Environmental Impacts of Cannabis Cultivation in California

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Abstract

Marijuana (*Cannabis spp.*) is a water intensive plant that requires 22.7 liters of water a day per plant to grow. On average, outdoor marijuana sites require nearly 430 million L/ km² of water for production. Water use associated with marijuana production has caused problems for populations of California trout and salmon populations. Estimations indicate that indoor cannabis production accounts for 3 percent of California’s electricity use and creates nearly 3 pounds of carbon dioxide for a single cannabis cigarette. Cannabis cultivation sites are also associated with land clearing and pesticide use, all of which threaten wildlife such as California Pacific Fishers. As the legalization of recreational marijuana use begins to expand the market for cannabis production in California, the constraints on the environment continue to increase. There is need for better, more in-depth research to provide information for policies and regulations that will help offset the environmental problems associated with marijuana cultivation.

Introduction

In the United States, *Cannabis spp.* is a rising agricultural crop that plays an important role in both the economy and environment (Carah et al. 2015). Legal marijuana markets are worth nearly $8 billion and are projected to grow upward to $21 billion by 2020 (Carah et al. 2015). Currently, California produces and supplies approximately 80 percent of the legal and illegal marijuana and is considered the largest domestic producer within the U.S. (Short-Gianotti et al. 2017). The North Coastal Basin of California, which includes Humboldt, Trinity, and Mendocino Counties, contributes roughly $2 to $4 billion worth of marijuana to the country's
overall economy (Short-Gianotti et al. 2017). As the market for cannabis continues to expand in California due to the legalization of recreational use, the demand on natural resources intensifies.

In November of 2016, Proposition 64, the Adult Use of Marijuana Act (AUMA) was passed, which legalized recreational cannabis sales in California as of January 1, 2018 (Nevius 2015). With the legalization of recreational marijuana, production sites have began to move further south into the Central Valley in order to keep up with an expanding market. The Central Valley’s soil type, geography, and abundant sun create ideal growing conditions for cannabis production (Carah et al. 2015). However, the area severely lacks water (Carah et al. 2015). Cannabis is a water intensive crop and in order to meet the demands of irrigation, water has been diverted through illegal damming (Bauer et al. 2015). Diversions and intensive water demands have resulted in reduced flows and completely dewatered streams (Bauer et al. 2015). Watersheds have also been polluted by pesticide and herbicide runoff from cannabis production (Gabriel et al. 2013). Soils have been degraded by illegal land clearing and logging which has caused runoff and a need for importing sediment (Wang et al. 2017). Cannabis production and transportation is also energy intensive and has caused air pollution including high levels of carbon dioxide emissions, nitrous oxides, and airborne fungal spores (Mills 2012). These environmental impacts of cannabis cultivation also severely hinder surrounding wildlife and fish and are projected to intensify as the market and production expands as a result of its current legal status (Gabriel et al. 2015).
Although current research points to extreme environmental damage, the assessment of the effects of cannabis production is hindered by lack of quantity and quality. The quasi-legal status of marijuana has led to a lack of funding for research and has thus led to anecdotal research that is based off of illicit production sites (Ashworth and Vizuete 2017). Lack of research for legal marijuana production has led to policies being based off of popular media speculation and poorly referenced and reviewed literature (Babcock 2017). An assessment of the environmental effects of cannabis cultivation is needed that is based off of reliable research. An analysis of where the research is lacking and how it can be improved is also needed (Carah et al. 2015).

This paper includes a literature search of peer reviewed scientific literature in order to evaluate the environmental impacts of cannabis cultivation. These impacts include a thorough analysis of natural resource demands such as, water, energy, soil, and air, along with effects on fish and wildlife. The following databases were utilized: PubMed, Web of Science, and EBSCO. Boolean search terms included; marijuana/ cannabis grows operations and environmental impacts on soil, water demand/use, energy, pollution, and effects on fish and wildlife. Over 200 articles were reviewed for relevancy and quality and 33 were selected. I intend to use the selected articles to identify where more in-depth analysis or research is needed so that decision-making by policymakers can be improved.

