

Post-Legalization Opening of Retail Cannabis Stores and Adult Cannabis Use in Washington State, 2009–2016

Erik M. Everson, MPH, Julia A. Dilley, PhD, Julie E. Maher, PhD, and Curtis E. Mack, BA


Objectives. To assess the relationship between adult cannabis use and time-varying local measures of retail cannabis market presence before and after legalization (2012) and market opening (2014) in Washington State.

Methods. We used 2009 to 2016 data on 85 135 adults' current (any) and frequent (20 or more days) past-month cannabis use from the Washington Behavioral Risk Factor Surveillance System linked to local retailer proximity and density. Multilevel models predicted use over time, accounting for nesting within communities.

Results. Current and frequent cannabis use grew significantly between 2009 and 2016; use did not significantly change immediately after legalization but increased subsequently with greater access to cannabis retailers. Specifically, current use increased among adults living in areas within 18 miles of a retailer and, especially, within 0.8 miles (odds ratio [OR] = 1.45; 95% confidence interval [CI] = 1.24, 1.69). Frequent use increased among adults living within 0.8 miles of a retailer (OR = 1.43; 95% CI = 1.15, 1.77). Results related to geospatial retailer density were consistent.

Conclusions. Increasing cannabis retail access was associated with increased current and frequent use.

Public Health Implications. Policymakers might consider density limits as a strategy for preventing heavy cannabis use among adults. (*Am J Public Health.* 2019;109:1294–1301. doi:10.2105/AJPH.2019.305191)

 See also Johnson and Doonan, p. 1165.

Washington and Colorado were the first US states to legalize the production, sale, and adult use of retail (“recreational” or nonmedical) cannabis in 2012. This change followed many states’ decriminalization of cannabis, beginning in the 1970s when Oregon and then 11 other states reduced penalties for possession of up to 1 ounce.¹ Starting with California in 1996, numerous states also legalized the possession or distribution of cannabis for specific medical purposes (including Washington in 1998).²

Whether potential increased adult use of a now-legal product (cannabis) is a “problem” has been a subject of much debate. Increasing adult cannabis use may lead to a variety of adverse public health effects, including cannabis dependence, traffic crashes, hospitalizations, and potentially some long-term health outcomes. Although cannabis has long been a commonly

used substance, recent major systemic reviews have produced inconclusive evidence about whether cannabis use causes some of the posited health outcomes.^{3,4} Furthermore, existing research on cannabis may be only partially generalizable to modern levels of product potency, individual differences in usage frequency, and emerging trends in both product types (e.g., extract oils) and usage forms (e.g., vaping vs smoking).⁵ Regardless of how cannabis is consumed, frequent use—such as daily or near-daily use—is likely of more concern than occasional use and has recently been identified as a risk.⁶

Studies on other commercialized controlled substances offer some insight on potential for preventing harms following legalization. Increased local access to off-premise-use alcohol outlets has been repeatedly associated with higher rates of problematic use and related adverse health outcomes.^{7–9} Hence, the *Community Guide to Preventive Services* recommends limiting alcohol outlet density, days of sale, and hours of sale as effective strategies for reducing excessive alcohol consumption and associated motor vehicle crashes.¹⁰ Similarly, greater local access to tobacco retail outlets has been associated with higher rates of tobacco use initiation¹¹ and lower success rates for quitting^{12–14} among select adult population groups. And although medical cannabis is not available to the general public, local retail medical availability in California was found to be associated with increased adult cannabis use.¹⁵

To control retail density, the Washington State Liquor and Cannabis Board, the state agency that oversees regulation of the cannabis market, established maximum numbers of retail licenses allowed.¹⁶ Initially following legalization, the state allowed a total of 334 retail licenses statewide, with specific allocations by city and county jurisdictions. The number was increased to 556 in 2016 to accommodate access to medical markets, which were concurrently integrated into the retail system.¹⁶ In light of the uncertainty about health harms, or in response to other community concerns, numerous local

ABOUT THE AUTHORS

Erik M. Everson, Julia A. Dilley, and Julie E. Maher are with Program Design and Evaluation Services, Multnomah County Health Department, and the State of Oregon Public Health Division, Portland. Curtis E. Mack is with Looking Glass Analytics, Olympia, WA.

Correspondence should be sent to Erik M. Everson, MPH, 800 NE Oregon St, Suite 260, Portland, OR 97232 (e-mail: erik.everson@dhsosha.state.or.us). Reprints can be ordered at <http://www.ajph.org> by clicking the “Reprints” link.

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jurisdictions acted to prohibit or otherwise further regulate retail sales.^{17,18} As of June 2016, 2 years after the initial opening of retail markets, about one third of Washington State's population still lived in a city or county where retail cannabis sales were permanently or temporarily banned. Because of local bans, only 377 of the potentially allowed 556 retailers reported sales in mid-2017, and there has been great variation in access to cannabis retailers among different regions of the state as a result.¹⁹

The objective of this study was to examine the effects of local access to cannabis retailers on adult cannabis use in Washington, where the retail cannabis market opened in July 2014. To our knowledge, our study is the first to examine the complex associations between local access to a new retail market and use of cannabis among adults.

