

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/279180798>

High Time for Conservation: Adding the Environment to the Debate on Marijuana Liberalization

Article in *BioScience* · June 2015

DOI: 10.1093/biosci/biv083

CITATIONS

26

READS

537

15 authors, including:



Jennifer Carah

The Nature Conservancy

12 PUBLICATIONS 60 CITATIONS

SEE PROFILE



Jeanette Howard

The Nature Conservancy, San Francisco, CA

41 PUBLICATIONS 551 CITATIONS

SEE PROFILE



Sally Thompson

University of California, Berkeley

106 PUBLICATIONS 2,373 CITATIONS

SEE PROFILE



Anne Short Gianotti

Boston University

20 PUBLICATIONS 418 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Flow and transport in vegetated region [View project](#)



Portfolio effects in Central Valley Chinook salmon [View project](#)

High Time for Conservation: Adding the Environment to the Debate on Marijuana Liberalization

JENNIFER K. CARAH, JEANETTE K. HOWARD, SALLY E. THOMPSON, ANNE G. SHORT GIANOTTI, SCOTT D. BAUER, STEPHANIE M. CARLSON, DAVID N. DRALLE, MOURAD W. GABRIEL, LISA L. HULETTE, BRIAN J. JOHNSON, CURTIS A. KNIGHT, SARAH J. KUPFERBERG, STEFANIE L. MARTIN, ROSAMOND L. NAYLOR, AND MARY E. POWER

The liberalization of marijuana policies, including the legalization of medical and recreational marijuana, is sweeping the United States and other countries. Marijuana cultivation can have significant negative collateral effects on the environment that are often unknown or overlooked. Focusing on the state of California, where by some estimates 60%–70% of the marijuana consumed in the United States is grown, we argue that (a) the environmental harm caused by marijuana cultivation merits a direct policy response, (b) current approaches to governing the environmental effects are inadequate, and (c) neglecting discussion of the environmental impacts of cultivation when shaping future marijuana use and possession policies represents a missed opportunity to reduce, regulate, and mitigate environmental harm.

Keywords: agriculture production, Cannabis, biodiversity, policy/ethics, endangered species

Marijuana is the subject of heated debates over whether the liberalization of marijuana policies would benefit or harm society (Kilmer et al. 2010, Caulkins et al. 2011). Countries as diverse as Uruguay, Morocco, and the Netherlands—as well as 23 US states—are experimenting with the decriminalization of marijuana, including the states of Colorado, Washington, Oregon, and Alaska, which have legalized recreational sale and possession (AP 2014, Hughes 2014). The policy debate, which has focused on the public-health and criminal outcomes of liberalization, has largely neglected another notable source of societal harm arising from widespread marijuana use: the environmental harm associated with its commercial-scale cultivation. Where this harm has been examined by policy analysts in a legalization and policy context in Washington State (O’Hare et al. 2013), it was assumed that the environmental impacts are largely associated with energy use in indoor cultivation and will shrink in state-legal markets through regulation and other mechanisms. In that case, it was also assumed that environmental considerations are of minor importance in framing marijuana policy (O’Hare et al. 2013).

These assumptions are questionable in warm, arid, or semi-arid regions with extensive outdoor marijuana cultivation, or where state-legal/medical markets and black

markets are significantly intertwined. California, where by some estimates 60%–70% of the marijuana consumed in the United States is grown (USDOJ NDIC 2007, Gabriel et al. 2013), serves as a good example of both conditions. California marijuana is primarily outdoor grown, and there is significant mixing between the medical and black markets (Short 2010, Bauer et al. 2015). Although the total area under marijuana cultivation in California is likely low compared with that of traditional Californian crops such as grapes, hay, or tomatoes, the site-specific impacts of marijuana production are significant and problematic. Illegal marijuana production in California is centered in sensitive watersheds with high biodiversity (Bauer et al. 2015), which represent habitat for several rare state- and federally listed species. The Mediterranean climate of much of the state results in the limited availability of surface water within these watersheds during marijuana’s growing season. The combination of limited water resources, a water-hungry crop, and illegal cultivation in sensitive ecosystems means that marijuana cultivation can have environmental impacts that are disproportionately large given the area under production.