Cannabis Life Cycle

Cannabis grows annually for one season during the months of October to April. There are six stages in the herbs life cycle. The first stage, germination, can
take twelve hours to nine days to produce a root and requires moisture and warmth. Optimal temperatures range from 75 to 86 degrees Fahrenheit (Laursen 2015). The germination stage is then followed by seedling. This stage occurs for one to four weeks and is characterized by leaf emergence (Laursen 2015). Vegetation is the third stage that occurs during the summer months and requires substantial nutrients and light. The plant begins to form thicker stems and branches and increases in size (Laursen 2015). Vegetation is then followed by the pre-flowering stage, which occurs in autumn. Here, the plant requires twelve hours of light exposure and twelve hours of darkness. This stage occurs for ten to fourteen days and includes node growth, which will eventually form either male or female flowers (Laursen 2015). The plant also begins to double in size. Next, the flowering stage occurs and can last six to twenty two weeks (Laursen 2015). Flowers begin to produce and the sex of the plant can be identified. The last stage, seed production, occurs when male sacks open and drop pollen and when female seeds are formed and pollinated, thus re-starting the life cycle (Laursen 2015).

**Water**

California’s diverse geography, soil, and climate have made it an ideal location for cannabis cultivation. For years illegal growers have used Northern California’s landscape, rich soils, and constant water supply to conduct growing operations (Slater 2017). Due to unregulated cannabis production, the Northern California region has experienced severe environmental impacts. Northern California’s Mediterranean climate consists of wet, cool winters with approximately 95 percent of precipitation occurring between the months of October and April.
(Bauer et al. 2015). The summer months, May through September, which coincide with Marijuana’s growing season, often experience drought and provide negligible amounts of precipitation (Bauer et al. 2015). As a result, water storage, diversions, and conveyance have been constructed to meet high water demands although availability may be scarce. This has compounded periods of flood and drought, which has severely impacted the surrounding ecosystems (Bauss 2017). Water diversions for agricultural irrigation accounts for up to 80 percent of total human water use in California’s Mediterranean region (Carah et al. 2015). Marijuana production contributes to the excessive water use particularly from stream and river diversion (Bauer et al. 2015). The amount of water use for cannabis cultivation has thus far gone mainly unregulated. As a result, reduced water flows have caused ecological problems such as changing the quality of aquatic habitat, reducing dissolved oxygen levels, and increasing water temperatures. All of which affect abundance and diversity of fish species and invertebrate (Bauss 2017). Integrated water management approaches are needed to properly allocate water for both human use and for the conservation of freshwater ecosystems.

**Water overuse**

On average, outdoor marijuana sites can produce 130,000 plants per km² (Carah et al. 2015). Cannabis requires 22.7 liters of water a day per plant to grow (Bauer et al. 2015). Using a water application rate produced by Bauer et al. (2015), an average outdoor site requires nearly 430 million L/ km² of water for marijuana production. In comparison, wine grapes, another water intensive plant grown in Northern California, require nearly 13 liters of water per day and average 271
million L/ km² of water for production (Hale, 2017). In order to fulfill the demand of water for marijuana production, extensive amounts of irrigation water are used (Bauer et al. 2015).

**Diversions**

Due to negligible levels of precipitation, cannabis cultivation sites are often located on land near reliable sources of surface water. Often, cultivators acquire water for irrigation by diverting springs and headwater streams (Granham et al. 2010). A study that examined the impact of water use on 40 different indoor and outdoor cannabis cultivation sites in 4 different watersheds across the Northern California region found that most sites were located in areas that contain highly sensitive watersheds (Bauer et al. 2015). Up to 32,000 plants were estimated per watershed (Bauer et al. 2015). Using the water application rate, water demands ranged up to 32,000 liters per day with each parcel of land using nearly 5,000 liters per day (Figure 1). All four of the evaluated watersheds had minimum stream flow. The irrigation needs of three of the four systems exceeded the summer low-flow periods and ranged in water demands between 34 to 100 percent of flow (Figure 1). The fourth watershed differed by having greater annual mean precipitation and lower levels of evapotranspiration (Bauer et al. 2015).

The findings produced by Bauer et al. (2015) were based off of small pumps predicted to be operating at standard pumping rate. If more than one pump was operated at once the streams could be dewatered. Once streams are dewatered by diversions or naturally run dry, growers use water stored earlier in the year until supplies have been exhausted. Groundwater is then used from wells and imported
to cannabis sites by trucks (Ashworth and Vizuete 2017). The amount of water used by imports and wet season storage has not yet been determined or documented (Bauer et al. 2015).

Attempts have been made to use data collected by the State Water Resources Control Board (SWRCB), in order to predict the overall impact of small surface water diversions on watersheds in Northern California. The SWRCB is the responsible agency for administering water rights (Carah et al. 2015). Less than 6 percent of the active water diversions are registered and on file with the SWRCB (Bauer et al. 2015). Thus, the unregistered diversions are not subjugated to standards or regulations set by the California Department of Fish and Wildlife and therefore the impact of water diversions for cannabis use is widely unknown.

