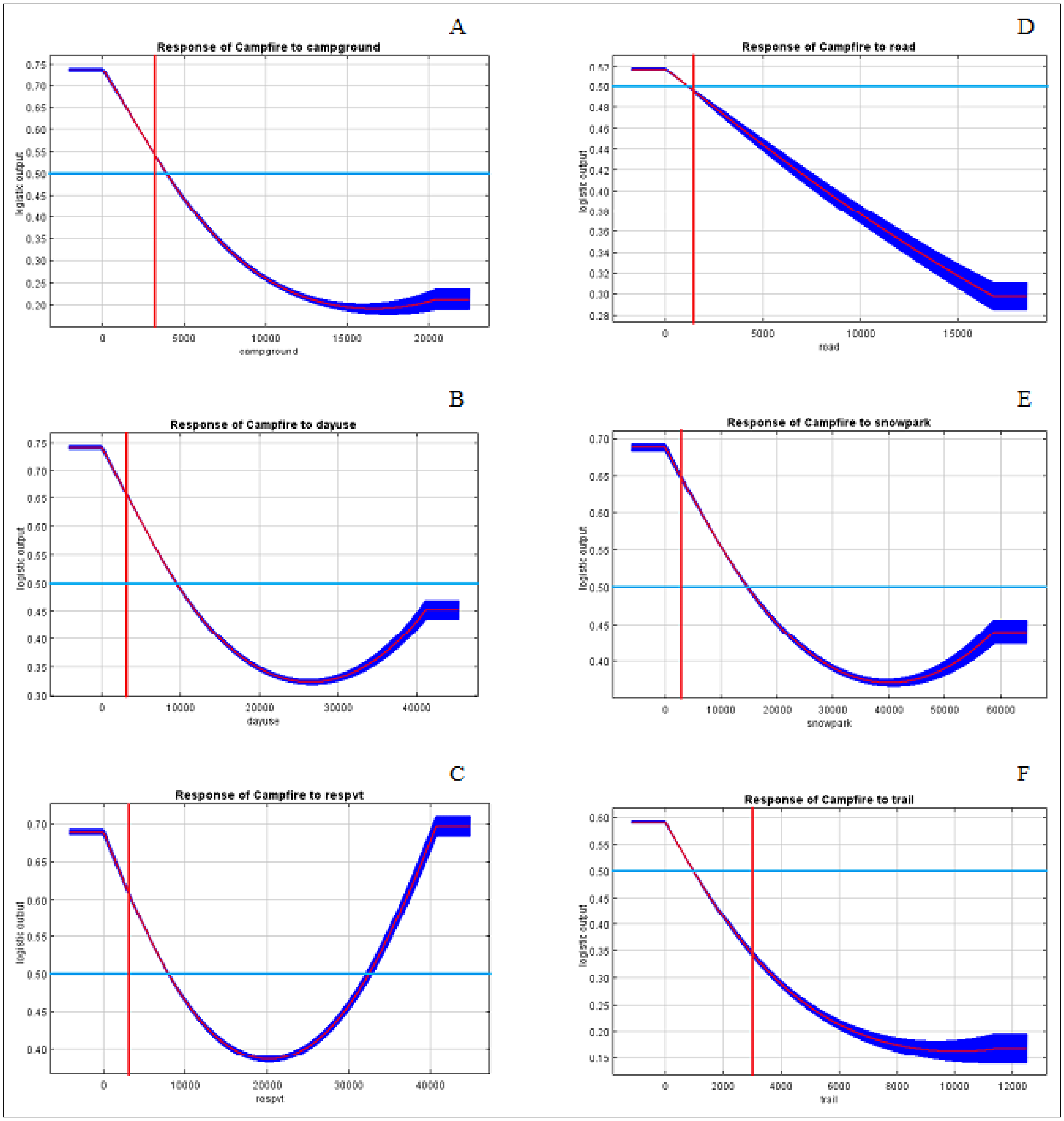

Figure 11. Maxent model response curves for campfire caused wildfires in relation to (A) campgrounds, (B) day use areas, (C) residential/private, (D) roads, (E) snowpark, and (F) trails. Values on the vertical axes are probability of occurrence and on the horizontal access are meters. Red vertical line indicates approximately three kilometers. Blue horizontal line at 0.5 probability.

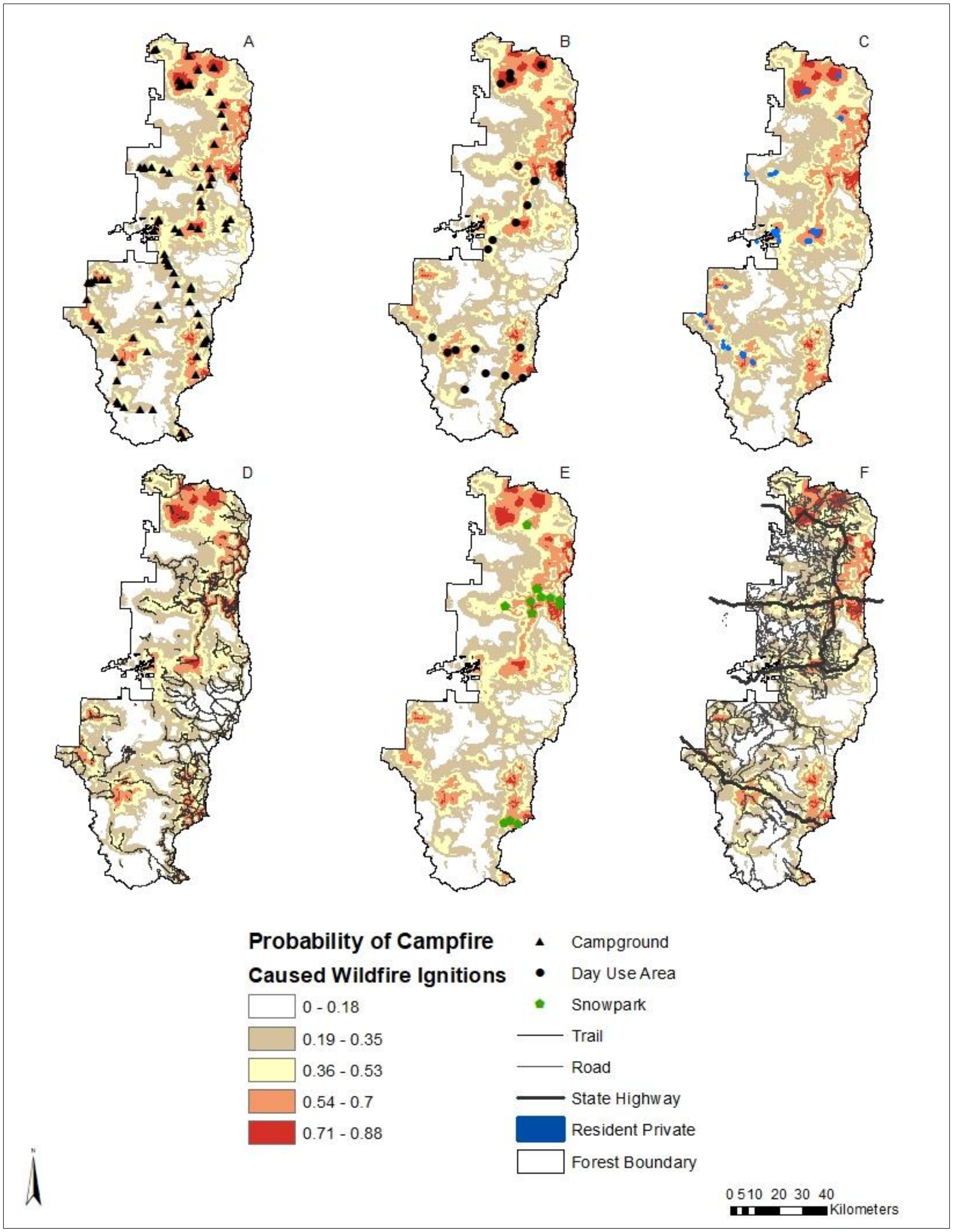

Figure 12. Predicted campfire ignitions in relation to (A) campgrounds, (B) residential/private, (C) day use areas, (D) trail, (E) administrative areas, and (F) boating areas.