Like all forms of agriculture, marijuana cultivation has implications for natural resources that should be part of the current and future policy discussion. However, regulation

BioScience XX: 1–8. © The Author(s) 2015. Published by Oxford University Press on behalf of the American Institute of Biological Sciences. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com.
doi:10.1093/biosci/biv083

Advance Access publication XXXX XX, XXXX

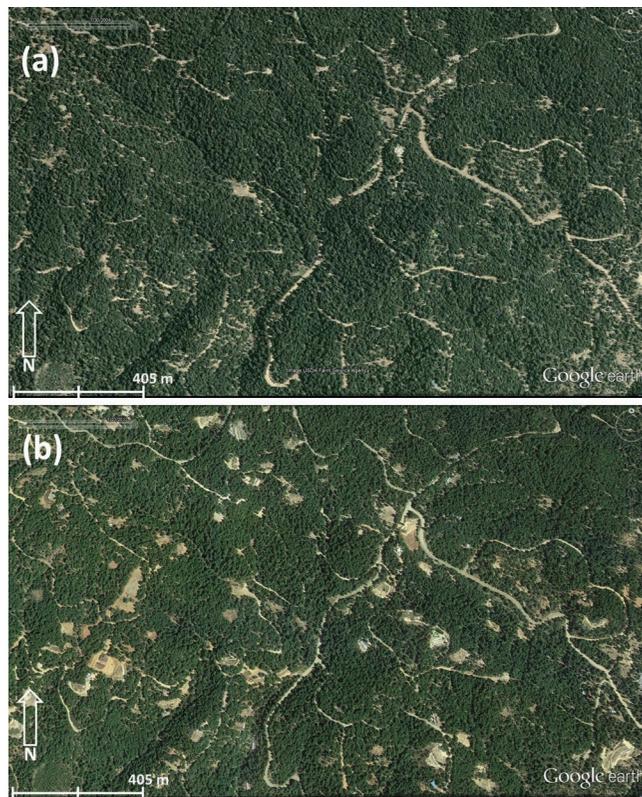


Figure 1. Land clearing, habitat conversion, and road building associated with marijuana cultivation in the Trinity River watershed (a) before conversion, 2004, and (b) after conversion, 2012. Source: Jennifer Carah; base imagery US Department of Agriculture Farm Service Agency through Google Earth (2004), and Google Earth (2012).

designed to mitigate environmental harm is more difficult to implement for marijuana cultivation than for other agricultural activities because of its unique and evolving legal status. Although many US states are legalizing recreational and medical marijuana possession and use, it remains illegal at the federal level, putting the industry in a semi-legal gray area in these states. This status separates marijuana from fully legal agricultural commodities and greatly complicates regulation of the industry. Without adopting a position on liberalization of marijuana use and possession policies, we argue here that (a) the environmental harm caused by marijuana cultivation in both the semi-legal and black-market context is significant and merits a direct policy response, (b) current approaches to and funding for governing the environmental effects are inadequate, and (c) neglecting discussion of the environmental impacts of cultivation when shaping future marijuana-use and -possession policies represents a missed opportunity to reduce, regulate, and mitigate environmental harm.

The environmental impacts of marijuana cultivation

Marijuana is a water- and nutrient-intensive crop (Cervantes 2006, HGA 2010). Its cultivation is associated with land

clearing (figure 1), the diversion of surface water (figures 2 and 3), agrochemical pollution, and the poaching of wildlife in the United States (Gabriel et al. 2013, Thompson et al. 2014, Bauer et al. 2015) and internationally (Armstead 1992, McNeil 1992, Bussman 1996). Where grown indoors, it can require extensive energy inputs with potentially negative effects on climate (Mills 2012, O'Hare et al. 2013). Marijuana cultivation in California is mainly concentrated in remote forested watersheds, on private, public, and Native American tribal lands, and is largely grown outdoors (Gabriel et al. 2012, Milestone et al. 2012, Thompson et al. 2014, Bauer et al. 2015), with environmental impacts often extending far beyond the specific cultivation site (Gabriel et al. 2013, Bauer et al. 2015). Both semi-legal and black-market marijuana plantations can be harmful to water resources and aquatic life. In the California north coast region, an estimated 22 liters (L) of water or more per plant per day are applied during the June–October outdoor growing season (HGA 2010). Using this water application rate and documented planting densities in greenhouses (900,000 plants per square kilometer [km^2]; Bauer et al. 2015), water application rates would be approximately 3 billion L per km^2 of greenhouse-grown marijuana per growing season. Outdoor planting densities appear to be much lower (Scott Bauer, California Department of Fish and Wildlife, personal communication, October 13, 2014), and if we assume a planting density of 130,000 plants per km^2 , water application rates would be approximately 430 million L per km^2 of outdoor-grown marijuana per growing season. For comparison, wine grapes on the California north coast are estimated to use a mean of 271 million L of water per km^2 of vines per growing season (CDWR 2001, 2002, 2003, 2004, 2005). Marijuana is therefore estimated to be almost two times more “thirsty” than wine grapes, the other major irrigated crop in the region.