Energy

In California, marijuana production requires a substantial amount of energy. Estimations indicate that indoor cannabis production accounts for 3 percent of California’s electricity use, which is the equivalent to more than a million California homes and cost around 3 billion dollars per years (Mills 2012). Marijuana production emissions are nearly equal to that of a million cars (Mills 2012). Large amounts of energy are required for marijuana production processes, equipment inefficiencies, and transportation (Figure 3).

During marijuana production energy is primarily consumed to maintain high intensity lighting levels (Johnson and Miller 2011). On average, indoor grow houses can contain anywhere from 50,000 to 100,000 watts of lighting (Jonlin and Lewellen 2017). During the “vegetation” phase of indoor growing operations, lights are left on
for more than 18 hours per day for three weeks to a month (Mills 2012). Following the vegetation phase “flowering” occurs and plants are exposed to 12 hours of intense lighting daily, for several weeks (Mills 2012). In larger operations, the flowering phase grow room is usually divided into two sections. On one side, lights are on while the other side is left completely dark. This technique is utilized to minimize the need for bigger cooling systems and reduces utility demand (Mills 2012).

Traditionally, growers have used high intensity discharge lamps, sodium HPS or other lighting including, T5 fluorescent lights, ceramic or metal halide, and induction lighting (Mills 2012). Although these light fixtures are inexpensive and produce enough heat to support plant growth, they frequently need to be replaced. A typical marijuana operation may use several hundred HPS lamps per year, which results in using a full megawatt of power (Mills 2012). This type of energy use creates additional strains on distribution networks and can cause substantial challenges for local communities (Carah et al. 2015).

Production of marijuana also requires filtering the air every 30 hours in order to produce and remove heat (Martyny et al. 2013). For example, heating and dehumidification is required during periods of non-illumination for drying and avoiding mold development. A typical indoor operation uses refrigeration-based dehumidifiers (Martyny et al. 2013). In order to later remove excessive heat the grow houses are then ventilated with air-conditioning. Typical HPS lamps generate 30 to 60 watts of heat per square feet per grow room (Mills 2012). Conventional office buildings generate less than 1 watt per square foot (Mills 2012). This amount
of heat requires continuous cooling to hold room temperatures around 80 degrees Fahrenheit (Jonlin and Lewellen 2017).

Other, less intensive uses of energy include heating of irrigation water and generating carbon dioxide (Carah et al. 2015). Carbon dioxide levels are raised in indoor grow houses to accelerate plant growth. Often the levels are raised up to 4 times above natural levels of carbon dioxide (Martyny et al. 2013). Although this practice contributes up to 2 percent of the total carbon footprint of cannabis production, it also shortens marijuana’s growth cycle and can reduce energy demand (Mills 2012). Energy required for transportation also plays a big role in marijuana production. Nearly 20 percent of total emissions produced during marijuana cultivation are generated by vehicles, which are used in production processes and for redistribution (Mills 2012).

Overall, typical production of indoor marijuana plants produces 3 pounds of carbon dioxide for one single cannabis cigarette. Producing one kilogram of marijuana results in nearly 5,000 kilograms of carbon dioxide emissions (Martyny et al. 2013). These results are reflective of average production protocols and do not take into account methods that require much more energy consumption. Energy intensive methods include using off site diesel power generation, which produces 50 percent more carbon dioxide emissions or production sites that use hydroponics to grow plants (Mills 2012). Research is needed to identify all forms of energy consumption on high intensity production sites in order for data to depict a more accurate estimation of energy use.
Although outdoor operations require substantially less energy for production they also require large amounts of energy and produce emissions. Operational differences include requiring more energy than indoor production for pumping water for irrigation and require drying techniques in times when natural sunlight is lacking (Carah et al 2015). Outdoor production also requires more land clearings to occur (Bauer et al. 2015). Not only does this process prevent further carbon sequestration, which can often be anywhere from 125 to 1500 tons of carbon dioxide stored per hectare of land but carbon is often mobilized after clearings (Wang et al. 2017). For every kilogram of cannabis produced, 150 kilograms of carbon are emitted which is 3 percent of the amount produced by indoor plants (Wang et al. 2017).