5.2.2. Smoking Caused Wildfires

Within the Willamette National Forest there were 51 recorded smoking related wildfires during the time period of this study. A Maxent model was created to look for predicted probabilities of smoking caused wildfire occurrences. The model revealed some strong evidence that certain environmental variables are correlated to smoking related wildfires with an AUC of 0.785.

Table 9 shows the percent contribution and the permutation importance of each variable. The variable contributions for smoking related wildfires as modeled by Maxent showed that residential/private and roads were the two main variables contributing to the model. The residential/private variable had a 16.5 percent contribution and a 5.8 percent permutation importance. Road had a 15.7 percent contribution and a 41.5 percent permutation importance. Other variables also contributed substantially to the model with snowpark at 15.3 percent, campground at 15 percent contribution, with an 18.6 percent permutation importance, day use at 13 percent, and town at 11 percent.

Table 9. Variable contributions for smoking caused wildfires

Variable	**Percent contribution**	**Permutation importance**
respvt	16.5	5.8
road	15.7	41.5
snowpark	15.3	6.7
campground	15	18.6
dayuse	13	3.5
town	11	10.7
admin	5.3	1.1
trail	4.4	10.9
boat	2.1	0.1
trailshelter	1.7	1.1

The Maxent model jackknife test response curves showed a reduction of occurrence probability over distance in all variables (Figure 13). All the variables show a decrease in probability over distance. Roads (Figure 13D) proved to be the variable with the most significant decrease over the shortest distance suggesting that smoking related occurrences happen very close to roads. The red vertical line in the graphs indicates approximately three kilometers, a distance a person might easily walk from a recreational site, road, or trail.

Looking at Figure 14, it can be seen how campgrounds, day use areas, residential/private, and towns in the northern half of the WNF (Figure 14A, B, C, and D) are located near the higher areas of probability. Areas of high probability show a distinct correlation with recreational sites and human infrastructures that are near the highway corridors. Comparing Figures 14A, B, C, and D to the highway corridors (Figure 14F), it can be seen that the areas of higher probability follow the highway corridors, except in a few areas. In Figure 14F, it is apparent that the road network extends occurrence probability.

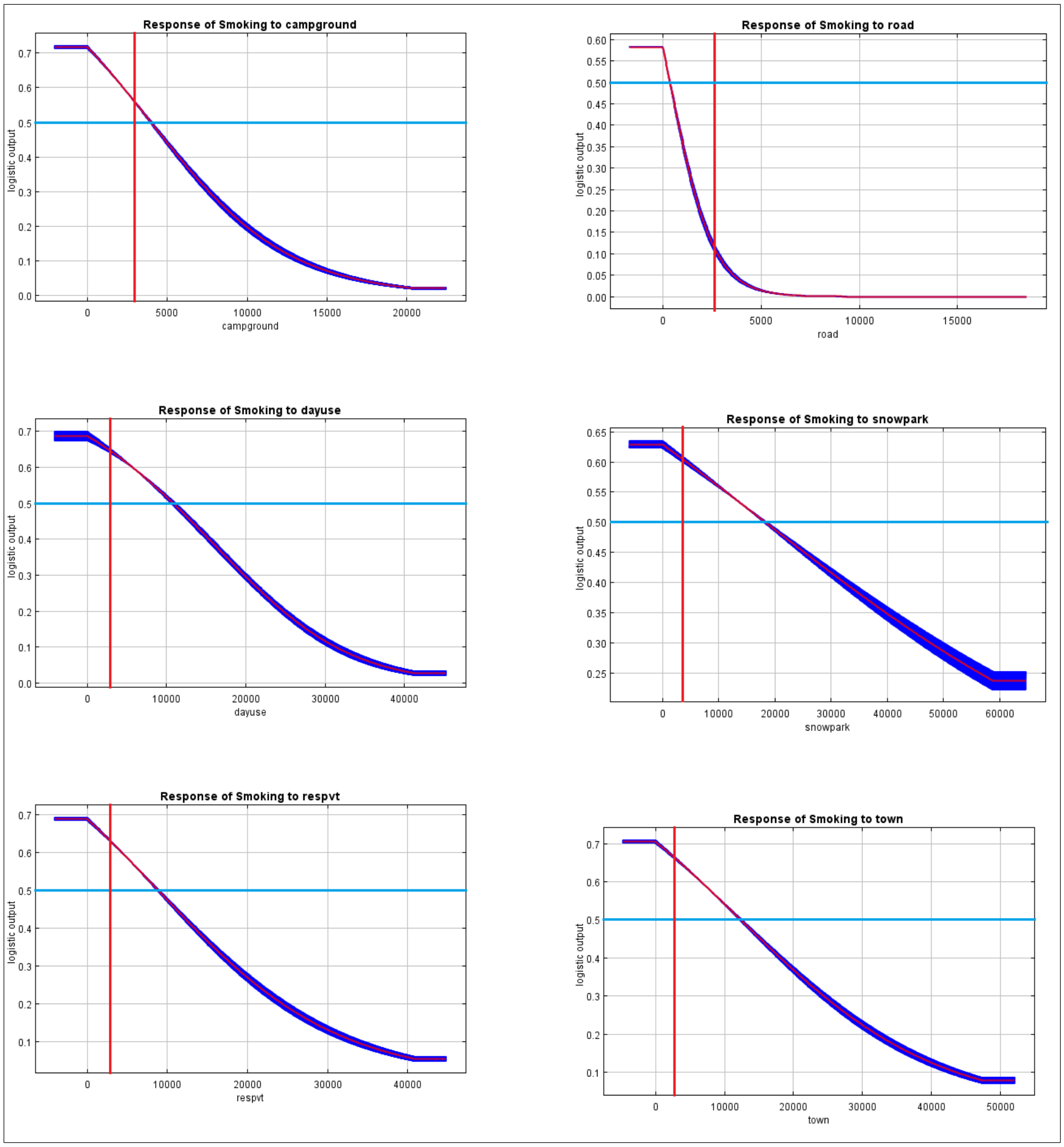

Figure 13. Maxent model response curves for smoking caused wildfires in relation to (A) campgrounds, (B) day use areas, (C) residential/private, (D) roads, (E) snowpark, and (F) towns. Values on the vertical axes are probability of occurrence and on the horizontal access are meters. Red vertical line indicates approximately three kilometers. Blue horizontal line at 0.5 probability.