Compared with more established forms of agriculture on the north coast, where abundant winter stream flow is sometimes captured and stored locally in ponds or tanks for later summer use, marijuana cultivation is typically irrigated with summer and fall surface water diversions directly from headwater streams and springs (Gabriel et al. 2013, Bauer et al. 2015). These diversions are localized in smaller, sensitive watersheds that are hotspots of biodiversity—and particularly aquatic biodiversity (Bauer et al. 2015). Although legally constructed water storage can be strategically located within a watershed network to mitigate the cumulative downstream effects of water abstraction (Grantham et al. 2010, Viers et al. 2013), surface water diversions for marijuana cultivation have been documented to significantly reduce or eliminate already low stream flow during California's Mediterranean-type dry summer season, particularly during drought years, and therefore threaten the survival of rare and endangered salmonids, amphibians, and other animals (Gabriel et al. 2013, Bauer et al. 2015).

For example, Bauer and colleagues (2015) found minimum stream flows in four northern Californian watersheds to be so low in the summer months that direct surface-water



Figure 2. A California outdoor marijuana garden adjacent to a drained wetland. The wetland was drained to irrigate the marijuana garden. Photograph: Scott Bauer.

diversions, based on small pumps operating at standard pumping rates, could dewater streams if more than one pump ran at once. For three of the four watersheds examined, existing demand for water for marijuana cultivation exceeded minimum instream flows in the summer by more than a factor of 2 (Bauer et al. 2015). These estimates can be scaled up to larger watersheds by considering the average summer water yields from larger rivers on a per-area basis. For comparison, the areally averaged water yield from the Eel River during the marijuana-growing season is approximately 50,000,000 L per km² per season (figure 4)—ten times lower than the estimated marijuana water requirement of 430,000,000 L per km² per season. Marijuana plantations, even if relatively small in area, can have a disproportionately large impact on water resources and flow.

Marijuana plantations can also pollute watersheds and poison wildlife. Pesticides, used heavily in black-market cultivation on public lands, make their way into terrestrial food chains, posing significant risks to mammalian and avian predators (Gabriel et al. 2013). For example, Gabriel

and colleagues (2012) and Thompson and colleagues (2014) found that more than 80% of deceased Pacific fishers (*Pekania pennanti*) they recovered in northern California and the southern Sierra Nevada were exposed to anticoagulant rodenticides, pesticides used to control wood rats (*Neotoma spp.*) in black market–marijuana cultivation. The likelihood of exposure increased and female survival rates decreased with the presence of marijuana cultivation sites within fisher home ranges (Thompson et al. 2014). The use of these pesticides is a significant threat to fishers, which are already rare and are candidates for listing under the Federal Endangered Species Act. In addition, where marijuana growers trespass onto public and tribal lands or large industrial timberlands to grow marijuana, they often camp out for many months at a time and poach wildlife for sport and sustenance (Milestone et al. 2012, Gabriel et al. 2013).

Land terracing, road construction, and forest clearing for both semi-legal and black-market marijuana plantations remove native vegetation (Milestone et al. 2012) and increase erosion (USDOJ NDIC 2007, Gabriel et al.



Figure 3. An illegally constructed pond and water diversion associated with a marijuana cultivation site in northern California. Photograph: Scott Bauer.

2013, Bauer et al. 2015). Erosion increases fine-sediment loading into streams, damaging spawning and rearing habitat for salmon and trout, such as federally endangered coho salmon (*Oncorhynchus kisutch*; USDOJ NDIC 2007). Nonbiodegradable trash and human excrement are commonly dumped around black-market marijuana cultivation sites on public and tribal lands (USDOJ NDIC 2007). The heavy use of pesticides, herbicides, fertilizers, and petroleum fuels in both semi-legal and black-market cultivation can also contaminate watersheds (USDOJ NDIC 2007, Gabriel et al. 2013). Environmental clean-up and remediation efforts in the affected watersheds are limited, even after enforcement actions are taken, because of lack of resources and staff in state or federal agencies (Gabriel et al. 2013).

Minimal governance of environmental impacts

Because of the clandestine nature of the business, hard data on California land in marijuana production or production volumes are unavailable (Kilmer et al. 2010). Several older estimates of US marijuana-consumption rates exist, although they span a large range and incorporate significant uncertainty (Kilmer et al. 2010). Numbers range from 1 million kilograms (kg; Abt Associates 2001) to estimates from the Drug Enforcement Administration (DEA) and the United Nations Office on Drugs and Crime (UNODC) of about 4.2 million kg (Drug Availability Steering Committee 2002; UNODC 2005) and almost 10 million kg estimated by an industry insider (Gettman 2007). If we take the midrange DEA–UNODC

estimate, assume that the US Department of Justice (USDOJ) estimate that California produces 60% of the marijuana consumed in the United States holds true (USDOJ NDIC 2007), and assume a \$6600-per-kg price (Kilmer et al. 2010), then wholesale marijuana sales in California total approximately \$16.7 billion (\$11.2 billion if one assumes a lower price of \$4400 per kg). Even considering the uncertainty, these estimates suggest that marijuana is the largest cash crop in California, with the next largest commodity, milk and cream, securing \$6.9 billion in wholesale sales (USDA 2012).

