Comparison of Spatial Characteristics of *Cannabis* Agriculture and Viticulture and Associated Effects on Freshwater Resources in Mendocino County, California

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ABSTRACT

Cannabis agricultural has been described as an "agricultural frontier" in California induced by legalization and high potential profits, conditions that drive opportunistic land use and environmental degradation. In particular, concerns have been raised about the potential impacts of cannabis agriculture on freshwater resources. Many of the regions in Northern California experiencing this frontier increase are also wine-producing areas that have already raised concerns about vineyard impacts on freshwater resources since the vineyard boom of the 1990s. To compare the spatial characteristics of both kinds of agriculture in a sample of watersheds in Mendocino, CA in 2018, I used manually mapped cannabis cultivation sites collected by Van Bustic, and vineyard data from the USDA's Cropscape Data Layer (CDL). I then calculated descriptive spatial characteristics for all cultivation sites in ArcGIS and created data visualizations using R. I found that individual vineyards tend to be much larger than cannabis cultivation sites (3.04 acres and 0.098 acres respectively). There is also a larger total land area of vineyards (3190 acres) in the sample compared to cannabis (889 acres). Vineyards tend to be concentrated on low-lying land with shallow slopes, while cannabis farms are spread out across a range of locations with varying elevations and slopes. Vineyards tend to be located closer to streams and closer to critical habitat for both Coho and Chinook salmon. Using the cultivation area of each farm near streams as a proxy for the amount of bare soil on each farm, I determined that vineyards currently present more cause for concern than cannabis cultivation sites. However, erosion and runoff control methods should continue to be implemented for both kinds of agriculture to protect freshwater resources in Mendocino County.

KEYWORDS

Land Use, Vineyards, Erosion, Geospatial, GIS, freshwater

INTRODUCTION

Cannabis production is rapidly increasing in Mendocino County. Between 2012 and 2016, the total area in the county used for cannabis cultivation increased by 112% (from 2.05 km^2 to 3.94 km^2) and cannabis plants increased by 230% (from 217,270 plants to 718,842 plants) (Butsic et al. 2018). These estimates have primarily been calculated with geospatial software, as the crop's status as a federally illegal substance makes it difficult for researchers to safely and legally obtain direct field measurements (United States Department of Justice 2009, Butsic et al. 2018). Federal regulatory agencies that are generally involved in regulating agriculture, such as the USDA and the EPA, cannot legally be involved with the regulation of cannabis infrastructure (Ashworth and Vizuete 2017). While the legal status of cannabis has prevented federal regulation, it has also pushed growers to operate in rural areas, particularly in small, upper watersheds that support critical habitat for reproducing and young salmonids and other sensitive species (Bauer et al. 2015).

Vineyards experienced a similar rapid expansion in Mendocino in the 1990s, leading to the conversion of hardwood forest, conifer-dominated forest, shrubland, oak woodlands, and commercial orchards into vineyard land (Merenlender 2000). Vineyards have increasingly been located on high slopes since the 1990s because the microclimate on hillsides can lead to higher quality grapes (Merenlender 2000). These changing spatial characteristics of vineyards have long generated concerns about soil disturbance and increased sedimentation in freshwater resources (Merenlender 2000). Sedimentation greatly impacts aquatic habitat quality, and the emergence of salmonids is reduced by 50% when fine sediments exceed 30% (Kondolf 2011). Land use conversion to vineyards in Northern California has taken place in less developed areas that tend to have higher salmonid spawning substrate quality than more developed areas (Lohse et al. 2008). As a result, land use conversion to vineyards and other forms of exurban development generally have more significant effects on aquatic habitat than urban development (Lohse et al. 2008).