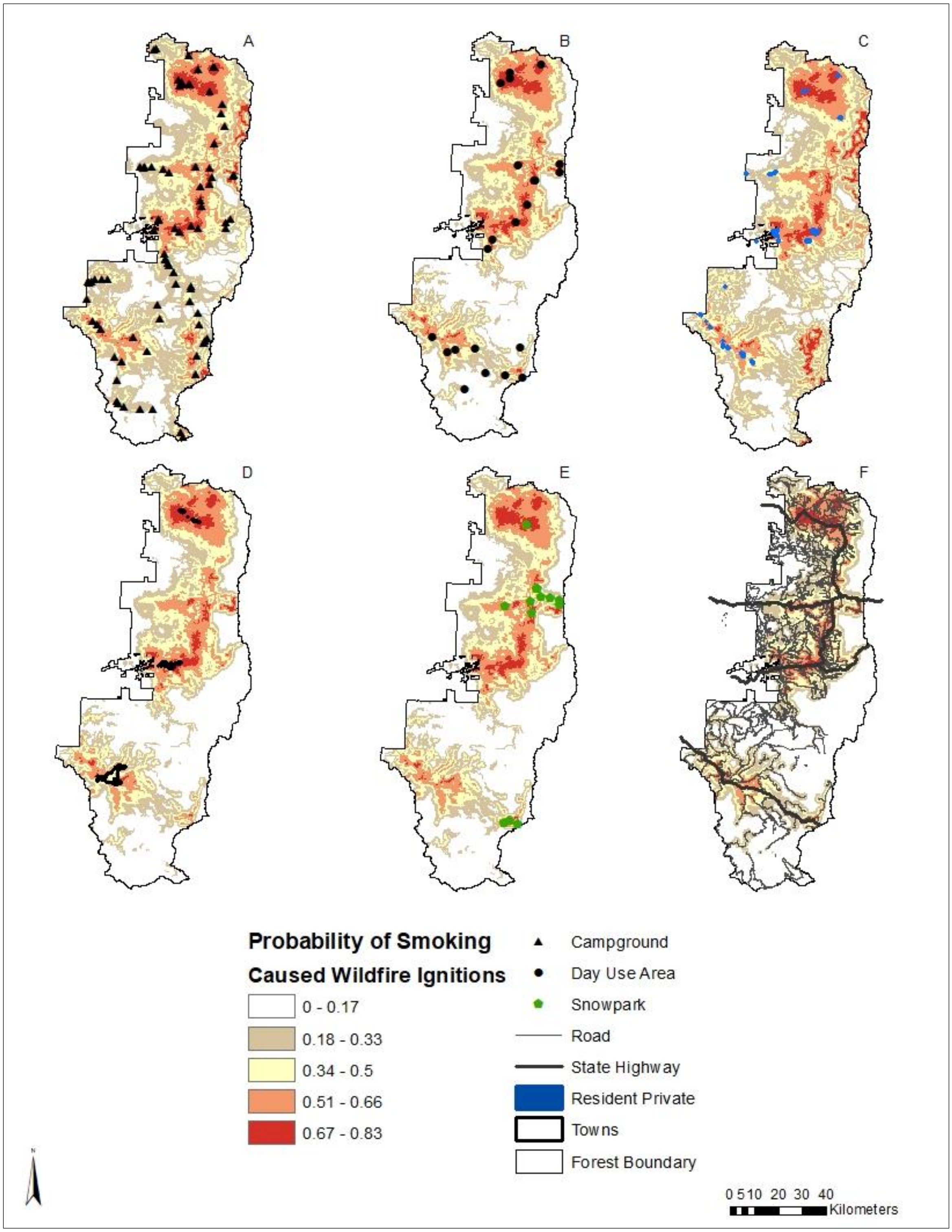

Figure 14. Predicted smoking ignitions with (A) campgrounds, (B) residential/private, (C) day use areas, (D) towns, (E) snowpark, and (F) roads and highways.

5.2.3. Total Wildfires for the Willamette National Forest

The USFS recorded 493 human caused wildfires within the Willamette National Forest between 1995 to 2008. This total amount includes all of the wildfires investigated within this study as well as railroad and miscellaneous cause types which were removed prior to any other investigation or modeling. The only change made to the data was a new csv file created from the complete wildfire data layer. This csv file utilized the Forest name as the presence data instead of wildfire categories. All environmental variable layers used in the campfire and smoking models were used in this model and the same 50-fold cross-validation parameter set was used.

The variable contributions for total wildfires in the Willamette National Forest (Table 10) saw campground with 27.6 percent, day use areas at 14.6 percent, and administrative areas at 11 percent. Others were under 10 percent. Permutation importance put snowparks at 23.8 percent, roads at 19.2 percent, day use areas at 13 percent, and residential/private at 12.5 percent.

Table 10. Variable contributions for total wildfire in the Willamette National Forest

Variable	**Percent contribution**	**Permutation importance**
campground	27.6	13
dayuse	14.6	4.5
admin	11	3.2
respvt	9.6	12.5
snowpark	9.6	23.8
trail	9.1	7.1
road	7.1	19.2
boat	6.5	8.7
town	2.8	6.2
trailshelter	2.2	1.7