METHODS

We obtained survey data on individual cannabis use outcomes and then linked them by respondent zip code and month of survey to measures of state legalization and local retail access. Multilevel models predicted use based on access while accounting for legalization, secular trends, demographic factors, and nesting within communities.

Adult Cannabis Use

We used 2009 to 2016 data from the Washington State Behavioral Risk Factor Surveillance System (BRFSS) to describe local cannabis use.²⁰ The BRFSS is a nationally conducted, state-administered telephone survey of adults. The Washington BRFSS randomly contacts households from a statewide pool of telephone numbers including landlines and, since 2011, cellular telephones. A total of 121 632 people participated in the BRFSS from 2009 to 2016; 58% were female, 58% were 55 years or older, and 87% primarily identified as non-Hispanic White. In 2016, Washington's BRFSS had a response rate of 39.3%²¹ (calculated according to the American Association for Public Opinion Research's response rate 4 formula²²).

The Washington BRFSS asked questions about cannabis use for a random subset of

90 622 total respondents between 2009 and 2016. Respondents were asked on how many of the past 30 days they used any cannabis products. We created primary outcome variables for current use, indicating any cannabis use in the past 30 days, and frequent use, an indicator²³ of use on at least 20 of the past 30 days. BRFSS data on individual demographic characteristics including age, gender, race/ethnicity, education, marital status, and type of telephone (landline or cellular) were also used. A total of 85 135 respondents had complete data on all of these measures.

We used Rural-Urban Commuting Area codes from the Washington Department of Health to define urban and non-urban areas on the basis of participants' zip codes.²⁴ We used 5-year county-level estimates of the percentages of individuals living below the federal poverty level from the 2011 to 2016 versions of the American Community Survey.²⁵

State Legalization Measure

Washington Initiative 502 passed in November 2012. Effective December 6, 2012, the measure legalized small-amount possession and private use of cannabis among adults 21 years or older.²⁶ For our analyses, we created a binary legalization effect term set to 0 for all months up through November 2012 and 1 for all months after. In addition, we created a term for month centered on legalization with values set to -1 for November 2012, 0 for December 2012, 1 for January 2013, and so on.

Retail Access Metrics

Washington's retail cannabis market opened on July 1, 2014. The number of cannabis retailers with active sales grew each month, from fewer than 20 in July 2014 to more than 300 by mid-2016. We obtained data from the Washington State Liquor and Cannabis Board BioTrackTHC "seed-to-sale" tracking system to determine the months and locations where retail cannabis sales activity had occurred. Using this data set, we computed 3 alternate measures of monthly local access to the retail market: proximity, geospatial density, and per capita density.

Proximity. Our first retail access metric measured the average distance to the nearest

retail location among residents of each zip code for each month of the study. To compute proximity, we first applied a grid overlay of 5000 foot by 5000 foot cells (0.9 square miles each) to the state of Washington using ArcGIS 10.5 software (Esri, Redlands, CA) and the Washington State Plane South (ftUS) NAD83(HARN) (EPSG:2927) projection. Using PostgreSQL 10.1 with PostGIS extension 2.4.2 (PostgreSQL Global Development Group), we determined the direct (crow-fly) distance between the center of each grid cell and all retailers with active sales for each month. We selected the shortest distance for each cell per month.

Although we did not know the intra-zip code locations of individual BRFSS respondents, we estimated the cell-level population distribution for each zip code. This distribution was based on 2014 census block group population estimates from the Washington Office of Financial Management,²⁷ which we initially apportioned to individual blocks using ratios from the 2010 US census²⁸ and then apportioned to grid cells based on area. Using this distribution, we weighted cell-level proximity computations up to the zip code level, resulting in the average distance to the nearest retailer for residents of each zip code.

Geospatial density. Our second retail access metric was computed in a manner similar to that for proximity but based on the nearest 5 active retail locations. After determining the nearest 5 retailers to each grid cell, we summed the inverse of each cell-to-retailer distance (such that a higher sum indicated more density) and then aggregated these sums to the zip code level. Whereas proximity represented a measurement of the minimum distance a local resident would need to travel to purchase retail cannabis, geospatial density was intended to assess the local retail environment. We adapted this metric from the spatial accessibility index included in the Centers for Disease Control and Prevention's *Guide for Measuring Alcohol Outlet Density*.²⁹

Per capita density. Our third access metric was defined at the "community" (contiguous city or unincorporated county) level to reflect the jurisdictional boundaries in which local cannabis-related policies are typically enacted. We computed per capita density for each community by dividing the number of active monthly retailers by the estimated 2014

population. We assigned each BRFSS respondent to his or her most likely community of residence. Using a crosswalk file based on 2010 census block-level population data,²⁸ we selected the most populous community subsection within each combination of zip code and county. Our resulting sample included 194 distinct communities, with 1 to 6935 participants in each community over the 8 years combined. We assigned a per capita density value to each BRFSS respondent on the basis of his or her community and month and year of survey participation.

