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Analysis

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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ABSTRACT

Cannabis cultivation in US national forests has been identified as a growing environmental issue. Rational choice theory often considers 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. The recent liberalization of marijuana policies across numerous states introduces the opportunity to analyze these claims. Here, utilizing regression analyses, we investigate the effects of recreational cannabis legalization and a host of relevant socio-economic and law enforcement factors in Washington and Oregon on illicit marijuana cultivation in Pacific Northwest national forests. To further investigate the regression results, structured questions were sent to a key informant of the United States Forest Service Law Enforcement and Investigations division who responded on behalf of the institution. Results demonstrate law enforcement and economic variables as significant in determining illicit cannabis cultivation in Pacific Northwest national forests, confirming the relevance of a rational choice framework. Recreational cannabis legalization is found to significantly contribute to a reduction in illicit cultivation sites in Oregonian national forests, while remaining insignificant in Washington, likely due to policy differences that are discussed.

1. Introduction

Illicit drug crop cultivation on public and protected lands has increasingly been recognized as an ecological issue and obstacle for land management agencies in governments around the world (Rose et al., 2016). In the United States, the illegal cultivation of cannabis has been observed as a major stressor impacting the management of public lands. According to the National Drug Intelligence Centre (NDIC, 2009), of > 8 million cannabis plants eradicated by law enforcement in 2008, 94% were outdoor grown. Over half of these plants were eradicated from public lands, with > 3 million eradicated in national forests in 2008 alone (NDIC, 2009). 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). Due to this trend, the Office of National Drug Control Policy (ONDCP) and the Drug Enforcement Administration (DEA) identify these three states as belonging to the "Marijuana Seven" (M7), a list of the top seven states where illicit marijuana cultivation frequently takes place (ONDCP, 2006). This pattern 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 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 in 2008 (NDIC, 2011) to 67 by 2011 (DHS, 2011). In 2016, Drug Trafficking Organizations (DTO) were identified as operating within 72 national forests (USFS, 2016).

The scale of this issue in US national forests has resulted in significant ecological impacts including the removal of native vegetation (Burns-Edel, 2016; CCLT, 2017), diversion of natural waterways (Bouchard et al., 2013; 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 ecological impacts, illicit cannabis cultivation has also affected the management goals of national forests with organized crime syndicates threatening the safety of forest visitors, researchers, and US Forest Service employees. Due to these safety concerns, research 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). Furthermore, the costs of

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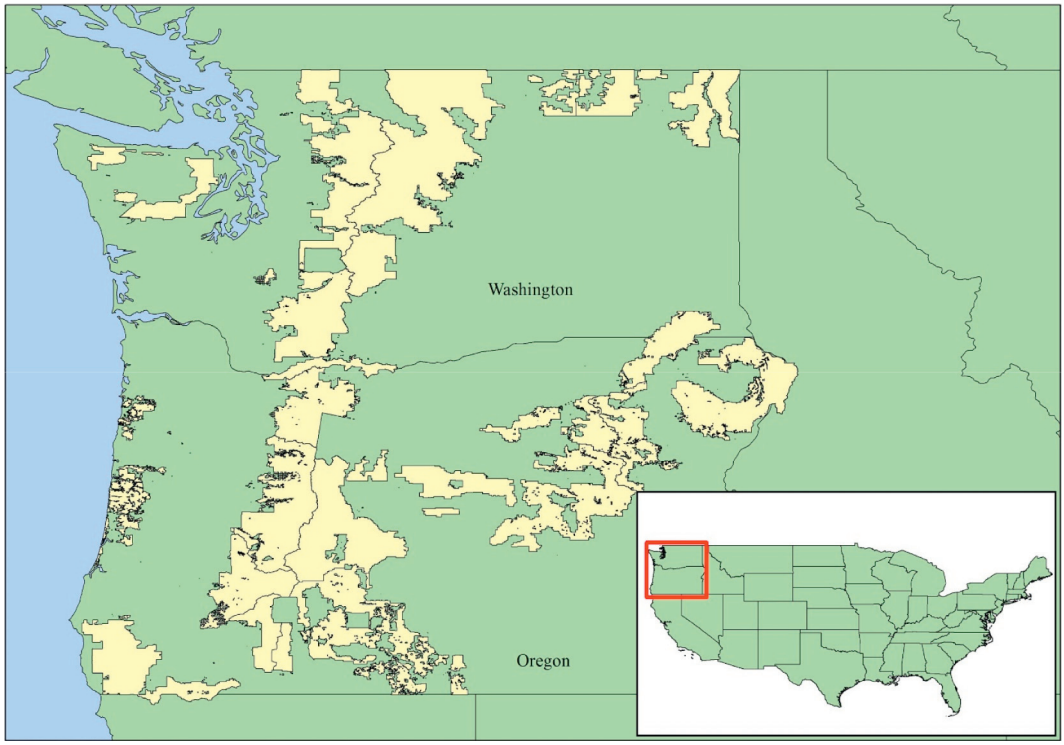

