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The effects of recreational cannabis legalization on forest management and conservation efforts in U.S. national forests in the Pacific Northwest

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Author’s declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:
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Cannabis cultivation in US national forests has been identified as a growing environmental issue resulting in the removal of native vegetation, diversion of waterways, agrochemical pollution, dumping of non-biodegradable trash and human waste, and the illegal poaching of wildlife. Those that adopt a rational choice framework often view law enforcement efforts as pushing this illegal activity into remote areas, including public lands, through the process of crime displacement. As such, the legalization of recreational cannabis has been prescribed as a possible solution to this environmental issue. With the liberalization of marijuana policies across numerous states, the opportunity to analyze these claims is now possible. Utilizing both quantitative and qualitative methods, this study investigates the effects of recreational cannabis legalization in Washington and Oregon on illicit marijuana cultivation in Pacific Northwest national forests. After gathering data from the US Forest Service, a series of regression analyses were conducted to determine the variables influencing the production of cannabis in national forests, and whether legalization can be identified as a significant factor impacting these trends. Further information was gathered by a consolidated interview process with the US Forest Service Law Enforcement and Investigations' Pacific Northwest office. In addition to confirming the relevance of a rational choice framework, this study finds the legalization of recreational cannabis to be a significant factor contributing to a downward trend in illicit marijuana production in national forests in both Washington and Oregon.

Keywords: crime displacement, illicit cannabis cultivation, Pacific Northwest, public lands, rational choice framework, recreational cannabis legalization, US Forest Service, US national forests

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List of Abbreviations

AR	Anticoagulant Rodenticide
CAMP	Campaign Against Marijuana Planting
CPR	Common Pool Resource
DEA	Drug Enforcement Administration
DTO	Drug Trafficking Organization
DPS	Distinct Population Segment
EPA	Environmental Protection Agency
FOIA	Freedom of Information Act
GSP	Gross State Product
LEI	Law Enforcement and Investigations
LEO	Law Enforcement Officer
MDMA	Methylenedioxymethamphetamine (ecstasy)
MMR	Multivariate Multiple Regression
NDIC	National Drug Information Center
NGO	Non-Governmental Organization
ONDCP	Office of National Drug Control Policy
OR	Oregon
PNW	Pacific Northwest
PT	Proposed Threatened
SRO	Safrole Rich Oils
USDA	United States Department of Agriculture
USFS	United States Forest Service

VIF	Variance Inflation Factor
WA	Washington
WSIN	Western States Information Network

1 Introduction

Illicit cannabis cultivation in US national forests has increasingly become recognized as an important environmental issue and hindrance to the proper management of public lands. This activity has been linked to deforestation and the removal of native vegetation (CCLT 2017), the diversion of natural waterways (Bauer et al. 2015), agrochemical pollution (Gabriel et al. 2012; Thompson et al. 2014), the dumping of non-biodegradable waste (Carah et al. 2015), and the poaching of wildlife (Gabriel et al. 2017). In addition to these direct ecological impacts, illicit cannabis cultivation has been noted as stifling research projects due to safety concerns (Gabriel et al. 2013), threatening the security of US Forest Service employees and visitors of national forests (Beckley 2010; Sullivan 2017), as well as posing additional strain on US Forest Service finances, time, and resources due to eradication and remediation efforts (CCLT 2017).

Those that view marijuana cultivation as operating within a rational choice framework often suggest that cannabis growers have been pushed into more remote locations, including national forests, due to the active pursuit of these individuals and crime syndicates by law enforcement (Corva 2014; McSweeney 2015). It is under this framework that some have suggested the legalization of recreational cannabis to be a solution for the problem of cannabis cultivation in national forests (Levy 2014). However, due to a long history of illegality in the United States as a schedule I drug, extensive investigation into the possible effects of cannabis legalization has not been possible.

Since November of 2012, with the legalization of recreational cannabis in Washington, liberalized marijuana policies have increasingly become embraced by individual state governments across the United States. Washington and Oregon, the two states comprising the Pacific Northwest, referred to as region 6 by the US Forest Service, voted to legalize recreational cannabis in 2012 and 2014 respectively (LBC 2014; OLCC 2015). With each of these states having at least a few years under a policy of legalization, an investigation of the preliminary impacts of liberalized marijuana policies can be conducted.

1.1 Research Problem

The aim of this study is to determine whether recreational cannabis legalization in the Pacific Northwest has impacted the abundance and/or scale of illicit marijuana cultivation in US national forests, and, consequentially, the environmental degradation linked to this activity.

In order to achieve this goal, three main objectives are necessary:

1. Gain a greater understanding on the impact that illegal cannabis grow sites in national forests have on forest management and conservation efforts from the perspective of the USDA Forest Service.
2. Identify whether there has been a reduction in abundance and/or size of cultivation sites within national forests after the implementation of legalization policies, and whether any changes can be attributed to legalization.
3. Establish whether any changing trends in the characteristics of cultivation sites after the implementation of recreational cannabis legalization has reduced the environmental impacts of this illegal activity.

1.2 Thesis Structure

First, a literature review is presented investigating the trends dictating illegal drug production in protected areas and the environmental impacts this practice presents, starting with a brief overview globally and then narrowing in on the specifics of marijuana cultivation in the United States. The theoretical notions often used to explain this phenomenon are also examined in this section, with a brief overview of Garrett Hardin's (1968) tragedy of the commons, followed by criminal theory including rational choice theory, crime displacement and the balloon effect. Lastly, this section presents the arguments for and against the legalization of recreational cannabis as a means to counteract illicit cannabis cultivation in national forests and the resulting environmental damage.

Next, Chapter 3 discusses the research methodology utilized in this study, including both quantitative and qualitative techniques in the form of multivariate regression analyses and a consolidated interview with the US Forest Service. The results are presented in Chapter 4 with regression output tables and a summary of the interview response organized in four main categories based on relevant subject matter. These results are then further discussed and connected in Chapter 5, the Discussion section, where potential causes and repercussions are explored. Finally, Chapter 6 contains the Conclusions and recommendations.

2 Literature Review

2.1 Tragedy of the Commons

In 1968, Garrett Hardin's "The tragedy of the commons" emphasized the difficulties of managing shared resources in a sustainable manner. According to Hardin's (1968) game theoretic model, individuals are inclined to act in such a way as to maximize their own benefit, thereby leading to the declining status of natural resources which are subject to open access. To exemplify this logic, Hardin (1968) presents the scenario of a communal pasture. Each herdsman is inclined to continually add additional animals to the shared land as each herdsman gains the direct benefits of their additional animals while the costs of overgrazing are diffused amongst the community as a whole. The "tragedy" is that by each acting to maximize their individual gain, the shared resource is exploited beyond its capacity, and all members of the community end up losing.

Within this paper, Hardin specifically identifies National Parks and federal lands as suffering from the "tragedy of the commons", proclaiming that "we must soon cease to treat the parks as commons or they will be of no value to anyone" (1245). For Hardin, the difficulties of sustainably managing open-access resources leave few options aside from privatization or other extreme measures that limit accessibility to the public as a whole.

However, the premise of Hardin's metaphor for natural resource management has received criticism for being overly simplistic. Hess and Ostrom (2007) identify four main critiques of Hardin's narrative: (1) the commons were completely open rather than managed, (2) Hardin presupposes a lack of communication between stakeholders, (3) priorities of each individual are assumed to not extend beyond self-interest, and (4) Hardin presents no alternative solutions aside from privatization and strict regulation. As a result, more contemporary reflections have preferred to identify U.S. federal lands as Common Pool Resources (CPR) (e.g. Rose et al. 2016), characterized as a "resource system that is sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use" (Ostrom 1990, 30). Despite Hardin's harsh assessment, many modern studies have gone on to demonstrate successful governance and management of CPRs through a variety of means (e.g. Harju et al. 2018)

Yet, despite the mounting research on CPR management, the proliferation of illegal drug production continues to be an issue on public lands and protected areas, both globally and within the United States. As Hardin had described within his own metaphor, the benefits received by the illegal production of drug crops has increasingly come at the cost of ecosystem health and public safety. As will be further investigated within this literature review, when considering the production of illegal crops on federal lands, Garrett Hardin's (1968) words seemingly ring true: "prohibition is easy to legislate (though not necessarily to enforce)" (1246).

2.2 Illegal Drug Production in Protected Areas

1961 marked the beginning of the global drug control system with the ratification of the United Nations Single Convention on Narcotic Drugs (Rolles et al. 2016). In 1971, American president Richard Nixon's proclamation of drug abuse as "public enemy number one" bolstered global efforts to eliminate the illegal drug trade and ignited what would become known as the War on Drugs (Mallea 2014). Yet, despite the numerous global conventions and worldwide prohibitions enacted against the production, trade, and use of various substances since these historic events, the total number of drug users around the globe has continued to increase, and production of illicit substances has risen to meet demand (UNODC 2016).

A growing number of academics and researchers have highlighted the proliferation of extensive drug enforcement and eradication policies as pushing cultivators of illicit crops into more remote, and often more ecologically vulnerable areas. This process has been termed "crime displacement", or the "balloon effect", a concept that will be discussed further in section 2.4. As a result, McSweeney (2015) has identified two main paradoxes that are prevailing within the relationship between illicit drugs and the environment: (1) the ratio of land utilized for drug production is insignificant in consideration of the land needs of global agriculture, yet illicit crop cultivation plays a disproportionately large role in the deforestation and degradation of some of the world's most biodiverse ecosystems, and (2) this environmental degradation is proliferating in drug trafficking regions despite sustained investments in drug prohibition and law enforcement programs.

From Central and South America to Southeast Asia, heavy deforestation and agrochemical pollution have been identified as direct environmental impacts of illicit drug production within protected and ecologically vulnerable regions. For example, Colombia experienced a dramatic 52% increase in coca production between 2015-2016, and a 27% jump in coca cultivation sites within Natural National Parks in the same year (UNODC 2017). In 2016, 17 of Colombia's 59 protected areas were recognized as being affected by coca crops (UNODC 2017). Sierra de la Macarena, a protected area of high species richness consisting of many rare and endemic species (Kattan et al. 2004), has been identified as the most affected area by coca with 30% of the park's total area being used for cultivation (UNODC 2017). Coca cultivation has been directly linked to forest loss, including deforestation in protected areas (MAAP 2017), with at least 60% of all illicit crops in Colombia being grown on newly deforested land (Rolles et al. 2016). Similar trends have been identified in Guatemala, Honduras, and Nicaragua, with anomalous forest loss accounting for 30%-60% of all deforestation in designated protected areas (e.g. biosphere reserve, natural park, world heritage site, etc.) with potentially strong links to drug trafficking (Sesnie 2017).

Similar impacts of illicit drug production have been increasingly recognized in Southeast Asia. In particular, the extraction of sassafras oil from rare *mreah prew phnom* (*Cinnamomum parthenoxylon*) trees in the Cardamom Mountains of Cambodia, to be later processed into safrole rich oils (SRO), a precursor for Methylenedioxymethamphetamine (MDMA; commonly known as ecstacy), has been demonstrated to be a cause of deforestation. With the recent establishment of the Cardamom National Park, a protected area of over 400,000 hectares designed to protect over 2,000 plant species and more than 50 globally threatened vertebrate species (Global Conservation 2018), the extraction of sassafras oil is another threat for the internationally recognized biodiversity "hotspot" (Lo Cascio & Beilin 2010). In order to extract sassafras oil, *mreah prew phnom* trees are felled and the roots are removed and boiled in cauldrons over wood fires for 5-8 days (Bradfield & Daltry 2008). According to research conducted by the Transnational Institute, for every safrole-rich tree felled, another ten are needed to maintain a fire long and intense enough to distill the oil (Blickman 2009). Since 1990, 20% of Cambodia's forests have been lost (FFI 2018), and the production of sassafras oil can be identified as a contributing factor to this process, including within some of Cambodia's protected parks. Similar sassafras production methods have also been observed in Myanmar, Laos, China, and Vietnam (Blickman 2009).

While the expansion of illicit drug cultivation into protected areas and ecologically vulnerable regions has been linked directly to environmental degradation, these practices have further been identified as sparking indirect ecological damage. As recognized by McSweeney et al. (2014), profits generated by drug production are often invested into ranching businesses, oil-palm operations, land speculation, and timber trafficking, a process labelled as "narco-capitalization" that often fuels continued deforestation and environmental devastation. Some illegal mining operations have also been identified as being narco-capitalized (OAS 2013).

In addition, some law enforcement and illicit crop eradication programs have been noted as further damaging biodiversity hotspots and ecologically important territories. The most well understood and studied examples of this phenomenon have been the aerial fumigation tactics utilized in Colombia since the 1970s (Rincón-Ruiz & Kallis 2013). Fumigation efforts intensified in 1999 under "Plan Colombia", an agreement providing US funds for drug eradication efforts in Colombia (Rincón-Ruiz & Kallis 2013). The result was the widespread use of glyphosate, the active ingredient in Monsanto's herbicide *Round Up*, as the primary substance utilized in aerial fumigation efforts, inflicting harm on wildlife, food crops, livestock, and the health of various human communities (McSweeney 2015). Glyphosate is a non-selective compound and any plant exposed to a sufficient amount of the chemical will die (Rolles et al. 2016). With aerial fumigation methods affecting two to three times more land than the intended target, the total loss of natural forest habitats in Colombia may amount to 3 million hectares over the last two decades due to this crop eradication method, thereby threatening the 55,000 native plant species, a third of which exclusively reside in Colombia (Rolles et al. 2016; Fjeldså et al. 2005).

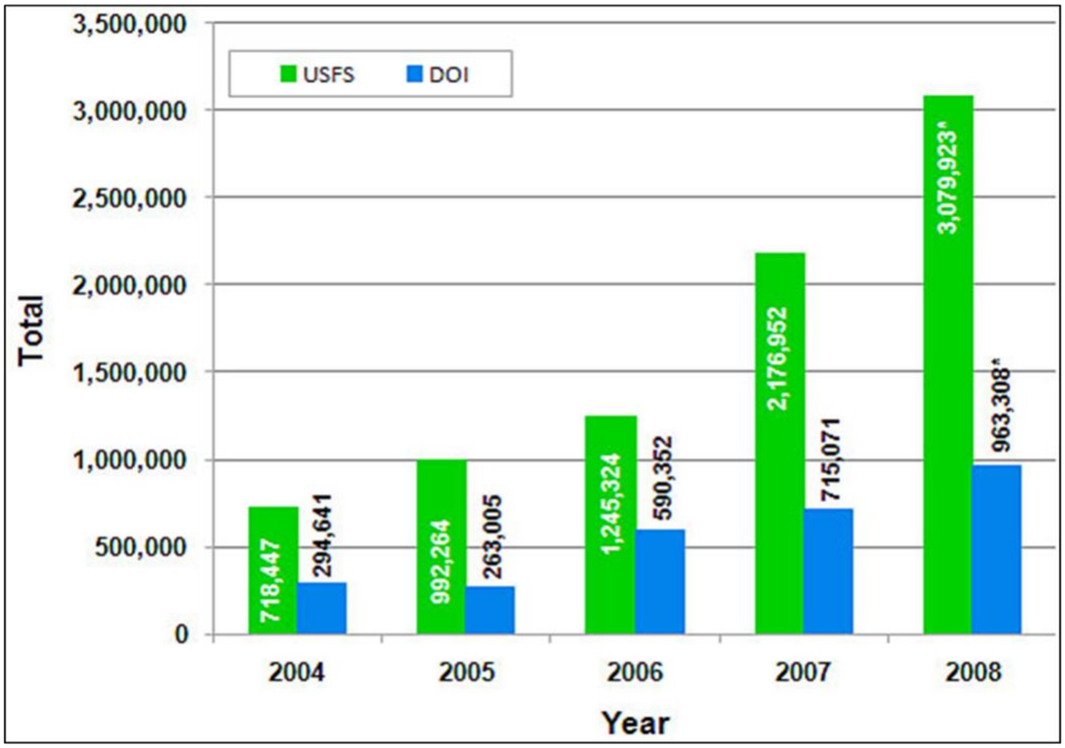
2.3 Marijuana Cultivation in US National Forests

Just as the cultivation of coca crops has emerged in Colombia's national parks, or the production of precursors for MDMA is threatening the health of one of Southeast Asia's largest rainforests, illicit cannabis cultivation has become increasingly common on federal lands within the United States. This practice has been identified as perpetuating ecological damage to some of America's most remote and "untouched" areas, as well as impacting management strategies and threatening public safety.

2.3.1 Current Trend

According to the National Drug Intelligence Center's (NDIC) *Domestic Cannabis Cultivation Assessment 2009* report, of the 8,013,308 cannabis plants eradicated by law enforcement in 2008, 94% (7,562,322) were outdoor grown. Over half of these plants were eradicated from public lands (4,043,231), with 3,079,923 cannabis plants eradicated in national forests in 2008 alone (NDIC 2009). As demonstrated in Figure 1, the number of eradicated cannabis plants in national forests quadrupled between 2004 and 2008 (NDIC 2009). Furthermore, as noted by Koch et al. (2016), this issue has disproportionately affected the West coast, with 76% of all eradicated outdoor cannabis plants in 2008 being eradicated in California, Oregon, and Washington (NDIC 2009). According to the US Attorney's Office (2012), 67% of all marijuana plants captured on the west coast were found on public lands in 2012. Due to this trend, the Office of National Drug Control Policy (ONDCP) and the Drug Enforcement Administration (DEA) identify California, Oregon, and Washington as belonging to the "Marijuana Seven" (M7), a list of the top seven states where illicit marijuana cultivation frequently takes place (ONDCP 2006).

Figure 1. Number of Cannabis Plants Eradicated From US Federal Lands, 2004-2008.



USFS = United States Forest Service, the primary agency managing US National Forests
DOI = Department of the Interior, the primary agency managing US National Parks

Source: Domestic Cannabis Cultivation Assessment (NDIC 2009)

This trend has largely continued, with US government agencies eradicating 10.3 million cannabis plants in 2010, 44% of which were discovered on federal lands (NDIC 2011, Koch et al. 2016). This translated into 3,549,641 plants eradicated in national forests, nearly half a million more than in 2008 (NDIC 2011). In addition, the number of national forests within which grow sites were discovered increased from 55 forests in 2008 to 59 in 2009 (NDIC 2011), jumping again to 67 forests by 2011 (DHS 2011). In a 2016 congressional report published by the US Forest

Service, it is noted that Drug Trafficking Organizations (DTO) were now operating within 72 national forests (USFS 2016).