Categorization of retail access metrics. We first divided proximity values for the entire study period into ventiles (twentieths) and visually examined both current use and frequent use prevalence across the ventile range. We found both relationships to be nonlinear, resembling 3-tier step functions, so we created a single set of cut points to capture the tier changes in the relationships. Specifically, we created a categorical variable with 5 levels of retail access: premarket, top 5% active market (within approximately 0.8 miles of a retailer), next 5% (0.8–1.1 miles), middle 80% (1.2–18.4 miles), and bottom 10% (beyond 18.4 miles). We followed the same categorization procedure for geospatial density and arrived at an identical set of percentile cut points for retail access categories. We categorized per capita density similarly but with a larger bottom access tier given the many communities and months with no retailers: premarket, top 5% active market (9.7 retailers or more per 100 000 population), next 5% (6.7–9.6 retailers), middle 53% (0.1–6.6 retailers), and bottom 37% (zero retailers active market).

Statistical Analyses

We used descriptive statistics to examine patterns of cannabis use prevalence (current use and frequent use) by participants' demographic characteristics and access to cannabis retailers for the most recent year of survey data (2016). Data for these prevalence estimates were weighted to represent the state population.

We fit generalized mixed models³⁰ with a random intercept by community effect as well as a random time by community effect. Hence, each community had its own intercept (given that baseline cannabis use might vary by community) and slope for time (given

that change in use might vary by community). The key fixed effects in each model included a term for time to describe the average secular trend in statewide cannabis use, a term for state legalization to estimate the average change in cannabis use after legalization, and a term for retail cannabis access. To adjust for other factors, our models also included fixed effect terms for urban classification by zip code, county poverty rate, and individual demographics (i.e., age, gender, race/ethnicity, education, marital status, and landline or cellular phone). Separate models were fit for current use and frequent use as the dependent variable.

We conducted all statistical analyses with Stata version 14.1 (StataCorp LP, College Station, TX). We used the .05 level of significance.

RESULTS

Figure 1 displays Washington statewide adult cannabis use prevalence over time. Quarterly current use prevalence more than doubled over the course of our study, increasing from 5.8% in quarter 1 of 2009 to 13.2% in quarter 4 of 2016; frequent use increased over that period as well, from 2.0% to 5.5%.

As shown in Table 1, a majority of the members of our 2016 BRFSS sample were White (86.9%), were 35 years or older (85.7%), and had at least some college education (73.1%). The 2016 prevalence of current cannabis use was highest among participants who were 18 to 34 years of age (24.2%), those who identified as male (16.9%), those without a high school degree or equivalent (20.9%), and those who had a partner but were not married (27.9%).

Figure 2 shows the monthly distribution of Washington residents, based on zip code-level density values and small-area population estimates, living in various categories of geospatial density. Access to retailers increased over time. When the market first opened in 2014, only 3.8% of state residents lived in a zip code with a geospatial density value of 1.0 or greater; by December 2016, however, 73.2% of residents lived in such environments.

Regardless of the retail access measure used, our adjusted models suggested that current cannabis use and frequent use were