However, marijuana cultivation is not subject to effective statewide governance (Short 2010). Cultivation for medical use was decriminalized as part of the Compassionate Use Act in 1996, specifically for ill individuals. Since the passage of that law, both the small- and large-scale cultivation of marijuana for medical purposes and the black market have increased dramatically (USDOJ NDIC 2007), particularly in the last 5 years, where watersheds in northern California have seen increases in area under production ranging from 55% to over 100% (Scott Bauer, California Department of Fish and Wildlife, personal communication, April 8, 2015). The production and sale of medical marijuana in California are currently regulated through a patchwork of county and state rules. However, all cultivation—including cultivation for medical purposes—remains illegal under federal law.

This semi-legal status greatly complicates local authority to regulate the medical market (Mozingo 2013) and sets the industry apart from traditional agriculture. For example, in recent

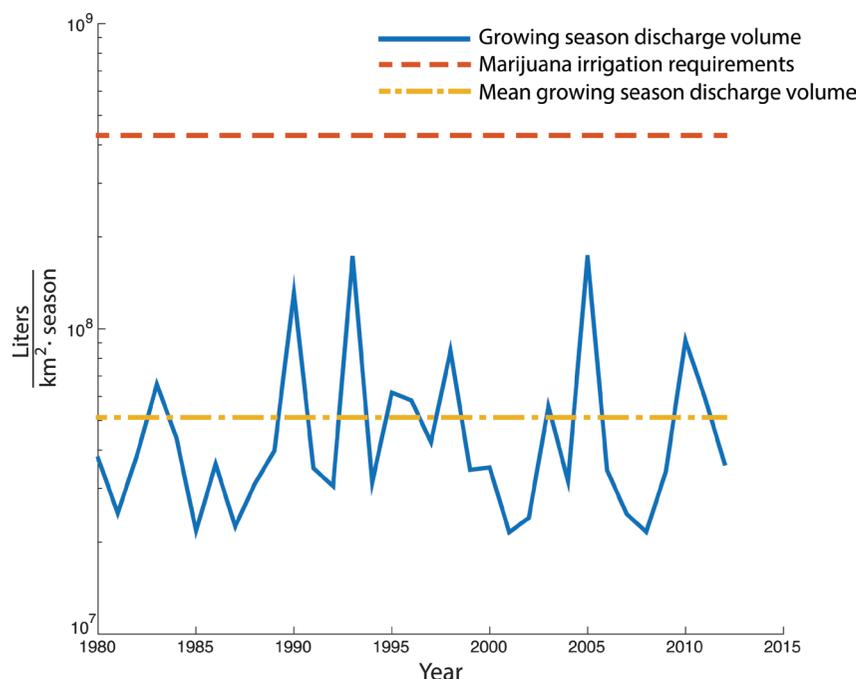


Figure 4. Actual growing season (June–October) discharge volumes (liters per square kilometer [km²] per season) for the Eel River watershed compared with mean growing season discharge volume and estimated marijuana irrigation water need. Note that marijuana water demand (on a per-area basis) exceeds water yield by almost ten times.

efforts in Mendocino County, the local authority's attempts to regulate medical markets have come into direct conflict with federal authorities, causing local officials to cease regulating the medical market (Mozingo 2013). This conflict also encourages secrecy and invisibility among producers for both the semi-legal medical and black markets, leading to lower levels of voluntary compliance with existing environmental regulation (Short 2010). The minimal regulation of medical markets further compounds the already significant intermixing of the medical and black markets in California (Short 2010). This intermixing creates further challenges for the effective enforcement of environmental laws and requires extensive coordination between natural-resource and law-enforcement agencies (Short 2010). In particular, the threat of violence associated with black market–marijuana cultivation complicates efforts and increases costs by natural-resource agencies to conduct field surveys or carry out enforcement or regulatory activities (Short 2010, Gabriel et al. 2013).