Unfortunately, the NDIC closed as of June 15, 2012 (DoJ 2012) due to loss of funding. Since this change in government structure, various pertinent annual reports such as the National Drug Threat Assessment have been published by the DEA, though the focus and structure has since changed and data regarding cannabis cultivation on federal lands is no longer included. Despite the omission of this data, concern regarding cannabis cultivation on federal lands continues to be expressed in these reports. For example, the 2016 National Drug Threat Assessment noted concerns expressed by the Central Valley Regional Water Control Board in California regarding water quality due to dramatic increases in marijuana growing activity on both public and private lands (DEA 2016). In addition, the consideration of illicit cannabis cultivation on public lands has continued to be highlighted within the Office of National Drug Control Policy's annual National Drug Control Strategy since at least 2009 (ONDCP 2009, 2010, 2011, 2012a, 2013, 2014, 2015, 2016).

Thus, the scale of illegal cannabis cultivation in national forests is considerably large and appears to be a practice that is only increasing. As noted by the US Forest Service (2016), approximately 22,108,886 marijuana plants were eradicated in national forests between 2000-2014. Furthermore, some reports, such as "Drug Availability Estimates in the United States" published by the Drug Availability Steering Committee, a coalition of 10 government agencies including the DEA, ONDCP, and the Department of Justice (DoJ), estimated eradication rates of domestic cannabis to be between 10-25% (Steering Committee 2002). Others have estimated that seizures of outdoor grown cannabis plants represent as little as 8% of total outdoor grown marijuana in the United States (Gettman 2006). Rose et al. (2016) suggest that eradicated cannabis plants on public lands represent as little as 15% of the estimated cultivation in these areas. While these estimations have often been referred to as rough approximations at best (ONDCP 2012b), with many unknown variables interacting within the black market, they are concerning nonetheless. As expressed by the US Forest Service (2016):

> "The cultivation of marijuana by Drug Trafficking Organizations (DTO) on National Forest System (NFS) and other public lands continues to be a significant problem. This activity increases the risk to the health and safety of the visiting public and employees and the continued viability of the Nation's natural resources."

2.3.2 Ecological Impacts

2.3.2.1 Deforestation and the removal of native vegetation

As noted by Burns-Edel (2016), clear-cutting of intact forests and the removal of native vegetation is common practice for the cultivation of illicit crops. In addition, growers will sometimes construct makeshift roads in order to gain easier access to and from the cultivation site (CCLT 2017). This manipulation of the landscape contributes to five major habitat stressors: fragmentation, shifting microclimatic conditions, increased erosion, fine sediment loading of waterways, and increased risk of wildfires.

In a survey of 4428 grow sites in Humboldt County California, Bustic and Brenner (2016) found 68% of grows[1] to be further than 500m from developed roads, suggesting that fragmentation is not only occurring in highly valued national forests, but it is further disrupting relatively undisturbed and sensitive habitats (Bauer et al. 2015). As noted by Butler et al. (2004), forest

[1] Cannabis cultivation sites

fragmentation in the Pacific Northwest has been linked to the shifting balance of ecosystems and the proliferation of well-adapted invasive species.

The removal of native vegetation can also increase erosion rates of nutrient-rich top soils. In their survey, Bustic and Brenner (2016) found 22% of grow sites to be located on steep slopes, defined as >30%, suggesting a high risk of erosion, sedimentation, and landslides. This finding is supported by Koch et al. (2016) who determined that growers prefer to establish sites on at least a mild slope, likely for the purpose of irrigation. Higher rates of erosion not only remove available nutrients for plant life, but also results in fine sediment loading of nearby streams and waterways (Carah et al. 2015). Sedimentation has been identified as a major stressor on aquatic life including stream-dwelling amphibians, such as larval tailed frogs and southern torrent salamanders (Welsh & Hodgson 2008), and salmonids (Suttle et al. 2004), many of which are considered threatened or endangered in the Pacific Northwest (NOAA 2012).

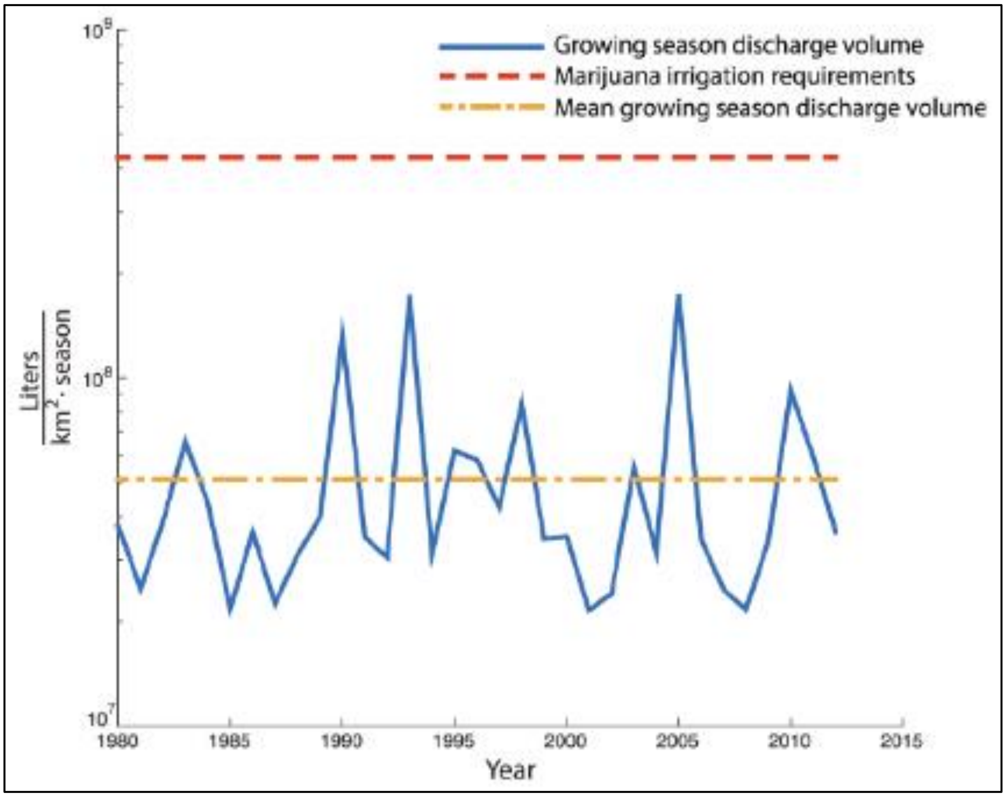
In addition, it should be noted that growers may camp out at a site for several months while tending their crops. The clearing of the land for cannabis cultivation creates abnormally high amounts of dry vegetation which presents a fire risk as growers may be utilizing open fires for cooking and heat (CCLT 2016).

2.3.2.2 Diversion of Natural Waterways

According to the National Drug Intelligence Center (2007), marijuana plants consume up to 22.7 liters of water a day, thereby establishing cannabis as a high water-use plant. Failure to meet the water requirements of cannabis can greatly hinder the growing process and reduce the total payoff for growers (Bouchard et al. 2013). In order to carefully irrigate their crops, cultivators often divert natural springs and headwater streams (Bauer et al. 2015). In a survey of 132 illegal cultivation sites in British Columbia, Canada, Bouchard et al. (2013) found that the average site was 380m from a water source, with 28% staying within 100m of a water supply. Grow sites located farther away from water sources require complex irrigation systems, or close proximity to a road in order to irrigate manually to compensate (Bouchard et al. 2013).

The diversion of natural waterways for the cultivation of cannabis has been identified as having significant impacts on water levels and the subsequent health of aquatic ecosystems. A study conducted by Bauer et al. (2015), under which four watersheds in Humboldt and Mendocino county, California were examined, suggested that the water demand for marijuana cultivation could exceed what is naturally supplied by three of the considered watersheds during low-flow events. The unsustainable nature of cannabis cultivation around the Eel River watershed in California can be visualized in Figure 2. In the Salmon Creek watershed, Bauer et al. (2015) estimated that marijuana grow operations could be demanding up to 173% of the low flow minimum. It is worth noting that Bauer et al. (2015) suspect that their methods underestimate the total number of cannabis plants in the considered region, and thus underestimate the associated water demands. In addition, calculations were conducted with the assumption that each plant utilizes 22.7 liters of water a day, although anecdotal evidence from the researchers' visitations to 40 sites suggest that irrigation systems are often inefficient and lose a substantial amount of water due to leaks, possibly contributing to an even greater water demand. While this study only considered four watersheds in California, in a region where illegal cannabis cultivation is also prevalent on private lands, it is clear that depending on the density of grow sites within national forests, and the size and dynamics of the waterways upon which these sites rely, the heavy use of water for marijuana operations also has the potential to greatly influence the natural water cycle on federal lands.

Figure 2. Actual growing season (June–October) discharge volumes (liters per square kilometer [km2] per season) for the Eel River watershed compared with mean growing season discharge volume and estimated marijuana irrigation



Source: High Time for Conservation: Adding the Environment to the Debate on Marijuana Legalization (Carah et al. 2015)

According to Dudgeon et al. (2006), overexploitation and flow modification are two of the greatest threats to the biodiversity of freshwater habitats. In the Pacific Coast Ecoregion, 60% of amphibian species, 34% of birds, 16% of reptiles, and 12% of mammals are riparian obligates, making them especially sensitive to shifts in waterway dynamics (Bauer et al. 2015). Land practices resulting in water diversions and diminished in-stream flows have been linked to juvenile and adult mortality in various salmonid species including Coho salmon (CDFW 2015). Reduced stream flows threaten salmonids by decreasing habitat availability, stranding fish, delaying migration, increasing intra and interspecific competition, decreasing food supply, and increasing the likelihood of predation (CDFW 2015). In fact, Bauer et al. (2015) observed the stranding and death of salmonids in dewatered streams just downstream of water diversions constructed by marijuana cultivation sites. In addition, reduced flow volume can result in increased water temperatures which has also been linked to reduced growth rates in salmonids, increased predation, and higher risk of disease (Marine & Cech 2004). Furthermore, warmer waters hold less dissolved oxygen, a critical component of freshwater habitat quality and the survival of many salmonids (Silver et al. 1963, Moore & Townsend 1998). This is of particular concern due to the threatened and endangered status of many salmonids in the Pacific Northwest (NOAA 2012), as mentioned above.

The impacts associated with water diversion and the overexploitation of natural waterways are even more worrisome given the current climate change predictions in America's West. According to the United States Environmental Protection Agency (EPA 2017), the average annual temperature in the Northwest has increased by 1.3°F over the last century and are projected to rise by 3°F - 10°F by 2100. Furthermore, the largest increases in temperature are expected to occur during the summer months, the conventional marijuana growing season (EPA 2017). The EPA (2017) notes that climate change will reduce annual snowpack, thus threatening the natural storage of available water, while summer precipitation may decline by as much as 30%. The projected result will be a decrease of natural water levels, while water sources simultaneously become warmer (EPA 2017). Given the considered impacts referenced above, the continued diversion of waterways by cannabis cultivators will only exacerbate the future threats posed by climate change (Figure 3).

Figure 3: A California wetland drained to irrigate a marijuana garden

Source: High Time for Conservation: Adding the Environment to the Debate on Marijuana Legalization (Carah et al. 2015); Photograph taken by Scott Bauer

2.3.2.3 Agrochemical Pollution

In 2009, the UC Berkeley Sierra Nevada Adaptive Management Project (SNAMP) fisher research team discovered the carcass of a deceased fisher (*Pekania pennanti*) with no obvious cause of death (Thompson et al. 2014). Necropsy determined that the individual had died from poisoning due to the ingestion of anticoagulant rodenticides (AR), toxicants used to control rodent pest populations in urban and agricultural settings (Gabriel et al. 2012). Further analysis of deceased fishers collected between 2006-2011 revealed that 79% of the tested carcasses were exposed to at least one AR compound (Gabriel et al. 2012). Given the remote nature of fishers' natural geographic range, distanced from both urban and agricultural centers where AR use is permitted, it was determined that the most likely source of AR exposure came from illegal marijuana cultivation sites in and around public lands (Gabriel et al. 2012). In his TEDxYosemite presentation titled "A Growing Problem on our Public Lands" (November 14^{th}, 2015), Dr. Mourad Gabriel described this experience with fishers as a "canary in the coal mine" incident, with fishers becoming the flagship species indicating the severity of agrochemical pollution caused by the proliferation of marijuana grow sites on US public lands.

In order to assess the hypothesis presented in Gabriel et al.'s (2012) study, Thompson et al. (2014) examined the correlation between the number of known cannabis cultivation sites and AR exposure amongst fishers, discovering evidence that female fisher survival was related to the number of grow sites an animal was likely to encounter within their range. Furthermore, a follow up study published by Gabriel et al. in 2015 found an increase in AR exposure incidents amongst fishers since their original 2012 paper, with an 85% exposure rate amongst fishers tested between 2012-2014. Within this same period, fishers were exposed to more than 1.7 AR compounds on average (Gabriel et al. 2015). Ten percent of deaths were determined to be the direct result of poisoning, although with predation and disease being the top threats to fishers' survival, it is likely that effects of AR exposure, including lethargy, weakness, and impaired immune response, may have increased the vulnerability of many individuals (Levy 2014; Gabriel et al. 2015).

Given that fishers inhabiting California, Oregon, and Washington, designated as a Distinct Population Segment (DPS), are considered a candidate species under the United States Federal Endangered Species Act, and are proposed threatened (PT) by the US Forest Service and the Bureau of Land Management (USFS & BLM 2015), the widespread exposure to ARs is of particular concern (Gabriel et al. 2012; Thompson et al. 2014). Fishers, once widespread throughout the west coast of North America, have experienced significant declines in populations and now only reside in 21% of their historic distribution in the Pacific states (Washington, Oregon, California) (Lofroth et al. 2010; Gabriel et al. 2015). Despite conservation efforts, Pacific fisher populations have failed to expand even within regions with plentiful suitable habitat and minimal fragmentation (Gabriel et al. 2015). Furthermore, Spencer et al. (2011) suggest the expansion of fisher populations to be extremely sensitive to mortality rates, specifically identifying human-influenced factors as a possible threat to the species well-being. The expansion of AR pollution as facilitated by illegal marijuana grow sites appears to be presenting an additional threat to the conservation of the struggling Pacific fisher.

Unfortunately, the Pacific fisher is not the only species impacted by the agrochemical pollution produced by illicit cannabis cultivation. Multiple studies have investigated AR exposure from grow sites in various owl populations, discovering 70% of Northern Spotted Owls, a species listed under both the Federal Endangered Species Act and the California Endangered Species Act, and 40% of tested Barred Owls were subjected to at least one AR compound (Franklin et al. 2018, Gabriel et al. 2018). Furthermore, an ecological monitoring project in California that set up Remote Infrared Wildlife Cameras at 19 eradicated marijuana grow sites, both before and after reclamation, detected a multitude of species including black-tailed deer (*Odocoileus hemionus* *columbianus*), American black bear (*Ursus americanus*), mountain lion (*Puma concolor*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), fisher, raccoon (*Procyon lotor*), ringtail (*Bassariscus astutus*), striped skunk (*Mephitis mephitis*), western spotted skunk (*Spilogale gracilis*), western gray squirrel (*Sciurus griseus*), Douglas squirrel (*Tamiasciurus douglasii*), deer mouse (*Peromyscus maniculatus*), chipmunk (*Tamias* spp.), dusky–footed woodrat (*Neotoma fuscipes*), snowshoe hare (*Lepus americanus*), common raven (*Corvus corax*), varied thrush (*Ixoreus naevius*), Steller's jay (*Cyanocitta stelleri*), and dark-eyed junco (*Junco hyemalis*) (Gabriel et al. 2017). The same monitoring and reclamation project discovered animal carcasses at 58% of the 59 grow sites investigated, many of which were suspected of poisoning (Gabriel et al. 2017). These results only confirm the experiences of law enforcement officers (Sullivan 2017), who sometimes refer to cultivation sites as "wildlife bombs" due to the dangers they present to the natural inhabitants of Pacific forests (Gabriel et al. 2013). Exemplifying this adage, Gabriel et al. (2013) re-tell the story of federal and state officers that encountered a black bear and her cubs seizing and convulsing due to pesticide exposure.

The vast ecological devastation induced by the agrochemical pollution of illegal marijuana grow sites is perpetuated by the sheer number of grow operations on public lands, and the widespread adoption of pesticide and fertilizer use amongst these cultivators operating within the black market. One reclamation operation in October of 2014, within which seven sites were remediated, removed a total of 104 pounds of rodenticide, 560 gallons of insecticide, and 8,188 pounds of fertilizer (Gabriel et al. 2017). A second reclamation operation conducted as a part of the same project in April 2015 recovered over 9,000 pounds of fertilizer, pesticides and trash (Gabriel et al. 2017). Unfortunately, the clandestine nature of marijuana cultivation on public lands limits researchers' ability to calculate the exact extent of this issue (Levy 2014). Furthermore, there is currently no standardized protocol for grow site remediation, and funding to document and quantify toxicants is difficult to secure, resulting in many instances where law enforcement officers leave chemicals at cultivation sites untouched due to safety concerns, especially since these chemicals are often left unlabeled (Gabriel et al. 2013). Yet, despite these uncertainties, researchers warn that the sheer number of illegal grow sites elevates this issue beyond point-source pollution and should be considered a landscape level problem (Thompson et al. 2018).

However, it is not just the widespread use of pesticides and fertilizers that is resulting in the magnitude of this issue, but also the methodology of use by growers. AR compounds and other pesticides have not only been observed around the marijuana plants themselves, but have also been noted as being dispersed along irrigation lines in order to deter animal damage (Gabriel et al. 2012). The extent of these irrigation lines throughout national forests is extensive, with single eradication projects removing as much as 40km of plastic piping (Gabriel et al. 2012), thereby spreading pesticide use well beyond the immediate perimeter of each grow site. In addition, growers will intentionally place carbamate pesticides in open sardine or tuna cans around the outskirts of their cultivation sites in order to kill black bears, gray foxes, raccoons, and other carnivores that may pose a threat to the health of their plants or food supplies (Gabriel et al. 2013). Furthermore, the use of different pesticides and AR compounds within sites and across different grow sites presents the risk of additive and synergistic effects (Thompson 1996, Thompson et al. 2014). Notably, malathion has been demonstrated to interact synergistically with other pesticides and is a compound that is commonly found at cannabis cultivation sites

(Thompson et al. 2014, Olgun 2004). Exposure to multiple toxicants has been observed in fishers with one necropsied individual containing six different AR compounds (Gabriel 2015a). Furthermore, Gabriel et al. (2015b) have identified an increase in the number of different poisons utilized by illicit cultivators with eight additional toxicants observed between 2012-2014 than in 2009-2012 (Gabriel et al. 2012, Gabriel 2015a). It should also be noted that many poisons found at illicit grow sites, including organophosphates, organochlorines, carbamates, and carbofuran, have been restricted or banned in the United States, Canada, and the European Union due to extremely dangerous levels of toxicity (Figure 4) (Gabriel et al. 2013, Gabriel et al. 2017).