Sources: Natural Earth 2018; US Forest Service 2018

Fig. 1. Map of the Pacific Northwest showing national forests (beige). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Sources: Natural Earth 2018; US Forest Service 2018.

eradication and remediation efforts are substantial (CCLT, 2017), potentially diverting resources and financial support from other projects and programs pursued by the Forest Service (FS).

2. Theoretical framework

With illicit cannabis cultivation on public lands persisting despite law enforcement efforts, rational choice theory best explains this phenomenon (Bouchard et al., 2013; Koch et al., 2016), and assumes that criminals actively engage in decisions concerning illegal behavior based on self-interest (Cornish and 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 and 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 and Clarke, 1987), leading to the concept of crime displacement.

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 displace their criminal behavior to other times, geographical areas, methods, targets, or offenses (Reppetto, 1976; Hesseling, 1994). Crime displacement has been noted as a possible effect of law enforcement efforts within a variety of crimes (Blasiak et al., 2015), but is particularly prevalent within the illegal drug trade (Sherman, 1990; Hesseling, 1994). This has given rise to the "balloon effect", i.e. when law enforcement places pressure in one geographic area, the drug trade simply bulges out with increased intensity in another location (Madsen, 2007). Thus, 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 (Gallupe et al., 2011; Nguyen et al., 2015), a pattern that can be noted in the history of cannabis cultivation in the western United States (Corva, 2014). This spatial displacement has pushed marijuana cultivation into large national forests with plenty of forest cover that are sparsely populated and difficult for law enforcement to fully patrol.

Given the observable crime displacement associated with law enforcement and eradication efforts of cannabis, a growing number of researchers have criticized prohibition as driving environmental degradation (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). We address this deficiency by investigating various factors, including the role of cannabis legalization in Washington and Oregon, on cannabis grow sites in national forests in these states from 2004 to 2016.

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, two main mechanisms were utilized. First, a series of regression analyses were performed utilizing a model based on the principles of a rational choice framework (Bouchard et al., 2013; Koch et al., 2016). 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. Thus, structured questions were subsequently sent to the US Forest Service, given their expertise and everyday experiences managing national forests, 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.

3.1. Study area

The Pacific Northwest, composed of Washington and Oregon was selected as the area of interest for this study (Fig. 1). 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 2018 (BCC, 2018). Given that many of the possible effects legalization may have on illicit cultivation are contingent on fully operating and functioning legal markets (Caulkins and Bond, 2012; O'Hare et al., 2013), detection of potential outcomes in California would be difficult. In contrast, Washington voted to legalize recreational cannabis in 2012 with commercial sales beginning in July of 2014 (WALCB, 2014), and legal sales of recreational cannabis in Oregon began in October of 2015 after approving Ballot Measure 91 in 2014 (OLCC, 2015). In addition, with the bulk of research conducted on national forests 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

Both Bouchard et al. (2013) and Koch et al. (2016) determined that illegal cannabis cultivation decisions largely fit within a rational choice framework and thus 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 well as many of the same independent variables within this study's empirical model.

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. 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, state specific regressions for Washington and Oregon were conducted.