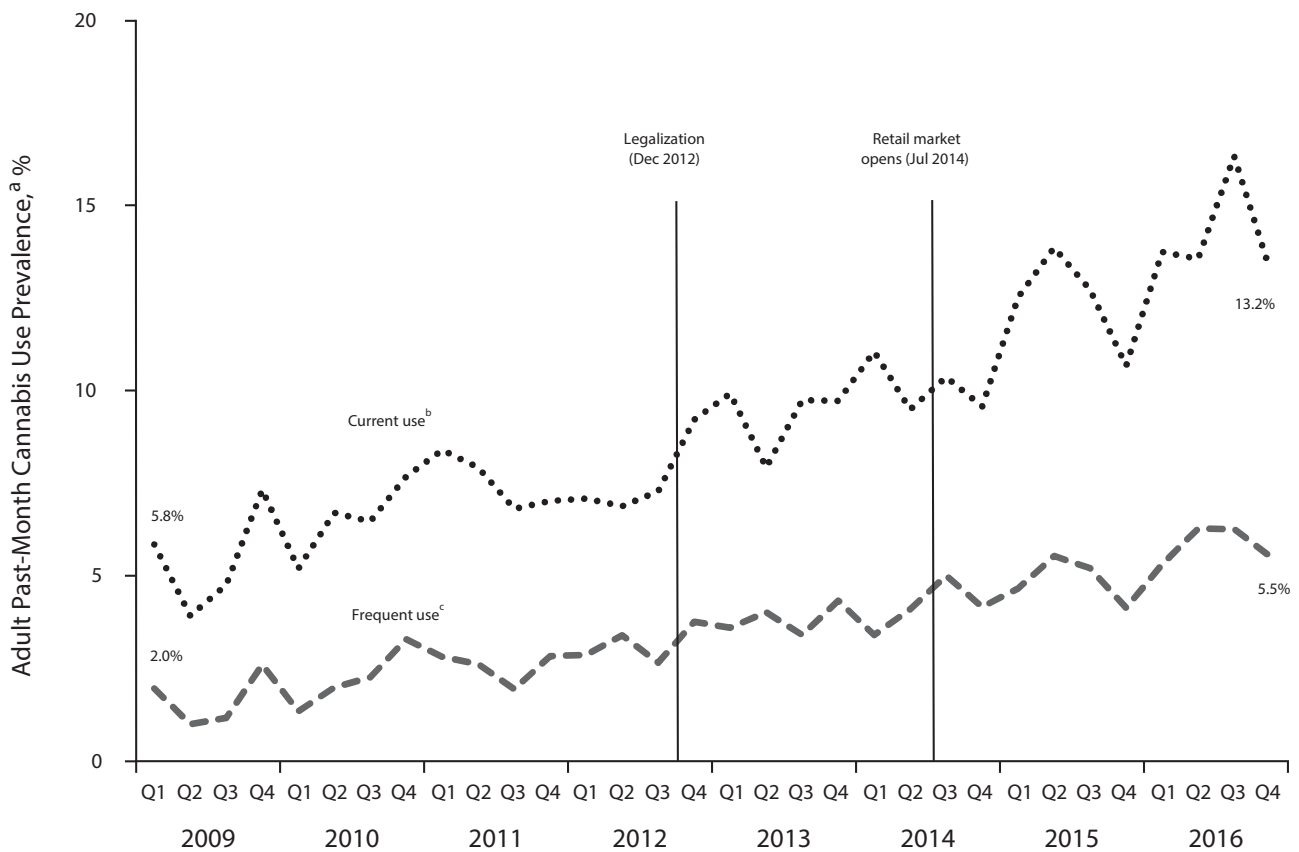
significantly increasing between 2009 and 2016 but did not significantly change directly after possession was legalized in 2012 (Table 2). The relationship between retail access and cannabis use varied according to the measures used, as detailed subsequently.

In the proximity model, current use of cannabis significantly increased with closer proximity to retailers; specifically, it increased in zip codes where residents lived an average of less than 0.8 miles from a retailer (odds ratio [OR] = 1.45; 95% confidence interval [CI] = 1.24, 1.69), between 0.8 and 1.1 miles (OR = 1.27; 95% CI = 1.08, 1.49), and between 1.2 and 18.4 miles (OR = 1.18; 95% CI = 1.08, 1.29). Current use did not significantly change in association with the retail market in areas more than 18.4 miles from a retailer (OR = 1.06; 95% CI = 0.89, 1.26).

The proximity model results for frequent use of cannabis varied somewhat from those for any current use. Although the retail market was associated with a significant increase in frequent use among zip codes averaging less than 0.8 miles from a retailer (OR = 1.43; 95% CI = 1.15, 1.77), frequent use did not significantly change in areas located 0.8 to 1.1 miles (OR = 1.02; 95% CI = 0.80, 1.29) or 1.2 to 18.4 miles (OR = 1.04; 95% CI = 0.89, 1.21) from a retailer.

Results for geospatial density were similar to those for proximity; the same terms reached statistical significance in the respective current use and frequent use models. As continuous measures, geospatial density and proximity had a correlation coefficient of –0.45 (data not shown; the value was negative because density was based on inverse distances).

In the per capita density model, results for current use of cannabis were largely similar to those for proximity and geospatial density. Current use increased significantly among communities with at least 9.7 retailers (OR = 1.36; 95% CI = 1.13, 1.64), 6.7 to 9.6 retailers (OR = 1.52; 95% CI = 1.22, 1.89), and 0.1 to 6.6 retailers (OR = 1.17; 95% CI = 1.07, 1.27) per 100 000 population. In contrast with the geospatial models, current use also increased significantly among communities with no retailers (OR = 1.17; 95% CI = 1.03, 1.32), although this lowest-access tier was much larger (37% of the sample) than the bottom tiers for geospatial density and proximity (10%).



^aPrevalence estimates were weighted to be representative of the state population. A different weighting methodology was used for data prior to 2011, and these data did not include cellular phones in the sample.

^bCurrent use: self-reported use of cannabis on any of the past 30 days.

^cFrequent use: self-reported use of cannabis on 20 or more of the past 30 days.

FIGURE 1—Adult Cannabis Current Use and Frequent Use Prevalence, by Quarter: Behavioral Risk Factor Surveillance System, Washington State, 2009 Quarter 1 to 2016 Quarter 4

Our per capita density model proved less predictive of frequent use than did the geospatial models. Whereas frequent cannabis use increased among areas in the top 5% tiers of proximity and geospatial density, it did not change significantly among communities with at least 9.7 retailers per 100 000 population (OR = 1.12; 95% CI = 0.82, 1.52).