In short, the semi-legal status of the medical market and the significant intermixing of the medical and black markets complicate regulation of the industry. As a result, local marijuana-specific laws and regulations, as well as other existing state and federal environmental laws that apply (e.g., the state Fish and Game Code and Water Code and the federal Clean Water Act and Endangered Species Act) are currently inconsistently and lightly enforced (Short 2010). The lack of a robust legislative mandate to prevent and address the environmental impacts associated with marijuana cultivation adds to this challenge (Short 2010).

A lack of adequate resources also plays a significant role (Short 2010, Gabriel et al. 2013). The small number of state agents currently available to regulate this industry and others—and to enforce environmental laws—is not sufficient to adequately address the large number of marijuana cultivation sites. As an example, the State Water Resources Control Board, the agency tasked with administering water rights in California, is chronically underfunded (Grantham and Viers 2014) and already suffers from lack of staffing capacity and from permitting backlogs in processing water-rights applications for traditional water users (Little Hoover Commission 2010). Without new revenues, adding marijuana cultivators to this permitting queue will only further stretch already-thin resources.

Opportunities to reduce the environmental impacts of marijuana cultivation

There is a clear increasing trend in the liberalization of attitudes and policy toward marijuana use and possession worldwide. This trend presents an opportunity to prevent and mitigate the environmental impacts of marijuana cultivation. The legal marijuana markets currently under development feature policies that target and attempt to ameliorate some of the social and public-health consequences of marijuana possession and use. For example, Colorado and Washington State both allocate their projected \$67 million and \$389 million tax revenues, respectively, from legal recreational marijuana sales to state funds supporting public health and education (WOFM 2012, CLCS 2013). Current and future marijuana policies should also aim to prevent and mitigate the significant negative environmental impacts of marijuana cultivation.

If liberalization proceeds, future efforts to govern the environmental effects of marijuana production should include both incentives as well as regulatory and enforcement efforts to help legal producers comply with environmental laws and protect environmental resources. In legal markets, technical assistance and outreach programs could play a significant role in encouraging the adoption of best management practices and voluntary compliance. Similar efforts could encourage the management of stream flows that integrate human and ecosystem needs and mitigate some of the impacts of agricultural water diversion from natural systems (Grantham et al. 2010). Other incentive programs, such as certification and ecolabeling, have been used widely to help reduce the environmental externalities for other agricultural crops and could play a similar role in marijuana production (O'Hare et al. 2013). In order to overcome barriers to

participation, however, incentive strategies will likely only be feasible where the legal status of production is clarified. Furthermore, additional financial resources would be necessary to initiate or expand incentive-based programs.

Whether or not marijuana policies are liberalized, improvements in the enforcement of existing environmental laws and in the implementation of regulatory programs are necessary and will require additional resources and a clear legislative mandate. For the first time, the 2014–15 California budget includes \$3.3 million in funding for the enforcement of environmental laws on lands used for marijuana cultivation (Taylor 2014). Despite this promising first step, the need remains for additional dedicated funding to regulate marijuana cultivation and enforce environmental laws, to monitor the environmental impacts on public and private lands, and to support remediation and restoration in affected watersheds.

The scale of the existing marijuana markets in California and elsewhere suggests that taxation and fines could fund these measures. However, none of the \$58 million–\$105 million in state revenue generated each year from California's \$980 million medical marijuana market is currently earmarked for environmental protection, research, or remediation (CSBE 2014). In California, the legalization of the recreational use of marijuana may be on the horizon and could generate a further \$0.65 billion–\$1.5 billion in tax revenue (CSBE 2009, Kilmer et al. 2010), a portion of which should be allocated to environmental protection, research, and remediation.

Some policy analysts assume that regulation in legal markets will address many environmental impacts (O'Hare et al. 2013). But, as was previously mentioned, no local markets are fully legal at the federal level in the United States, complicating state regulatory authority (PF and CACP 2015). In the most recent federal spending bill, the inclusion of a clause prohibiting the US Justice Department from spending money to enforce a federal ban on growing or selling marijuana in US states that have legalized it for medical use (Halper 2014) may help ease regulatory authority in medical markets. But existing models for state-level liberalization have taken very inconsistent approaches in addressing production and environmental impacts. Therefore, the liberalization of use and possession policies per se may not adequately prevent or mitigate the environmental impacts from large-scale commercial cultivation without deliberate consideration.

In addition, black markets (and the environmental impacts associated with black-market cultivation) are unlikely to disappear in the face of local liberalization policies (PF and CACP 2015). For example, black market–marijuana cultivation remains a problem in Colorado despite the legalization of recreational use (PF and CACP 2015). Legalization will likely increase consumption—and may increase demand for black market marijuana—depending on how markets are regulated and enforcement conducted (Keefe 2013, PF and CACP 2015). Production for export to other states will still be illegal (at the state and federal level), and addressing the environmental concerns associated with this illegal production requires a commitment to both addressing illegal

production explicitly and remediating the environmental impacts from illegal production. This is of particular concern in California, because the state currently supplies such a large percentage of the marijuana consumed in the United States (Gabriel et al. 2013).