As marijuana production continues to expand in California predictions indicate a greater demand on energy use. Following the legalization of medical marijuana use an energy explosion occurred in Northern California (Slater 2017). For example, Humboldt County residential electricity use increased around 50 percent during this time as more citizens began to grow marijuana (Slater 2017). In order to reduce energy demand, production sites need to invest more in cost effective and energy efficient practices such as controls for lighting, air conditioning, and fans. Growers also need to utilize daylight in indoor operations. Estimates indicate that the application of efficient practices could reduce the costs of a typical operation by $40,000 per year (Mills 2012). A more in-depth analysis of cannabis cultivation and greater transparency is needed in order to formulate solutions on how to reduce energy demands in operations that are atypical.
Soil

For most agricultural farmers, soil quality plays a huge role in choosing where to grow their crops. However, for marijuana, over 90 percent of the site locations are on land with poor soil quality (Butsic et al. 2017). Site location for illicit marijuana growth is primarily chosen based off of access to water, sunlight, and areas that are concealed from law enforcement and civilians (Babcock 2017). In order to compensate for poor soil, growers bring in nutrient efficient soil for both indoor and outdoor production. Although, many areas where cannabis cultivation takes place have local businesses designed to supply large quantities of soil, the exact quantity and occurrence of the imports is undocumented (Winston et al. 2014).

Cannabis cultivation also involves land clearing and road construction, both of which cause environmental damage and can be extremely demanding on soil. In areas where the soil quality is already poor, the situation is worsened by removal of native vegetation, which can cause erosion and stream sedimentation (Keenan and Kimmins 1993). When trees are cut down in large quantities, the surrounding ecosystem loses its main source of water retention, resulting in floods and leaching of nutrients from the soil (Keenan and Kimmins 1993). When there is an increase in water runoff, topsoil is often eroded into near by streams and rivers (Winston 2014). The resulting elevated levels of sedimentation in the water increases nutrient content and excess fine sediment has been documented to deteriorate ecosystem conditions for salmon and trout populations (Yager et al. 2012).
Clear-cutting also results in changes in microbial composition (Carah et al. 2017). Soil microbes depend on the interaction between soil and plant species. When the plants are removed the amount of microbiota are reduced in response to changes in temperature and water content (Winston 2014). Soil microbes play an important part in various ecological processes such as suppression of root diseases, nitrogen fixation, and growth stimulant production (Winston 2014). By hindering microbial formation, the overall ecosystem is at a disadvantage.

The effects of clear cutting for marijuana cultivation are often intensified due to site location. Often, cannabis production sites are found in close proximity to other cultivation sites. For example, when a site has up to 200 plants there is a 36 percent probability of finding a neighboring site. When there are nearly 5,000 plants on a site the probability increases to 67 percent (Butsic et al. 2017). Clustering of sites leads to increasing number of roads constructed and clear cutting occurring in centralized areas, which can cause more erosion and sedimentation levels to increase in streams (Bauer et al. 2015). Although clustering of sites may reduce the spread of marijuana production to other parts of communities, it magnifies the environmental problems in certain areas. Clustering can intensify soil degradation to areas that already experience poor soil quality.

**Air Pollution**

Air pollution poses a potential threat for indoor marijuana producers such as, inhaling toxic chemicals like carbon dioxide, carbon monoxide, volatile organic compounds (VOCs), nitrous oxides (NOx), and airborne fungi (Johnson and Miller 2011). A study that sampled thirty indoor growing facilities for levels of these
chemicals found carbon dioxide levels ranging from 500 ppm to 1500 ppm, while normal indoor carbon dioxide levels range from 300 to 1000 ppm (Martyny et al. 2013). Carbon monoxide levels were well below the designated range established by the Environmental Protection Agency (Martyny et al. 2013). More than half of the examined facilities increased carbon dioxide levels by un-venting propane and natural gas burners while the remainder of the facilities used carbon dioxide tanks (Martyny et al. 2013). These unvented combustion appliances also produce NO₂ but there has been little research of this chemical contaminant in cannabis production (Ashworth 2017).