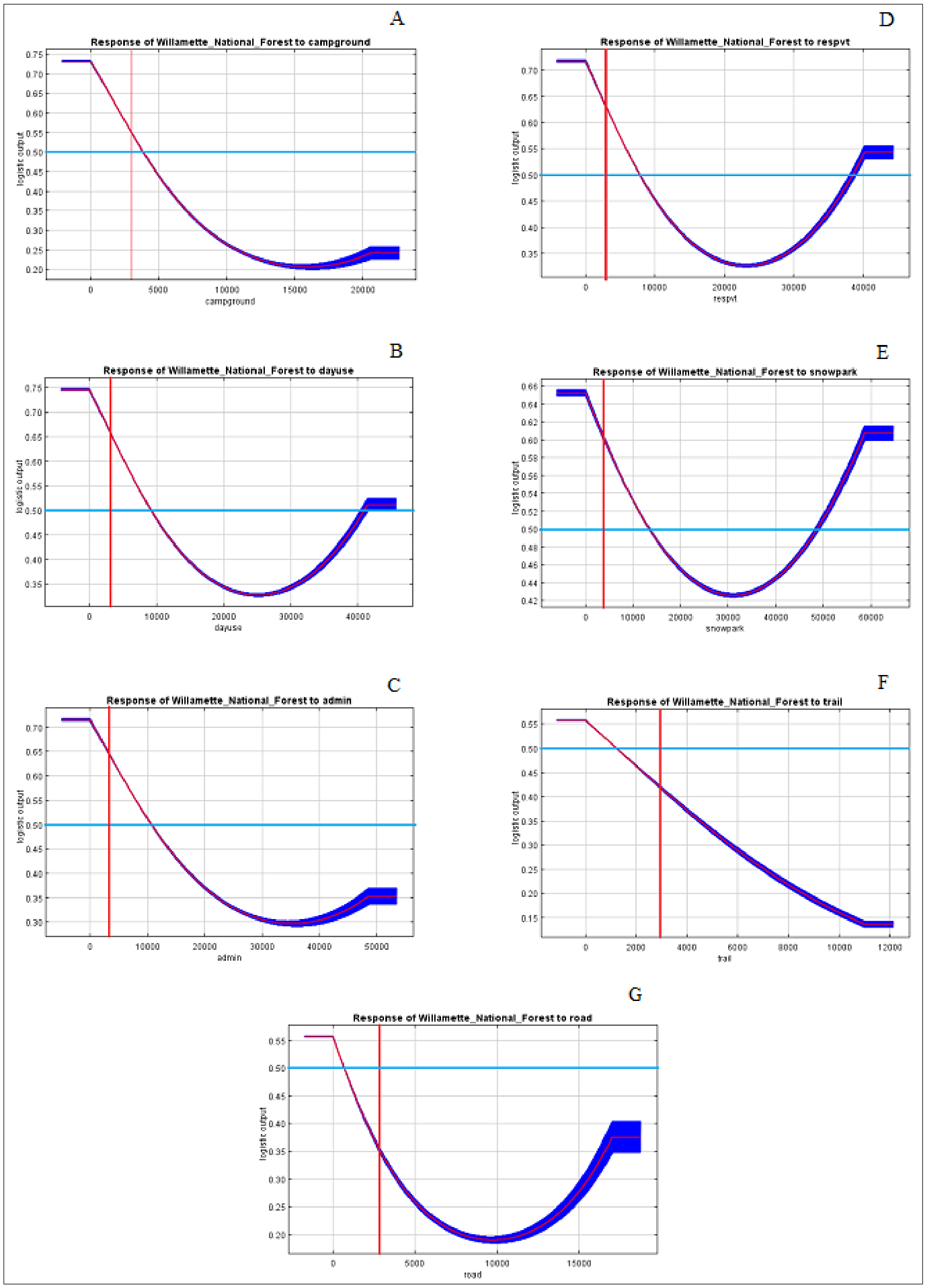

Figure 15. Maxent model response curves for smoking caused wildfires in relation to (A) campgrounds, (B) day use areas, (C) administrative areas (D) residential/private, (E) trail, and (F) roads. Values on the vertical axes are probability of occurrence and on the horizontal access are meters. Red vertical line indicates approximately three kilometers. Blue horizontal line at 0.5 probability.

The total wildfire model Jackknife test response curves (Figure 15) were very similar to those of the campfire model (Figure 11) when comparing them out to a distance of three kilometers. This was not surprising given that campfires accounted for 52 percent of the total wildfires reported. All variables showed a constant and rapid decrease out to the 3-kilometer mark indicating that fire occurrence probability diminishes quickly away from all sites.

When looking at the maps in Figure 16, you can see that the high probability areas are located near areas of multiple sites and infrastructures. In Figures 16A, B, C, and D, you can see that when campgrounds, day use areas, administrative areas, residential/private, and snowparks are located near each other, probabilities are higher than in areas where sites and infrastructures are less clustered. It is interesting to see that, like smoking, the areas of higher collective probability follow the highway corridors (Figure 16E) while other roads, which cover a significant amount of territory, occur where lower probabilities were also modeled.

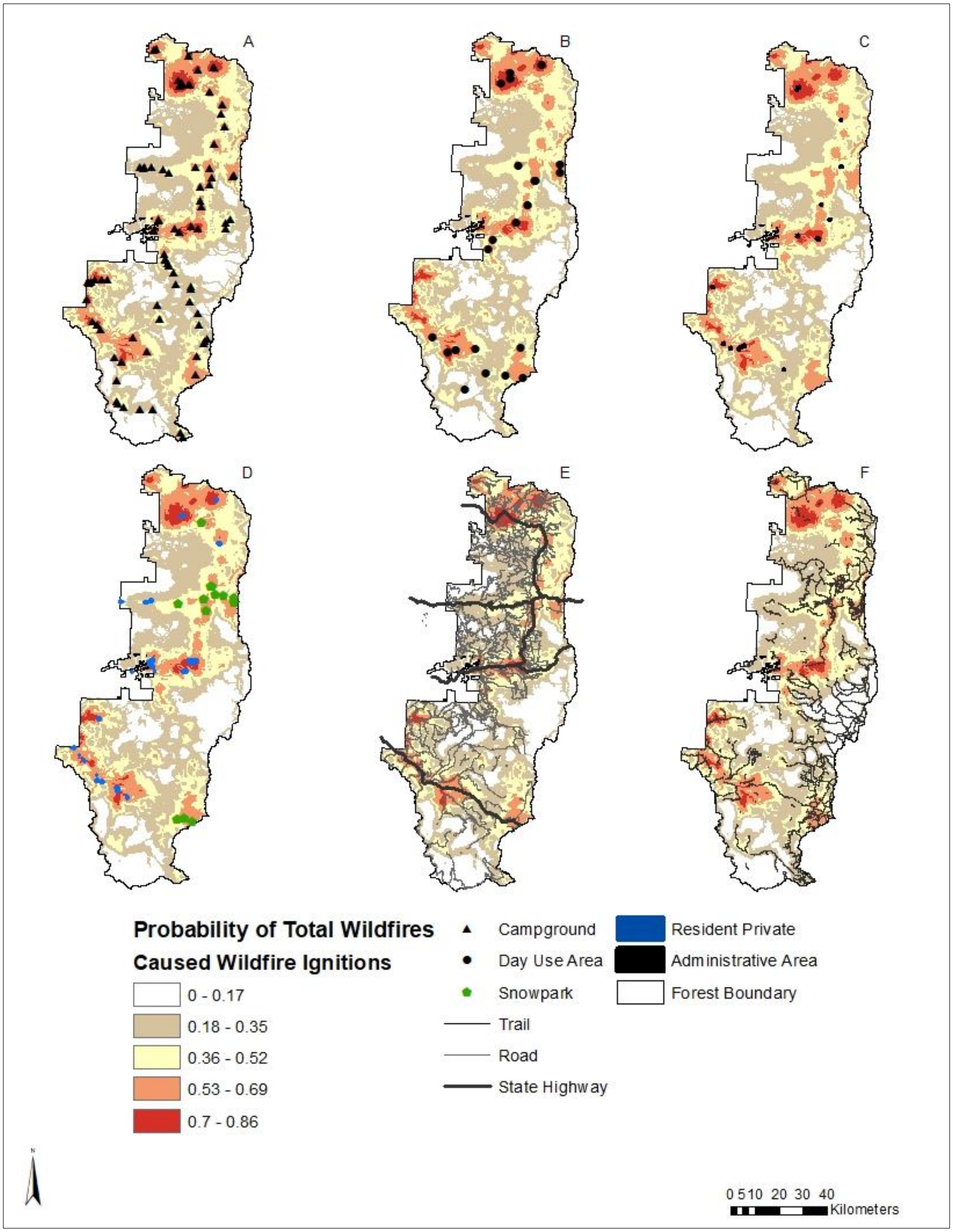

Figure 16. Predicted wildfire ignitions in relation to (A) campgrounds, (B) day use areas, (C) administrative areas, (D) residential/private and snowparks, (E) roads and highways, and (F) trails.

Chapter 6 Discussion and Conclusion

The goal of this study was to examine the relationship between the location of human activities and the location of wildfire ignitions in order to gain some insight about the potential locations of future wildfires. This thesis examined the relationship between different causes of wildfires and various kinds of recreational sites and human infrastructures found within the Willamette National Forest. It explored the hypotheses that (1) there would be more campfire caused wildfires near campgrounds, (2) smoking caused wildfires would be more abundant near day use areas, towns, and residential areas, and (3) wildfires would be more prominent in areas with many recreational sites or near human infrastructures. The results of the models suggest a number of ways in which the wildfire danger might be addressed.