Due to the various ecological concerns regarding cannabis cultivation in national forests, three dependent variables were considered in these models: the annual number of discovered illegal cannabis grow sites in national forests, the annual number of eradicated plants, and the number of cannabis plants found per individual grow site. Consideration of all three variables provides a means to investigate multiple trends, including aspects such as cultivation density, which would not necessarily be captured otherwise.

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, this study considered legalization in Washington to occur in 2013, as opposed to November of 2012, and legalization in Oregon was defined as commencing in 2015. A breakdown of these dummy variables can be found below:

β_1 WA Recreational Cannabis Legalization = 1 if Year $\geq$ 2013

β_1 = 0, otherwise

β_2 OR Recreational Cannabis Legalization = 1 if Year $\geq$ 2015

β_2 = 0, otherwise

These dummy variables were defined by the vote to legalize recreational cannabis, prior to the start of commercial sales, as this study is open to the possibility that the anticipation of legal markets may have possibly been enough to elicit change in cannabis cultivation patterns. For example, in response to upcoming changes, growers in the illegal market may begin a transition into the legal marketplace, including the application for permits and other legal processes, thereby decreasing or halting their illegal activities altogether. As rational actors, growers may wish to reduce their chances of encountering legal trouble prior to the opening of legal cannabis markets if they wish to transition into them. Thus, defining these dummy variables by the date of commercial sales may place limits on this study's ability to detect possible effects that legalization of recreational cannabis may pose.

3.2.1. Washington model

Y_1 Annual Number of Discovered 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 = $\beta_0 + \beta_1$ Recreational Cannabis Legalization (Washington State) + β_2 Cannabis Price + β_3 USFS Law Enforcement and Investigations Annual Budget + β_4 Annual Number of Local and State Law Enforcement Personnel + β_5 Unemployment Rate + β_6 Poverty Rate + β_7 Gross State Product + ε.

3.2.2. Oregon model

Y_1 Annual Number of Discovered 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 = $\beta_0 + \beta_1$ Recreational Cannabis Legalization (Oregon) + β_2 Cannabis Price + β_3 Law Enforcement Density + β_4 USFS Law Enforcement and Investigations Annual Budget + β_5 Annual Number of Local and State Law Enforcement Personnel + β_6 Unemployment Rate + β_7 Poverty Rate + β_8 Gross State Product + β_9 Population Density + ε.

With cannabis cultivation in national forests being an illegal activity of clandestine nature, the model developed relies on the available data concerning grow sites discovered by law enforcement personnel. Although there are certainly illegal marijuana grow sites that remain undetected within US national forests, it is difficult to account for these as estimates on their abundance can vary considerably (ONDCP, 2012). Thus, this study assumes that relying solely on data of discovered instances remains the best proxy for the purposes of this research.

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 (LEI) division. It should be noted that a small number of the grow site coordinates provided by the US Forest Service fell outside of national forest boundaries. However, due to the extremely close proximity these coordinates had to national forest lands, they were designated as belonging to the national forest closest to them. Given the inclusion of these coordinates in the US Forest Service LEI data set, the US Forest Service must consider these sites as significantly impacting lands within national forest jurisdiction. Data on the price of cannabis was collected from the Western States

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

Variable	Description	Scale	Data source
Annual number of discovered illegal cannabis grow sites in Pacific Northwest national forests	Number of discovered grow sites in national forests per year from 2004 to 2017	Exact coordinates; Google Earth Pro[a] used to locate which national forest each site was discovered in	US Forest Service via Freedom of Information Act request (unpublished data)
Annual number of eradicated illegal cannabis plants in Pacific Northwest national forests	Data on the number of plants at each discovered grow site in Pacific Northwest national forests from 2004 to 2017	Exact coordinates; national forest	US Forest Service via Freedom of Information Act request (unpublished data)
Number of cannabis plants found per grow site in Pacific Northwest national forests	The scale of each discovered grow site in Pacific Northwest national forests from 2004 to 2017	Exact coordinates; national forest	US Forest Service via Freedom of Information Act request (unpublished data)
Law enforcement density	Number of sworn law enforcement officers divided by national forest area	National forest	US Forest Service via Freedom of Information Act 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	Western States Information Network via special request (unpublished data)
Unemployment rate	Annual averages of the percentage of labor force unemployed from 2004 to 2016	State/county	US Bureau of Labor Statistics (2005–2018)
Poverty rate	Total county population living in poverty (%) from 2004 to 2016	State/county	US Bureau of the Census, Small Area Income and Poverty Estimates program (2004–2015, 2017)
Gross state product	Gross domestic product by state in millions of dollars from 2004 to 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
US Forest Service 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	US Forest Service (2005–2018)
Annual number of local and state law Enforcement personnel	Total annual number of police officers/ "persons with power of arrest" who are employed full-time	State	US Bureau of the Census, Annual Survey of Public Employment and Payroll program (2004–2017)