The reduction of environmental harm associated with marijuana cultivation and the enforcement of environmental laws are important social aims, regardless of the legal status of marijuana. The current levels of ambiguity and secrecy surrounding the industry impede the revelation of associated environmental impacts, as well as the creation and implementation of solutions. Inherent trade-offs and tension between marijuana cultivation and ecosystem needs exist, as they do in virtually all types of agriculture, and those trade-offs should be quantified and debated openly, as they are in other industries. There is a significant need to broaden the conversation to encompass environmental concerns and to explore how current and future marijuana policy can use both incentives and regulatory tools to prevent and mitigate the environmental damage associated with marijuana cultivation.

Acknowledgments

The authors are grateful to Nancy Smith for her support of this work. The authors also wish to thank Scott Morrison, Theodore Grantham and two anonymous reviewers who provided thoughtful suggestions and critiques that improved the manuscript. Participation in this project by Sally Thompson, Stephanie Carlson, David Dralle, and Mary Power was supported by the National Science Foundation CZP EAR-1331940 for the Eel River Critical Zone Observatory.

References Cited

- Abt Associates. 2001. What America's Users Spend on Illegal Drugs 1988–2000. Office of National Drug Control Policy. (8 April 2015; www.ncjrs.gov/ondcpubs/publications/pdf/american_users_spend_2002.pdf)
- [AP] Associated Press. 2014. Following legalization in US, Uruguay, marijuana gets second look. *Christian Science Monitor*. (11 December 2014; www.csmonitor.com/World/Latest-News-Wires/2014/0215/Following-legalization-in-US-Uruguay-marijuana-gets-second-look)
- Armstead L. 1992. Illicit narcotics cultivation and processing: The ignored environmental drama. *Bulletin of Narcotics* 44: 9–20.
- Bauer SD, Olson JL, Cockrill AC, van Hattem MG, Miller LM, Tauzer M, Leppig G. 2015. Impacts of surface water diversions for marijuana cultivation on aquatic habitat in four northwestern California watersheds. *PLOS ONE* 10 (art. e0120016). doi:10.1371/journal.pone.0120016
- Bussman, R. 1996. Destruction and management of Mount Kenya's forests. *Ambio* 25: 314–317.
- Caulkins JP, Kilmer B, MacCoun RJ, Pacula RL, Reuter P. 2011. Design considerations for legalizing Cannabis: Lessons inspired by analysis of California's Proposition 19. *Addiction* 107: 865–871.
- [CDWR] California Department of Water Resources. 2001. Irrigated Crop Acres and Water Use, North Coast Hydrologic Region. California Department of Water Resources. (11 December 2014; <http://www.water.ca.gov/landwateruse/anaglwu.cfm#>)
- . 2002. Irrigated Crop Acres and Water Use, North Coast Hydrologic Region. CDWR. (11 December 2014; www.water.ca.gov/landwateruse/anaglwu.cfm#)
- . 2003. Irrigated Crop Acres and Water Use, North Coast Hydrologic Region. CDWR. (11 December 2014; www.water.ca.gov/landwateruse/anaglwu.cfm#)