It was assumed that campgrounds would show a higher spatial relationship to campfire caused wildfires simply based on the amount of campgrounds found within the WNF. Knowing that each campsite within a campground contained some sort of firepit, fireplace or barbeque station, the possibilities of wildfires resulting from a campground was expected to show high probabilities of occurrence. Though results from the Maxent model did suggest that campgrounds were a significant factor in campfire caused wildfires, it was surprising to find that other site types (residential/private, trail, snowpark, and day use) showed a higher than normal relationship to campfire caused wildfires.

Wildfire caused by smoking is a serious issue, especially during the hot, dry days of summer. It was originally assumed that smoking caused wildfires would be more abundant around day use areas, towns, and residential areas. These three areas did show a high probability of occurrence to wildfires caused by smoking, though it was unexpected to find that roads and campgrounds also showed a high probability. These are areas that have a higher volume of human activities, and as such these areas are more prone to wildfires caused by smoking.

Looking at the total collection of human caused wildfires, it was assumed that there would be a spatial relationship to areas of higher human density or higher human activities. As expected, the results of this study have shown that areas with large numbers of recreational sites or human infrastructure contribute to an increased potential for wildfire ignitions. Trails and roads that may have higher than normal traffic patterns (popular trails and roads to popular destinations) increase the potential for wildfires as well.

6.1. Future Work

The study of spatial distribution of wildfires and their relationships with human activities is a broad subject and can be studied in many ways. This thesis attempted to get an overall view of whether the spatial correlation between humans and wildfires could be identified. A study of trends in the numbers and characteristics of visitors involved in various recreational activities in the WNF might provide additional information to further explore the relationship between wildfires and human activities. An even deeper understanding might be teased out with detailed weather information, though it is likely that data at the fine resolution that would be needed for this could be found. Combining the human causes of wildfire ignitions with environmental factors might prove to be beneficial in predicting overall fire risks. This combination might include such variables as fuel load, aspect, slope, and even humidity.

6.2. Fires and Park Users

Wildfires are a severe problem throughout the United States and their impact is more than just the acres and firefighting costs that the news reports. There is loss of wildlife habitat. Fire-damaged lands may take years, maybe decades, before the land heals enough to grow anything of economic value again. Within natural areas such as the WNF, tourism, hunting, fishing, and hiking are a few of the many activities people undertake, and closures due to wildfires create significant loss of income for the agencies and businesses that depend on revenue from such activities. Understanding the dynamic relationship between park users and wildfires is an important topic that merits continued exploration. It is hoped that this research has provided a small contribution in that direction.

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Appendix A. Locations of Individual Wildfire Causes