[a] Given the purposes of this procedure, simply to locate the national forest and state in which each grow site was discovered, the potential location inaccuracies of Google Earth Pro are found to be insignificant (Potere, 2008; Farah and Algarni, 2014).

Information Network (WSIN), a division of Regional Information Sharing Systems (RISS). The reported data were 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.

As the WSIN Drug Pricing Reference Guide is produced every two years, biennial data was available from 2004 through 2016. Price estimates were determined for odd years by calculating the mean of prices from adjacent years. Data on additional explanatory variables, including economic factors and population density, were collected from a variety of government sources available to the public (Table 1).

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 these variables, data collected for a certain year had to be applied to all years considered in the regression analyses, a practice that has been utilized in related studies with similar methods (Koch et al., 2016). 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 2000s, suggesting that only very minor discrepancies, if any, should be expected from this process.

Although the US Forest Service was able to provide data from 2004 to 2017, in order to ensure that all explanatory variables were included in the regressions, observations in 2017 were excluded as 2017 data on numerous independent variables was not yet available at the time of study. Thus, the regressions were limited to data from 2004 to 2016. In addition, no illegal grow sites were discovered in Washington's national forests for two years (2004, 2013) within this time frame. To account for these years, two additional observations were included to denote a lack of discovered grow sites (value = 0), and thus cannabis plants, for 2004 and 2013 in Washington. The addition of these 0 value observations, which lack a specific geographic location, required all explanatory variables to be utilized at the state level in the Washington regression. This mandated the removal of law enforcement density and population density from this state specific model as these variables were treated as constant across time, due to the data limitations mentioned above, with variations in location being the only source of fluctuation. Alternatively, Oregon has consistently had discovered grow sites in national forests every year from 2004 to 2016, and thus does not encounter the same issues when conducting a state level regression. Thus, law enforcement density in Oregon national forests and population density per Oregonian county were included in the Oregon model, resulting in slightly different state specific models as can be observed above.

3.3. Structured questions

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 categories are targeted at establishing whether illegal cannabis cultivation in national forests has had similar impacts in the Pacific Northwest as those established in previous studies, particularly from California. Questions on the effects of recreational cannabis legalization were developed to elucidate results from our regression analyses. Questions and methods adhered to an approved research ethics protocol and were pre-approved by the United States Forest Service (Appendix A).

Due to the nature of this research, with cannabis remaining illegal at the federal level as a schedule 1 drug (Levy, 2014), and the US Forest Service being an agency of the federal government, opinions and accounts from individual Forest Service employees were unable to be collected as authorization for an interview process of this format could not be granted. Upon review of the questions, the US Forest Service decided that they could best answer with a single regional response

Table 2
Descriptive statistics of illegal grow sites and individual cannabis plants discovered in Washington and Oregon national forests (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	387,178	556,527	943,705
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

from the US Forest Service Law Enforcement and Investigation's Pacific Northwest office. Thus, all responses should be considered as representative of the organization's official outlook, and not necessarily exemplary of the possibly varying individual opinions spanning across the agency's thousands of employees. This exchange was conducted remotely via email with the Assistant Special Agent in Charge of the US Forest Service Law Enforcement and Investigation's Pacific Northwest office.

4. Results

Data provided by the US Forest Service present a total of 245 discovered marijuana cultivation sites in national forests in the Pacific Northwest from 2004 to 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.