This issue of agrochemical pollution not only directly threaten wildlife, but also presents risks across trophic levels and the ecosystem as a whole. The use of pesticides alongside fertilizers increases the likelihood of uptake into surrounding vegetation (Thompson et al. 2014). Furthermore, it has been demonstrated that field margin plant communities, the vegetation surrounding agricultural developments, are impacted in various ways by the use of fertilizers and pesticides on crops (Schmitz et al. 2014). Fertilizers promote the growth and spread of species with high nutrient uptake while indirectly reducing the competitive ability of smaller species (Schmitz et al. 2014). Pesticides can severely impact the health of various species and eventually lead to complete disappearance (Schmitz et al. 2014). Synergistic and additive effects of the use of fertilizers and pesticides in conjunction is also a concern (Schmitz et al. 2014). Given the heavy and widespread use of fertilizers and pesticides amongst illicit cannabis grow sites in national forests, often in conjunction with banned chemical compounds, within remote and heavily forested regions, there is no reason to suspect that cultivation sites would not have comparable, if not more severe, effects on surrounding vegetation than regulated agricultural developments. In addition, the leaching of these fertilizers and pesticides into waterways pose a concern (Thompson et al. 2014). Toxicology testing in streams nearby nine eradicated cannabis grow sites revealed that 33% tested positive for diazinon, a highly toxic insecticide that has been banned from over the counter use due to water contamination concerns (Gabriel et al. 2017). The presence of fertilizers can further harm the health of these habitats by galvanizing eutrophication, a process that has been directly linked to illegal marijuana cultivation (Levy 2014).

While research on the agrochemical pollution cause by illicit cannabis grow sites has only emerged fairly recently, with the majority of analysis occurring thanks to the dedication of Dr. Mourad Gabriel since his first publication on the matter in 2012, those most involved in this area of study warn of the potentially devastating effects of this phenomenon:

"Given the facts that the primary compounds in OP and carbamate pesticides were initially developed as nerve agents in World War II (Grue et al. 1997), that the use of pesticide based weapons is an ongoing concern (Burklow et al. 2003; Terry 2012), and that exposure to multiple neurological agents is one plausible scenario for the elusive Gulf War Illness (Golomb 2008), the contamination occurring at illegal marijuana cultivation sites is more akin to leaking chemical weapon stockpiles than typical use or misuse of agricultural products (Zabrodskii et al. 2012)." (Thompson et al. 2014, 97)

Figure 4: A collection of toxicants discovered at a marijuana grow site on public lands including Weevilcide, a restricted-use poison.

Source: "Pot Poisons Public Lands" (Levy 2014); Photograph taken by Mourad Gabriel

2.3.2.4 Dumping of Non-Biodegradable Waste

The dumping of non-biodegradable waste has also been a well-documented impact of illicit cannabis cultivation sites in US national forests (Carah et al. 2015). Given the remoteness of grow sites, and the careful care provided for crops in order to maximize yields and profits, growers will often spend months at a time inhabiting their camps (Gabriel et al. 2013, 2017). This results in the build-up of various supplies and trash. In 2012, authorities removed 180,000 pounds of trash from eradicated grow sites in California's public forests (CCLT 2017). In one remediation project from 2014-2016, 61,174 pounds of trash were removed from just 29 grow sites in three national forests and one American Indian reservation[2] (Gabriel et al. 2017). In 2016, Forest Service staff removed over 11,000 pounds of garbage from just one illegal grow site (Sullivan 2017). These types of statistics exemplify why those operating in the field testify that the production of hundreds of pounds of trash and debris is typical of discovered grow sites on public lands (Gabriel et al. 2017).

Not only does this trash pollute some of the most remote and naturally pristine areas in the United States, but many discarded items present additional risks to wildlife. In 2013, 244 propane tanks and 61 car batteries were removed from grow sites in California (Gabriel et al. 2017). Sulfuric acid, just one component in car batteries, is corrosive to the skin, eyes, respiratory track and gastrointestinal track, and can result in death (NIH 2016). Furthermore, trash dumps at grow sites have been observed to attract wildlife, putting animals at greater risk of exposure to toxicants or violence from growers defending their supplies and crops (Gabriel 2015a).

2.3.2.5 Poaching of Wildlife

Illicit cannabis cultivation sites in national forests have also been linked to the illegal poaching of wildlife (Carah et al. 2015; CCLT 2017). As mentioned above, growers may inhabit their campsites for months at a time, and poaching may be done for subsistence or entertainment (Gabriel et al. 2013, 2017). Gabriel et al. (2017) report that wildlife carcasses were discovered at 34 of the 59 (58%) sites visited during their reclamation project, with the majority appearing to be shot. Deceased black-tailed and mule deer, species well-recognized within the trophy hunting

[2] American Indian is the official term used by the United States government to refer to indigenous peoples.

community (B&C 2017), were found at 33% of investigated grow sites (Gabriel et al. 2017) (Figure 5). Other big game species have been identified as being at risk of illegal poaching by cannabis growers such as elk (Gabriel & Wengert 2017).

Figure 5: Deer antlers, as well as an assortment of food and medicines, found at a large marijuana grow site in Plumas National Forest.

Source: "Illegal Pot Farms are Poisoning California's Forests" (Smith 2017); Photograph by Morgan Heim/bioGraphic

2.3.3 Impacts on Forest Management

The mission statement of the United States Forest Service, the department responsible for the management of the US national forests network, is to "sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations" (USFS 2015a). In order to continually pursue the principles embodied in this mantra, the National Forest Management Act of 1976 mandated intensive long-range planning for the handling of national forests (Williams 2005). A key legacy of this legislation is the publishing of the USDA Forest Service's strategic plans. By utilizing the "USDA Forest Service Strategic Plan: FY 2015-2020" (USFS 2015a), the current goals and objectives of the Forest Service can be recognized, and the impediments introduced by illegal marijuana grow sites within national forests can be realized.

The US Forest Service's Strategic Plan for 2015-2020 (USFS 2015a) introduces three main "strategic goals" and one "management goal", each of which are broken down into three key objectives. The impacts of illicit cannabis cultivation can be seen as impeding on all three of the strategic goals, including "Sustain our Nation's Forests and Grasslands", "Deliver Benefits to the Public", and "Apply Knowledge Globally", as well as impacting many of the objectives inherent to these goals.

2.3.3.1 Strategic Goal #1: Sustain our Nation's Forests and Grasslands

Marijuana cultivation sites on public lands can be seen as impeding two key objectives within the Forest Service's first strategic goal: (1) Objective A, to "foster resilient, adaptive ecosystems to mitigate climate change", and (2) Objective B, to "mitigate wildfire risk" (USFS 2015a). In order to support climate adaptive ecosystems, the Forest Service (2015a) highlights the importance of ensuring resilient land and water conditions at the watershed level. As described above, heavy water use by grow sites has been observed as decreasing water levels (Bauer et al. 2015) while the widespread application of pesticides and fertilizers, as well as the runoff of human waste and excrement, has been linked to polluted waterways (Gabriel et al. 2013, 2017).

While the depletion of watersheds will only amplify the predicted effects of climate change in America's West (EPA 2017), heavy water use and agrochemical pollution have the potential to further impact ecosystem functioning and resiliency across trophic levels.

The impact on ecosystem resiliency can be exemplified with the potential effects marijuana grow sites may be having on salmonid species, many of which are anadromous and considered keystone species in riparian habitats. Bauer et al. (2015) link the illegal diversion of waterways for cannabis cultivation and unsustainable depletion of water levels, as well an associated rise in water temperatures, to a significant decline in habitat quality and increased mortality for salmonids. With the heavy use of fertilizers by grow sites which have been directly linked to eutrophication (Levy 2014), if extreme levels are reached, salmonids may also be threatened by hypoxic conditions due to declines in dissolved oxygen content (Bauer et al. 2015), an issue that is further contributed to by warmer waters (Missaghi et al. 2017). In addition, the runoff of pesticides into waterways has been observed to include toxicants, such as diazonin, that are harmful for fish and other aquatic life (Gabriel et al. 2017). Pacific salmon, including many populations that are dependent on waterways within national forests, have been identified as disproportionately impacting ecosystem structure and functioning within the Pacific Coast Ecoregion. As a result of their migration patterns, anadromous salmon species deliver marine derived nutrients, including nitrogen (N), carbon (C), and phosphorus (P), from the Pacific Ocean to river and riparian habitats (Helfeild & Naiman 2006; Richardson et al. 2017). These nutrients support the growth of trees and riparian vegetation, as well as serve as a fundamental food source for a variety of predators including bears, wolves, and eagles (Levi et al. 2015). Considering the decline of anadromous salmonids in the Pacific Northwest (Gustafson et al.

2007; Bryant et al. 2008), with numerous populations of sockeye, chum, chinook, and coho salmon, as well as steelhead and trout, listed under the Endangered Species Act (USFWS 2018), the additional stressors introduced by marijuana cultivation sites may further inhibit the vast benefits these species provide for the functioning of many areas within national forests, and thereby limit ecosystem resiliency to climate change.

In addition, the build-up of dry vegetation associated with the clearing of native plants and trees by growers when developing a cultivation site increases the risk of forest fires (CCLT 2017), thereby impeding Objective B. Furthermore, the improper disposal of potentially flammable trash, such as propane tanks, introduces another significant threat to wildfire mitigation (Gabriel et al. 2017).

2.3.3.2 Strategic Goal #2: Deliver Benefits to the Public

As noted by the USDA Forest Service Strategic Plan (USFS 2015a), around 60 million Americans rely on drinking water that originates in national forests and grasslands. The protection and proper management of these water sources is often more cost effective than the development of new infrastructure, such as water purification plants (USFS 2015a). As such, Objective D under Strategic Goal #2 of the Forest Service Strategic Plan for 2015-2020 (USFS 2015a) highlights the provision of abundant clean water as a priority. However, as outlined above, marijuana grow sites in national forests do not only deplete water levels, but also contaminate water sources with toxicants, fertilizers, and human waste, thereby harming wildlife and potentially compromising the safety of people’s drinking water (Bauer et al. 2015; Sullivan 2017).

In addition to providing clean water, the US Forest Service strives to connect the American public to the outdoors to "escape from daily routines and experience the serenity of nature, the mystery of wild places, the history of past cultures, and the excitement of engaging in the greatest variety of outdoor activities" (USFS 2015a, 22). Yet, the proliferation of marijuana cultivation sites within the national forest system threatens the safety of visitors. With many grow sites being operated by organized crime syndicates, and the value of their crops often worth millions of dollars, growers have increasingly armed themselves, often with high-caliber assault rifles, shotguns, and military-style ammo clips (Markey 2003). In 2012, the DEA reported seizing over 10,000 weapons on marijuana cultivation sites, many of which were discovered on public lands (ONDCP 2014). In an interview with National Geographic News (Markey 2003), a regional drug investigator for the US Forest Service discloses that "there's not a type of gun that we haven't found". With numerous instances of hunters, hikers, and backcountry users being chased and shot at by marijuana growers after stumbling upon cultivation sites (Markey 2003; Kirchner et al. 2013), the US Forest Service has begun publishing tips and advice for recognizing and avoiding possible grow sites, both for Forest Service employees and the public in general (Beckley 2010; Sullivan 2017). This threat to safety not only restricts visitors from accessing certain areas of the national forest system, but could also potentially be a deterrent from visiting the forests at all.

2.3.3.3 Strategic Goal #3: Apply Knowledge Globally

The Forest Service recognizes the importance of information collection and sharing in order to influence management decisions, as outlined within Objective G, to advance knowledge, under Strategic Goal #3 (USFS 2015a). However, the abundance of marijuana grow sites within national forests has impeded in fully achieving this objective. The fact that these grow sites are often patrolled by armed individuals, with some sites even harboring booby traps (Sullivan 2017), has not only presented safety concerns for the public, but also researchers and Forest Service employees. With several recent accounts of biologists being chased and shot at by growers, and subsequent heightened safety concerns, some study designs are being altered to avoid areas in which grow sites are common, thus impacting the quality and completeness of data (Gabriel et al. 2013). This is exemplified by the King River Fisher Project, operating out of the USFS Pacific Southwest Research Station, which estimates that 10-25% of the project study area becomes inaccessible during each field season due to safety concerns (Gabriel et al. 2013). While in the past research biologists typically worked independently in the field, consideration of the threats posed by marijuana grow sites has now resulted in wildlife crews composed of at least two individuals (Gabriel et al. 2013). Although the effects of these changes have not been fully explored, Gabriel et al. (2013) suspect that there are now increased labor and equipment costs which may be impacting the size and duration of many studies on public lands.

Increased costs associated with field research does not bode well with the current funding priorities provided for the USDA Forest Service. The current trend is a total loss of funding for the Forest Service, with discretionary appropriations losing $938 million from 2017 to 2018, and an additional decrease of $486 million proposed for 2019 (USFS 2017, 2018a). Given the growing awareness about the impacts of illegal cannabis cultivation in national forests, Law Enforcement and Investigations has continued to receive increases in funding for marijuana eradication efforts, with an additional $2.7 million provided in 2018 and a proposed increase of $3.36 million for 2019 (USFS 2017, 2018a). For both 2018 and 2019, the US Forest Service dictates that the additional funding going towards marijuana eradication efforts will include an increase in restoration programs for discovered grow sites (USFS 2017, 2018a). The cost of these efforts is large, with the U.S. Office of National Drug Control Policy estimating clean-up costs to range from $14,900-$17,700 per acre (0.4 hectares) (CCLT 2017). In addition, The Nature Conservancy estimates that the initial restoration of grow sites in California alone could cost over $90 million annually, rising to $120 million if enforcement costs are considered (CCLT 2017). The losses of total funding, and increases in appropriations for marijuana eradication, have coincided with dramatic reductions in financing for Research and Development programs (USFS 2017, 2018a). One can suppose that given the high costs of marijuana eradication and restoration efforts, as well as the limited funding available for the US Forest Service, that if the issue of cannabis cultivation on public lands was not so extensive then more funding could be potentially available for research and development, a key component of the Forest Service's third Strategic Goal.

2.4 Crime Displacement

2.4.1 Theory

With the illegal drug trade persisting despite law enforcement efforts (UNODC 2016), academics and researchers have often found rational choice theory to best explain this phenomenon (e.g. Loughran et al. 2016). Rational choice theory assumes that criminals actively engage in decisions and choices made with regards to their illegal behavior, and that these choices are based on self-interest (Cornish & Clarke 1987). While many authors have taken a nuanced position on the matter, recognizing that actors may be limited by time, circumstance, cognitive ability, and availability of information, rationality is still identified at the root of many crimes (Cornish & Clarke 1987; Loughran et al. 2016). When offenders are considering criminal behavior, they respond selectively to the opportunities, costs, and benefits of that particular crime, and decide whether or not to displace their efforts elsewhere (Cornish & Clarke 1987). It is out of this theory that the concept of crime displacement emerges.

When law enforcement efforts are designed to discourage specific crimes, they are based on three basic mechanisms: increasing the effort in committing the crime, increasing the risks associated with the crime, and reducing the anticipated rewards of the crime (Hesseling 1994). In this way, the fundamental characteristics of the crime, or what Cornish and Clarke (1987) referred to as "choice-structuring properties", are altered. As rational actors concerned with their own self-interest, potential offenders are then required to re-evaluate the opportunities, costs, and benefits of that particular crime. However, while the goal of law enforcement is to make criminal activities wholly unattractive, depending on the individual, the characteristics of the crime, and the law enforcement efforts enacted, offenders may simply change their behavior "along illegitimate means, which is designed to circumvent either specific preventive measures or more general conditions unfavorable to the offender's usual mode of operating" (Gabor 1990, 66). In this way, they may displace their criminal behavior to other times, geographical areas, methods, targets, or offenses (Reppetto 1976; Hesseling 1994).

The concept of crime displacement can be best understood through the simple case of auto theft in Britain in the 1970s. In January of 1971, all new cars manufactured or imported to Britain were required to be fitted with steering column locks in an attempt to reduce autocrime (Mayhew et al. 1976; Webb 1997). Yet by 1974, vehicle theft was found to be 80% higher than in 1970 in the Metropolitan Police District (Mayhew et al. 1976). Investigating these findings, a government report found that 20.9% of auto theft in 1969 was comprised of the illegal taking of new cars, while new cars only represented 5.1% of autocrime in 1973 (Mayhew et al. 1976; Hesseling 1994). Thus, it was determined that in response to the mandating of steering column locks, a policy measure that increased the costs and complications of vehicle theft, offenders simply displaced their activity to older models that were unlikely to be fitted with the preventative technology (Mayhew et al. 1976).