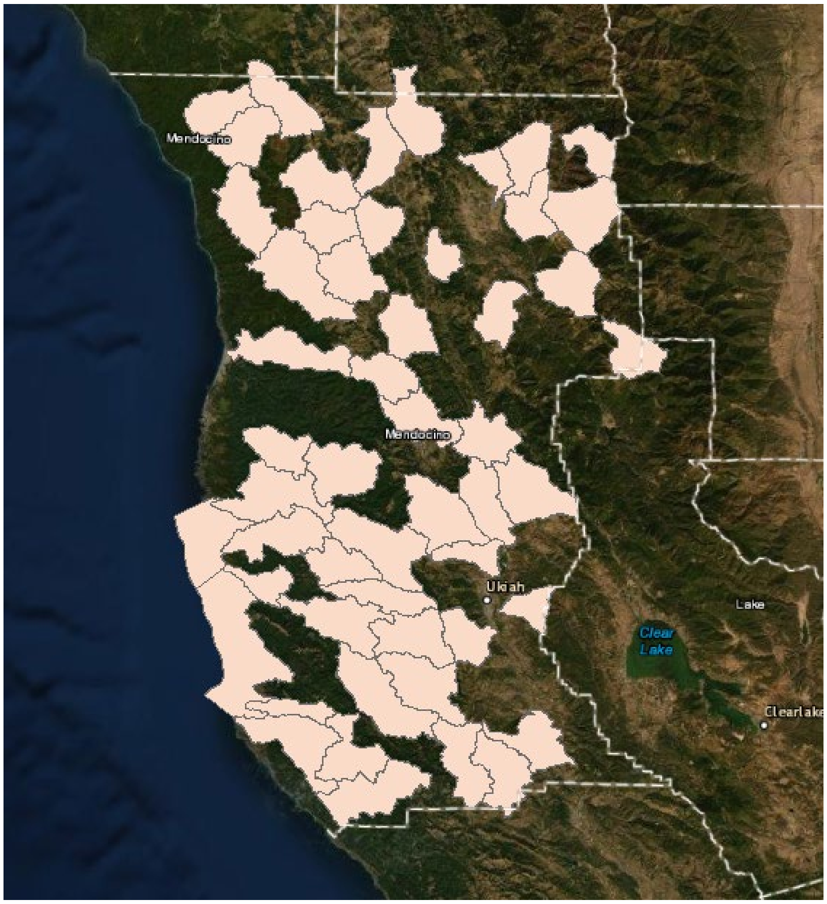
Cannabis cultivation sites' potential impact on nearby streams is concerning as well because of their spatial similarities to vineyards. Cannabis cultivation in Northern California also tends to be located in rural areas on high slopes near streams, which can lead to increased erosion in sensitive habitats (Carah et al. 2015, Butsic et al. 2018). Between 2012 and 2016, cannabis production in Mendocino and Humboldt Counties increased by 41% on steep slopes (defined as slopes greater than 30°) (Butsic et al. 2018). During the same time period, there was an 80%-116% increase in cultivation sites within 500 m of high-quality habitat for threatened and endangered salmonids (Butsic et al. 2018). Comparing the spatial characteristics of cannabis cultivation sites to viticulture will improve understanding about the scale of the environmental impacts associated with cannabis agriculture.

The objective of this paper is to develop methods for analyzing and comparing cannabis and vineyard agriculture's effects on freshwater resources and high-quality salmonid habitat in Northern California. In this paper, I determine the spatial relationships between cannabis cultivation sites and streams. I also assess whether these relationships present concern for habitat degradation within riparian areas and aquatic habitat. I expect that while cannabis cultivation sites may be located on higher slopes and at higher elevation compared to vineyards, they will be smaller and located further from high-quality salmonid habitat. This paper provides critical information on the potential land use impacts of cannabis cultivation and helps to contextualize the impacts of the industry by comparing it to another common form of agriculture in the county.

METHODS

Study site

Mendocino County is located along the north coast of California and experiences a Mediterranean climate, with cool, wet winters and hot, dry summers. The county has a high number of vineyards and cannabis cultivation sites. Other land uses in the county include orchards, other agriculture, animal grazing, timber harvest, and urban and residential development (Lohse et al. 2008). I analyzed vineyards and cannabis cultivation sites within a representative sample of watersheds in Mendocino County (the same sample used in Butsic et al. 2018). Compared to the entire county, the sample has similar elevation and land cover (Butsic et al. 2018).



Map 1. Representative sample of watersheds in Mendocino County.