Airborne fungi posed the largest potential health hazard. Marijuana plants experience moisture when the plant is cultivating and during the drying process (Jonlin and Lewellen 2017). Mold is produced when plants become moist by irrigation and cannot dry due to poor ventilation (Cuypers et al. 2017). In order to conceal odors emitted from marijuana operations and to keep the facilities warm and humid, ventilation is often inhibited. While the plant is drying, water that was once bound to cells is accessible to become fungus while the plant begins to decay. Plants with moisture contents greater than 12 percent are able to grow fungi (Martyny et al. 2013). Mold and marijuana production also require temperatures around 70 to 80 degrees Fahrenheit and humidity levels ranging from 50 to 70 percent (Martyny et al. 2013). In grow rooms; airborne fungal spores were elevated more than five-fold higher than outdoor levels (Martyny et al. 2013). During the plant removal process airborne fungal spores levels increased up to 34 fold and were similar in range to mold contamination observed in demolition buildings.
(Martyny et al. 2013). These indoor air pollutants pose a threat to respiratory health.

**Pesticides**

In California, little to no research has been conducted on the use of pesticides on marijuana plants. Currently, there are no registered pesticides for cannabis use in the United States and the Environmental Protection Agency will not register one as long as it is classified as a Schedule 1 drug (Stone 2014). In Belgium however, research has been conducted on the risks associated with pesticide residue on indoor marijuana plants, infrastructure required for cultivation, and plant removal (Cuypers et al. 2017). Indoor marijuana cultivators in both Belgium and the United States have similar growing techniques, but the pesticides used vary due to differing pesticide laws and regulation in the different countries. In Belgium, 72 indoor plant sites were sampled for pesticides. Cuypers and colleagues (2017) found pesticide use in 64 percent of the plants sampled including nearly 20 different pesticides, such as bifenazate, imidacloprid, and cypermethrin. Although, most of the chemicals found had a low volatility, they were detected in 65 percent of the carbon filter cloths used in the sensors in cultivation rooms (Cuypers et al. 2017). In order to defuse marijuana’s intense smell, growers use turbines to circulate air through carbon filters (Johnson and Miller 2011). The high percentage of pesticides found in the carbon filters suggests that pesticides prevail in the atmosphere of the cultivation rooms during and possibly after cultivation (Cuypers et al. 2017). Research is needed to determine whether the volatility of the pesticides increases when dismantling and removing the plants. Research is also needed to determine
the risks the chemicals pose on marijuana growers and staff as they can be exposed through both dermal and inhalation of the vapors.

Water samples from the 72 sites in Belgium were also tested for pesticide compounds. Out of 41 water samples, 24 were collected from tanks attached to an irrigation system, 4 were from stagnant water, and 13 samples were from bottles that were not labeled. 20 percent of the samples tested contained pesticides however; no pesticides were found in the tank water connected to a plant irrigation system (Cuypers et al. 2017). Therefore, the data suggests that pesticides were most likely applied by spraying chemicals on the plants directly and not by mixing them with irrigation water.

In California, pesticides are used to prevent the damage of cannabis plants from Spider mites, aphids, and fungi (Thompson et al. 2014). Attempts have been made to detect the types of pesticides used in the United States by screening 50 samples of confiscated illegal marijuana plants (Schneider et al. 2014). Pesticides were found in 12 percent of the 50 indoor cannabis plants (Schneider et al. 2014). Researchers were unable to collect on site samples and had to rely on plants taken by authorities. Identification of pesticides along with data on location were made unavailable therefore, a thorough assessment of pesticide use is still needed in the U.S.

Most of the data on pesticide use for marijuana production is primarily collected from authorities when raids are conducted (Stone 2014). For example, in 2008, California authorities removed approximately 3.6 million illegally grown outdoor marijuana plants (Stone 2014). These plants were removed from federal
and state public lands and were found with thousands of pounds of pesticides. Similarly, in 2011 authorities in the Mendocino National Forest removed over 630,000 marijuana plants along with nearly 23,500 kg of trash and approximately 70 kg of pesticides (Gabriel et al. 2015). Authorities also found significant amounts of anticoagulant rodenticide near plants along irrigation lines (Figure 2). This may be due to the combined use of pesticides and fertilizer, which increases the possibility of chemical uptake in nearby vegetation.

Although authorities have found pesticides present on marijuana sites, research is needed from the scientific community on the frequency of use and location of chemical prevalence. A toxicological risk assessment is also needed to determine under what conditions the pesticides can be used, at what quantity, and where they can be sprayed. Constraints to conducting this type of research includes a lack of systematic monitoring of pesticide use on marijuana sites and much of the data that has been collected is anecdotal and severely lacks in peer review.