The data show a decrease in the number of discovered grow sites in national forests after the vote to legalize recreational cannabis in Washington and Oregon (Fig. 2). In fact, officials found an average of 9.2 cultivation sites in Washington national forests per year from 2004 to 2012, and only 1.6 per year after the vote to legalize recreational cannabis from 2013 to 2017. 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 13.00 sites found per year from 2004 to 2014, and 3.67 sites per year after the vote from 2015 to 2017.

However, the number of discovered grow sites peaked in 2008 and had been decreasing from that point until the vote to legalize recreational cannabis in Washington in 2012 (Fig. 3). 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 to 2017, the annual level of discovered grows remained much lower than 2005–2011.

4.1. Regression analyses

An initial multivariate multiple regression (MMR) was run (STATA/IC 14.2) to determine which explanatory variables were statistically significant ($p < .05$) for each dependent variable. In order to reduce multicollinearity and heteroscedasticity, three individual regressions were subsequently run, one for each dependent variable in which only significant explanatory variables were included and robust standard errors were utilized. After accounting for multicollinearity and heteroscedasticity, the model was best able to predict the annual number of discovered grow sites for both states. Given that this likely to be the most accurate parameter in representing the actual abundance of illegal cannabis operations in national forests, these are the results reported below.

4.1.1. Washington

The model is best able to predict the annual number of discovered grow sites in Washington national forests with an R-squared value of 0.9082 ($F(4,87) = 692.24$, $p < .001$; Table 3). Further testing proved multicollinearity to be absent with all variance inflation factors (VIF) < 10, and tolerance levels > 0.1.

The annual number of local and state law enforcement officers as well as the price of illegal cannabis are found to have a positive relationship with the dependent variable of interest. The state poverty rate and unemployment rate are found to negatively influence the

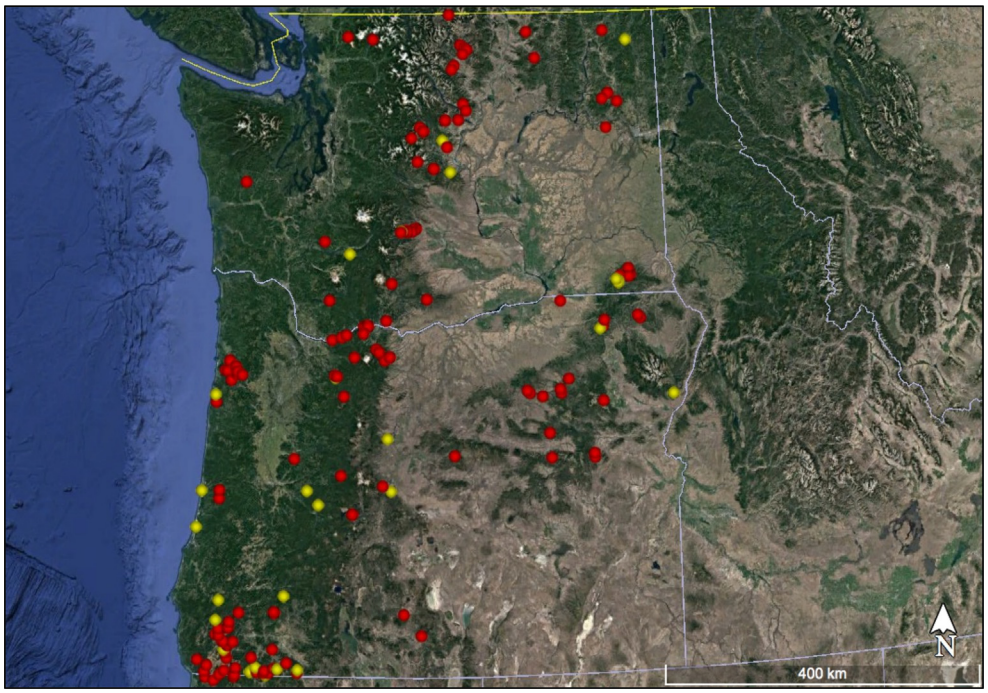

Fig. 2. Discovered marijuana grow sites in national forests in the Pacific Northwest before (2008–2012; red dots) and after cannabis legalization in Washington (2013–2017; yellow dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