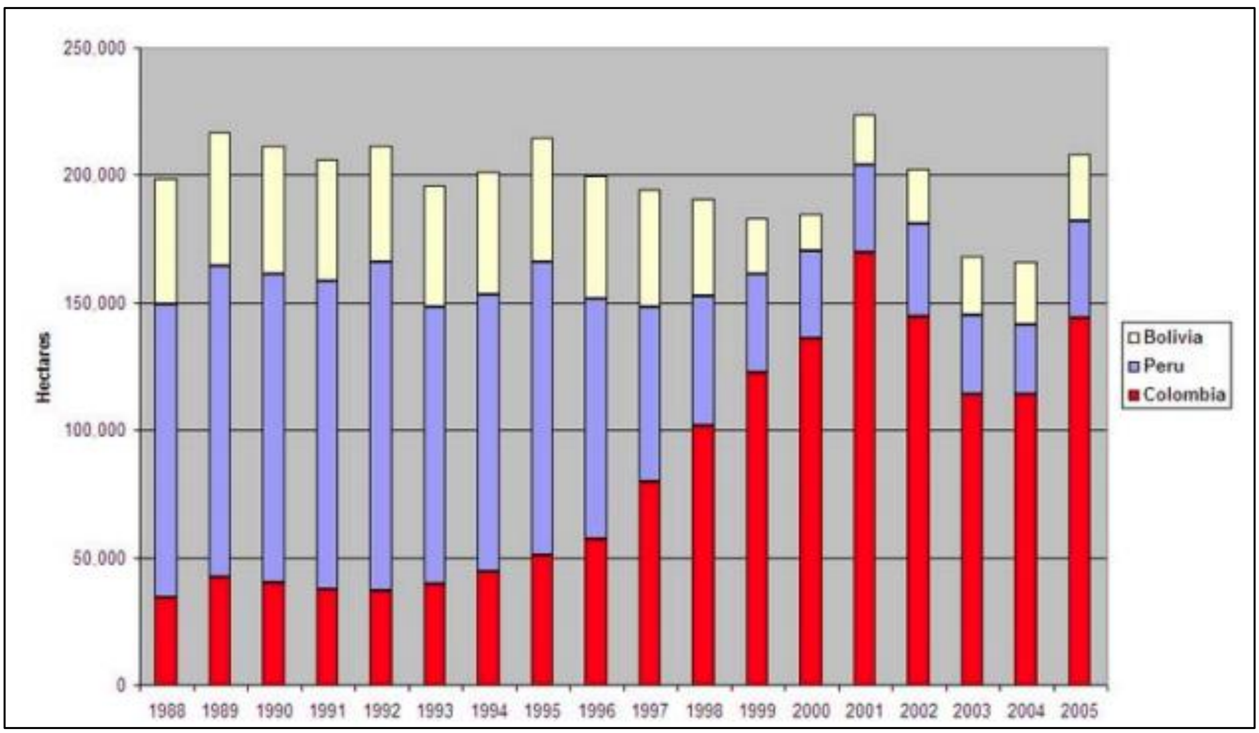
While crime displacement has been noted as a possible effect of law enforcement efforts within a variety of crimes (Blasiak et al. 2015), the illegal drug trade has been observed as being extremely susceptible to displacement (Sherman 1990; Hesseling 1994). This has given rise to the idea of the "balloon effect", which uses the analogy of a balloon to illustrate that when law enforcement places pressure in one geographic area, the drug trade simply bulges out with increased intensity in another location, just as the air inside a balloon does when squeezed (Madsen 2007). Critics of this concept point out that such an analogy implies an impervious drug trade and dismisses the effects that drug enforcement efforts may have (Windle & Farrell 2012). In fact, studies have found that when displacement does occur, it is often less than 100%, thereby signaling a net benefit in terms of the impact of law enforcement (Brantingham & Brantingham 2003; Windle & Farrell 2012). Furthermore, the very sentiment that these offenders are "forced" to displace their efforts suggests that law enforcement creates obstacles and inconveniences that can cost time, money, and resources for criminal groups, and thus weakening them in some regard (Windle & Farrell 2012). However, what these critiques fail to consider (e.g. Windle & Farrell 2012) are the possible externalities that crime displacement can have, where pressure that causes the relocation of criminal activity can have a disproportionate impact (Madsen 2007), a result that has been well documented when considering drug crop cultivation and drug trafficking (e.g. McSweeney 2015).

2.4.2 Crime Displacement and Drug Cultivation

The spatial displacement of illicit crop cultivation has been a well-observed consequence of newly introduced law enforcement schemes around the world. Considering the cases of coca production in Columbia and sassafras oil in Myanmar, examples that have been demonstrated as contributing to ecological devastation in protected areas (section 2.2), it can be seen that the proliferation of drug crop production in these areas has been the result of these illegal activities being displaced from other regions. In fact, given the continued emergence of the "balloon effect" in Latin America's history of drug enforcement, an alternative term for this consequence has developed: *efecto cucaracha*, or the "cockroach effect" (Self 2013; Bagley 2012)

Prior to the late 1980s, Peru and Bolivia were the primary coca producers in the world with Peru providing 65% of the global coca supply, Bolivia 25%, and Columbia only contributing around 10% (Bagley 2012). U.S. financed crop eradication programs in Bolivia and Peru in the late 1980s and 90s resulted in "partial victories", in which targeted areas saw a decrease in coca production, yet coca cultivation in Columbia increased dramatically producing 90% of global supply by 2000 (Bagley 2012). This has led researchers to note that the effects of U.S. assistance in coca eradication were not uniform across the Central Andes, and total coca production in this region remained essentially unchanged (Rouse & Arce 2006; Figure 6). This rise in production in Columbia resulted in additional U.S. support for coca eradication efforts, including "Plan Columbia" in 1999, and the widespread use of aerial fumigation tactics within Columbian borders (Rincón-Ruiz & Kallis 2013). However, as with law enforcement efforts in Peru and Bolivia, the increased fumigation in Columbia has been observed as not eradicating but displacing coca production (Rincón-Ruiz & Kallis 2013). Once again coca cultivation moved back into Peru and Bolivia as total production decreased in Columbia (OAS 2013; Blasiak et al. 2015). In addition, displacement emerged within Columbia in the form of diffusion, under which the concentration of production dispersed over a greater area, often moving into more ecologically sensitive areas (Rincón-Ruiz & Kallis 2013; McSweeney 2015). It should also be noted that displacement of coca cultivation has now occurred between continents, with the very first coca plantation discovered in Southern Mexico in 2014 (Hamilton 2014).

Figure 6. Coca production in the Central Andes



Source: "Colombian coca cultivation in 2005" (CIP 2006). Data collected by the State Department International Control Strategy Reports, 1996-2005

The displacement of cultivation in the Central Andes has not only occurred spatially, but also temporally. With Colombian security forces successfully decreasing local coca cultivation through a combination of aerial and manual eradication programs, efforts were reduced in 2012 (DEA 2017). However, with the decreased presence of law enforcement, coca cultivation increased 134% between 2013-2016 (DEA 2017). With the seemingly rigid demand of many drug markets, once periods of intensified law enforcement efforts end, cultivation often reappears at a similar scale to what it once was.

This sort of obvious displacement has not only occurred with cultivation, but the trafficking routes utilized to distribute coca products as well. For example, during the height of Colombian cocaine production, increased monitoring of flights between Bogota and European capitals did not result in a reduction of cocaine trafficking, but rather the development of new routes through "transit countries" in West Africa (Blasiak et al. 2015). Furthermore, when interdiction efforts were raised in the mid-2000's to disrupt the flow of cocaine to North America through the eastern Caribbean, trafficking increased through Central America, a process that has been demonstrated to be contributing to forest loss in Honduras, Guatemala, and Nicaragua (Sesnie et al. 2017).

Similar trends have been experienced in Southeast Asia with the extraction of sassafras oil. While China and Vietnam used to be the leading producers of this precursor to MDMA (ecstasy), Vietnam prohibited the production of safrole-rich oils in 1999, and China introduced stricter controls on the legal market and increased law enforcement crackdowns in the black market in 2005 (Blickman 2009). The subsequent result of increased regulation, a process that not only impacts the legal market but increases difficulties of diverting legally produced compounds into the black market, has subsequently resulted in increased production in Cambodia, Myanmar, and Laos (Bradfield & Daltry 2008; Blickman 2009). The consequence of this displacement has been the complete deforestation of primary production areas in Myanmar (Blickman 2009), and an increased threat of deforestation and habitat loss in Cambodia's protected areas (Bradfield & Daltry 2008).

2.4.3 Crime Displacement and Illicit Cannabis Cultivation in the US

The rise of cannabis cultivation in US national forests can be recognized as the result of historically evolving supply-targeted law enforcement practices. Beginning in 1972, transnational policing efforts by the US government focused on cannabis eradication in Mexico, the biggest supplier of marijuana to American markets (Corva 2014). Similar to the "Plan Colombia" coca eradication efforts in the early 2000s, in 1975 the US began supporting and financing the aerial spraying of marijuana grows in Mexico with paraquat, a non-selective herbicide (Kornbluth 1978; Corva 2014). The use of paraquat not only eradicated a substantial portion of Mexican cannabis, but the potential health effects of the controversial herbicide deterred American consumers from Mexican product (Kornbluth 1978; Corva 2014). At the same time, increased border security in the 1970s further increased risks of transnational trafficking (Bouchard 2007). By 1979, marijuana imports from Mexico dropped by 75% (Corva 2014).

These transnational law enforcement efforts created conditions that incentivized the domestic cultivation of cannabis in the US, thereby displacing production in Mexico and largely replacing the import model that had previously dominated American marijuana markets. While the small-scale home garden growing of marijuana was popularized in the 1960s in certain counties in California, namely Humboldt, Mendocino, and Trinity, during the "back to land" movement by "new settlers" looking to escape urban living, this practice was done for spiritual and/or political reasons by small communities (Corva 2014). However, the disruption of the marijuana trade from Mexico in the 1970s caused cannabis prices to rise significantly, reaching around $2000 per pound by 1980 (Corva 2014). This incentivized a boom in domestic production within Humboldt, Mendocino, and Trinity counties amongst local residents struggling from unemployment due to the loss of fishing and timber jobs, as well as the counter culture "new settlers" that were well-versed in homegrown cannabis cultivation (Corva 2014; Meisel 2017). The rise in prices also resulted in a "green rush", where citizens from around the country migrated towards these three counties, often referred to as the "Emerald Triangle", drawing comparisons to Southeast Asia's opium producing "Golden Triangle", to participate in the marijuana trade (Corva 2014; Meisel 2017). In addition, with intensified law enforcement efforts in Mexico and along the border, drug trafficking organizations found production in the US to be more efficient than international shipping strategies, and displaced cultivation efforts to be closer to the markets in which they would sell (Bouchard 2007).

In response to this sudden increase in concentrated domestic cultivation, the US government introduced various drug eradication efforts targeting the Emerald Triangle, including California's Campaign Against Marijuana Planting (CAMP) in 1983, a joint task force coordinating federal, state, and local agencies (Corva 2014). CAMP utilized aerial surveillance strategies with helicopters allowing for the eradication of outdoor grows without the need of a search warrant

(Corva 2014). These tactics resulted in a second wave of displacement and adaptation (Bouchard 2007). Eradication efforts continued to push prices up and incentivized cultivation, while increased enforcement programs in the Emerald Triangle pushed growers into other Californian counties and states where the risk of eradication was lower (Corva 2014). Aside from this dispersal of cannabis cultivation, some growers adopted different techniques, such as planting multiple smaller gardens that were harder to detect from the air or indoor growing whereby aerial detection is not possible and inspection would require a search warrant and other legal barriers (Bouchard 2007; Corva 2014).

The geographic spread of marijuana production required law enforcement efforts to expand as well (Corva 2014). By the early 2000s, with law enforcement conforming their strategies to the evolving displacement of cannabis cultivation, marijuana eradication programs such as CAMP became concentrated on public land “mega-grows”, and other large operations popping up on timber estates (Corva 2014). Thus, just as modern studies have indicated (e.g. Gallupe et al. 2011; Nguyen et al. 2015), cultivators of illicit cannabis will adapt their strategies in response to increased police presence or arrest history and often move locations to areas where detection is less likely. In the US, this sort of spatial displacement, or “balloon effect”, has pushed marijuana cultivation into national forests, large areas with plenty of forest cover that are sparsely populated and difficult for law enforcement to fully patrol.

2.5 Legalization of Recreational Cannabis as a Potential Solution

Given the observable crime displacement associated with law enforcement and eradication efforts of cannabis, a growing number of academics, NGOs, and activists have criticized prohibition as driving environmental degradation. According to Tony Silvaggio, an environmental sociologist at the Humboldt Institute for Interdisciplinary Marijuana Research, "the root cause of environmental damage on public lands is the failed federal policy of marijuana prohibition. Prohibition inflates the price and makes it profitable to grow weed anywhere" (Levy 2014). Mark Kleiman, a professor of public policy with expertise and legislative experience working on drug policy, suggests that "as with alcohol, we gave cannabis prohibition a try, and we couldn't hold it together. At some point, you stop fighting the tiger. Legalization is going to happen" (Levy 2014). With a trend of liberalizing attitudes towards cannabis, and a recent wave of legalization efforts, many believe it is time to investigate the environmental benefits that the legalization of recreational cannabis may accommodate (e.g. Levy 2014; Carah et al. 2015; Rolles et al. 2016).

Proponents of legalization propose that the dismissal of marijuana prohibition may provide the opportunity to combat the illicit cultivation of cannabis on public lands through a variety of means. By establishing a legal market, it is presumed that legal sales will undercut and divert clientele away from the black market, thereby decreasing profits and illicit cultivators' abilities to remain in business (Caulkins & Bond 2012; O'Hare et al. 2013). At the same, the state can both slash law enforcement expenses and generate revenue through taxation of legal cannabis products, of which a portion can be dedicated to increased law enforcement and remediation efforts directed at illegal grows on public lands (Gettman 2007; Caulkins et al. 2011; Carah et al. 2015). For example, in Oregon 15% of all tax revenue raised through cannabis sales is invested into state law enforcement (DOR 2018). Revenue generated through legal cannabis has been substantial, with the Washington State Liquor and Cannabis Board (LCB 2018) citing $319 million earned in cannabis tax and licensing fees in 2017 alone. This has been achieved due to a consistent trend of increasing legal sales, climbing from $259 million in 2015 to $1.3 billion in the 2017 fiscal year (OST 2018), perhaps signaling a transition of clientele towards the legal market.

If cannabis cultivation can largely be contained within the legal market, it can be regulated, and responsible growing practices can be both enforced and encouraged to varying degrees. While cannabis is a schedule I controlled substance under federal law, and is therefore not addressed by federal regulations that apply to legal crops, legalization provides state governments with the opportunity to develop their own regulatory frameworks and ensure safe and environmentally responsible methods are utilized (Levy 2014). For example, the regulatory structure for recreational cannabis in Washington restricts marijuana farmers to chemicals approved for organic foods, explicitly banning the use of many environmentally detrimental pesticides that are often used in illegal grows (Levy 2014). The licensing and permitting process also provides room for government regulation regarding location and sources of irrigation, while inspections and government enforcement ensure all guidelines are met (O'Hare et al. 2013). In addition, various incentives can be introduced to promote environmentally friendly practices within the industry, such as eco-labeling (O'Hare et al. 2013; Carah et al. 2015). At the same time, establishing a legal market allows environmental organizations, NGOs, and activists to provide technical assistance and outreach programs that encourage the adoption of best management principles amongst cannabis cultivators (Carah et al. 2015).

However, many uncertainties remain when considering transitions to legalized recreational cannabis (Caulkins et al. 2012; Koch et al. 2016). If taxation of legal cannabis is set too high, and prices are subsequently inflated, in state demand for illegally produced marijuana may still persist (Caulkins & Bond 2012). In addition, liberalized attitudes towards cannabis may drive up market demand, particularly through processes such as drug tourism, thereby putting upwards pressure on prices and providing room for the black market to undercut legally produced products (Koch et al. 2016). Furthermore, given the illegal status of cannabis as a schedule I drug federally, and the current pattern of individual state initiatives to liberalize cannabis policy, illegal grows may persist in states with legalized recreational marijuana due to opportunities to export product to states where the substance remains illegal (Caulkins & Bond 2012; Levy 2014; Carah et al. 2015).

2.6 Conclusion

The sustainable management of common pool resources (CPR) has long been a challenge globally, as well as within the network of US public lands. The benefits of CPR exploitation often accrue on an individual basis while the costs are diffused amongst all users, thereby incentivizing unsustainable actions motivated by self-interest. The illicit cultivation of cannabis in US national forests is a pressing example of unsustainable exploitation of a CPR, as black-market profits and employment incentivize this practice, while the environmental costs are diffused amongst all users of the national forest system, from communities that rely on national forests for drinking water to conservationists to recreational users.

The environmental costs of cannabis cultivation in national forests include the clearing of native vegetation and deforestation, the diversion of natural waterways, widespread agrochemical pollution, the dumping of non-biodegradable waste, and the poaching of wildlife. These impacts have not only been identified as threatening struggling and endangered species, but impacting habitat and ecosystem resiliency as a whole, with many ecological impacts traversing through multiple trophic levels. While the results of this practice are already considered detrimental to forest well-being, many of the identified ecological impacts threaten to amplify the predicted effects of climate change. In addition, the ecological impacts of cannabis cultivation, as well as the extraordinary monetary costs of eradication and remediation efforts and the dangers that grow sites impose on US Forest Service employees, researchers, and the public as a whole, impede on the current strategic goals of the US Forest Service in managing this network of public lands.

However, the current widespread proliferation of cannabis cultivation in national forests has been identified as a recent phenomenon. While the majority of the cannabis supply in the United States used to originate from Mexico, transnational policing efforts incentivized the displacement of cannabis cultivation within American borders. Intensifying domestic enforcement efforts further displaced marijuana cultivators into more remote and discrete locations with less risk of detection, including public lands. In addition, mounting security along the US Mexico border further incentivized Mexican drug trafficking organizations to displace their production of cannabis to US soil.

With crime displacement recognized in the history of US cannabis cultivation as driving marijuana production into national forests as a result of law enforcement efforts, the legalization of recreational cannabis has been proposed as providing an avenue to squeeze out black-market producers, and thus halt the ecological damage inflicted by grow sites operating on America's public lands. However, others have noted the uncertainties that legalization poses, predicting that it may in fact bolster demand for cannabis and thereby support the cultivators operating in national forests. As such, a knowledge gap in the academic literature has emerged and the impacts of recreational cannabis legalization are not well-understood. With the liberalization of marijuana policies in states around the country, and functioning legal cannabis markets operating in the Pacific Northwest, a region identified in the literature as affected disproportionately by cannabis cultivation in national forests, an opportunity is now available to investigate the impacts of this policy shift on the health of national forests.