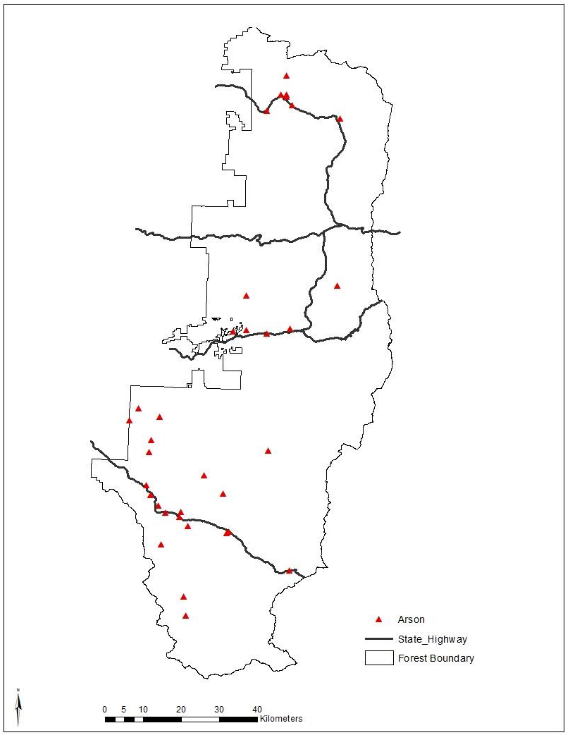

Figure 17. Arson related wildfires

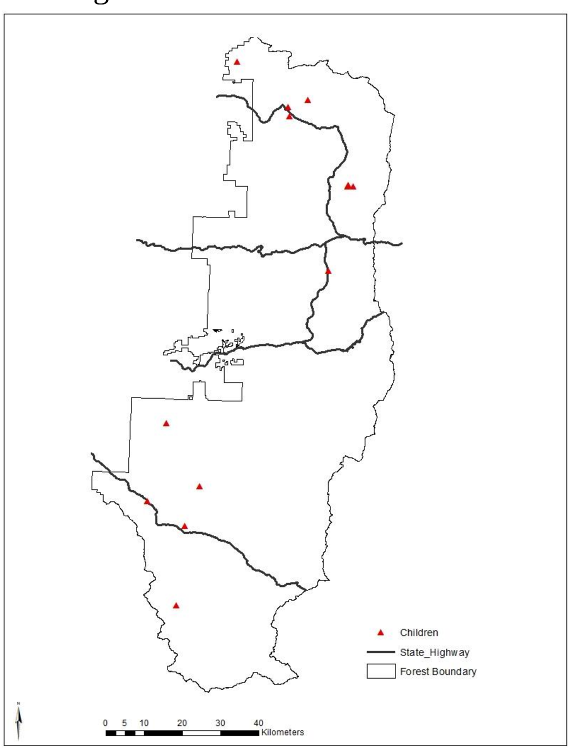

Figure 18. Children related wildfires

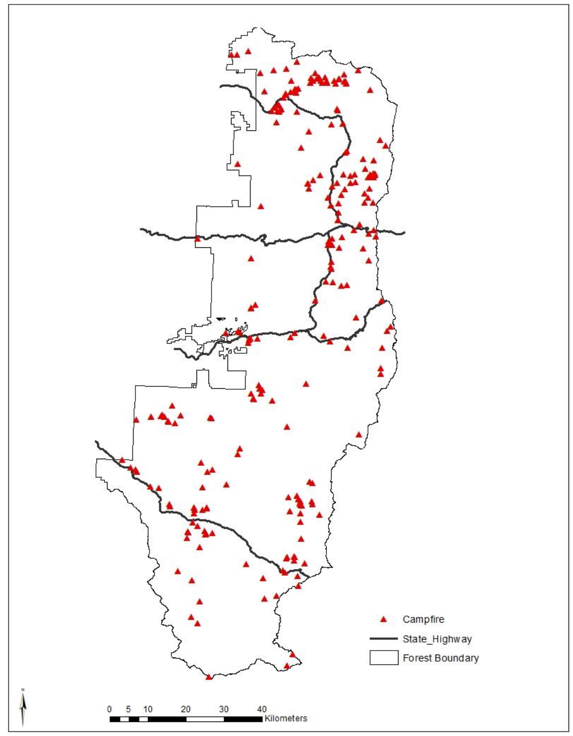

Figure 19. Campfire related wildfires

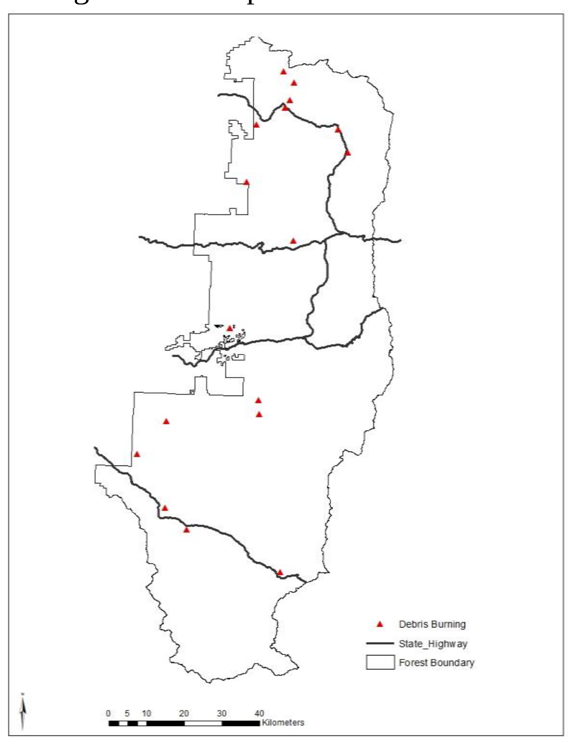

Figure 20. Debris Burning related wildfires

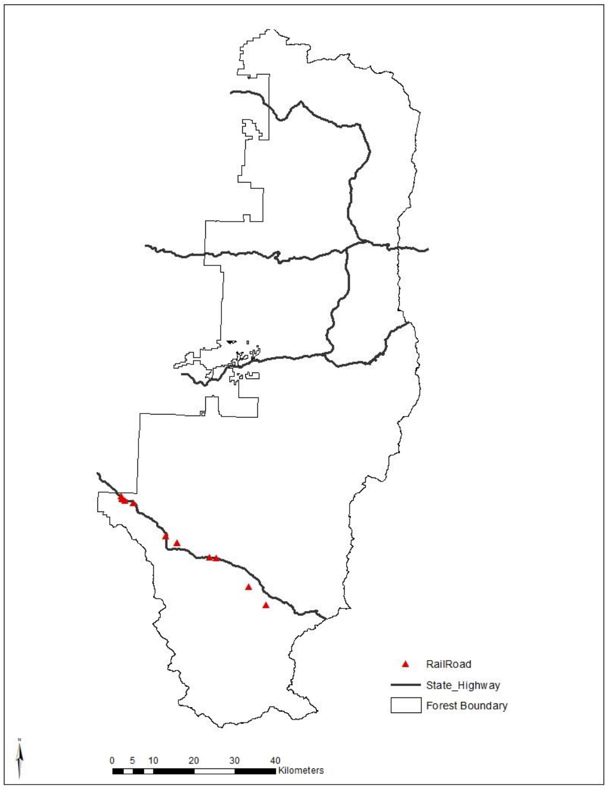

Figure 21. Railroad related wildfires

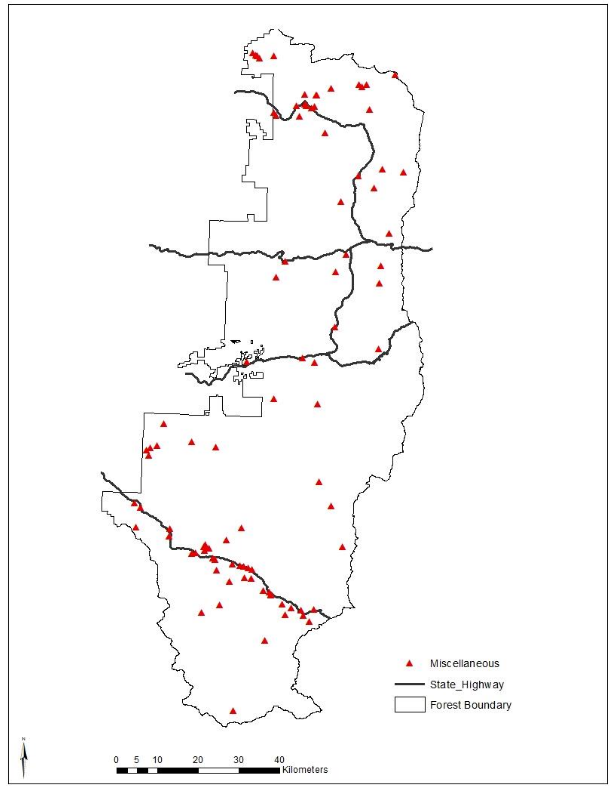