DISCUSSION

This study was the first to our knowledge to explore the association between changing access to retail cannabis and adult cannabis use. We found that adult current use significantly increased in areas located within 18.4 miles of a cannabis retailer, with a larger increase occurring in areas located within 0.8

miles of a retailer. Frequent past-month use, likely the more serious public health concern, increased significantly in areas located within 0.8 miles of a retailer.

Washington already had among the highest US state rates of cannabis use prior to retail sales,³¹ suggesting that individuals determined to obtain cannabis may have had little difficulty doing so. The lack of a broad market-related change in frequent cannabis use suggests that most adults prone to such behavior may not have been further compelled to engage in it by the mere existence of the retail market. In the market's highest-access areas, however, elevated levels of convenience or promotion may have had sufficient influence such that additional adults became frequent users. Notably, the number of high-access areas increased over the course

our study: by December 2016, approximately 1 in 10 Washington residents (10.1% for proximity, 11.0% for geospatial density) lived in a location where the level of retail access was associated with increased frequent use.

We found local retail access, but not state legalization of possession itself, to be associated with increased cannabis use. Local jurisdictions in legalized states may therefore have some ability to limit increased use through enacting policies such as retail bans, moratoriums, caps on retail license numbers, or density or zoning restrictions. Despite challenges such as bordering communities with less stringent policies, community-level policies may help to prevent especially high levels of local retail access, such as the areas within 0.8 miles of a retailer for which frequent use increased.

TABLE 1—Sample Characteristics and Cannabis Use Prevalence by Demographic Characteristics: Behavioral Risk Factor Surveillance System, Washington State, 2016

Characteristic	Observations, No. (%)	Cannabis Use Prevalence (95% CI)	
		Current ^a	Frequent ^b
State total, 2016	11 765 (100.0)	14.2 (13.4, 15.2)	5.7 (5.2, 6.4)
Age group, y			
18–34	1 683 (14.3)	24.2 (21.9, 26.7)	9.4 (7.9, 11.1)
35–64	5 647 (48.0)	12.6 (11.6, 13.7)	5.5 (4.8, 6.3)
65–99	4 435 (37.7)	4.7 (4.0, 5.5)	1.3 (1.0, 1.8)
Gender			
Female	6 574 (55.9)	11.8 (10.7, 13.0)	4.0 (3.4, 4.8)
Male	5 191 (44.1)	16.9 (15.6, 18.3)	7.6 (6.6, 8.6)
Education			
< grade 12	562 (4.8)	20.9 (16.7, 25.7)	11.0 (8.1, 14.8)
High school degree or equivalent	2 599 (22.1)	17.3 (15.4, 19.3)	7.8 (6.5, 9.2)
Some college	3 525 (30.0)	14.1 (12.6, 15.6)	5.4 (4.5, 6.4)
College	5 079 (43.2)	9.9 (8.9, 11.0)	2.8 (2.3, 3.5)
Telephone type			
Landline only	982 (8.3)	11.8 (9.0, 15.5)	6.0 (4.2, 8.7)
Landline survey, own both	5 688 (48.3)	9.3 (8.2, 10.4)	3.1 (2.5, 3.8)
Cellular survey, own both	1 806 (15.4)	11.6 (9.9, 13.5)	4.3 (3.2, 5.7)
Cellular only	3 289 (28.0)	18.7 (17.2, 20.3)	7.9 (6.9, 9.1)
Race/ethnicity			
Non-Hispanic White	10 220 (86.9)	14.6 (13.6, 15.6)	5.8 (5.2, 6.5)
Non-Hispanic Black	234 (2.0)	25.5 (18.9, 33.5)	11.6 (7.1, 18.3)
Non-Hispanic American Indian/Alaska Native	144 (1.2)	26.0 (17.8, 36.4)	8.0 (4.1, 15.1)
Non-Hispanic Asian	377 (3.2)	6.7 (3.9, 11.0)	1.0 (0.4, 2.5)
Non-Hispanic Hawaiian/Pacific Islander	35 (0.3)	11.9 (3.1, 36.5)	2.7 (0.4, 16.7)
Other non-Hispanic	113 (1.0)	9.2 (4.5, 17.9)	4.2 (1.2, 13.3)
Non-Hispanic, no race preference	38 (0.3)	37.5 (20.9, 57.6)	20.2 (7.6, 43.6)
Hispanic	604 (5.1)	11.8 (9.1, 15.2)	6.5 (4.5, 9.3)
Marital status			
Married	6 488 (55.1)	9.4 (8.5, 10.4)	3.4 (2.9, 4.1)
Divorced	1 715 (14.6)	15.0 (12.7, 17.5)	6.6 (5.2, 8.3)
Widowed	1 339 (11.4)	5.4 (4.0, 7.2)	2.3 (1.4, 3.8)
Separated	178 (1.5)	21.7 (15.2, 30.0)	11.2 (6.6, 18.5)
Never married	1 608 (13.7)	25.0 (22.3, 27.8)	10.4 (8.7, 12.5)
Unmarried with partner	396 (3.4)	27.9 (22.5, 33.9)	11.0 (7.5, 15.9)
Refused	41 (0.3)	16.1 (6.2, 35.5)	9.7 (3.0, 27.2)
Urban status			
Nonurban	4 004 (34.0)	15.2 (13.6, 17.1)	6.8 (5.6, 8.1)
Urban	7 761 (66.0)	13.9 (12.9, 15.0)	5.4 (4.7, 6.1)
Community ^c retailer per capita density ^d			
Highest (≥9.7)	1 120 (9.5)	15.7 (12.8, 19.1)	7.0 (5.0, 9.6)
High (6.7–9.6)	983 (8.4)	16.4 (13.5, 19.7)	6.0 (4.2, 8.5)
Medium (0.1–6.6)	6 390 (54.3)	13.9 (12.8, 15.1)	5.2 (4.5, 6.0)
None (0.0)	3 272 (27.8)	13.9 (12.1, 16.0)	6.6 (5.3, 8.1)