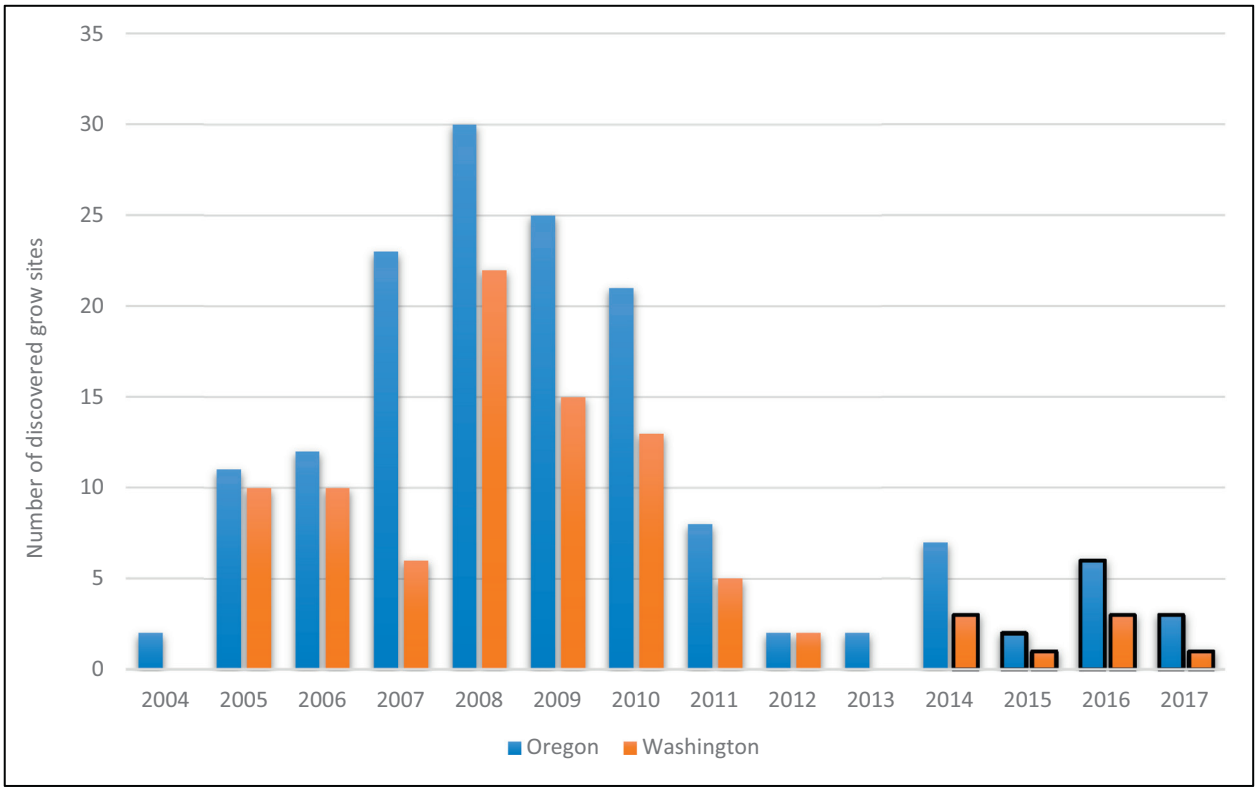

Fig. 3. Number of marijuana grow sites discovered in national forests in the Pacific Northwest (2004–2017).
Black bordered bars represent post-legalization.
Source: US Forest Service Law Enforcement and Investigations by Freedom of Information Act request.

Table 3
Washington regression for annual number of discovered grow sites (n = 92). Only significant variables included, robust standard errors.

R-squared = 0.9082			
Independent variable	Standardized coefficient	Robust standard error	P > | t |
Annual number of local & state law enforcement officers	1.011183	0.0021511	0.000
Poverty rate	−0.4342564	3.166948	0.022
Price of illegal cannabis	0.320026	0.0082715	0.001
Unemployment rate	−0.2426039	0.8538321	0.036

Table 4
Oregon regression for annual number of discovered grow sites (n = 151). Only significant variables included, robust standard errors.