Data sources

I used a manually mapped dataset of 2018 cannabis cultivation sites in Mendocino County provided by my collaborator Van Butsic, University of California, Berkeley. For vineyards, I used the USDA's Cropland Data Layer (CDL), a raster, geo-referenced, crop-specific land cover data layer created annually using satellite imagery and agricultural ground truthing. CDL has a 30 meter resolution. To conduct my analysis, I also used 1/3-arc-second digital elevation models for Mendocino County from USGS, the National Hydrography Dataset from the USGS, and an intrinsic potential dataset from NOAA (Table 1). The Intrinsic Potential dataset uses geomorphic and hydrological attributes to estimate the potential for stream reaches to provide favorable habitat characteristics for spawning and rearing, using a DEM, precipitation data, and species-specific weighting functions. The model does not predict current conditions but instead predicts the locations of favorable habitat in pristine conditions. This is important, seeing as I am primarily concerned with the potential impacts that these two different kinds of land use could be having on what would, in pristine conditions, be high-quality salmonid habitat. I specifically used this dataset to identify high-quality habitat for Coho salmon (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*), two federally protected species with endangered and threatened stocks in parts of California ("All Species Directory Page | NOAA Fisheries" n.d.).

Although the cannabis data was mapped by hand using Google Earth, the vineyard data used was from the USDA's Cropscape database, which displays agricultural crops in California at a resolution of 30 m. I conducted accuracy assessments to ensure that at least 90% of the land included in the vineyard polygons was vineyard land and at least 90% of the land not included in the vineyard polygons was not vineyard land. Both the vineyard data and the cannabis data passed these assessments and had approximately the same level of accuracy, despite the large cell size of the vineyard data.

Table 1. Spatial variable descriptions and sources.

Variable	**Description**	**Source**
Cultivation area	Total cultivation area at a site	Manually mapped farm area for cannabis and USDA Cropland Data Layer for vineyards (cross-referenced to parcel)
Parcel size	Average parcel size of agricultural sites	Manually mapped farm area for cannabis and USDA Cropland Data Layer for vineyards(cross-referenced to parcel)
#Parcels/site	Number of parcels that farms fall into	Parcel data (Provided by collaborator Ted Grantham)
Slope	Slope at centroid of farm	USGS 1/3-arc second digital elevation model
Elevation	Elevation at centroid of farm	USGS 1/3-arc second digital elevation model
Distance to stream	Distance from stream to farm edge	Stream hydrography (Provided by collaborator Ted Grantham)
Distance to high-quality coho salmon habitat	Distance from stream to farm edge	NOAA Intrinsic Potential
Distance to high-quality Chinook salmon habitat	Distance from stream to farm edge	NOAA Intrinsic Potential

Spatial analyses

I used ArcMap 10.7 to conduct all spatial analyses. First, I converted the vineyard data to vector format (Raster to Polygon Tool). I then calculated the average and sum of the Shape_Area fields for both vineyards and cannabis to determine average and total cultivation area. I created slope and elevation layers using a DEM and Surface Analysis tools (Slope and Elevation Tools respectively). I calculated the slope and elevation of each site by finding the centroids and using the Extract Values to Points Tool ("How To: Locate polygon centroids and convert them to points in ArcView and ArcEditor" n.d.). To calculate distance to the nearest stream, I used the Near Tool to determine the distance between each agricultural site and the nearest FlowLine object in the stream hydrography dataset. For each species, I used a species-specific IP value of greater than or equal to 0.7 to identify high-quality salmonid habitat (Butsic et al. 2018). I then used the Near Tool to determine the distance between each agricultural site and the nearest high-quality salmonid habitat site for each species. To test the significance of differences between each type of agricultural for all spatial characteristics, I ran Mann-Whitney-Wilcoxon tests.

Determining a significant distance from streams

The California State Water Resources Control Board has developed strict regulations on cannabis cultivation and its potential effects on freshwater resources. Cannabis cultivation sites must be 50 feet from ephemeral watercourses, 100 feet from intermittent watercourses, or wetlands, and 150 feet from perennial watercourses, waterbodies (e.g. lakes and ponds), or springs ("Leading the Way in Sustainable Practices: How the Cannabis Cultivation Policy Is Rethinking Water Management in California" n.d.). Based on these policies, I considered 150 feet to be an adequate distance for protecting high-quality salmonid habitat and compared the number and percent of farms with at least one edge within 150 feet to understand the potential effects of each kind of agricultural activity on salmonid habitat throughout Mendocino County.

RESULTS

As I anticipated, I found that vineyards tend to be much larger than cannabis cultivation sites. I also found there was a larger land area of vineyards within the sample compared to cannabis. Vineyards tend to be located on much shallower slopes and at much lower elevations. Vineyards are, on average, closer to streams and closer to critical habitat for both Coho and Chinook salmon (Table 2).