Figure 23. Miscellaneous related wildfires

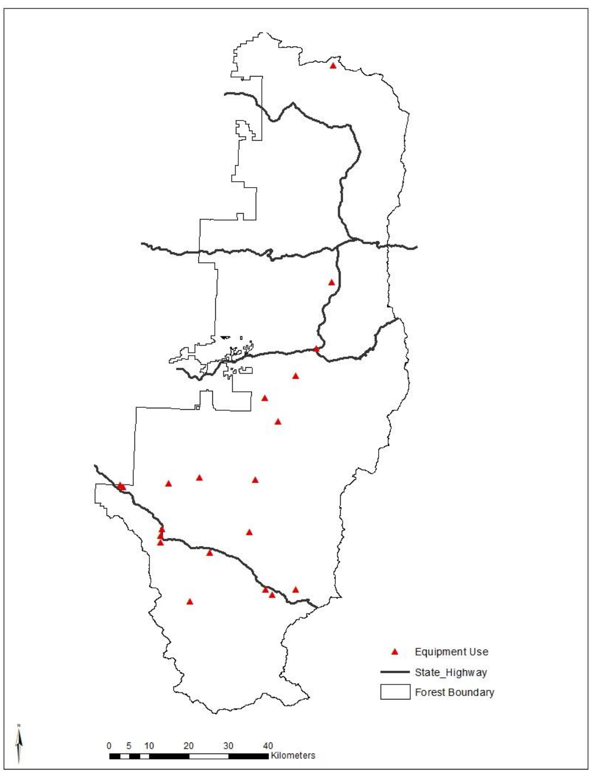

Figure 22. Equipment use relate wildfires

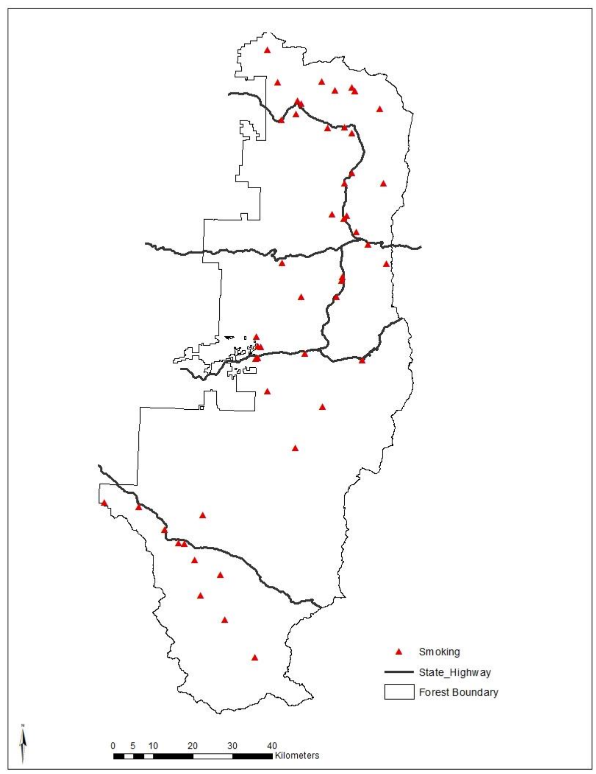

Figure 24. Smoking related wildfires

Appendix B: Recreational Sites and Human Infrastructures

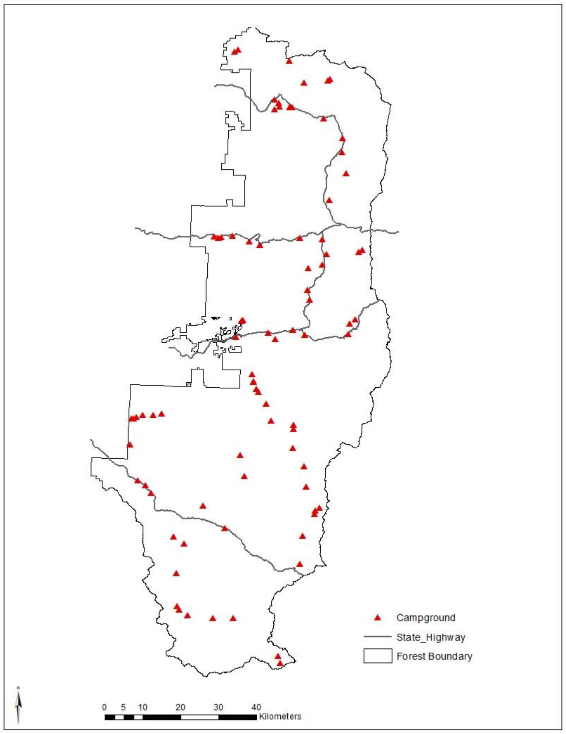

Figure 25. Campground

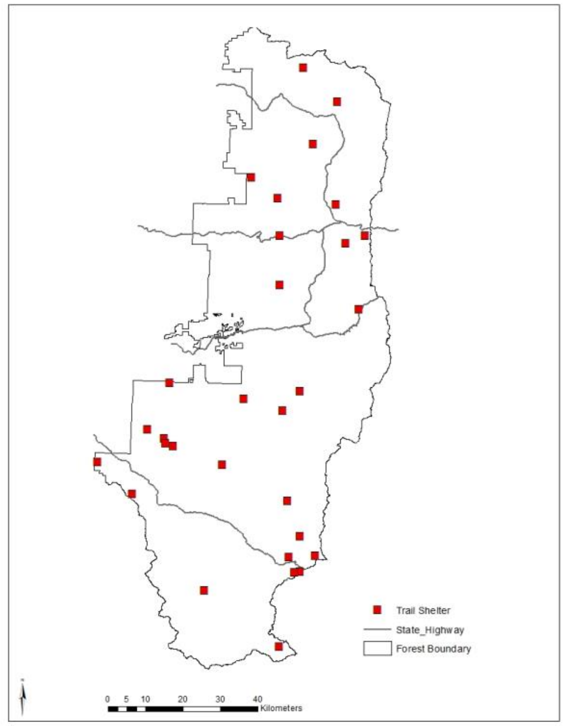

Figure 27. Trail shelter

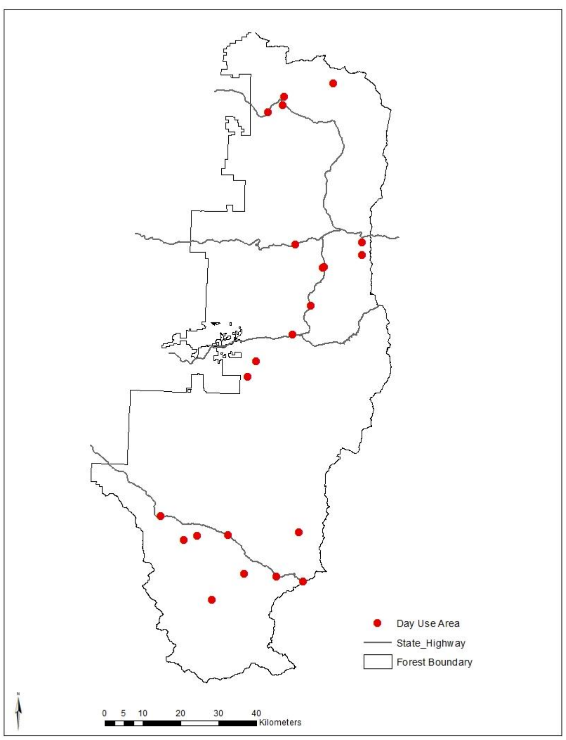

Figure 26. Day Use Area