R-squared = 0.9140			
Independent variable	Standardized coefficient	Robust standard error	P > | t |
Poverty rate	−0.8057791	0.3518184	0.000
Gross state product	0.647897	0.0000514	0.000
Marijuana price	0.6447108	0.0010584	0.000
Vote to legalize cannabis in Oregon	−0.6352913	3.8301	0.000
Unemployment rate	−0.1341372	0.0740814	0.000

number of discovered grow sites in Washington national forests.

4.1.2. Oregon

As found in the Washington regression, 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 ($F(5,145) = 512.79$, $p < .001$; Table 4). Further testing proved multicollinearity to be absent (VIF < 10).

Similar to the Washington regression, unemployment and the poverty rate are both found to have a negative relationship with the annual number of discovered grow sites in Oregon. Both gross state product (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. Structured questions

4.2.1. Characteristics of grow sites

The US Forest Service Law Enforcement and Investigations unit for the Pacific Northwest supports 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 suggests that marijuana growers often prefer locations that are remote, yet with close enough road access to allow ingress and egress, proximate 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 [0.4–8.1 ha]". 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 finds 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 … 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 notes the dangers presented by marijuana cultivation sites to both visitors and employees. Growers are often observed 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", further 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:

> "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 [National Forest Service] (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."

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, and 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 DTOs, will remain a significant and escalating challenge into the foreseeable future:

> "Marijuana cultivation by Drug Trafficking Organizations on public lands, and National Forest System 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 responses to the structured questions 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 observed previously, and 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 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

5.2.1. The annual number of discovered grow sites in Washington

When considering the number of discovered grow sites in Washington national forests, both unemployment and poverty rates demonstrate a negative effect. 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, thereby suggesting that a positive relationship

should occur (Koch et al., 2016). Thus, our findings challenge this conventional understanding, and instead suggest that there is a decline in the amount of grow sites in national forests when economic conditions are poor. This may be because as unemployment and poverty rates rise the size of the local cannabis consumer base declines as individuals have less ability to afford recreational marijuana, and thus a reduction in cannabis production occurs as growers respond to local market pressures. This explanation is further supported by the stronger negative effect displayed by the poverty rate, suggesting that as economic conditions worsen, and individuals fall from unemployment to below the poverty line, the demand for recreational cannabis declines further. 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. As prices rise, there is incentive for a greater level of production as to capitalize on higher profits, and thus the number of 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 and Garrod, 2014), and an increase in production represents supply rising to match shifting demand levels.

Lastly, the number of local and state law enforcement personnel is found to be positively related to the annual number of discovered grow sites in Washington national forests. This is likely due to two possible mechanisms. As suggested by the US Forest Service in their responses to the structured questions, local and state personnel often cooperate and share resources with the Forest Service LEI division, and a greater number of these cooperating personnel may simply strengthen efforts to detect illegal operations. However, given that local and state law enforcement primarily act outside of federally operated public lands, drawing from the concept of crime displacement, the addition of more officers may incentive illegal cannabis operations to move into national forests.

5.2.2. Annual number of discovered grow sites in Oregon national forests

When considering the annual number of discovered grow sites in Oregon national forests, unemployment and poverty rate are again found to both demonstrate a negative relationship. This supports the idea that growers respond to local economic conditions and that a significant portion of illicit cannabis grown in Oregon national forests is destined for local consumers. In addition, as new growers are not entering the scene when local economic conditions are unfavorable, it may be the case that much of the cannabis produced in national forests within these states is controlled by DTOs, as suggested by the US Forest Service.

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 (GSP), which is thought of as a broad indicator of economic conditions (Salazar et al., 1997). Increasingly favourable economic conditions may allow more individuals to purchase recreational cannabis, while already established consumers are able to purchase more, thereby increasing demand. Thus, the increase in number of grow sites associated with rising GSP may indicate supply catching up to a changing demand.