Table 2. Comparison of spatial characteristics of cannabis cultivation sites and vineyards. Reported values are means ± standard error. W- and p-values are the results from Mann-Whitney-Wilcoxon tests.

	Cannabis Cultivation Sites (N=9058)	**Vineyards (N=862)**	**W-value**	**p-value**
Total Acreage in Sample	889 acres	3190 acres	N/A	N/A
Avg. Size	0.098 (±0.004) acres	3.04 (±0.196) acres	100418	<2.2e-16*
Avg. Slope (at farm centroid)	3.04 (±0.027) degrees	0.89 (±0.049) degrees	5628273	<2.2e-16*
Avg. Elevation (at centroid)	444.93 (±2.755) meters	240.45 (±4.491) meters	5743224	< 2.2e-16*
Avg. Parcel Size	45.47 (±0.870) acres	35.84 (±1.836) acres	1865787	0.3737
Avg. Parcels/Farm	1.20 (±0.005)	1.64 (±0.044)	3007269	< 2.2e-16*
Avg. Distance to Stream	711 (±6.518) feet	541 (±17.11) feet	4588154	< 2.2e-16*
Avg. Distance to High-Quality (IP>=0.7) Coho salmon habitat	31,349 (±358.0) feet	27,737 (±745.9) feet	4280579	2.772e-06*
Avg. Distance to High-Quality (IP>=0.7) Chinook salmon habitat	7,845 (±71.0) feet	4,636 (±157.7) feet	5071012	< 2.2e-16*

I found that 99.2% of all cannabis grows in the sample are under 1 acre, meaning only 0.8% of cannabis grows are over 1 acre (Figure 1a). Meanwhile, 64.9% of vineyards are above 1 acre (Figure 1a). Vineyards tend to be concentrated on low-lying land with shallow slopes, while cannabis farms are spread out across a range of locations with varying elevations and slopes (Figure 1b-c).