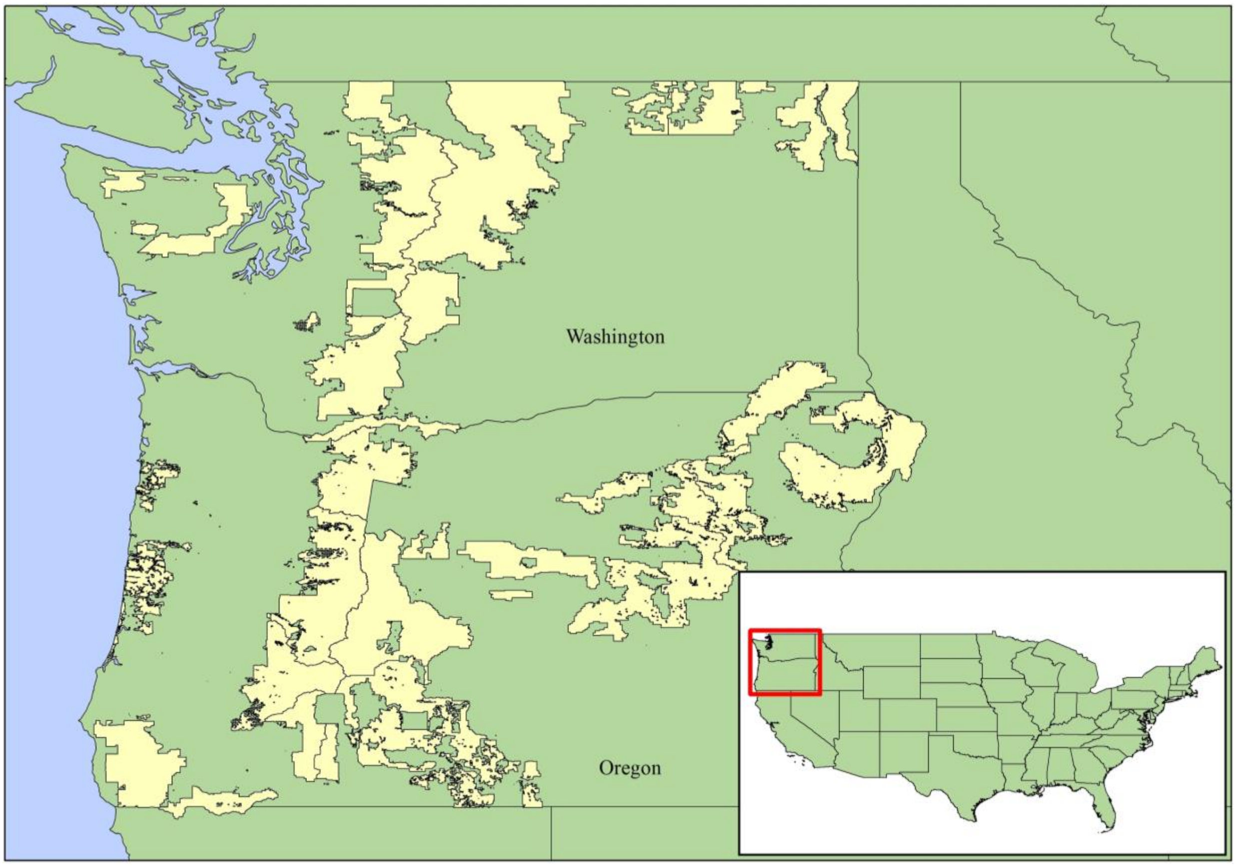
3 Methods

In order to investigate the impacts recreational cannabis legalization has had on illegal grow sites in national forests, and the environmental effects associated with this illicit activity, a methodology comprised of two main mechanisms was developed to most accurately assess this policy shift. First, a series of regression analyses were performed utilizing a model based in the principles of a rational choice framework, as has been done by others investigating the illicit cannabis trade (Bouchard et al. 2013; Koch et al. 2016). This provides insight into what variables are most closely correlated to the observed trends of illicit cannabis cultivation in national forests. The second mechanism developed was an interview structure to gain further information from the US Forest Service. While the regression analyses provide a robust quantitative indication of correlations, the complexity and research limitations of investigating an illegal practice demands clarification of these results. Given the US Forest Service's expertise in managing national forests, and their everyday experiences within these areas, their perspectives and opinions were collected to help assess and interpret the results of the regression analyses, and effectively fill in any research gaps where data on illegal cannabis operations are unavailable. Compounding these two mechanisms provides a more accurate assessment that establishes both quantitative and qualitative data in order to produce a complete picture of the current situation.

3.1 Study Area

The Pacific Northwest, composed of Washington and Oregon, also referred to as region 6 by the US Forest Service, was selected as the area of interest for this study. While much of the literature on illicit cannabis cultivation in US national forests has focused on California, legal commercial markets only began operating in January of 2018 (BCC 2018). With such a recent shift in policy, detection of possible effects would be difficult. In contrast, Washington voted to legalize recreational cannabis in 2012 with commercial sales beginning in July of 2014 (LBC 2014), and legal sales of recreational cannabis in Oregon began in October of 2015 after approving Ballot Measure 91 in 2014 (OLCC 2015).

Figure 7. Map of the Pacific Northwest. National forests are denoted in beige.



Sources: Natural Earth 2018, United States Forest Service 2018

The selection of these two states, as opposed to California, provides significantly more time under a legalization policy, while previous literature has also identified the Pacific Northwest as suffering disproportionately from the impacts of illicit cannabis cultivation in national forests (Koch et al. 2016). Given that many of the possible effects legalization may have on illicit cultivation are contingent on fully operating and functioning legal markets, as discussed in section 2.5, the selection of regions where an extended time under legalization has occurred was crucial for adequately capturing any preliminary impacts liberalized cannabis policy may be having. In addition, with the bulk of research conducted on the environmental impacts of illicit cannabis cultivation in national forests occurring in California, the selection of the Pacific Northwest provided an opportunity to confirm whether similar environmental impacts have been documented in this region as well.

3.2 Regression Analyses

3.2.1 Theoretical Framework

Regression methods have been used frequently by both ecologists (Austin 2007, Elith & Leathwick 2009) and policy researchers (French & Heagerty 2008). Furthermore, recent studies examining correlations between illegal cannabis grow sites and possible explanatory variables have developed regression models for their investigations. Bouchard et al. (2013) utilized regression methods to determine illegal grow site characteristics that most greatly influence the number of cannabis plants cultivated. Koch et al. (2016) developed probit and logit models to estimate the probability of cannabis cultivation across all national forests within California, Oregon, and Washington.

Both Bouchard et al. (2013) and Koch et al. (2016) determine that illegal cannabis cultivation decisions largely fit within a rational choice framework, a proposition that has been explored since Cornish and Clarke's concept of choice-structuring properties (1986). As such, Koch et al. (2016) establish that growers' decisions to engage in illegal cannabis cultivation in national forests stem from a consideration of benefits and costs, including opportunity costs. Therefore, economic variables, such as unemployment and poverty rate, as well as variables contributing to the risk of being caught, including population and law enforcement density, have been correlated to discovered grow sites in national forests (Koch et al. 2016). This study builds upon the conclusions reached by Bouchard et al. (2013) and Koch et al. (2016) and adopts the same rational choice framework. As such, many of the independent variables utilized by Koch et al. (2016) are considered within this study's empirical model.

3.2.2 Empirical Model

Due to the consideration of numerous dependent and independent variables, a multivariate multiple regression (MMR) model was developed:

Y_1 Abundance of Illegal Cannabis Grow Sites in PNW National Forests; Y_2 Annual Number of Eradicated Cannabis Plants in PNW National Forests; Y_3 Number of Cannabis Plants Found per Discovered Grow Site in PNW National Forests = β_0 + β_1 Recreational Cannabis Legalization (Washington State) + β_2 Recreational Cannabis Legalization (Oregon State) + β_3 Cannabis Price + β_4 Law Enforcement Density + β_5 USFS Law Enforcement and Investigations Annual Budget + β_6 Unemployment Rate + β_7 Poverty Rate + β_8 Gross State Product + β_9 Population Density + ε

Two dummy variables were created to capture the effects of the vote to legalize recreational cannabis in both Washington (WA) and Oregon (OR). Given that the vote to legalize in both states occurred in November, after the typical summer growing season for outdoor cultivation, the year following the vote was considered to be when legalization occurred. Thus, Washington voted to legalize recreational cannabis in November of 2012, so the summer growing season of 2012 was rightfully considered to be pre-vote and 2013 was considered to be the first year post-vote. The same consideration was given to legalization in Oregon, with legalization defined as occurring in 2015 as opposed to November of 2014. A breakdown of these dummy variables can be found below:

β_1 WA Recreational Cannabis Legalization $= 1$ if Year ≥ 2013

$\beta_1 = 0$, otherwise

β_2 OR Recreational Cannabis Legalization $= 1$ if Year ≥ 2015

$\beta_2 = 0$, otherwise

It is worth noting that the US Forest Service is not organized by state but by regions, with Washington and Oregon together comprising region 6 (USFS 2018a). As federal lands, US national forests are not treated as belonging to specific states, but all national forests in Washington and Oregon are considered as associated with a single administrative unit, and are managed as such. Umatilla National Forest exemplifies this system as it spans across the border between Oregon and Washington, with federal land on both sides. However, with Washington and Oregon legalizing recreational marijuana in different years, and the possibility of state specific dynamics, including variations in cannabis regulations after the implementation of legalization, associating the two states as a single homogenous region may conflate the data. As such, regressions were conducted in consideration of both the Pacific Northwest as a whole, as well as state specific regressions for Washington and Oregon, to ensure all possible dynamics are accounted for.

State specific models retained the same general format as the Pacific Northwest model presented above:

Washington Model

Y_1 Abundance of Illegal Cannabis Grow Sites in WA National Forests; Y_2 Annual Number of Eradicated Illegal Cannabis Plants in WA National Forests; Y_3 Number of Cannabis Plants Found per Discovered Grow Site in WA National Forests = β_0 + β_1 Recreational Cannabis Legalization (Washington State) + β_2 Cannabis Price + β_3 USFS Law Enforcement and Investigations Annual Budget + β_6 Unemployment Rate + β_7 Poverty Rate + β_8 Gross State Product + ε

Oregon Model

Y_1 Abundance of Illegal Cannabis Grow Sites in OR National Forests; Y_2 Annual Number of Eradicated Illegal Cannabis Plants in OR National Forests; Y_3 Number of Cannabis Plants Found per Discovered Grow Site in OR National Forests = β_0 + β_1 Recreational Cannabis Legalization (Oregon) + β_3 Cannabis Price + β_4 Law Enforcement Density + β_5 USFS Law Enforcement and Investigations Annual Budget + β_6 Unemployment Rate + β_7 Poverty Rate + β_8 Gross State Product + β_9 Population Density + ε

Slight adjustments were made based on data limitations, which will be further explained in sections 4.1.1 and 4.1.2. All regressions were run using STATA/IC 14.2, a data management and statistical analysis software commonly used by researchers and academics.

3.2.3 Data Collection

In order to collect data regarding discovered cannabis grow sites in national forests, as well as law enforcement density, a Freedom of Information Act (FOIA) request was filed with the US Forest Service Law Enforcement and Investigations division. Due to previous communication with the Assistant Special Agent in Charge of the Pacific Northwest, this process was expedited by submitting this request directly to the Pacific Northwest office.

Data on the price of cannabis was collected by request from the Western States Information Network (WSIN), a division of Regional Information Sharing Systems (RISS), a company providing services that facilitate information sharing between criminal justice and law enforcement officials. One aspect of these services is their Drug Pricing Reference Guide, which allows law enforcement officials to share up-to-date drug prices they encounter in the black market. A limited data set was provided from this pricing guide that included the price of cannabis in Washington and Oregon. The reported data was collected from a handful of counties from each state, with these locations sometimes shifting from year to year. As a result, an average of these prices was calculated and utilized as being representative of the price of cannabis in each state per year.

The WSIN Drug Pricing Reference Guide is produced every two years, and thus data was available for 2004, 2006, 2008, 2010, 2012, 2014, and 2016. Price estimates were determined for odd years in which price data was unavailable by calculating the mean of prices from adjacent years. For example, the estimated price of cannabis for 2005 was calculated by adding the prices from 2004 and 2006 and then dividing the sum in half, as demonstrated in the equation below:

$$Price_t = \frac{Price_{t-1} + Price_{t+1}}{2}$$

Data on the additional explanatory variables, including economic factors and population density, was collected from a variety of government sources available to the public. Details can be found below in Table 1.

Table 1. Information on variables and data sources used in the regression analysis

Variable	Description	Scale	Data Source
Abundance of illegal cannabis grow sites in PNW national forests	Number of discovered grow sites in national forests per year from 2004-2017	Exact coordinates; Google Earth used to locate which national forest each site was discovered in	USDA Forest Service via FOIA request (unpublished data)
Number of eradicated illegal cannabis plants in PNW national forests	Data on the number of plants at each discovered grow site in PNW national forests from 2004-2017	Exact coordinates; National forest	USDA Forest Service via FOIA request (unpublished data)
Number of cannabis plants found per grow site in PNW national forests	The scale of each discovered grow site in PNW national forests from 2004-2017	Exact coordinates; National forest	USDA Forest Service via FOIA request (unpublished data)
Law enforcement density	Number of sworn law enforcement officers divided by national forest area	National forest	USDA Forest Service via FOIA request (unpublished data)
Cannabis Price	Price of cannabis on the black market in Oregon and Washington (2004, 2006, 2008, 2010, 2012, 2014, 2016)	County; Averages calculated for each state	WSIN via special request (unpublished data)
Unemployment Rate	Annual averages of the percentage of labor force unemployed from 2004-2016	County	US Bureau of Labor Statistics (2005-2018)
Poverty Rate	Total county population living in poverty (%) from 2004-2016	County	US Bureau of the Census, SAIPE program (2004-2015, 2017)
Gross State Product	Gross domestic product by state in millions of dollars from 2004-2016	State	US Bureau of Economic Analysis (2018)
Population Density	Total county population divided by county area	County	US Bureau of the Census, 2010 census estimates
USFS Law Enforcement and Investigations Annual Budget	Total annual budget provided to the United States Forest Service Law Enforcement and Investigations	Annual for the entire federal office	USDA Forest Service (2005-2018)

3.2.4 Limitations

Due to the illicit nature of cannabis cultivation in national forests, and the relatively recent introduction of liberalized marijuana policies in the Pacific Northwest, numerous limitations can be noted when structuring regression analyses that are representative of the statistical reality.

Because the cultivation of cannabis in national forests is a clandestine activity, statistical models can only be constructed based on the available data of discovered grow sites. Given the possibility that discovered grow sites may only represent a fraction of the actual total, the assumption must be made that everything else being equal, similar quantities of grow sites, and similar sizes, would be discovered each year. Contributing to the accuracy of this assumption, is the inclusion of various other related explanatory variables, such as law enforcement density. In addition, the interview response from the US Forest Service Law Enforcement and Investigations can be utilized to clarify the correlations established through the regression analysis, and thus help with the interpretation of the results, particularly if the results due not appear to match the perspective of officials on the ground. Unfortunately, aside from building a robust model based on previous research, and considering the perspectives and opinions of experts in the field, the only other possible solution to this limitation is including a predictive model with an estimate of how many actual cultivation sites are occurring in national forests in the Pacific Northwest aside from just those discovered. However, as mentioned previously in section 2.3.1, the few nation-wide estimation models that have been produced have often been criticized as rough approximations at best (ONDCP 2012b), and narrowing these models to a more precise spatial scale can only enhance these issues of model accuracy.

It must also be noted that legalization policies in the Pacific Northwest have only been introduced relatively recently, and given that many of the hypothesized benefits of legalization rely on the development of markets, the long-term effects of this policy shift may not be able to be fully realized given the current data. In addition, the continued prohibition of cannabis in other states may dampen the current effects that legalization in the Pacific Northwest could have as illegal producers within Oregon and Washington may continue to supply the black market across state borders (Levy 2014). Again, the interview response provided by the US Forest Service Law Enforcement and Investigation's Pacific Northwest office can help gain additional information beyond what the data can provide, but these limitations can only be truly overcome by recognizing this study as an initial investigation, upon which future research should continue to build upon.

Lastly, the limitations of available data should be recognized. Data on certain variables, such as population density and law enforcement density, have not been consistently collected annually. Thus, for some variables, data collected for a certain year had to be applied to all years considered in the regression analyses. However, it should be noted that Koch et al.'s "Predicting cannabis cultivation on national forests using a rational choice framework" (2016), a paper that served as a base in many respects for this investigation, makes the same concession in order to consider population density. In addition, officials from the US Forest Service's Pacific Northwest office contend that only slight changes in law enforcement density have occurred since the early 2000's, suggesting that only very minor discrepancies, if any, should be expected from this process.

3.3 Interview

The interview format was originally designed to collect the experiences, perspectives, and opinions of multiple US Forest Service patrol captains operating in different national forests in the Pacific Northwest. This was done to collect a fuller picture of the current situation, capture any differences between national forests, and to compile numerous opinions on the effects of cannabis legalization on illicit cannabis cultivation in national forests from those operating on the ground.

Given that the US Forest Service is a federal agency, and the nature of my questions revolve around a federally classified schedule 1 drug, the interview questions were submitted for review to the US Forest Service before any in-depth conversations could take place. Upon review, the US Forest Service decided that they could best answer these questions with a single regional response from the US Forest Service Law Enforcement and Investigation's Pacific Northwest office. These responses were written and provided remotely by email.

It should be noted that the Assistance Special Agent in Charge of the US Forest Service Law Enforcement and Investigation's Pacific Northwest office stipulated that although individual employees may have their own personal opinions with regards to the potential effects of cannabis legalization, as a federal agency they are required to express the stance of the federal government on the matter.

3.3.1 Structure

Questions were derived based on four key themes: characteristics of grow sites, ecological impacts of grow sites, the effects of grow sites on forest management, and the effects of recreational cannabis legalization. The questions developed in the first three of these categories are targeted at establishing whether illegal cannabis cultivation in national forests has had similar impacts in the Pacific Northwest as those that have been established in previous studies, many of which were focused on the larger cannabis producing state of California. The questions developed in the final category, the effects of recreational cannabis legalization, were developed as a means to help analyze and interpret the results produced by the regression analyses. Being experts in the field, the US Forest Service can provide clarification to any correlations and trends that appear. The interview format can be found in Appendix I.

3.3.2 Sampling

Given the main purpose of the interview process was to provide expertise on the effects of cannabis cultivation in national forests and to clarify and introduce any dynamics missing from the regression analyses, responses were gathered from the US Forest Service Law Enforcement and Investigation's Pacific Northwest office. Thus, a purposive sampling method was utilized.

3.3.3 Ethics

In adherence to the CEU Research Ethics Policy and Guidelines, all regulatory steps required by the US Forest Service were completed before the interview process began. Total transparency was provided with regards to the proposed interview method and questions beforehand, as required by the US Forest Service, and informed consent was ensured. Confidentiality was clearly explained and offered, however, as a single official response from the Pacific Northwest office, confidentiality and anonymity are inherently provided. The purpose of this research and the planned use of this data within an academic thesis was clearly explained and understood.