- . 2004. Irrigated Crop Acres and Water Use, North Coast Hydrologic Region. CDWR. (11 December 2014; www.water.ca.gov/landwateruse/anaglwu.cfm#)
- . 2005. Irrigated Crop Acres and Water Use, North Coast Hydrologic Region. CDWR. (11 December 2014; www.water.ca.gov/landwateruse/anaglwu.cfm#)
- Cervantes J. 2006. Marijuana Horticulture: The Indoor/Outdoor Medical Grower's Bible. Van Patten.
- [CLCS] Colorado Legislative Council Staff. 2013. Retail Marijuana Taxes. CLCS. (11 December 2014; [www.leg.state.co.us/LCS/Initiative%20Referendum/1314initrefr.nsf/b74b3fc5d676cdc987257ad8005bce6a/e3e37fa33a36873887257b6c0077ac93/\\$FILE/Retail%20Marijuana%20Taxes_FN.pdf](http://www.leg.state.co.us/LCS/Initiative%20Referendum/1314initrefr.nsf/b74b3fc5d676cdc987257ad8005bce6a/e3e37fa33a36873887257b6c0077ac93/$FILE/Retail%20Marijuana%20Taxes_FN.pdf))
- [CSBE] California State Board of Equalization. 2009. AB 390: Staff Legislative Bill Analysis. CSBE. (11 December 2014; www.boe.ca.gov/legdiv/pdf/ab0390-1dw.pdf)
- . 2014. Media Resource: Medical Marijuana/Legalization of Marijuana. CSBE. (11 December 2014; www.boe.ca.gov/news/marijuana.htm)
- Drug Availability Steering Committee. 2002. Drug Availability Estimates in the United States. Office of National Drug Control Policy. (8 April 2015; www.ncjrs.gov/ondcppubs/publications/pdf/drugavailability.pdf)
- Gabriel MW, et al. 2012. Anticoagulant rodenticides on our public and community lands: Spatial distribution of exposure and poisoning of a rare forest carnivore. PLOS ONE 7 (art. e40163). doi:10.1371/journal.pone.0040163
- Gabriel MW, Wengert GM, Higley JM, Krogen S, Sargent W, Clifford DL. 2013. Silent forests? Rodenticides on illegal marijuana crops harm wildlife. *Wildlife Professional* 7: 46–50.
- Gettman J. 2007. Lost Taxes and Other Costs of Marijuana Laws. *Drug Science.org*. Bulletin of Cannabis Reform no. 4. (27 May 2015; www.drugscience.org/Archive/bcr4/bcr4_index.html)
- Grantham TE, Viers JH. 2014. 100 years of California's water rights system: Patterns, trends and uncertainty. *Environmental Research Letters* 9 (art. 084012). doi:10.1088/1748-9326/9/8/084012
- Grantham TE, Merenlender AM, Resh VH. 2010. Climatic influences and anthropogenic stressors: An integrated framework for streamflow management in Mediterranean-climate California, USA. *Freshwater Biology* 55: 188–204.
- Halper E. 2014. Congress quietly ends federal government's ban on medical marijuana. *Los Angeles Times*. (14 January 2015; www.latimes.com/nation/la-na-medical-pot-20141216-story.html)
- [HGA] Humboldt Growers Association. 2010. Review of Humboldt County Medical Marijuana Health and Safety Code. Humboldt County. (11 December 2014; <http://library.humboldt.edu/humco/holdings/HGA2.pdf>)
- Hughes T. 2014. Where America landed on marijuana. *USA Today*. (11 December 2014 www.usatoday.com/story/news/politics/elections/2014/11/04/voters-deciding-on-marijuana/18485541/)
- [HGA] Humboldt Growers Association. 2010. Humboldt County 314-55.1 Medical Marijuana Land Uses. HGA. (11 December 2014; <http://library.humboldt.edu/humco/holdings/HGA2.pdf>)
- Keefe PR. 2013. Buzzkill: Washington State discovers that it's not so easy to create a legal marijuana economy. *New Yorker*. (11 December 2014; www.newyorker.com/magazine/2013/11/18/buzzkill)
- Kilmer B, Caulkins JP, Pacula RL, MacCoun RJ, Reuter PH. 2010. Altered State: Assessing How Marijuana Legalization in California Could Influence Marijuana Consumption and Public Budgets. RAND Corporation. (11 December 2014; www.rand.org/content/dam/rand/pubs/occasional_papers/2010/RAND_OP315.pdf)
- Little Hoover Commission. 2010. Managing for Change: Modernizing California's Water Governance. Little Hoover Commission.
- McNeil JR. 1992. Kif in the Rif: A historical and ecological perspective on marijuana, markets, and manure in northern Morocco. *Mountain Research and Development* 12: 389–392.
- Milestone JF, Hendricks K, Foster A, Richardson J, Denniston S, Demetry A, Ehmann M, Cuvelier C, Schifsky D, Fireman D. 2012. Continued cultivation of illegal marijuana in US western national parks. Pp. 209–216 in Weber S, ed. *Rethinking Protected Areas in a Changing World: Proceedings of the 2011 George Wright Society Biennial Conference on Parks, Protected Areas, and Cultural Sites*. George Wright Society.
- Mills E. 2012. The carbon footprint of indoor Cannabis production. *Energy Policy* 46: 58–67.
- Mozingo J. 2013. Mendocino County spars with feds over conflicting marijuana laws. *Los Angeles Times*. (17 December 2014; <http://articles.latimes.com/2013/jan/20/local/la-me-mendo-pot-20130122>)
- O'Hare M, Sanchez DL, Alstone P. 2013. Environmental Risks and Opportunities in Cannabis Cultivation. BOTEC Analysis Corp. (11 December 2014; http://lcb.wa.gov/publications/Marijuana/SEPA/BOTEC_Whitepaper_Final.pdf)
- [PF and CACP] Police Foundation and Colorado Association of Chiefs of Police. 2015. Colorado's Legalization of Marijuana and the Impact on Public Safety: A Practical Guide for Law Enforcement. PF and CACP. (8 April 2015; www.policefoundation.org/sites/g/files/g798246/ff/201501/Legalized%20Marijuana%20Practical%20Guide%20for%20Law%20Enforcement.pdf?utm_source=Sue%27s+Mail+Chimp+List+Verify&utm_campaign=97e9b3c326-February_11_2015_E_Highlights_NFIA2_11_2015&utm_medium=email&utm_term=0_fcd3118b18-97e9b3c326-334338205&mc_cid=97e9b3c326&mc_eid=3a66d7e699)
- Short AG. 2010. *Governing Change: An Institutional Geography of Rural Land Use, Environmental Management, and Change in the North Coastal Basin of California*. PhD dissertation. University of California, Berkeley, United States.
- Taylor M. 2014. The 2014–15 Budget: California Spending Plan. Legislative Analyst's Office. (11 December 2014; www.lao.ca.gov/reports/2014/budget/spending-plan/california-spending-plan-080414.pdf)
- Thompson C, Sweitzer R, Gabriel M, Purcell K, Barrett R, Poppenga R. 2014. Impacts of rodenticide and insecticide toxicants from marijuana cultivation sites on fisher survival rates in the Sierra National Forest, California. *Conservation Letters* 7: 91–102.
- [UNODC] United Nations Office on Drugs and Crime. 2005. World Drug Report. UNODC. United Nations Publication no. E.05.XI.10.
- [USDA] US Department of Agriculture. 2012. California Agricultural Statistics 2012 Crop Year. USDA. (27 May 2015; www.nass.usda.gov/Statistics_by_State/California/Publications/California_Ag_Statistics/Reports/2012cas-all.pdf)
- [USDOJ] NDIC] US Department of Justice National Drug Intelligence Center. 2007. Domestic Cannabis Cultivation Assessment. NDIC.
- Viers JH, Williams JN, Nicholas KA, Barbosa O, Kotzé I, Spence L, Webb LB, Merenlender A, Reynolds M. 2013. Vinecology: Pairing wine with nature. *Conservation Letters* 6: 287–299.
- [WOFM] Washington Office of Financial Management. 2012. Initiative 502: Fiscal Impact through Fiscal Year 2017. WOFM. (11 December 2014; www.ofm.wa.gov/ballot/2012/502_fiscal_impact.pdf)