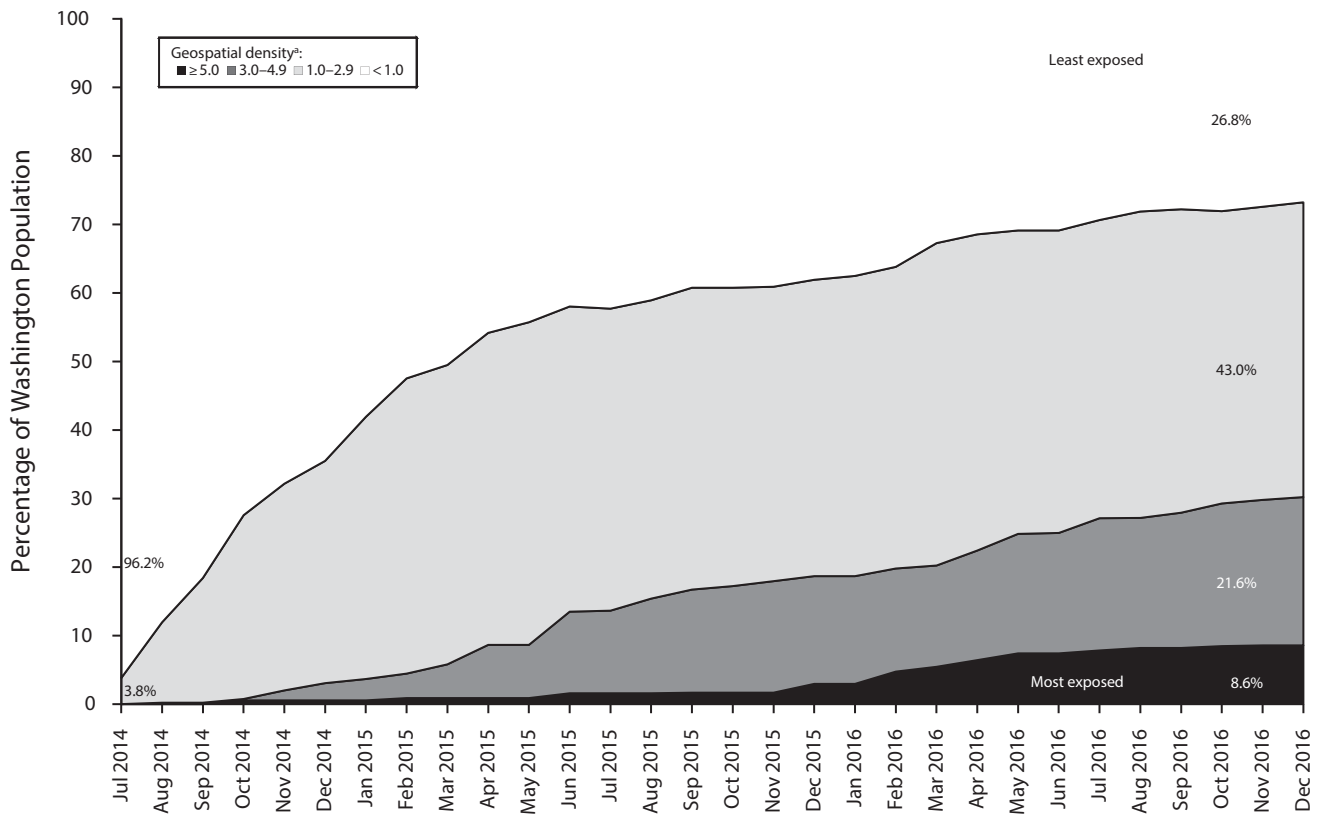
Note. CI = confidence interval. Prevalence estimates were weighted to be representative of the state population.

^aCurrent use: self-reported use of cannabis on any of the past 30 days.

^bFrequent use: self-reported use of cannabis on 20 or more of the past 30 days.