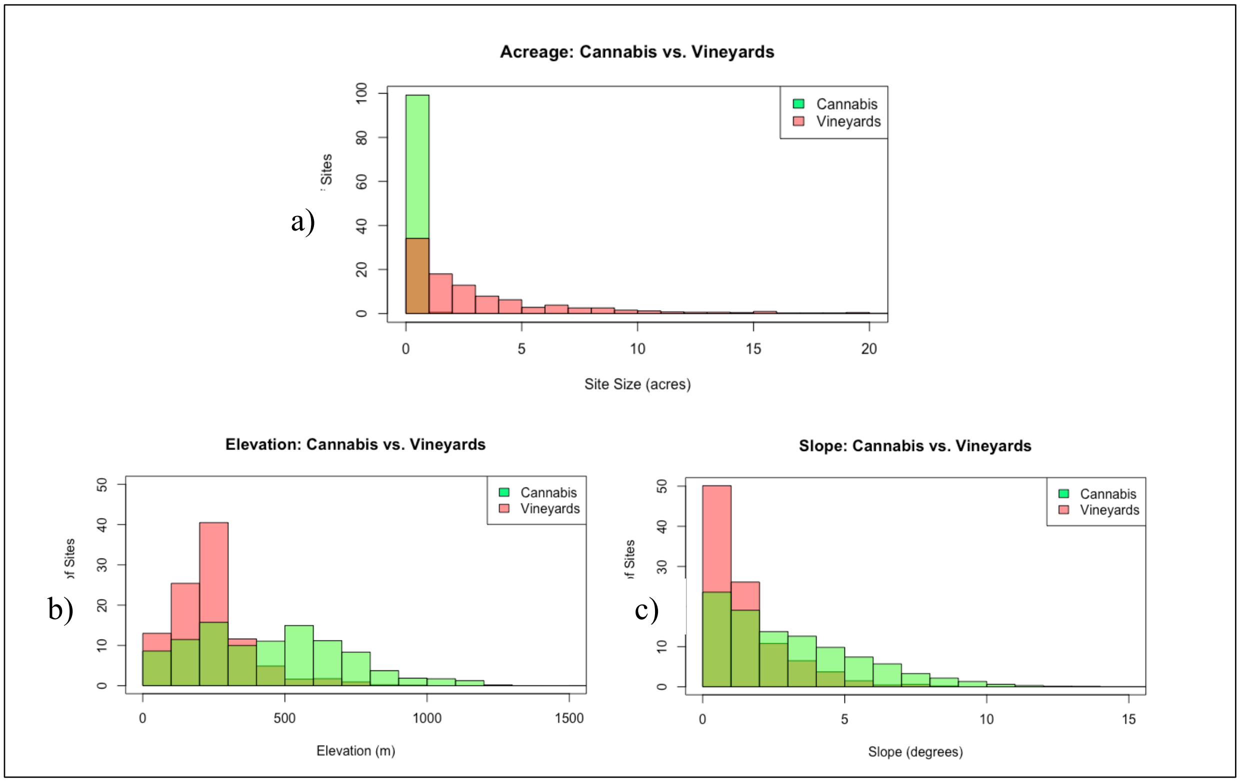


Figure 1. Percent of individual sites in relation to a) acreage, b) elevation at centroid, and c) slope at centroid for cannabis cultivation sites and vineyards. The y-axis on the acreage graph has a larger range [0,100] than the elevation and slope graphs [0,50].

A higher percentage of sampled vineyards (23.1%) lie within 150 feet of streams compared to cannabis cultivation sites (15.0%) (Figure 2a). There is also a greater total acreage of vineyards (1132.9 acres) within 150 ft compared to cannabis cultivation sites (30.5 acres) (Figure 2b).

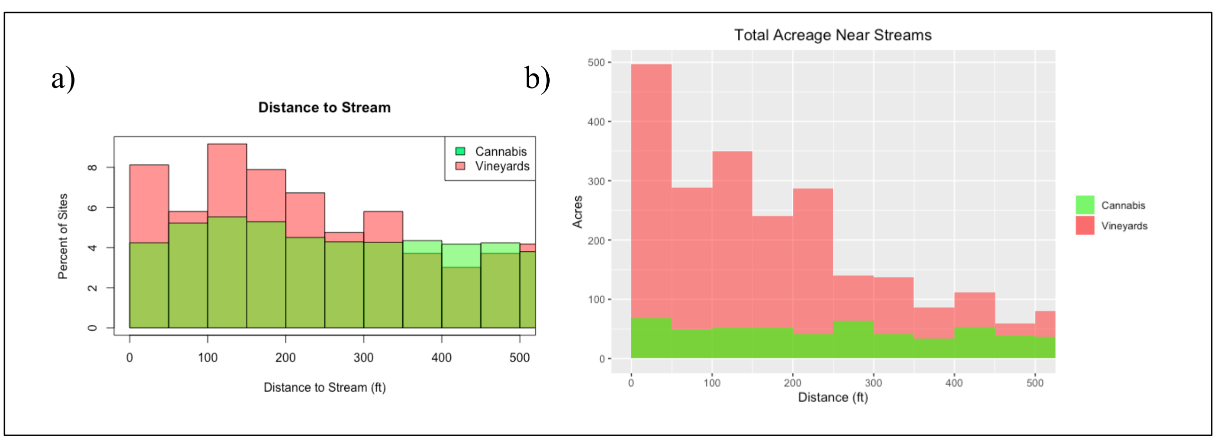


Figure 2. Distance to stream for cannabis cultivation sites and vineyards by a) percent of sites and b) total acreage of sites.

Vineyards and cannabis have similar percentages of sites within 150 feet of high-quality Coho salmon habitat (1.16% and 0.84% respectively) (Figure 3a). There is, however, a much greater total acreage of vineyards (34.7 acres) within 150 ft compared to cannabis cultivation sites (8.9 acres) (Figure 3b).