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

5.2.3. The role of US Forest Service Law Enforcement and Investigations

Although LEI budget was found insignificant in the regressions presented, the US Forest Service LEI's access to resources may still impact their ability to discover grow sites in Pacific Northwest national forests. In the response to the structured questions, 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 for both states, the regressions ran with the annual number of eradicated plants as the dependent variable found LEI budget to be significant and positive.

In addition, law enforcement density of LEI officers within national forests is found to be insignificant. 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). With this in mind, it is likely that the demonstrated insignificance of this variable 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.

5.2.4. Legalization as a potential solution

Legalization of recreational cannabis is found to contribute to a decline in illegal marijuana cultivation in Oregonian national forests. Within their response to the structured questions, 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 as well as state and local law enforcement officers, who in part represent outside support and resources, were included in the regression model. Despite the inclusion of these measures, legalization in Oregon remains significant, indicating that legalized recreational cannabis has been instrumental in declining illegal marijuana production.

However, when taken together, the results of these regressions present a mixed picture of the effects of legalization, with legalized cannabis remaining insignificant in Washington. It should be noted that differences between the state models, specifically the exclusion of law enforcement density and population density in the Washington model due to data limitations, may have contributed to differences in results. On the other hand, the difference in results between these states may be due to a number of state specific characteristics. Perhaps crucially, Washington places a 37% tax on commercial sales of cannabis, a burden that is largely paid for by consumers, while Oregon has a considerably smaller tax rate of 17% (Hansen et al., 2017). In fact, Hansen et al. (2017) suggested that consumer marijuana demand is price elastic in the medium to long-term, and as Washington has incurred additional taxation total sales of commercial cannabis has decreased, indicating that Washington is close to the peak of the Laffer curve in its maximization of taxation revenue (Hansen et al., 2017). This difference in taxation may incentivize some consumers to return to the illicit market where the cost of cannabis may be cheaper, thus negating some of the beneficial effects legalization may be able to provide with regards to illegal production, as is seen in Oregon (Caulkins and Bond, 2012). In addition, 15% of recreational cannabis tax revenue in Oregon is accorded to state law enforcement (OLCC, 2018), while the tax revenue generated in Washington has largely been allocated to health, education, and social programs, with no significant portion specifically allotted to law enforcement services (WAST, 2018). Thus, while legalization may demonstrate promise, the way in which liberalized policies are enacted may be crucial in determining the end result.

In addition, it is clear that despite apprehensions that cannabis legalization may provide a social and economic climate that allows for the illegal market to flourish, through drug tourism for example (Koch et al., 2016), this appears to have not been the case in the Pacific

Northwest.

6. Conclusion

In conclusion, the legalization of recreational cannabis is significantly correlated with a reduction in the annual number of discovered grow sites in national forests in Oregon, while found insignificant in Washington. This study posits that the difference in results between states may be due to variance in legalization policies, and supports further investigation of these differences. Given the decrease in abundance of marijuana grow sites in Oregon 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 Oregon 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 (Bouchard et al., 2013; Koch et al., 2016). With many illegal cannabis grows in Pacific Northwest national forests suspected of being operated by DTOs, 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 the annual number of grow sites in Washington and 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.

Liberalized marijuana policies are seemingly sweeping across the US with recreational cannabis currently legalized in nine states, from Alaska to California to Massachusetts. Recently, Canada became the second country in the world to legalize recreational cannabis nationwide after Uruguay. The results of this study suggest that for areas impacted by illegal cultivation of cannabis on public and protected lands, legalization may assist in decreasing the proliferation of this activity, and thereby serve within a broader ecological conservation strategy. However, legalization policies must actively prioritize incentives and measures that discourage the continuation of illicit production for these beneficial effects to occur. Additionally, in order to ensure that illicit production on public lands is not simply being traded for ecologically damaging legal practices, landscape specific environmental concerns should be built into recreational cannabis legalization policies.

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Declarations of interest

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Appendix A. Structured questions and responses

A.1. 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?

A.2. 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?

A.3. 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.

A.4. 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:
  - o Do you think these changes can be attributed to legalization itself? And if so, how do you think legalization has impacted this trend?
  - o 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?
  - o 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?
  - o 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:
  - o 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)?
  - o 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?

- o 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?

A.5. 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?

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