**Threat to Wildlife**

The use of anticoagulant rodenticide (AR) in marijuana cultivation sites has emerged as a significant concern for surrounding wildlife populations (Thomspon et al. 2014). ARs are designed to suppress pest populations by creating clotting and coagulation injuries when consumed (Gabriel et al. 2012). Second generation ARs are more acutely toxic and can persist in the environment and tissue for longer compared to first generation ARs. *Pekania pennanti* or California Pacific Fishers, have been exposed and threatened by second-generation anticoagulant rodenticide (SGARs) as a result of cannabis cultivators trying to control populations of *Neotoma*
spp., more commonly referred to as wood rats (Carah et al. 2015). Fishers are currently under review as candidates to be listed under the federal Endangered Species Act (Gabriel et al. 2013). At the University of California Davis, 58 toxicological screenings were performed on fishers found on community and public lands used for marijuana production in Northern California (Gabriel et al. 2012). The results showed approximately 46 of the 58 fishers or 80 percent of the population were exposed to anticoagulant pesticides, with nearly 100 percent of the exposures being SGARs (Gabriel et al. 2012). In April of 2009, researchers from the UC Berkley Sierra Nevada Adaptive Management Project found a dead male fisher. After performing a necropsy it was confirmed that the fisher died of AR poisoning. Three SGAR compounds, brodifacoum, bromadiolone, and chlorophacinone were found in the animal’s liver along with over 250 ml of blood in its abdominal cavities (Thompson et al. 2014).

Researchers monitored the poisoned California fishers over their lifetimes and found that the individuals tested overlapped with cannabis cultivation sites that used these rodenticides. Using spatial analysis, clustering of rodenticide exposure was also detected, which suggests widespread contamination of ARs in fisher’s range (Thompson et al. 2014). In California, fisher historical habitat primarily consists of areas encompassed by public forest and parklands. Fishers are rarely exposed to developments in suburban neighborhoods or agricultural crops, which are the most common places to find the use of ARs (Thompson et al. 2014). It is common for wildlife to come into contact with ARs through legal agricultural spraying or when the compound is used within 50 feet of a suburban development
Since June 2011, the Environmental Protection Agency has regulated the use of SGARs to agricultural stores making them unavailable to consumers at retail (Gabriel et al. 2013). Thus rendering the use of ARs illegal on California public lands, yet fishers are being exposed to the rodenticides.

The documented cases of fisher mortalities that had been exposed to SGARs typically occurred during the months of April to June when it is time for cannabis cultivators to plant seedlings. During the seedling process, cultivators use heavy amounts of toxic pesticides in order to prevent rodents from damaging the new plants (Thompson et al. 2014). This time of the season is also crucial for female fishers to raise their kits (Gabriel et al. 2013). Researches have discovered SGARs in the tissue of dead kits, which has raised concerns over the effects of bioaccumulation of the rodenticides that may be transferred from mother to kit through milk or early stages of fetal development through the placenta (Thompson et al. 2014). Cases of bioaccumulation of AR have also been documented in several invertebrates, including Aporrectodea calignosa (earthworms) and Cantareus asperses (snails), both of which are included in the wide range of resources fishers consume (Gabriel et al. 2013).

Due to a lack of funding, researchers are unable to determine whether or not a threshold for the amount of exposure to SGARs a fisher can experience. Researchers found cases of fisher mortality at low levels of SGAR exposure and instances of high levels of exposure while no obvious health affects occurred. Without proper documentation of environmental damage and lack of funding,
wildlife, including the California fisher, will continue to be threatened by the toxic
pesticides used in the production of marijuana.