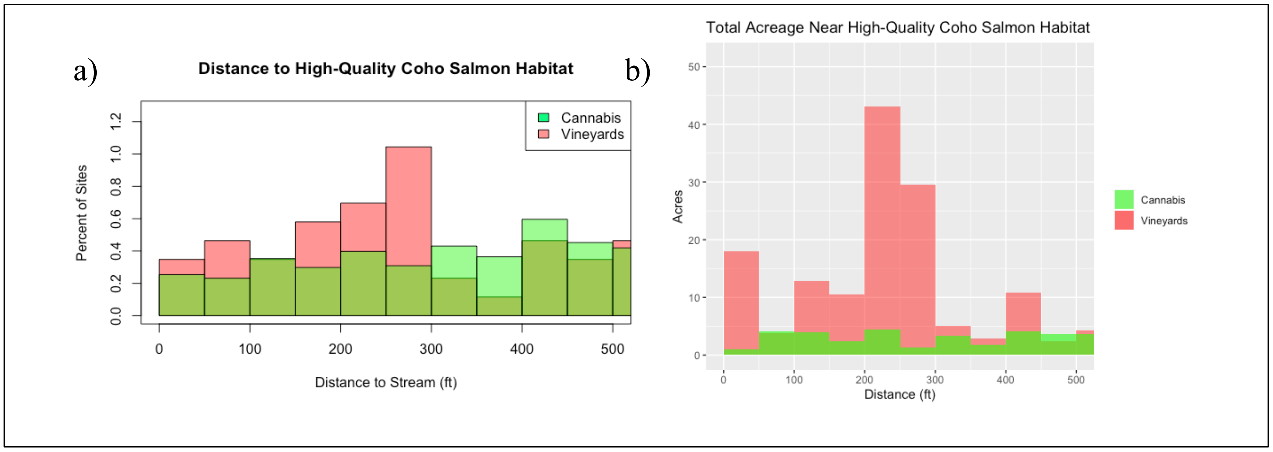


Figure 3. Distance to high-quality Coho salmon habitat for cannabis cultivation sites and vineyards by a) percent of sites and b) total acreage of sites.

A higher percentage of sampled vineyards (4.87%) lie within 150 feet of high-quality Chinook salmon habitat compared to cannabis cultivation sites (1.20%) (Figure 4a). There is also a much greater total acreage of vineyards (242.4 acres) within 150 ft compared to cannabis cultivation sites (12.9 acres) (Figure 4b).

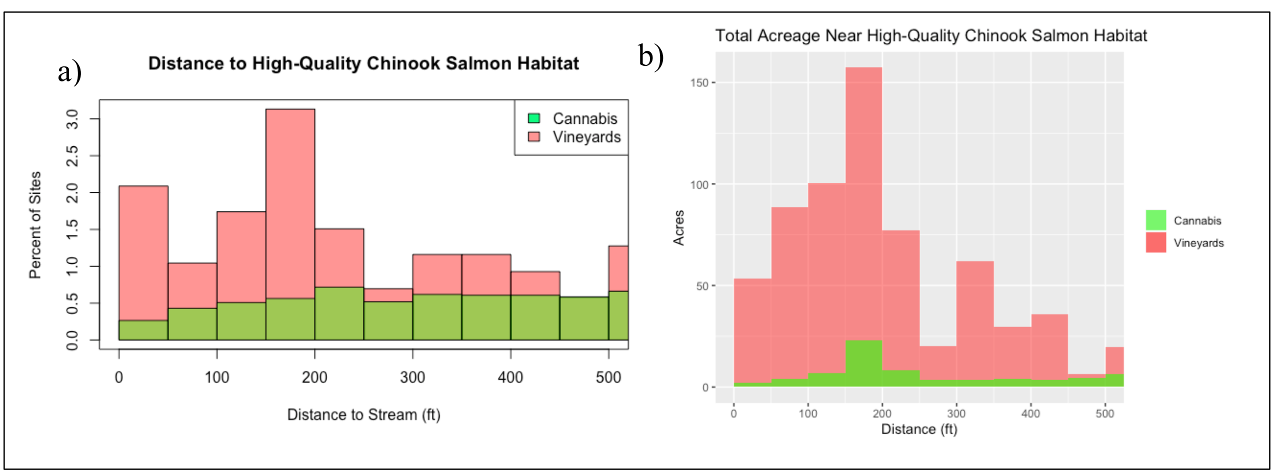


Figure 4. Distance to high-quality Chinook salmon habitat for cannabis cultivation sites and vineyards by a) percent of sites and b) total acreage of sites.