^cCommunity: city or unincorporated county (n = 190 in 2016), assigned according to respondent zip code and county.

^dNumber of active cannabis retailers per 100 000 estimated population in each community.



Note. Data were derived from the Washington Office of Financial Management and the Washington State Liquor and Cannabis Board.

^aGeospatial density: population-weighted sum of inverse distances from home zip code to the nearest 5 active retail locations. Higher values indicate more retail access.

FIGURE 2—Percentages of Residents Living in Areas of Various Categories of Geospatial Density of Recreational Cannabis Retailers: Washington State, July 2014 to December 2016

Also, although occasional adult cannabis use may not prove to be a substantial public health problem, our results suggest that restricting retailer density to fewer than 6.7 locations per 100 000 community population may help mitigate increases in use. Given the variation in cannabis use prevalence among demographic groups, however, the effectiveness of such policies may vary by neighborhood. For example, restricting retail density to a set limit would likely have a different mitigation effect on a college campus than in a suburban community.

Our per capita density model showed that even communities with no active retailers experienced a market-associated increase in current use of cannabis. This suggests that the efficacy of any jurisdictional policy restricting local retail access may be tempered by retail availability in nearby communities. Thus, in nonremote communities, a regional- or

state-level policy approach may be necessary to effectively limit retail access. Washington limited retailer density at the city and county levels by establishing caps on the number of issuable retail licenses. It is also noteworthy that per capita density, although commonly used in regulations, did not characterize access as meaningfully as the geospatial-based metrics included in our study.

To regulate alcohol-related problems, Washington has already established community-requested “alcohol impact areas”³² that include limitations on retail hours and the sale of specific products. This may be another model for limiting retail access to cannabis markets in a different way than restricting numbers of licenses, if communities are experiencing adverse consequences.

Other factors may affect the concept of access to retail cannabis, including price. Average retail prices fell considerably over our

study period and will likely continue to decrease,⁵ although lower prices may be more likely to affect individual usage volumes than prevalence of occasional or current use. Visibility, including that due to advertising, could also be important. One study showed that more than half of Oregon adults had recently seen cannabis advertising such as retail storefront and billboard promotions, with greater exposure among residents of neighborhoods containing cannabis retailers.³³ Regulatory approaches to address prices (e.g., taxes) and limit retail promotions may be another relevant consideration for policymakers to broadly influence accessibility.

Although our study included 30 months of market data, longer-term cannabis use trends may vary as the retail market stabilizes. Longer-term study is needed to determine whether increases in current use will be sustained.

TABLE 2—Odds Ratios for Past-Month Cannabis Use: Behavioral Risk Factor Surveillance System, Washington State, 2009–2016

Retail Access Metric	OR ^a (95% CI)		Adjusted OR ^b (95% CI)	
	Current Use ^c	Frequent Use ^d	Current Use ^c	Frequent Use ^d
Proximity^e				
Time (12 mo)	1.14 (1.09, 1.18)	1.19 (1.12, 1.26)	1.11 (1.07, 1.16)	1.16 (1.10, 1.23)
Legalization	1.10 (0.96, 1.26)	1.07 (0.88, 1.30)	1.12 (0.98, 1.29)	1.09 (0.89, 1.33)
Retail access				
Top 5% (<0.8 mi)	1.46 (1.25, 1.72)	1.46 (1.15, 1.86)	1.45 (1.24, 1.69)	1.43 (1.15, 1.77)
Next 5% (0.8–1.1 mi)	1.24 (1.04, 1.47)	1.01 (0.81, 1.25)	1.27 (1.08, 1.49)	1.02 (0.80, 1.29)
Middle 80% (1.2–18.4 mi)	1.08 (0.99, 1.18)	0.96 (0.83, 1.11)	1.18 (1.08, 1.29)	1.04 (0.89, 1.21)
Bottom 10% (>18.4 mi)	0.93 (0.79, 1.11)	0.90 (0.69, 1.17)	1.06 (0.89, 1.26)	0.97 (0.75, 1.26)
Geospatial density^f				
Time (12 mo)	1.13 (1.09, 1.18)	1.19 (1.12, 1.26)	1.11 (1.06, 1.15)	1.16 (1.10, 1.23)
Legalization	1.11 (0.96, 1.27)	1.06 (0.87, 1.29)	1.14 (0.99, 1.31)	1.09 (0.90, 1.33)
Retail access				
Top 5% (≥4.70)	1.28 (1.05, 1.56)	1.28 (0.96, 1.7)	1.39 (1.13, 1.71)	1.40 (1.07, 1.83)
Next 5% (3.36–4.69)	1.36 (1.16, 1.59)	0.97 (0.73, 1.28)	1.45 (1.25, 1.69)	1.01 (0.76, 1.35)
Middle 80% (0.18–3.35)	1.11 (1.02, 1.20)	0.98 (0.84, 1.13)	1.20 (1.10, 1.31)	1.05 (0.90, 1.22)
Bottom 10% (<0.18)	0.87 (0.73, 1.03)	0.85 (0.65, 1.12)	0.97 (0.81, 1.16)	0.93 (0.71, 1.22)
Per capita density^g				
Time (12 mo)	1.14 (1.09, 1.19)	1.20 (1.14, 1.27)	1.11 (1.07, 1.16)	1.17 (1.10, 1.24)
Legalization	1.09 (0.95, 1.24)	1.03 (0.85, 1.25)	1.13 (0.98, 1.29)	1.07 (0.88, 1.30)
Retail access				
Top 5% (≥9.7 per 100 000)	1.13 (0.93, 1.36)	0.93 (0.67, 1.29)	1.36 (1.13, 1.64)	1.12 (0.82, 1.52)
Next 5% (6.7–9.6 per 100 000)	1.31 (1.08, 1.59)	1.01 (0.74, 1.38)	1.52 (1.22, 1.89)	1.17 (0.85, 1.62)
Middle 53% (0.1–6.6 per 100 000)	1.08 (1.01, 1.16)	0.94 (0.8, 1.11)	1.17 (1.07, 1.27)	1.00 (0.84, 1.20)
Bottom 37% (0.0)	1.07 (0.95, 1.19)	0.98 (0.83, 1.15)	1.17 (1.03, 1.32)	1.06 (0.90, 1.25)