Jennifer K. Carah (jcarah@tnc.org) is an ecologist, Jeanette K. Howard is the lead freshwater scientist, Lisa L. Hulette is a senior project director, and Stefanie L. Martin was an associate project director at The Nature Conservancy of California, in San Francisco. Jennifer works on stream and salmonid habitat conservation and restoration. Jeanette works on freshwater systems conservation planning and water resource sustainability. Lisa directs The Nature Conservancy of California's Salmon Program, and Stefanie is a conservation program manager who focuses on evaluating the economic value of conservation and the effects of market dynamics on conservation approaches. Sally E. Thompson is an ecohydrologist who studies hydrology, spatial ecology, and water resource sustainability and David N. Dralle is a graduate student who studies mathematical methods in ecohydrology in the Department of Civil and Environmental Engineering at the University of California, Berkeley. Stephanie M. Carlson is an ecologist who studies ecology and conservation of freshwater fishes in the Department of Environmental Science, Policy, and Management and Mary E. Power is an ecologist who studies river food webs and upland river-coastal ocean linkages in the Department of Integrative Biology at the University of California, Berkeley. Anne G. Short Gianotti is a geographer in the Department of Earth and Environment at Boston University; she studies human-environment

relations, environmental governance, and sustainable development. Scott D. Bauer is a senior environmental scientist with the California Department of Fish and Wildlife (CDFW) in Eureka; he works on CDFW's Watershed Enforcement Team, a program created in the summer of 2014 to regulate and enforce existing environmental laws at marijuana cultivation sites. Mourad W. Gabriel is the executive director for the Integral Ecology Research Center, a nonprofit research organization in Blue Lake, California; he studies wildlife disease ecology and the environmental impacts associated with marijuana

cultivation. Brian J. Johnson is California director of Trout Unlimited in Berkeley. Curtis A. Knight is executive director of California Trout in San Francisco. Sarah J. Kupperberg is an ecologist with McBain Associates, in Arcata, California. Sarah studies stream ecology, amphibian biology, and the impacts of hydropower facilities on aquatic resources. Rosamond L. Naylor is an economist in the Department of Environmental Earth Science at Stanford University. She studies the economic and biophysical dimensions of food security and the environmental impacts of crop and animal production.