DISCUSSION

Although stream diversions associated with cannabis agriculture have been studied and resulting policies have forced legal cannabis growers to stop diverting surface water during the growing season (April-October), there has been less research on the potential for erosion and agrochemical runoff (Dillis et al. 2019). Using spatial data, I determined that while cannabis cultivation sites tend to be smaller than vineyards and occupy a smaller total area across Mendocino County, they are more likely to be located on steep slopes and at high elevations. Vineyards are located closer to streams and closer to high-quality salmonid habitat. There is also more total vineyard area close to high-quality habitat for both Chinook and Coho salmon compared

Spatial variables and freshwater resources

The amount of bare soil on an agricultural field is the primary factor affecting erosion rates from agricultural fields, while slope is considered a secondary factor (Battany and Grismer 2000). Field slopes between 4-16% (2.3-9.1 degrees) have a minor impact on soil losses according to rainfall simulation experiments conducted on a commercial vineyard in nearby Napa County (Battany and Grismer 2000). Only about 2.4% of CCSs (21.5 acres) throughout the sample are located on slopes above 9 degrees and only about 0.4% of CCSs (3.82 acres) in the sample are located within 150 feet of streams and located on slopes above 9 degrees. A greater total acreage of vineyards (1132.9 acres) lies within 150 ft of streams compared to CCSs (30.5 acres). The same trend is present for agricultural sites near high-quality salmonid habitat.

In this paper, I consider cultivation area of sites near high-quality habitat to be a proxy for the amount of bare soil, although there are limitations to this assumption because both kinds of agricultural land could be using cover crops for erosion control. In addition, there are challenges to mitigating the environmental impacts of the cannabis industry in California, as growers continue to operate illegally (Short Gianotti et al. 2017). However, in terms of spatial characteristics, vineyards' large size and proximity to streams (including those with high-quality salmonid habitat) present more cause for concern than the spatial characteristics of cultivation sites.

All data presented in this paper should be interpreted as a current snapshot of the landscape. The difference in spatial distribution between the two crops types is likely due to strict regulations on legal cannabis growth in the state and the history of vineyards occupying prime agricultural land near large streams prior to the boom in the cannabis industry. This is supported by the fact that the top zoning district where vineyards occur is agricultural land (63.59% of vineyards), while only 9.29% of cannabis farms lie on agricultural land (Table A1-2). As cannabis agriculture expands, there may be large-scale conversions of current vineyard land to cannabis agriculture, similarly to how prime agricultural land became occupied by vineyards in the 1990s. Changes in the spatial characteristics of both industries should be monitored so that funding and outreach can be allocated to all agricultural operations near high-quality habitat.

Management concerns and impacts on freshwater resources

Both vineyards and cannabis cultivation sites tend to use pesticides, herbicides, and other agrochemicals that could potentially degrade aquatic habitat (Baughman et al. 2000, Louchart et al. 2001, Silva et al. 2011, Taylor and Birkett 2020). Pesticide application can lead to intense, event-based contamination of surface waters at the field and watershed scales (Louchart et al. 2001). The frequency of detection and the total concentration of pesticides tend to be higher in surface water than groundwater, largely a result of overland runoff. Pesticides and other agrochemicals may be lethal, especially for juvenile salmon (Moyle et al. 2017). Even if these chemicals are sublethal, they can make salmonids more vulnerable to disease, predation, and other stresses (Moyle et al. 2017).

Agricultural development can also lead to erosion, as land is cleared and soil is exposed to wind and precipitation. When agricultural activities are located near streams, wind and precipitation can deliver organic sediments and nutrients to streams, leading to an increase in decomposition rates and depleted oxygen levels (Thompson and Larsen 2004). Increased sediments in streams can also reduce salmonid feeding efficiency by decreasing visibility (Thompson and Larsen 2004). Finally, high sediment levels on stream bottoms can reduce the survival rates of salmonid eggs (Thompson and Larsen 2004).

Environmental protection and further opportunities for research

The potential impacts discussed in this paper could be mitigated with different land use practices. In the early 2000s, tillage was proposed as an erosion control method on vineyards, as research in southern France demonstrated that tilling the soil between vine rows led to reduced herbicide concentration in surface waters due to increase soil infiltration (Louchart et al. 2001). However, it was later discovered that this high infiltration is temporary and that following tillage, soil soon becomes compacted, leading to structural deterioration of the soil and higher runoff rates (Ruiz-Colmenero et al. 2011). Cover crops reduce erosion significantly, with permanent cover crops showing more promise than spring-mowed covers crops (Battany and Grismer 2000, Ruiz-Colmenero et al. 2011). In years of low rainfall, however, these crops may reduce grape yields and lead to an unsustainable drop in profits (Ruiz-Colmenero et al. 2011). Research on the use of cover crops on both kinds of agricultural lands should continue and implementation of cover crop usage should be incentivized. As cannabis agriculture expands, a critical question is whether expansion in occurring more rapidly in certain zoning districts.