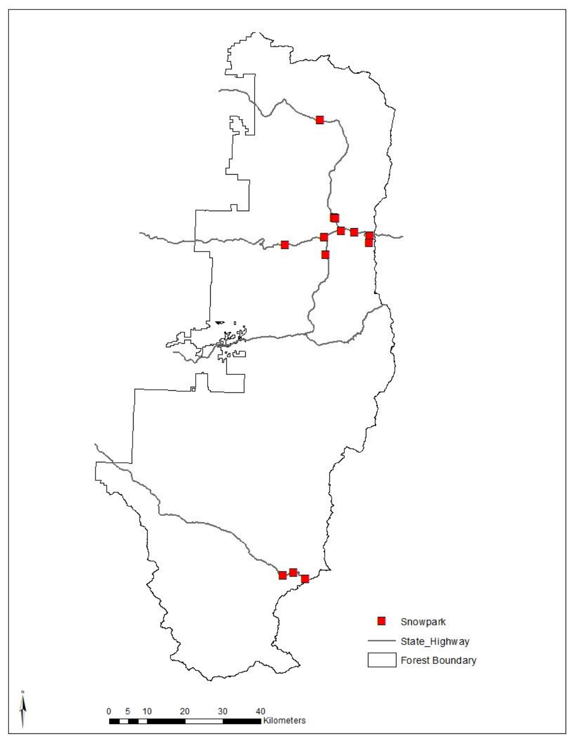

Figure 28. Snowpark

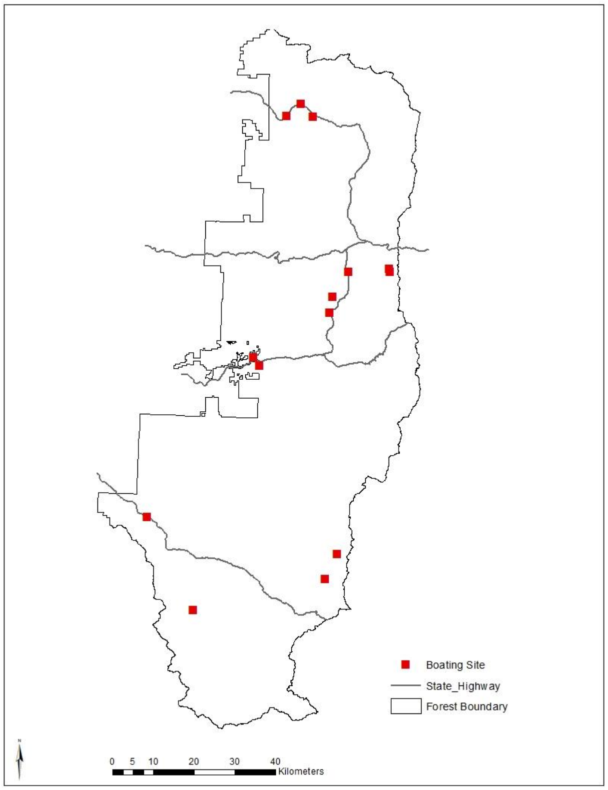

Figure 29. Boating areas

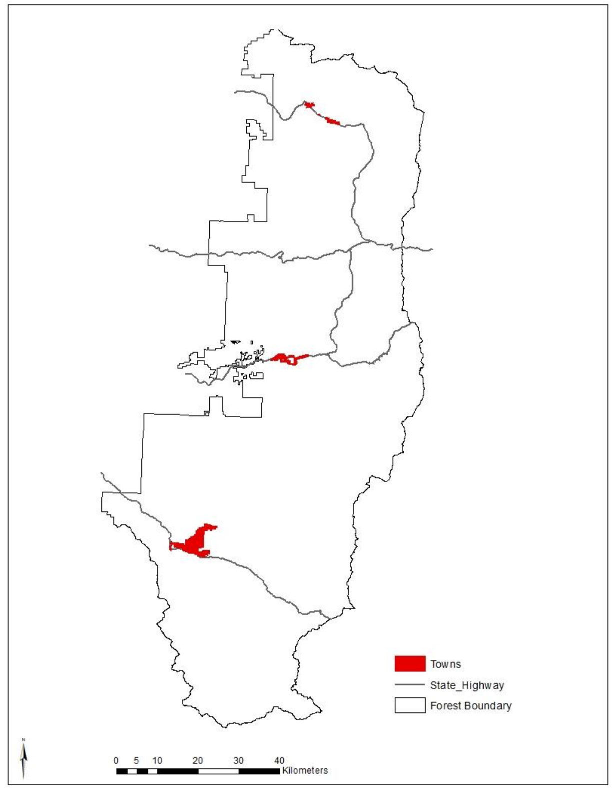

Figure 30. Towns and communities

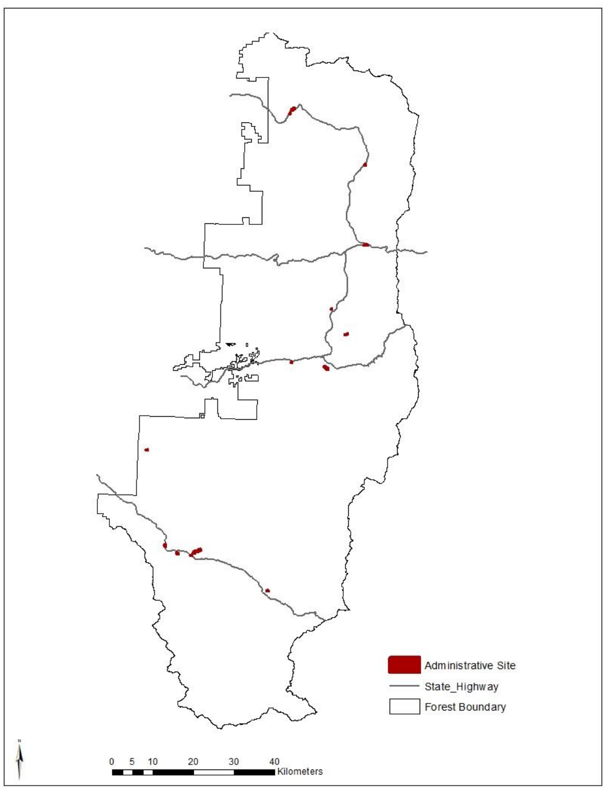

Figure 31. Adminstrative areas

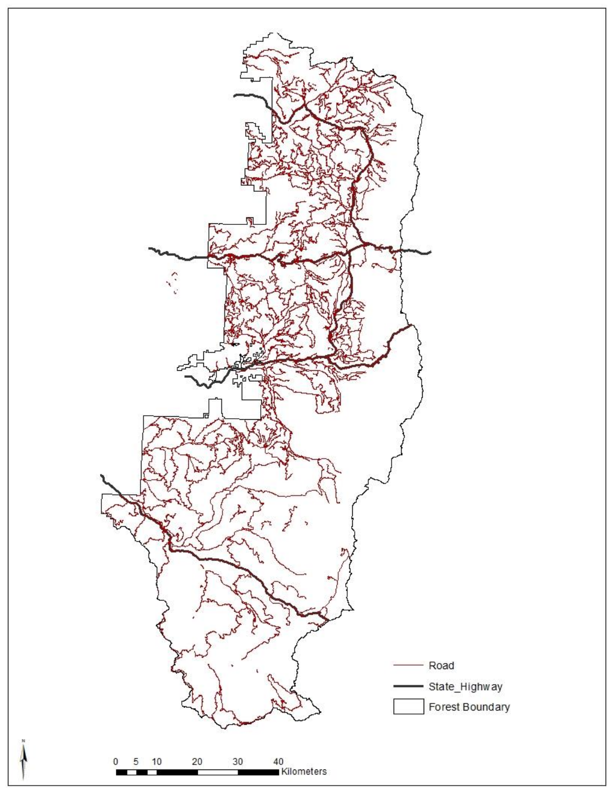

Figure 32. Roads

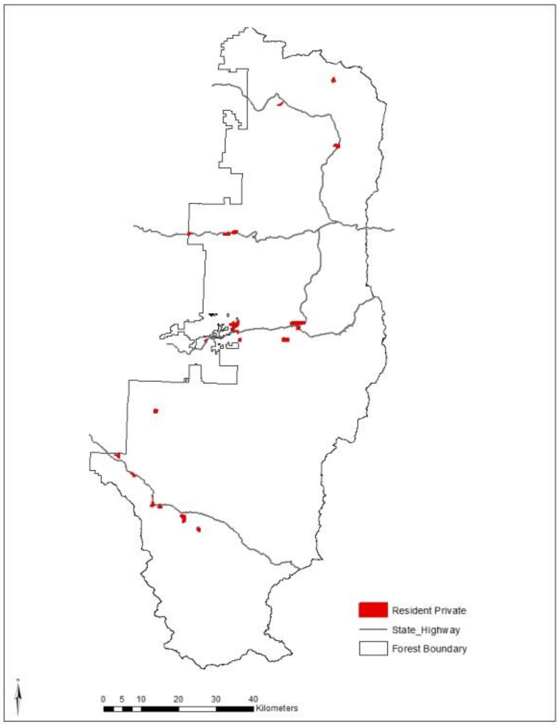

Figure 33. Residential/private

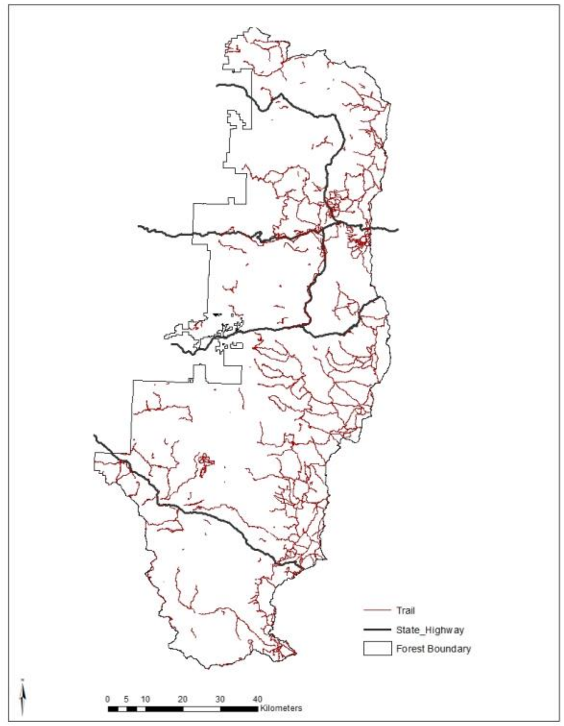

Figure 34. Trails