**Fish Species**

In the Eel River of northwestern California, several fish species are
threatened by the environmental impacts of marijuana production. Historically, the
Eel River is the third largest flowing river in California. It originates in Mendocino
County and flows to an estuary in the Pacific Ocean. Naturally, the Eel River receives
large amounts of sediment from landslides and erosion (Power et al. 2015). The
impacts of erosion and landslides would ordinarily be buffered by naturally
occurring riparian vegetation trapping the fine sediments. However, due to land
clearing and road construction associated with cannabis cultivation much of the
native vegetation has been removed from the banks of the Eel River (Power et al.
2015). The failure of several water ridge top impoundments has also led to
landslides and increased the amount of fine sediment in the river resulting in the Eel
becoming more wide and shallow (Power et al. 2015). Thus, increasing the
vulnerability of the river to become warmer and easier to dewater. Currently,
concerns have risen over the releasing blooms of cyanobacteria. Less water flow and
warmer temperatures result in algal production that is not being consumed by
organisms. These conditions increase pH and lower dissolved inorganic carbon
concentrations thus creating favorable conditions for cyanobacterial growth. These
toxic blooms have caused the death of 11 dogs in the Eel River since 2002 (Power et
al. 2015).
The change in river temperatures, sediment load, and flow velocity have threatened the populations of Chinook, Coho, and Steelhead fish that are commonly present in the Eel River (Table 1). Ideally, salmon and trout use the space between cobbles and boulders to escape predation (Kondolf, 2000). The area where water flows down to the gravel provides an important food supply for juvenile salmon and trout. Excess or fine sediment can challenge the salmon or trout’s source of cover and food by congesting the spaces between the gravel (Chapman 1988). Water temperature also plays an important role in salmon and trout populations. Each species requires cool, fresh water and increased temperatures can decrease egg survival rates, increase the susceptibility of disease, lower the fecundity in the species, and more (McGeer et al., 1991). Bauer et al. (2016) found that water demand for the production of marijuana crops exceeded the stream flow in three of four watersheds in the Eel River region. This type of water overuse could lead to increased river temperatures and severely affect the flow, which could be the tipping point in an ecosystem that supports large populations of salmon and trout (Table 1).

**Site Location**

Site location plays a huge role in the environmental impacts associated with marijuana production. Few studies have been conducted on how cannabis cultivators choose the size and location of their operations. In comparison to other forms of agriculture in California, most crops are well mapped and documented (Koch et al. 2016). Few studies have attempted to document and predict where cultivation sites are likely to take place (Koch et al. 2016, Butsic and Brenner 2016,
and Butsic et al. 2017). Over 4,400 cannabis-cultivating sites in 60 different watersheds have been analyzed to create models that can be used to predict where growers will locate their sites (Butsic and Brenner 2016). Predictor variables include drug markets, environmental conditions, and policies.

Site preparation typically requires large amounts of equipment including PVC for irrigation and tools for removing native vegetation. Ideal locations would be close to a road, which is why nearly 70 percent of cultivation sites were found less than 500 meters from developed roads (Koch et al. 2016). 15 percent of sites were within 100 meters of roads (Butsic and Brenner 2016). The need for access to roads suggests a risk of landscape fragmentation that could occur in order for sites to be developed (Figure 4).

Very flat and steep slopes are not favored; this may be due to irrigated water being more easily transported on slightly sloped land. Less than 20 percent of sites were on steep slopes (Koch et al 2016). The degree of slope increases the risk of sedimentation, landslides, and erosion (Butsic and Brenner 2016). Sites that face south are favored. This may be due to greater sunlight availability that will lead to greater growth for the plants. Lower elevation also plays a role due to higher temperatures and potential for greater plant productivity (Butsic et al. 2017).

Access to freshwater sources such as rivers and streams are favorable. Studies suggest spatial clustering within watersheds is common (Butsic et al. 2017). On average anywhere from 70 to 481 grows occurred in one watershed in Northern California (Butsic and Brenner 2016). There is a significant positive correlation to watershed area and density of plants. A large number of plants would require more
irrigation water and thus impact the overall health of the watershed. For example, five percent of cultivation sites are less than 100 meters from threatened fish habitat (Koch et al. 2016). In these particular sites the number of plants were estimated around 300,000, which would require approximately 700,000 cubic meters of water (Bauer et al. 2015). This amount of water could severely impact streams and threaten fish populations.

Growers are also more likely to establish sites on national forest lands when marijuana prices are higher. For example, in 2010, government agencies removed over 10 million marijuana plants of which 94 percent were grown outdoors and nearly half were discovered on federal lands in California national forests (Babcock 2017). The United States Department of Justice National Drug Intelligence Center also reported a nation wide increase of outdoor marijuana grows of nearly 150 percent between the years of 2005 to 2010 (Koch et al. 2016).

Marijuana sites are also often found in close proximity to one another. Clustered sites not only intensify environmental impacts in centralized regions but they are also linked to increasing levels of fragmentation (Butsic et al. 2017). Wang et al. (2017) examined 62 grow sites in Humboldt County and compared the impacts of fragmentation to that of timber harvest that occurred from 2000 to 2013. Results showed that 1 km² of cannabis had the same if not more impact on forest fragmentation than 1 km² of timber harvest (Wang et al. 2017). Cannabis cultivation sites had nearly double the loss of core area and three times the amount of fragmented patches with greater amounts of exposed edge (Wang et al. 2017).
These types of forest patches exhibit irregular shape and are less intact resulting in increased risk of impacting biodiversity and ecosystem functions (Wang et al. 2017).