Note. CI = confidence interval; OR = odds ratio. All models clustered by community (n = 194; city or unincorporated county assigned according to respondent zip code and county). Retail access terms describe the change in cannabis use between premarket and active-market periods for locations of the given access categorization. For example, in the proximity models, the top 5% (<0.8 mi) term describes the change in use prevalence associated with the retail market among locations within 0.8 mi of a retailer, for only the months those locations met the <0.8 mi access criterion.

^aOdds ratio taken from generalized linear mixed model with time, legalization, and retail access measure as independent variables.

^bOdds ratio taken from generalized linear mixed model adjusted for age, gender, education, race/ethnicity, marital status, urban status, county poverty rate, and survey telephone type.

^cCurrent use: self-reported use of cannabis on any of the past 30 days.

^dFrequent use: self-reported use of cannabis on 20 or more of the past 30 days.

^eProximity: population-weighted average distance from home zip code to nearest active retail location.

^fGeospatial density: population-weighted sum of inverse distances from home zip code to the nearest 5 active retail locations.

^gPer capita density: number of active cannabis retailers per 100 000 estimated population in each community.

Limitations

Our study has several limitations. First, we assumed Washington BRFSS respondents to be representative of the state population in estimating associations between access and cannabis use. Second, because cannabis has been illegal and has carried social stigma, it is possible that some survey respondents opted not to disclose their actual use. If this

underreporting decreased over time in conjunction with state legalization, this may have led to an exaggerated increase in actual cannabis use. However, we do not have reason to believe that survey respondents were more or less likely to admit use according to their proximity to a retailer.

Third, our retail access measures involved limitations. We computed geospatial retail

access on the basis of survey respondents' residential zip codes. Some of Washington's less populated zip codes span large areas, such that actual retail access may vary considerably according to intra-zip code location. We used small-area population estimates to accurately compute population-average access for each zip code, reducing attenuation of findings that would have resulted from this limitation. For the per capita model, we assigned survey respondents to the most likely community given their zip code and county, but an estimated 21.4% of respondents were incorrectly assigned to a community neighboring their actual residence. These misclassifications may have attenuated our findings and limited the per capita model's predictive ability, although defining retail access on the basis of jurisdictional boundaries is moderately imprecise by nature.

Fourth, our study did not account for average retail cannabis prices, which decreased substantially over time as the market grew.⁵ To what extent decreasing prices magnified the effect of access on use is an area for further study.

Fifth, we analyzed access to retail cannabis but did not account for cannabis availability from other sources. In addition to the outright illicit market, Washington had a large number of minimally regulated medical cannabis "collective gardens" in operation between 2009 and June 2016.³⁴ Because we did not account for alternate sources, we overestimated the net proportional increase in cannabis access attributable to the retail market (although not for the law-abiding general public). Our findings may thus underestimate the potential effect of introducing retail access as compared with locations with smaller or less easily accessible medical and illicit markets.

Public Health Implications

We found the Washington retail cannabis market to be associated with increased past-month adult use throughout most of the state and increased frequent use among locations with especially high retail access. Although the public health implications of increasing cannabis use are not yet clear, our findings suggest that local jurisdictions can mitigate

increased usage through policies limiting retail access in residential locations. **AJPH**

CONTRIBUTORS

E. M. Everson, J. A. Dilley, and J. E. Maher designed the study, interpreted results, and wrote the article. E. M. Everson led the data analysis. C. E. Mack advised on geospatial analysis design and performed geospatial computations.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

HUMAN PARTICIPANT PROTECTION

No protocol approval was needed for this study because no human participants were involved and secondary data were used.

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