4 Results

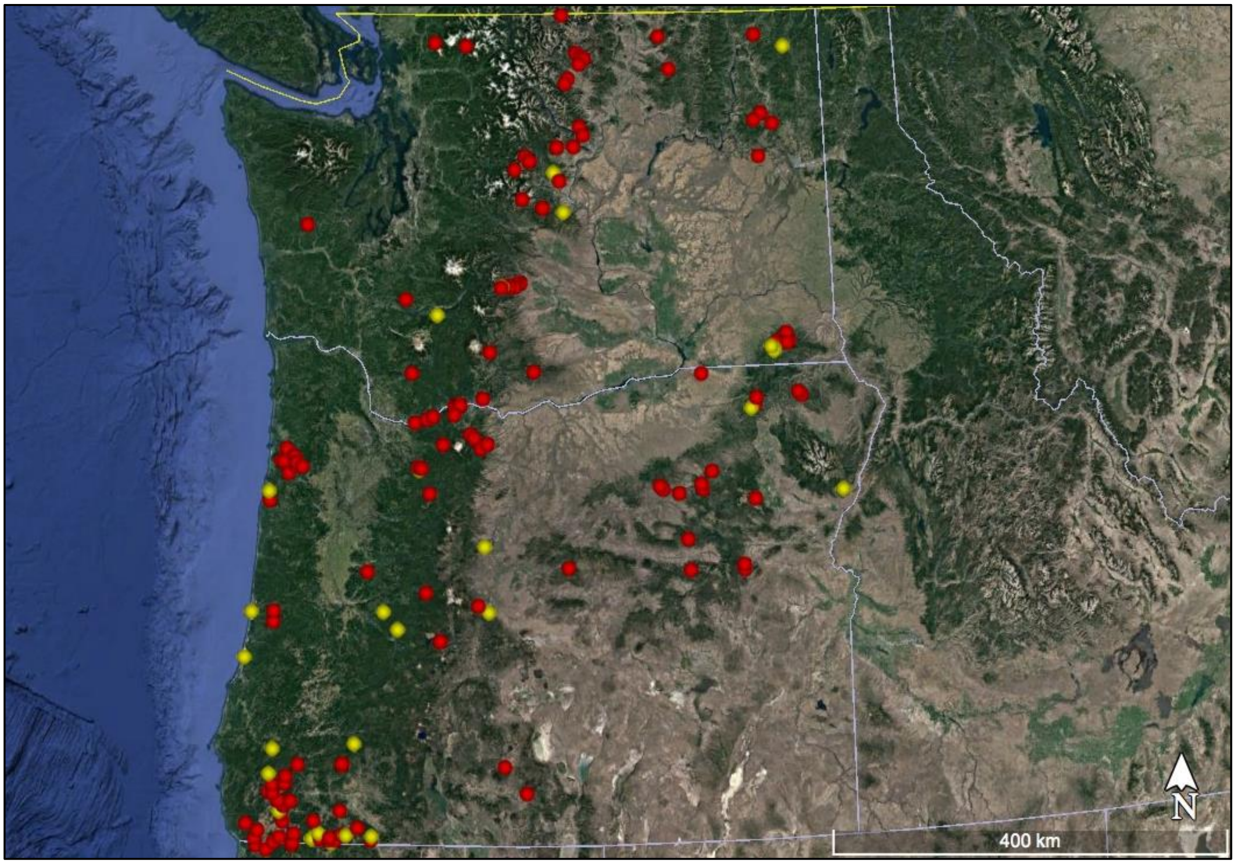
A preliminary look at the data provided by the US Forest Service presents a total of 245 discovered marijuana cultivation sites in national forests in the Pacific Northwest from 2004-2017 (Table 2). Rogue River-Siskiyou national forest had the largest number of discovered grow sites with 59, while Wallowa-Whitman contained the largest single grow site of 91,035 plants.

Table 2. Descriptive Statistics of Illegal Grow Sites and Individual Cannabis Plants Discovered in Washington and Oregon (2004-2017)

	Washington	Oregon	COMBINED
Grow sites			
total number of grow sites	91	154	245
mean sites discovered/year	6.5	11	17.5
range of sites discovered/year	0-22	2-30	2-52
Individual plants			
total number of plants	387178	556527	943705
mean plants/site	4254.7	3613.8	3851.8
s.d.	5842.3	8556.8	7654.9
range	1-25,765	1-91,035	1-91,035

The data provided demonstrates a decrease in the number of discovered grow sites in national forests after the vote to legalize recreational cannabis in Washington and Oregon. In fact, officials found an average of 10.25 cultivation sites in national forests per year from 2004-2012, and only 1.6 per year after the vote to legalize recreational cannabis from 2013-2017. Oregon also experienced a sharp decrease in the number of grow sites found in national forests over the same time period, with an average of 14.89 discovered per year from 2004-2012, and an average of 4 discovered per year after Washington voted to legalize cannabis (2013-2017). This trend of decreasing discovered grow sites across both states after Washington's vote to legalize can be visualized in Figure 8. Oregon also experienced a decrease in the average number of discovered grow sites in national forests after its own vote to legalize recreational cannabis with an average of 13 sites found per year from 2004-2014, and 3.67 sites per year after the vote from 2015-2017.

Figure 8. Discovered Marijuana Grow Sites in National Forests in the Pacific Northwest Over the Past 10 Years (2008-2017)

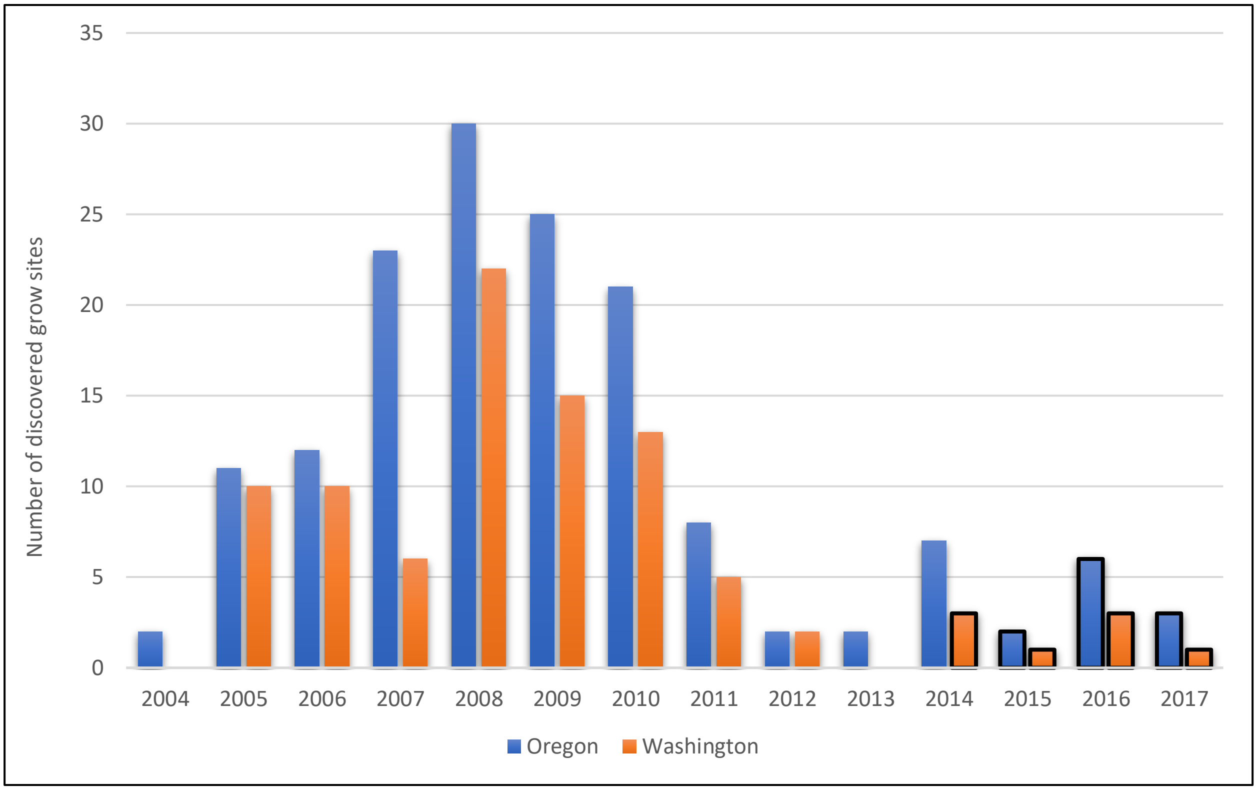


Marijuana grow sites discovered before Washington's vote to legalize recreational cannabis (2008-2012) are denoted in red. Marijuana grow sites discovered after Washington's vote to legalize recreational cannabis (2013-2017) are denoted in yellow.

Sources: USDA Forest Service Law Enforcement and Investigations by FOIA request; mapped using Google Earth Pro.

However, as can be seen in Figure 9, the number of discovered grow sites peaked in 2008 and had already been decreasing every year from that point until the vote to legalize recreational cannabis in Washington in 2012. In 2013, the number of discovered grow sites reached lows that had not been seen since 2004, and although the number of discovered cultivation sites fluctuated slightly from 2014-2017, the level of annual discovered grows remained much lower than had been observed from 2005-2011.

Figure 9. Number of Marijuana Grow Sites Discovered in National Forests in the Pacific Northwest per Year (2004-2017).



Black bordered bars represent post-legalization

Source: USDA Forest Service Law Enforcement and Investigations by FOIA request

4.1 Regression Analyses

In order to ensure that all explanatory variables could be included in the regression, observations that occurred in 2017 were excluded as 2017 data on county poverty rate is not yet available. As such, a total of 241 observations for each variable can be noted in Table 3, as opposed to the complete data set of 245 discovered grow sites from 2004-2017.

Table 3. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
grow_sites	241	31.57261	14.72059	2	52
annual_pla~s	241	118274	64624.94	501	177433
mj_plants	241	3820.278	7672.166	1	91035
unemployment	241	8.580498	2.748892	4.1	14.5
poverty_rate	241	15.80124	3.403301	7.9	23.9
gsp	241	245071.7	87010.63	142328	476934
pop_density	241	76.05436	221.3187	1	1704.9
law_density	241	2.85e-06	1.35e-06	1.30e-06	5.62e-06
lei_budget	241	127.8159	16.46708	82.829	145.047
mj_price	241	2599.378	258.9396	2066.67	3004.17
WA_vote	241	.0995851	.3000691	0	1
OR_vote	241	.0497925	.2179687	0	1

Examining the regression output (Table 4) demonstrates that the designed rational choice model is significant ($p<0.01$) and is able to predict the trends in annual number of discovered grow sites and annual number of eradicated plants to a high degree, with an R-squared value of 0.4517 and 0.8122 respectively. However, while utilizing the model to explain the number of marijuana plants found per discovered site remains statistically significant ($0.01<p<0.05$), although to a lesser degree, it does a much worse job at explaining and predicting this phenomena with an R-squared value of only 0.0862. In addition, when considering the number of marijuana plants per discovered grow site as the dependent variable, all of the explanatory variables utilized are insignificant ($p>0.05$) except for LEI budget ($p<0.01$) and law enforcement density ($p<0.05$). This signals that the model is a good means to explain and predict the annual number of discovered grow sites, as well as the annual total number of eradicated plants, but there are likely other unknown factors that are significant in predicting the number of plants grown at each site.

Table 4. Multivariate Multiple Regression Output

Equation	Obs	Parms	RMSE	"R-sq"	F	P
grow_sites	241	10	11.11055	0.4517	21.14434	0.0000
annual_pla~s	241	10	28544.87	0.8122	111.0159	0.0000
mj_plants	241	10	7475.495	0.0862	2.421593	0.0120

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
grow_sites						
unemployment	-1.301195	.4086153	-3.18	0.002	-2.106285	-.4961061
poverty_rate	-.7087441	.2517603	-2.82	0.005	-1.204784	-.2127042
gsp	7.27e-06	.0000102	0.71	0.476	-.0000128	.0000273
pop_density	-.0027634	.0035476	-0.78	0.437	-.0097532	.0042263
law_density	-848668.3	650016.7	-1.31	0.193	-2129387	432050.9
lei_budget	.3578343	.0553217	6.47	0.000	.2488347	.4668339
mj_price	.0115306	.0041435	2.78	0.006	.0033667	.0196946
WA_vote	-21.35737	3.527947	-6.05	0.000	-28.30844	-14.4063
OR_vote	-3.603605	4.591407	-0.78	0.433	-12.64999	5.442783
_cons	-18.6159	11.04817	-1.68	0.093	-40.38396	3.152173
annual_plants						
unemployment	-916.1216	1049.801	-0.87	0.384	-2984.531	1152.288
poverty_rate	-1843.879	646.8143	-2.85	0.005	-3118.289	-569.4694
gsp	.0214689	.0261261	0.82	0.412	-.0300069	.0729447
pop_density	1.635887	9.114329	0.18	0.858	-16.32195	19.59373
law_density	-2.24e+09	1.67e+09	-1.34	0.180	-5.53e+09	1.05e+09
lei_budget	2673.997	142.1307	18.81	0.000	2393.959	2954.035
mj_price	49.51739	10.64546	4.65	0.000	28.54277	70.492
WA_vote	-103601.3	9063.888	-11.43	0.000	-121459.8	-85742.89
OR_vote	15027.06	11796.09	1.27	0.204	-8214.626	38268.75
_cons	-304638.5	28384.61	-10.73	0.000	-360564.3	-248712.7

Table 4 Cont. Multivariate Multiple Regression Output

mj_plants						
unemployment	185.2486	274.928	0.67	0.501	-356.4384	726.9357
poverty_rate	-28.83083	169.3915	-0.17	0.865	-362.5806	304.919
gsp	-.0033064	.006842	-0.48	0.629	-.0167872	.0101744
pop_density	-.7268709	2.386913	-0.30	0.761	-5.429775	3.976033
law_density	-9.64e+08	4.37e+08	-2.20	0.029	-1.83e+09	-1.02e+08
lei_budget	100.3754	37.22201	2.70	0.008	27.03736	173.7134
mj_price	-2.216642	2.787895	-0.80	0.427	-7.709595	3.276311
WA_vote	-3275.601	2373.704	-1.38	0.169	-7952.478	1401.276
OR_vote	1156.632	3089.23	0.37	0.708	-4930.037	7243.3
_cons	-496.9233	7433.526	-0.07	0.947	-15143.1	14149.25

Analyzing the model in the context of the annual number of grow sites further reveals some interesting results. A number of explanatory variables are observed to be insignificant ($p>0.05$), namely Gross State Product (GSP), population density, law enforcement density, and the vote to legalize recreational cannabis in Oregon. On the other hand, the vote to legalize recreational cannabis in Washington is not only significant ($p<0.01$), but provides the largest coefficient of the explanatory variables, demonstrating a large negative impact on the annual number of discovered grow sites. Surprisingly, unemployment ($p<0.01$) and the poverty rate ($p<0.01$) both provide negative coefficients. On the other hand, the Forest Service Law Enforcement and Investigation’s annual budget ($p<0.001$) and the price of illegal cannabis ($p<0.01$) produce positive coefficients.

The same explanatory variables are found to be significant for predicting the annual number of eradicated marijuana plants, with the exception of unemployment ($p>0.05$). As with the annual number of grow sites, the vote to legalize in Oregon is found to be insignificant ($p>0.05$), but legalization in Washington is determined to be significant ($p<0.01$) with a strong negative relationship on the annual number of eradicated cannabis plants in Pacific Northwest national forests.

4.1.1 State Level Models

As mentioned above (section 3.2.2), associating Washington and Oregon as a single homogenous region may conflate the data. Legalization of recreational marijuana occurred in different years, and the possibility of state specific dynamics, including variations in cannabis regulations after the implementation of legalization, should be accounted for. As such, state specific regressions were run for both Washington and Oregon to ensure all possible dynamics are considered.

4.1.1.1 Washington

According to the data provided by the US Forest Service via FOIA request, there were two years between 2004-2016 in which no illegal grow sites were discovered in Washington's national forests, namely 2004 and 2013. In order to account for these years, two additional observations were included to denote a lack of discovered grow sites, and thus cannabis plants, for 2004 and 2013, bringing the sample size up to 92 (Table 5). Due to the absence of a particular location for the observations in which no grow sites were discovered, to retain consistency within the model all explanatory variables had to be brought up to the state level. This required the removal of law enforcement density and population density as explanatory variables in the model as these variables were treated as constant across time, with variations in location being the only source fluctuation. Bringing these explanatory variables up to the state level would produce variables that are constant in value regardless of the observation, rendering them unworkable in the Washington regression.

Table 5. Washington Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
grow_sites	92	12.63043	6.586228	0	22
annual_pla~s	92	55886.37	38136.06	0	108314
mj_plants	92	4207.989	5827.4	0	25765
unemployment	92	6.922826	2.040421	4.7	10
poverty_rate	92	12.20761	.8989901	11.3	14.1
gsp	92	351888.4	38162.86	270385	476934
lei_budget	92	126.7513	17.94508	82.829	145.047
mj_price	92	2487.845	180.269	2066.67	2872.73
WA_vote	92	.0869565	.2833153	0	1

As with the Pacific Northwest regression, the model remains significant ($p<0.05$) for predicting the annual number of discovered grow sites in Washington national forests, the annual number of eradicated cannabis plants in Washington national forests, and the number of marijuana plants per grow site in Washington national forests (Table 6). In order to reduce multicollinearity and heteroscedasticity, three individual regressions were run, one for each dependent variable, in which only significant explanatory variables were included and robust standard errors were utilized (Table 7,8,9).