Decriminalization and legalization of marijuana production play an important role on the effect of illicit outdoor cultivation occurring on public lands (Vanhove et al. 2011). Research suggests that in states with legal cannabis markets, demand for illicit cultivation continues to persist (Vanhove et al. 2011). This may be due to illicit growers attempting to avoid regulations and taxes enforced on licensed growers. Or, in places such as Colorado and Oregon where production and distribution were legalized, illicit grows on federal lands increased to supply states where marijuana is prohibited (Vanhove et al. 2011). As legalization occurs, shifts in prices may also affect the likelihood of cultivation in national forests. For example, sharing the market with legal cultivators could decrease prices for illegal cannabis, which would result in more grows occurring on public lands (Babcock 2017).

Although the outcomes of the legalization of recreational marijuana are unknown, researchers have found that sites tend to be clustered, centralized near watersheds; occur on mildly steep locations, on public lands, and far from developed roads. These types of site locations have led to disproportionate negative ecological affects and further research is needed to develop better land-use planning techniques that could be implemented into policy.

Conclusion

The environmental effects associated with marijuana production are severe. The impacts are predicted to worsen as the market for recreational marijuana expands. As demand for marijuana increases, California streams and rivers are
threatened to become dewatered which will affect trout and salmon populations, energy demand will worsen, along with the use of toxic chemicals that threaten the health of employees and wildlife. Currently, state officials have established a report addressing the negative environmental problems associated with cannabis cultivation. This report is largely based off of popular media sources and lacks in scientific literature. Californians need to address issues within the state’s report in order to ensure environmental protection, restoration, and mitigation. Strong provisions and funding for research and protection are needed. Along with regulations that will require marijuana growers to implement sustainable practices such as, monitoring and controlling water use, using renewable energy, establishing protocols for pesticide use, and only growing in permitted areas. Strong enforcement of these provisions will be necessary as well as a partnership between growers, scientists, and lawmakers. The environmental impacts associated with cannabis cultivation have gone widely overlooked and a push for sustainable practices needs to be taken now.
Figure 1. Growing season discharge for the months of June to October in the Eel River watershed compared to marijuana water demand (Carah et al. 2015).
Figure 2. Rodenticides confiscated by law enforcement from illicit cannabis operations in northwestern California, which fall within fisher (*Martes pennanti*) range (Gabriel et al. 2012).
Table 1. Aquatic species within the Eel River (Bauer et al. 2016).

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Conservation Status in California</th>
<th>Study Watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oncorhynchus kisutch</td>
<td>coho salmon</td>
<td>State and federally-threatened</td>
<td>URC, RCS, SC, OC</td>
</tr>
<tr>
<td>Oncorhynchus tshawytscha</td>
<td>Chinook salmon</td>
<td>federally-threatened</td>
<td>URC, RCS, SC, OC</td>
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<td>Oncorhynchus clarki</td>
<td>coastal cutthroat trout</td>
<td>SSC(^1)</td>
<td>URC</td>
</tr>
<tr>
<td>Oncorhynchus mykiss</td>
<td>steelhead trout</td>
<td>federally-threatened</td>
<td>URC, RCS, SC, OC</td>
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<tr>
<td>Rana aurora</td>
<td>northern red-legged frog</td>
<td>SSC</td>
<td>URC, RCS, SC, OC</td>
</tr>
<tr>
<td>Rana boylii</td>
<td>foothill yellow-legged frog</td>
<td>SSC</td>
<td>URC, RCS, SC, OC</td>
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<tr>
<td>Rhyacotriton variegatus</td>
<td>southern torrent salamander</td>
<td>SSC</td>
<td>URC, RCS, SC, OC</td>
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<td>coastal tailed frog</td>
<td>SSC</td>
<td>URC, RCS, SC</td>
</tr>
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<td>Emys marmorata</td>
<td>western pond turtle</td>
<td>SSC</td>
<td>RCS, SC, OC</td>
</tr>
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<td>Margaritifera falcata</td>
<td>western pearlshell</td>
<td>S1S2(^2)</td>
<td>URC</td>
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</tbody>
</table>
Figure 3. Energy use and carbon footprint of average indoor cannabis production (Mills 2012).
Figure 4. Land clearing and road construction associated with cannabis cultivation sites near the Trinity River watershed. Figure (a) demonstrates the sites before conversion in 2004 and figure (b) is after conversion in 2012 (Carah et al. 2015)
Work Cited