Evaluation of the model

In this paper, I used a geospatial approach as a method for comparing cannabis and vineyard agriculture's effects on surrounding freshwater habitat. This approach was successful for developing an understanding of the spatial characteristics and potential effects of both kinds of agriculture across Mendocino County. Field observations and measurements of cover crops or other erosion control methods would provide better context for this data. Simulated rainfall experiments would clarify the potential impacts of both kinds of agriculture on nearby streams (Battany and Grismer 2000). With more field data, more complex soil loss equations could be used to further expand our understanding of the freshwater impacts of these crops (Kouli et al. 2009, Salls et al. 2018).

Evaluation of the Model and Research Limitations

In this paper, I used geospatial methods to compare cannabis and vineyard agriculture's effects on surrounding freshwater habitat. This approach was successful for developing an understanding of the spatial characteristics and potential effects of both kinds of agriculture across Mendocino County. Simulated rainfall experiments would clarify the potential impacts of both kinds of agriculture on nearby streams (Battany and Grismer 2000). With more field data, complex soil loss equations, such as the Revised Universal Soil Loss Equation, could be used to further expand knowledge about the freshwater impacts of these crops (Kouli et al. 2009, Salls et al. 2018).

In my research, I did not consider the use of cover crops and other erosion control methods on each agricultural site and instead considered cultivation area near streams to be a proxy for the amount of bare soil located on sites near streams. This study also does not take into account the amount or types of pesticides and herbicides applied to each cultivation type. Expanding upon this study to include field measurements of agrochemical applications and erosion control methods would clarify the potential impacts of each cultivation type on surrounding freshwater resources and salmonid populations. Conducting water quality sampling and determining whether chemical runoff from vineyards and cannabis cultivation sites is negatively impacting nearby freshwater habitats would bolster findings from this research.

Conclusions

As cannabis cultivation expands throughout the state, special attention should be paid to the potential effects that the industry will have on freshwater resources. Although the spatial characteristics of cannabis cultivation sites do not raise particular concern when compared to other forms of agriculture such as vineyards in Mendocino County, the agrochemicals and erosion control practices used on cannabis cultivation sites are not well-regulated, especially as many growers continue to operate illegally. Funding and outreach efforts to support erosion control and other sustainability goals on cannabis farms should be extended to other types of agriculture, including vineyards, that lie near habitats of concerns. As cannabis continues to exist in a legal gray-area, research must continue to evaluate the potential environmental impacts of the crop.

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APPENDIX

Table A1. Zoning information: vineyards

Zone code	Zoning District	# of Parcels	%Frequency
AG	Agricultural Land	496	63.59%
RL	Rangelands	126	16.15%
RR	Rural Residential	94	12.05%
UR	Upland Residential	25	3.21%
TP	Timberland Production	13	1.67%
PF	Public Facilities	7	0.90%
FL	Forestland	7	0.90%
SR	Suburban Residential	7	0.90%
RC	Rural Community	3	0.38%
C1	Limited Commercial	1	0.13%
C2	General Commercial	1	0.13%
No zone data	N/A	15	1.92%

Table A2. Zoning information: cannabis cultivation sites

Zone Code	Zoning District	# of Parcels	% Frequency
RL	Rangeland	1147	24.26%
RR	Rural Residential	989	20.92%
UR	Upland Residential	870	18.40%
TP	Timberland Production	501	10.60%
AG	Agricultural Land	439	9.29%
FL	Forestland	307	6.49%
SR	Suburban Residential	138	2.92%
RC	Rural Community	85	1.80%
R1	Single-Family Residential	78	1.65%
RMR	Remote Residential	55	1.16%
PF	Public Facilities	40	0.85%
C2	General Commercial	16	0.34%
I2	General Industrial	13	0.27%
C1	Limited Commercial	13	0.27%
OS	Open Space	11	0.23%
RV	Rural Village	6	0.13%
I1	Limited Industrial	5	0.11%
R2	Two-Family Residential	4	0.08%
MRR	Mendocino Rural Residential	4	0.08%
R3	Multiple-Family Residential	3	0.06%
MFL	Mendocino Forestland	1	0.02%
FV	Fishing Village	1	0.02%
MPF	Mendocino Public Facility	1	0.02%
MTR	Mendocino Town Resdential	1	0.02%
No zone data	N/A	60	1.27%