Table 6. Washington Multivariate Multiple Regression Output

Equation	Obs	Parms	RMSE	"R-sq"	F	P
grow_sites	92	7	4.113094	0.6357	24.72231	0.0000
annual_pla~s	92	7	19546.13	0.7546	43.56845	0.0000
mj_plants	92	7	5555.614	0.1510	2.520233	0.0271

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
grow_sites						
unemployment	1.060875	.4405195	2.41	0.018	.1850038	1.936745
poverty_rate	-7.777658	1.450763	-5.36	0.000	-10.66216	-4.893153
gsp	-.0000939	.0000454	-2.07	0.042	-.0001842	-3.55e-06
lei_budget	.282821	.0676458	4.18	0.000	.148323	.4173189
mj_price	.0061678	.0055535	1.11	0.270	-.004874	.0172097
WA_vote	1.695642	4.938951	0.34	0.732	-8.124316	11.5156
_cons	81.9297	14.40444	5.69	0.000	53.28982	110.5696
annual_plants						
unemployment	9391.484	2093.425	4.49	0.000	5229.195	13553.77
poverty_rate	-62040.98	6894.276	-9.00	0.000	-75748.65	-48333.31
gsp	-.0436454	.2159016	-0.20	0.840	-.4729157	.3856248
lei_budget	1642.908	321.4645	5.11	0.000	1003.75	2282.065
mj_price	122.8722	26.39119	4.66	0.000	70.3994	175.3449
WA_vote	-25615.84	23470.75	-1.09	0.278	-72281.98	21050.29
_cons	251900.9	68452.36	3.68	0.000	115799.3	388002.6
mj_plants						
unemployment	21.99575	595.0159	0.04	0.971	-1161.055	1205.047
poverty_rate	-1110.495	1959.566	-0.57	0.572	-5006.638	2785.647
gsp	.1387837	.0613659	2.26	0.026	.0167719	.2607956
lei_budget	-72.64795	91.37013	-0.80	0.429	-254.3162	109.0203
mj_price	10.48112	7.501191	1.40	0.166	-4.433259	25.3955
WA_vote	-17166.95	6671.111	-2.57	0.012	-30430.9	-3902.991
_cons	-46598.56	19456.28	-2.40	0.019	-85282.85	-7914.274

Table 7. Washington Regression for Annual Number of Discovered Grow Sites. Only Significant Variables Included, Robust Standard Errors

Linear regression

Number of obs	= 92
F(4, 87)	= 58.07
Prob > F	= 0.0000
R-squared	= 0.6295
Root MSE	= 4.0999

grow_sites	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
unemployment	.972378	.4525569	2.15	0.034	.0728721	1.871884
poverty_rate	-6.360503	.6181348	-10.29	0.000	-7.589113	-5.131893
gsp	-.0000839	.0000138	-6.06	0.000	-.0001114	-.0000564
lei_budget	.2508611	.0479548	5.23	0.000	.1555458	.3461764
_cons	81.25809	7.880365	10.31	0.000	65.59501	96.92117

Table 8. Washington Regression for Annual Number of Eradicated Plants. Only Significant Variables Included, Robust Standard Errors

Linear regression

Number of obs	= 92
F(5, 86)	= 89.97
Prob > F	= 0.0000
R-squared	= 0.7545
Root MSE	= 19437

annual_pla~s	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
unemployment	9415.089	2591.172	3.63	0.000	4264.009	14566.17
poverty_rate	-62050.84	10622.42	-5.84	0.000	-83167.51	-40934.17
lei_budget	1587.333	170.1376	9.33	0.000	1249.11	1925.555
mj_price	123.8496	42.0747	2.94	0.004	40.20784	207.4913
WA_vote	-30061.62	7114.571	-4.23	0.000	-44204.92	-15918.32
_cons	241498.8	42583.97	5.67	0.000	156844.7	326152.9

Table 9. Washington Regression for Number of Cannabis Plants per Discovered Grow Site. Only Significant Variables Included, Robust Standard Errors

Linear regression

Number of obs	=	92
F(2, 89)	=	7.96
Prob > F	=	0.0007
R-squared	=	0.1152
Root MSE	=	5542.9

mj_plants	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
gsp	.0723635	.0227417	3.18	0.002	.0271762	.1175509
WA_vote	-10625.57	2836.185	-3.75	0.000	-16261.01	-4990.133
_cons	-20331.93	7431.483	-2.74	0.008	-35098.13	-5565.727

After accounting for multicollinearity and heteroscedasticity, the model is best able to predict the annual number of eradicated cannabis plants in Washington national forests with an R-squared value of 0.7545 (Table 8). Further testing proves multicollinearity to not be an issue with all variance inflation factors (VIF) less than 10, and tolerance levels greater than 0.1 (Table 10).

Table 10. Variance Inflation Factors for Table 8

Variable	VIF	1/VIF
poverty_rate	9.15	0.109299
mj_price	5.21	0.191932
unemployment	4.33	0.230823
lei_budget	2.13	0.469627
WA_vote	1.29	0.778035
Mean VIF	4.42	

Unemployment and poverty rate are found to have opposite effects on the annual number of eradicated plants in Washington national forests, with unemployment found to have a positive relationship and poverty rate a negative relationship with the dependent variable of interest. Both the annual US Forest Service LEI budget and the price of illicit cannabis are determined to have a positive relationship with the annual number of eradicated marijuana plants. Finally, legalization of recreational cannabis demonstrates a negative influence on the annual number of marijuana plants eradicated in Washington national forests.

4.1.1.2 Oregon

Unlike Washington, Oregon has consistently had discovered grow sites in national forests every year from 2004-2016, and thus does not encounter the same issues when conducting a state level regression. However, in order to retain as much consistency between regressions as possible, all explanatory variables that could be brought up to the state scale were. Law enforcement density and population density were kept in the Oregon regression (Table 11), but due to the issues discussed with the Washington regression (Section 4.1.1.1), were kept at the national forest and county level respectively.

As found in the Pacific Northwest and Washington specific regressions, the model proves to be significant ($p<0.05$) for all dependent variables, namely annual number of discovered grow sites in Oregonian national forests, the annual number of eradicated cannabis plants in Oregonian national forests, and the number of marijuana plants per grow site in Oregonian national forests (Table 12). Remaining consistent with the methodology utilized in the previous section, individual regressions were conducted for each dependent variable in which only significant independent variables were included to reduce multicollinearity, and robust standard errors used to account for heteroscedasticity (Table 13,14,15).

Table 11. Oregon Regression Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
grow_sites	151	19.37086	8.776952	2	30
annual_pla~s	151	66702.77	44399.68	501	116098
mj_plants	151	3533.457	8578.896	1	91035
unemployment	151	7.702649	2.415394	4.8	11.3
poverty_rate	151	14.34437	1.29798	12.9	17.3
gsp	151	181221.8	17429.55	142328	227032
pop_density	151	100.5755	270.3013	1	1704.9
law_density	151	3.27e-06	1.38e-06	1.30e-06	5.62e-06
lei_budget	151	128.2074	15.85553	82.829	145.047
mj_price	151	2670.447	274.9342	2100.84	3004.17
OR_vote	151	.0529801	.2247392	0	1

Table 12. Oregon Multivariate Multiple Regression Output

Equation	Obs	Parms	RMSE	"R-sq"	F	P
grow_sites	151	9	2.601153	0.9169	195.7298	0.0000
annual_pla~s	151	9	24189	0.7190	45.42207	0.0000
mj_plants	151	9	8273.123	0.1196	2.411603	0.0180

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
grow_sites						
unemployment	-.5054206	.1867384	-2.71	0.008	-.874567	-.1362741
poverty_rate	-5.173233	.3442685	-15.03	0.000	-5.853787	-4.49268
gsp	.0002443	.0000514	4.75	0.000	.0001427	.000346
pop_density	-.000236	.0008592	-0.27	0.784	-.0019344	.0014624
law_density	202802.6	170934	1.19	0.237	-135101.7	540706.8
lei_budget	.0728075	.0418451	1.74	0.084	-.0099124	.1555274
mj_price	.019588	.0015266	12.83	0.000	.0165702	.0226057
OR_vote	-21.31735	2.498193	-8.53	0.000	-26.25581	-16.3789
_cons	-7.962129	5.719331	-1.39	0.166	-19.26817	3.343908
annual_plants						
unemployment	898.5621	1736.543	0.52	0.606	-2534.255	4331.379
poverty_rate	6470.499	3201.468	2.02	0.045	141.8007	12799.2
gsp	-3.879468	.478164	-8.11	0.000	-4.824708	-2.934228
pop_density	8.569939	7.989773	1.07	0.285	-7.224332	24.36421
law_density	-9.63e+08	1.59e+09	-0.61	0.546	-4.10e+09	2.18e+09
lei_budget	4517.353	389.1321	11.61	0.000	3748.112	5286.594
mj_price	-.3996012	14.19629	-0.03	0.978	-28.46297	27.66377
OR_vote	135184.7	23231.54	5.82	0.000	89260.31	181109
_cons	87046.8	53185.99	1.64	0.104	-18091.85	192185.4
mj_plants						
unemployment	-593.3858	593.9325	-1.00	0.319	-1767.478	580.7064
poverty_rate	2201.048	1094.966	2.01	0.046	36.5067	4365.589
gsp	-.2996465	.1635417	-1.83	0.069	-.6229375	.0236444
pop_density	-.2962118	2.732662	-0.11	0.914	-5.698169	5.105745
law_density	-1.47e+09	5.44e+08	-2.71	0.008	-2.55e+09	-3.96e+08
lei_budget	306.1775	133.091	2.30	0.023	43.08181	569.2731
mj_price	-.6813184	4.855414	-0.14	0.889	-10.27955	8.916917
OR_vote	12143.44	7945.65	1.53	0.129	-3563.611	27850.49
_cons	-2399.473	18190.67	-0.13	0.895	-38359	33560.05

Table 13. Oregon Regression for Annual Number of Discovered Grow Sites. Only Significant Variables Included, Robust Standard Errors

Linear regression

Number of obs	= 151
F(5, 145)	= 512.79
Prob > F	= 0.0000
R-squared	= 0.9140
Root MSE	= 2.6177

grow_sites	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
unemployment	-.4874219	.0740814	-6.58	0.000	-.6338407	-.3410031
poverty_rate	-5.448687	.3518184	-15.49	0.000	-6.144041	-4.753332
gsp	.0003263	.0000514	6.35	0.000	.0002247	.0004278
mj_price	.0205816	.0010584	19.45	0.000	.0184897	.0226735
OR_vote	-24.81063	3.8301	-6.48	0.000	-32.38066	-17.24059
_cons	-11.4898	3.752066	-3.06	0.003	-18.90561	-4.073996

Table 14. Oregon Regression for Annual Number of Eradicated Plants. Only Significant Variables Included, Robust Standard Errors

Linear regression

Number of obs	= 151
F(4, 146)	= 201.10
Prob > F	= 0.0000
R-squared	= 0.7157
Root MSE	= 23996

annual_pla~s	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
poverty_rate	7965.862	3043.884	2.62	0.010	1950.095	13981.63
gsp	-4.03624	.4796281	-8.42	0.000	-4.984151	-3.088329
lei_budget	4649.916	308.5023	15.07	0.000	4040.209	5259.623
OR_vote	140543.3	31752.39	4.43	0.000	77789.62	203297
_cons	80292.68	30332.03	2.65	0.009	20346.11	140239.2

Table 15. Oregon Regression for Annual Number of Eradicated Plants. Only Significant Variables Included, Robust Standard Errors. Initial Attempt

```
Linear regression                               Number of obs     =        151
                                                F(3, 147)         =       8.16
                                                Prob > F          =     0.0000
                                                R-squared         =     0.0949
                                                Root MSE          =     8244.5
```

mj_plants	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
poverty_rate	571.0677	982.8558	0.58	0.562	-1371.285	2513.42
law_density	-1.36e+09	5.48e+08	-2.48	0.014	-2.44e+09	-2.78e+08
lei_budget	77.62397	17.32331	4.48	0.000	43.38906	111.8589
_cons	-10154.41	11915	-0.85	0.395	-33701.23	13392.4

Although poverty rate was initially found to be significant in the multivariate multiple regression for Oregon (Table 11), when insignificant variables are removed and robust standard errors are utilized, the poverty rate is no longer significant when predicting the number of cannabis plants per discovered grow site (Table 14). Thus, poverty rate was also removed from this model (Table 15).

Table 16. Oregon Regression for Annual Number of Eradicated Plants. Only Significant Variables Included, Robust Standard Errors

```
Linear regression                               Number of obs     =        151
                                                F(2, 148)         =       3.50
                                                Prob > F          =     0.0329
                                                R-squared         =     0.0890
                                                Root MSE          =     8243.5
```

mj_plants	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
law_density	-1.40e+09	6.03e+08	-2.32	0.022	-2.59e+09	-2.06e+08
lei_budget	98.31849	37.19463	2.64	0.009	24.81734	171.8196
_cons	-4496.014	2721.707	-1.65	0.101	-9874.441	882.4129

After accounting for multicollinearity and heteroscedasticity, the model is best able to predict the annual number of discovered grow sites in Oregon national forests with an R-squared value of 0.9140 (Table 12). Further testing proves multicollinearity to not be an issue with all variance inflation factors (VIF) less than 10, and tolerance levels greater than 0.1 (Table 9).

Table 17. Variance Inflation Factors for Table 13

Variable	VIF	1/VIF
unemployment	4.33	0.230944
poverty_rate	3.48	0.287502
mj_price	3.34	0.299822
gsp	3.31	0.302464
OR_vote	2.85	0.350313
Mean VIF	3.46	

In this case, unemployment and the poverty rate are both found to have a negative relationship with the annual number of discovered grow sites in Oregon. Both GSP and the price of illicit cannabis are determined to have a positive relationship with the dependent variable. In addition, recreational cannabis legalization in Oregon is determined to negatively influence the number of discovered grow sites in national forests.

4.2 Interview

4.2.1 Characteristics of Grow Sites

The US Forest Service Law Enforcement and Investigations unit for the Pacific Northwest confirms much of what has been observed as typical characteristics of marijuana grow sites in national forests within previous literature. As observed by Bouchard et al. (2013) and Koch et al. (2016), the Forest Service confirms that marijuana growers often prefer locations that are remote, yet with close enough road access to allow ingress and egress, close to a water source, and areas that receive abundant sunlight, often desiring southern exposure. As demonstrated by the data, grow sites are observed to range in size from "several hundred to upwards of 10,000 plants", with the spatial extent of a typical site generally falling within "one to 20 acres". The Forest Service notes that many forests have been affected by chronic occupancy of grow sites while others have rarely had to deal with the issue. This is largely assumed to be the result of differing characteristics between forests, with some having better suited physical attributes for growing. In addition, forests can sometimes differ dramatically in the abundance of discovered grow sites from year to year. It is posited that this may often be the result of law enforcement efforts and the disruption of Drug Trafficking Organizations (DTOs), but the Forest Service acknowledges that this is a clandestine activity influenced by complex dynamics that are not fully understood and these trends may be affected by unknown factors.

4.2.2 Ecological Impacts

The US Forest Service suggests that the same ecological impacts of marijuana cultivation in national forests are experienced throughout the Western United States:

"Trees and naturally occurring vegetation are cleared to open the canopy for the marijuana, natural terrain is terraced or re-contoured causing erosion problems, and creeks and stream's natural flows are blocked and diverted to water the marijuana plants. Hundreds to thousands of pounds of trash and human waste are generated from the continuous occupation of these sites, and often contaminate the water sources. One of the greatest impacts are the chemicals used."

Agrochemical pollution is identified as being one of the most significant impacts, with extremely large quantities of fertilizers, soil amendments, pesticides, herbicides, and rodenticides observed, many of which are restricted to regulated commercial use or banned completely in the United States. It is noted that these chemicals contaminate soil, watersheds, and wildlife, demonstrating far-reaching consequences throughout trophic levels and across the landscape as a whole.

Illegal poaching of wildlife is observed to be a consistent theme seen at discovered grow sites, with evidence typically suggesting "opportunistic poaching rather than large scale subsistence poaching for food."

4.2.3 Forest Management

The US Forest Service confirms that marijuana cultivation impacts its ability to manage national forests, particularly due to the cost, time, and labor involved in investigations and remediation. These costs vary significantly depending on the location and difficulty of access, size of the grow, the amount and types of chemicals present, and the amount of established infrastructure and trash. However, the Forest Service suggests that a typical site can cost anywhere from "$15,000 to over $100,000 for cleanup and remediation". It is acknowledged that these costs have an effect on Forest Service budgets and causes shifting of finances between programs. In addition, because these efforts are time and labor intensive, resources are often diverted from other projects:

"Grow site remediation does have an effect on FS budgets and causes shifting between program areas. The cost can vary significantly depending on the location and difficulty of access, size of the grow, amount and type of chemicals present, and the amount of established infrastructure and garbage.

Generally it can cost between $15,000 per site to over $100,000 for cleanup and remediation. Investigation and remediation of sites are very labor and time intensive resulting in the diversion of those resources from other work."

It should also be recognized that the US Forest Service confirms the dangers presented by marijuana cultivation sites to both visitors and employees. Growers are observed to often be armed with rifles and handguns and are described as being willing to protect their crops with violent actions against anyone who may enter their grow site. These sites are also sometimes protected with "improvised anti-personnel devices", furthering contributing to safety risks. In addition, the large volumes of hazardous waste produced by grow sites present significant health risks to the public as well as Forest Service employees. "Personnel conducting enforcement, cleanup and regulatory activities are also at considerable risk from these substances via direct exposure such as contact and inhalation."

4.2.4 Effects of Cannabis Legalization

According to the US Forest Service, while there may have been a decline in discovered grow sites in the Pacific Northwest in recent years, they are of the opinion that this is unlikely to be the result of recreational cannabis legalization. It is posited that decreases in resources and partnerships are more likely to be contributing to a decline in the agency's ability to discover and document grow sites. In fact, the US Forest Service suggests that legalization of recreational cannabis has resulted in many state and local cooperators reducing or eliminating resources that typically assist the Forest Service with counter marijuana cultivation operations. These resources are often redirected to addressing regulatory concerns or crimes related to legal marijuana cultivation on private lands. It should also be noted that the US Forest Service reports no observable difference in the size and location of grow sites after the implementation of legalization in the Pacific Northwest:

> "Generally there have been no notable differences in the sites pre or post legalization."

> "In general legalization or decriminalizing the use and possession of marijuana has also affected the Forest Service's ability to address illegal marijuana cultivation on NFS lands. Many state and local cooperators are reducing or even eliminating the resources that typically assist the Forest Service with counter marijuana cultivation operations. These resources are now often committed to addressing regulatory concerns or crimes related to "legal" growing activities on private lands."

In addition, the US Forest Service does not believe that the long-term effects of legalization will reduce illegal marijuana cultivation in national forests. The Forest Service reports that their partners and stakeholders often express the view that states with liberalized marijuana policies create a more suitable climate for illicit grows. Social, political, and economic factors influencing illegal marijuana cultivation are acknowledged as complicated and continually changing as some states legalize recreational marijuana, some have decriminalized possession, while others remain dedicated to the criminalization of cannabis. However, the US Forest Service remains convinced that illegal marijuana cultivation in national forests, particularly by Drug Trafficking Organizations, will remain to be a significant and escalating challenge into the foreseeable future:

> "Marijuana cultivation by Drug Trafficking Organizations (DTO's) on public lands, and National Forest System (NFS) lands in particular, is a significant issue that continues to escalate…it is expected that marijuana cultivation on public lands will continue to pose a significant problem for many years."

5 Discussion

5.1 Impacts of Marijuana Cultivation in National Forests in the Pacific Northwest

The interview responses regarding grow site characteristics, ecological impacts, and forest management demonstrate that the US Forest Service encounters similar effects as a result of marijuana grow sites in Pacific Northwest national forests as those that have been observed in previous literature. This provides confirmation that cannabis cultivation in national forests in the Pacific Northwest should be regarded as a significant ecological issue with impacts that resonate across trophic levels and throughout ecosystems. As such, this is a problem that warrants greater academic research and government efforts in the development of methods and policies that curb this illicit activity, and the environmental degradation inherent to it.

5.2 Variables Influencing Cannabis Cultivation in National Forests

In this discussion on the variables influencing cannabis cultivation in national forests, focus will placed on the models with the best fit, and are thus most accurate in explaining this phenomenon. As demonstrated above (Section 4.1.1.1, 4.1.1.2), this includes the models attributed to the annual number of plants eradicated in Washington (R-squared = 0.7545) and the number of discovered grow sites in Oregon (R-squared = 0.9140). Reference to other models will be included if clarification of results is needed.

5.2.1 Annual Number of Eradicated Marijuana Plants in Washington National Forests

When considering the annual number of eradicated marijuana plants in Washington national forests, unemployment and poverty rate are found to have opposite effects. The logic often applied to these explanatory variables dictates that individuals are incentivized by the profits of marijuana cultivation when employment and financial opportunities are limited (Koch et al. 2016). This would suggest a positive relationship, as is found with unemployment (Table 8). However, poverty rate contradicts this logic and is determined to have a negative relationship (Table 8).

This combination of effects may signal some underlying dynamics in the illicit cannabis trade in Washington. The fact that unemployment has a positive relationship is in accordance with a typical rational choice model and suggests that unemployed locals may respond to declining economic opportunities by engaging in illicit cannabis cultivation, particularly in national forests where initial investment costs may be lower (Bouchard et al. 2013). This is supported by the finding that unemployment retains this positive relationship in the model applied to the annual number of discovered grow sites in Washington (Table 7), suggesting that as unemployment rises additional grow sites are created. However, the negative relationship found with poverty may indicate that if rates of poverty increase, the size of the local cannabis consumer base may decline as individuals have less ability to afford recreational marijuana, and thus growers respond to local market pressures and reduce the amount of production. As state specific variables, both of these results suggest that at least a significant portion of the cannabis grown in Washington national forests is produced for the purpose of being sold within the state.

In congruence with this rational choice framework, the price of illicit cannabis has a positive relationship on the number of discovered grow sites (Table 8). As prices rise, there is incentive for a greater level of production as to not miss out on higher profits, and thus the number of the illicit marijuana plants in national forests increases. In addition, although it is difficult to determine the exact dynamics of illegal markets, a rise in prices may also signal greater demand for a product (Wilson & Garrod 2014), and an increase in production represents supply rising to match shifting demand levels.

Lastly, the US Forest Service Law Enforcement and Investigations' annual budget was found to have a positive relationship with the annual number of eradicated cannabis plants (Table 8). This is likely because an increase in funding provides the US Forest Service with the financial means and resources to improve their ability to discover grow sites and properly record these findings. The fact that LEI budget preserves this positive relationship in the regression on annual number of discovered grow sites in Washington (Table 7) further supports this interpretation. These additional resources may also provide the agency with the confidence to engage with larger grow sites that may be operated by DTOs. This result confirms the claims by the US Forest Service in their interview response that the availability of resources plays a large role in their ability to locate and eradicate illicit marijuana cultivation in national forests.

5.2.2 Annual Number of Discovered Grow Sites in Oregon National Forests

When considering the number of discovered grow sites in Oregon national forests, unemployment and poverty rate are found to both demonstrate a negative relationship (Table 13). Although this is a different result than experienced in the Washington regression on annual number of eradicated plants, the fact that growers respond to local economic conditions again suggests that a significant portion of illicit cannabis grown in Oregon national forests is destined for local consumers. Just as in the Washington regression, the negative relationship found with poverty rate may be indicative of a shrinking consumer base as poverty levels rise. The difference between the two models with respect to unemployment may signal some state specific dynamics in Oregon. In particular, as unemployment rises the reduction of grow sites is possibly due to an already saturated illicit marketplace in Oregon, with little room for new growers to break into the scene. In fact, while Oregon has a greater area under national forest designation than Washington, when considering the average number of discovered grow sites (Table 1), Oregon generally has a slightly higher concentration of cannabis cultivation sites within its national forest system. Thus, Oregon's illicit cannabis demand may already be met by established growers, or competition for adequate locations for cannabis cultivation in national forests may already be high. On the other hand, Oregon may have less local growers contributing to marijuana production in national forests. According to the US Forest Service interview response, Drug Trafficking Organizations (DTO) often manage cannabis cultivation sites, and an increase in unemployment may again simply indicate a shrinking consumer base. If DTOs respond to local economic conditions, then they may decrease the number of sites they manage in response to demand. In either case, it is clear that unlike in Washington, Oregonian locals do not appear to be incentivized to engage in illicit cannabis cultivation in national forests based on unfavorable local economic conditions.

Further supporting the rational choice model, and the proposition that a significant portion of the marijuana grown in Oregon national forests is produced for local markets, is the positive relationship found between the number of grow sites and gross state product (Table 13). GSP can be thought of as a broad indicator of economic conditions across the state (Salazar et al. 1997). As GSP rises, the Oregon economy grows, and the number of grow sites in national forests increases. Just as with unemployment and poverty rate, variance in GSP might influence the demand for illicit cannabis. If GSP rises and economic conditions become increasingly better, more individuals are able to purchase recreational cannabis thereby growing the consumer base, and the established consumers are able to purchase more. Thus, the increase in number of grow sites may indicate supply catching up to a changing demand.

Just as with the Washington regression on annual number of eradicated plants, the price of illicit cannabis remains significant and positively related to the number of discovered grow sites in Oregon (Table 13). This once again supports the rational choice model and demonstrates that growers react to local economic variables.

Although LEI budget was found insignificant in this regression, the US Forest Service LEI's access to resources may still impact their ability to discover grow sites in Oregon national forests. In the interview response, the LEI Pacific Northwest office placed emphasis on the importance of access to resources for effective enforcement and counter marijuana cultivation operations. It is also important to note that in the other two regressions ran for Oregon, both on the annual number of eradicated plants and the number of plants found per grow site, LEI budget was found to be significant and positive (Table 14, 16). In this case, it should also again be noted that LEI budget is a variable at the federal level. While adequate distribution of funds amongst US Forest Service regions would be expected, it may be possible that given the greater abundance of cannabis cultivation in Oregon national forests than Washington, the financial means provided for the Pacific Northwest has been sufficient enough to render significance in Washington but chronically inadequate for Oregon, thereby persisting as insignificant in the regression model with the best fit despite its potential. Contributing to this possibility is the fact that California has consistently been identified as disproportionately being affected by this issue

(Carah et al. 2015; Koch et al. 2016), with many high-profile cannabis eradication operations being conducted (Corva 2014), thereby requiring a disproportionate portion of LEI funding and possibly diverting resources from other regions such as the Pacific Northwest.

Lastly, law enforcement density is found to be insignificant in both the regressions on annual discovered grow sites and number of eradicated plants (Table 13, 14), the two models with the most explanatory power. This non-finding may be signaling an important dynamic. Previous research has demonstrated law enforcement density to impact growers' decisions on where to locate their production sites (Koch et al. 2016). Furthermore, in the Oregon regression on number of plants per grow site performed in this study, law enforcement is found to be significant with a negative coefficient (Table 16), suggesting that law enforcement density impacts the size of a grower's site presumably to reduce the risk of being caught. Given these two findings, it is clear that law enforcement density is a factor considered by illicit cannabis cultivators in US national forests. With this in mind, it is likely that the demonstrated insignificance of this variable in the regressions focusing on total annual abundance and production indicates a situation of pervasive underrepresentation of Law Enforcement Officers (LEOs) in national forests in the Pacific Northwest. This is further supported by the fact that all administrative zones, usually containing multiple national forests, have a low number of LEOs dedicated to law enforcement in the region, ranging from only four to nine (USFS unpublished data). Thus, it is likely that law enforcement density has the potential to further decrease the abundance and size of grow sites in Pacific Northwest national forests if a greater density level is achieved that sufficiently increases the risk of being caught.

5.3 Legalization as a Potential Solution

Although the US Forest Service suggested within their interview response that legalization of recreational cannabis has likely not been the reason for the observed decrease in marijuana cultivation in national forests, legalization in both Washington and Oregon were found to be significant in the best fitting models for each state (Table 8, 13). In both of these cases, recreational cannabis legalization was found to put considerable negative pressure on the abundance or scale of marijuana production.

Within the interview, the US Forest Service LEI office for the Pacific Northwest pointed to a decline in funding and resources as decreasing their ability to discover and properly record grow sites. In order to account for this dynamic, the LEI annual budget was included in the regression model. Although the LEI budget does not encapsulate the effects of outside support and resources gained through partnerships, as specified by the US Forest Service in their interview response, the LEI budget would be expected to be a central contributor to the financial means and access to resources for the Law Enforcement and Investigations division.

The LEI budget was found to be significant and positively related to the annual number of eradicated plants in Washington (Table 8). Considering that legalization remains significant with such a high coefficient in Washington despite the significance of the LEI budget, it is likely that legalization has contributed to a decrease in marijuana production in national forests within this state. While access to resources for the Pacific Northwest LEI may have the potential to contribute to grow site discoveries in Oregon, as explained above (Section 5.2.2), the insignificance of LEI budget in the Oregon regression model with best fit indicates that it is likely that legalization has been instrumental in declining marijuana production.

This finding seemingly contradicts the claims that only complete federal legalization will put an end to rampant illicit cannabis cultivation in national forests (Caulkins & Bond 2012; Levy 2014; Carah et al. 2015). Instead, legalization on a state by state basis may still prove to be an effective means to reducing this illegal practice, at least at a local scale. However, it should be noted that this relationship may not be applicable to states that already contribute disproportionately to the national supply of illicit cannabis, as the exporting of marijuana may relieve growers from the local economic pressures of within state legalization. In particular, close monitoring of the effects of the recent legalization policy in California should be considered. In a state that produces an estimated 60-70% of the cannabis consumed across the United States (Carah et al. 2015), recreational cannabis legalization may reduce California's total production by reducing the demand within state for illicitly produced marijuana, as is suggested to have been the effect in Washington and Oregon, but the substantial fraction of illicit cannabis exported to other states across the nation is likely to persist to some degree (Caulkins & Bond 2012; Levy 2014).

5.4 Future Research

Given the findings of this study, and the insights gained through the research process, future research in a number of areas would not only produce relevant and interesting results, but may be important in further understanding the impacts of recreational cannabis legalization on marijuana cultivation in national forests:

1. A qualitative analysis that engages in individual interviews with law enforcement officials operating within national forests would provide significant insight into what experts on the ground are encountering, and their resulting opinions on legalization. Although this study attempted to engage in this type of analysis, and was informed that as a federal agency the US Forest Service must maintain an official viewpoint in congruence with the federal government, if this policy is ever relaxed as to allow the expression of personal opinions, the results would be extremely useful.

2. Similarly, a qualitative analysis that engages in interviews with individuals incarcerated, or previously charged, for the illicit cultivation of cannabis in national forests would provide greater insight into growers' motivations and decisions, as well as provide valuable information regarding growers' reactions to the legalization of recreational cannabis.

3. Comparative analyses on differences in legalization policies between states, and the subsequent results of these differences with regards to illicit cannabis cultivation, would provide insight into how liberalized cannabis policies can best be structured to ensure the greatest environmental results.

4. With the recent legalization of recreational cannabis in California, a similar analysis as was conducted in this study could be performed to determine if similar impacts of legalization are found. California has continually been noted as the largest producer of illicit cannabis in the United States and is known for distributing domestically produced

marijuana across state borders (Carah et al. 2015; Koch et al. 2016). Arguably, California is the most important state with regards to curbing illicit cannabis cultivation in national forests. Thus, investigating the impacts of cannabis legalization in California will be an extremely important task as legal markets begin to further develop.

5. Lastly, continued analysis on the impacts of cannabis legalization on illicit marijuana cultivation in national forests in the Pacific Northwest should be conducted as additional data materializes over time.

6 Conclusion

In conclusion, the legalization of recreational cannabis is heavily correlated with a decrease in the annual number of eradicated plants and a reduction in the annual number of discovered grow sites in national forests in Washington and Oregon. Given this decrease in abundance and size of marijuana grow sites in Pacific Northwest national forests, and the US Forest Service's testimony that there have been no notable differences in grow site characteristics after the introduction of legalization, this study suggests that liberalized marijuana policies in the Pacific Northwest have contributed to a decrease in ecological damage in national forests resulting from illegal marijuana cultivation.

In addition, this study re-affirms the application of a rational choice framework to the analysis of illegal marijuana cultivation, as has been done by previous literature (Bouchard et al. 2013; Koch et al. 2016). With many illegal cannabis grows in Pacific Northwest national forests suspected of being operated by Drug Trafficking Organizations, a rational choice framework explains the relationship between economic factors, such as unemployment, poverty rate, gross state product, and the price of illegal cannabis, and responses to market pressures demonstrated by both the annual number of marijuana plants in Washington and the abundance of grow sites in Oregon.

Lastly, the US Forest Service Law Enforcement and Investigations' annual budget, an indicator for the level of financial support and resources available, as well as law enforcement density, are determined to impact the ability of the US Forest Service to discover and record illegal cannabis operations in Pacific Northwest national forests. Thus, a trend of decreasing annual budgets for the US Forest Service, and a relatively stagnant density of law enforcement in Pacific Northwest national forests, should be of environmental concern.

6.1 Recommendations

Increased budget for the US Forest Service, particularly the Law Enforcement and Investigations division: The LEI budget was found to have a positive relationship with the number of annual cannabis plants eradicated in national forests in Washington, and is thought to impact the effectiveness of law enforcement efforts in Oregon as well. Thus, it is demonstrated that a larger budget provides the agency with the support and resources to better locate and properly record marijuana cultivation sites, a finding confirmed by US Forest Service themselves. This not only reduces the number of ecologically damaging sites, but further discourages illicit production of cannabis in national forests as the risks of being caught increase. In addition, fewer cannabis cultivation sites, especially less large grow sites, ensures national forests are safer for both the public and researchers, thereby allowing greater public utilization as well as better quality research to be produced. Lastly, greater data collection by the US Forest Service provides more information available for studies such as this one to work with, and thus contributes to more accurate and complete research projects on challenges faced by the agency.

Increased law enforcement density in Pacific Northwest national forests: Given the insignificant results of law enforcement density when considering the abundance of grow sites and total number of eradicated plants, yet the negative relationship between law enforcement density and the number of plants per grow site in both the Pacific Northwest and Oregon specific model, it is likely that density of LEOs is not high enough across the entire Pacific Northwest national forest system to impact the total scale of production. This is further supported by the fact that all administrative zones, usually containing multiple national forests, have a low number of LEOs dedicated to law enforcement in the region, ranging from only four to nine (USFS unpublished data). If reducing cannabis cultivation in national forests is to be considered a priority, increasing law enforcement density is likely to deter this activity and lead to a reduction in the number of grow sites, as well as the size of grow sites that persist, thereby limiting the ecological damage.

Continued efforts to eradicate environmentally damaging marijuana cultivation practices after recreational cannabis legalization: Although legalization in Washington and Oregon appears to have contributed to a reduction in illicit cannabis cultivation in national forests, the effectiveness of legalization towards meeting this goal can be further enhanced by introducing legalization policies that continue to encourage environmentally conscious legal production. This can include stipulations that require a percentage of tax revenue gained through legal sales to be utilized in strengthening law enforcement efforts in national forests, both by increasing the US Forest Service's financial resources and by increasing law enforcement density as outlined above. In addition, landscape specific environmental issues, such as water use concerns, must be built into legalization policies to ensure that illicit production in national forests is not simply being traded for ecologically damaging legal practices.

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7.1 Personal Communications

Bragonier, Scott. Assistant Special Agent in Charge, United States Forest Service Law Enforcement and Investigations, Pacific Northwest (Region 6). Email communication, 6 June 2018.

Appendix I – Interview Questions

Characteristics of Grow Sites

- How abundant are illegal cannabis grow sites within the national forest that you operate within? How does this compare with other national forests?
- How large is a typical discovered site?
- How many plants does a typical discovered site contain?
- What kind of landscape attributes do growers look for when determining where to set up a grow site?

Ecological Impacts

- In your experience, have cannabis grow sites presented any ecological impacts to the national forest you operate in?
- Have similar ecological impacts been experienced in other national forests?
- Of these impacts, which would you say are the most significant?
- Has illegal poaching of wildlife been connected to cannabis grow sites within the forest you operate in?

Forest Management

- The mission statement of the USDA forest service is to "sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations". How do grow sites impact forest management and the goals of the US Forest Service?
- How has the presence of cannabis grow sites impacted your work in particular?
- Has the presence of cannabis grow sites, and the resulting law enforcement and remediation efforts, deterred available funding and resources from other forest management programs and activities? If so, how?
- Does the presence of cannabis grow sites present safety concerns, both for public visitors and US Forest Service employees? Please explain.

Effects of Cannabis Legalization

- In your experience, have you noticed any discernable differences in the abundance/spatial extent/locations of grow sites in the national forest you operate in after the legalization of recreational cannabis?

- If there are any differences:

    - Do you think these changes can be attributed to legalization itself? And if so, how do you think legalization has impacted this trend?

    - If legalization cannot be attributed to a change in the abundance/characteristics of grow sites, what other factors do you think may be significantly impacting this trend?

    - Has this change in the number/characteristics of grow sites impacted your ability to manage the national forest you work in? Or the work of others? How so?

    - Have the ecological impacts experienced as a result of grow sites diminished or increased alongside the change in abundance/spatial extent/location of cultivation sites?

- If there are not any discernable differences after legalization:

    - Do you think legalization has had no impact on the abundance/characteristics of illegal grow sites? Or do you think other factors may be counteracting the effect legalization may be having? If so, what sort of factors can you identify (e.g. criminalization in other states may still create incentives for illegal cultivation in states with more suitable climatic conditions)?

    - Do you think legalization of recreational cannabis may impact the abundance/characteristics of illegal grow sites in national forests in the future? (i.e. as legal markets continue to develop, etc.) If so, how?

    - With no discernable difference in the number/characteristics of grow sites, has the extent of environmental degradation associated with this activity remained at a similar level? If not, has it increased/decreased?

Concluding Remarks

- To sum up your position on the subject, do you think the legalization of recreational cannabis can be used as a means to decrease the abundance of illegal grow sites in national forests and diminish the subsequent environmental impacts associated with this activity? Why or why not?