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Measuring the Association Between Cannabis Dispensary Density and Adult Consumption in a Statewide Setting: Does Urbanicity Matter?

Pamela J. Trangenstein[1], Thomas K. Greenfield[1], Deidre M. Patterson[1], & William C. Kerr[1]
[1]Alcohol Research Group, Public Health Institute

ABSTRACT

Objective: This study used data from early stages of non-medical cannabis legalization in Washington State to 1) Compare cannabis dispensary density measures by urbanicity, 2) Test if dispensary density was associated with cannabis use overall and by urbanicity. **Method:** Data are from the Privatization of Spirits in Washington Surveys (n = 2,162 adults) and licensing records. We graphed six cannabis dispensary density measures by urbanicity. Logistic regressions tested if dispensary density was associated with 1) cannabis use at least bimonthly and 2) daily/near-daily cannabis use after adjusting for urbanicity. Regressions stratified by urbanicity determined whether associations differed in urban vs. suburban/rural areas. **Results:** Crude counts and counts per population were higher in suburban/rural areas. Counts per land area, counts in a 3- to 5-mile buffer, proximity, and clustering detected greater densities in urban areas. Monthly/bimonthly cannabis use was associated with counts per buffer in the full sample (aOR = 1.08 [1.02, 1.14]) and urban areas (aOR = 1.08 [1.02, 1.14]). Clustering was associated with monthly/bimonthly use in suburban/rural areas (aOR = 7.85 [1.31, 47.17]). Daily/near-daily use was associated with proximity and clustering in the full sample (proximity: aOR = 0.78 [0.64, 0.97]; clustering: aOR = 2.44 [1.32, 4.51]), urban areas (proximity: aOR = 0.67 [0.49, 0.92]; clustering: aOR = 2.29 [1.22, 4.32]), and suburban/rural areas (proximity: aOR = 0.66 [0.45, 0.97]; clustering: aOR = 11.10 [1.55, 79.36]). **Conclusions:** In Washington's early non-medical cannabis market, dispensary availability (counts) was associated with monthly/bimonthly use. Accessibility (proximity) and clustering were associated with daily/near-daily use. Dispensary density thresholds and minimum distances between dispensaries may reduce regular and frequent cannabis use in Washington.

Key words: = cannabis dispensary density; non-medical cannabis; cannabis policy

Several aspects of the environment, such as the density of retailers in an area , the distances between individuals and retailers, and the respective retailer's attractiveness, may determine how likely a customer is to visit a retailer (Huff, 1963). Alcohol availability theory furthers that making purchases more convenient, such as by increasing the number of retailers, may reduce the total cost of buying a product, which may increase consumption by altering routine behaviors (Stockwell & Gruenewald, 2004). An emerging literature applies availability theory to cannabis (Ambrose et al., 2021; Mair et al., 2015), finding cannabis dispensary density is associated with cannabis use patterns in the United States (US) (Manthey et al., 2023) and abroad (Palali &

Corresponding Author: Pamela J. Trangenstein, PhD, Alcohol Research Group, 6001 Shellmound Street, Suite 450, Emeryville, CA 94608. Phone: (510) 597-3440. Email: ptrangenstein@arg.org

van Ours, 2015). However, most of this literature has focused solely on medical cannabis (Freisthler & Gruenewald, 2014; Mair et al., 2015; Shi et al., 2018; Shih et al., 2019) or adolescents/young adults (García-Ramírez et al., 2019; Harpin et al., 2018; Hust et al., 2020; Paschall & Grube, 2020; Shih et al., 2021). Studies on cannabis dispensary density and adult non-medical cannabis use are needed to appraise the potential consequences of emerging non-medical cannabis markets more fully.

Several studies have compared cannabis dispensary density measurement methods (Ambrose, 2020; Ambrose et al., 2021; Wadsworth et al., 2021; Young-Wolff et al., 2021) with inconsistent results. Most comparative studies conclude continuous measures of distance/time to the nearest retailer are associated with cannabis use patterns (Ambrose et al., 2021; Young-Wolff et al., 2021). The number of dispensaries within a 15-minute drive from pregnant women's homes in California were monotonically associated with prenatal cannabis use (Young-Wolff et al., 2021). Yet, past 30-day adult cannabis use prevalence and frequency was not associated with ZIP Code-level counts of dispensaries in Washington (WA) after adjusting for time to the nearest dispensary (Ambrose et al., 2021).

While comparisons of cannabis dispensary density measurement are increasingly common, few have explored the conceptual underpinnings for these measures and what differences across measurement methods suggest about the dynamics of cannabis dispensaries and use. Penchansky and Thomas' seminal conceptualization of access (Penchansky & Thomas, 1981) and availability theory (Stockwell & Gruenewald, 2004) suggests cannabis dispensary density measures that summarize the overall availability of cannabis (i.e., counts) or clustering of retailers (i.e., spatial access indices) may begin to indicate the degree of competition among dispensaries, thus affecting prices. Conversely, proximity measures (i.e., time/distance to the nearest dispensary) may measure accessibility and convenience for cannabis purchases.

In geographically diverse areas, urbanicity likely affects the performance of cannabis density measures, particularly those that account for underlying population when data are sparse (Waller & Gotway, 2004). Distance functions differently in urban and suburban/rural settings, where people typically travel longer distances (Guagliardo, 2004). For example, the association between time to the nearest dispensary and cannabis use was stronger in rural/suburban WA than in urban WA (Ambrose et al., 2021). Further exploration into the role of urbanicity in cannabis dispensary density measurement and associations may identify opportunities to improve the validity of future spatial studies.

To address these gaps, this study had three aims: 1) graphically compare cannabis dispensary density measurement methods by urbanicity, 2) determine whether the availability, accessibility, and clustering of non-medical cannabis dispensaries were associated with cannabis use patterns, and 3) test whether urbanicity modifies the association between cannabis dispensary density and cannabis use patterns. Based on previous research (Fiala, 2020) and the dispensary allocation process (Caulkins & Dahlkemper, 2013), we hypothesized cannabis dispensary density would be higher in urban (vs. suburban/rural) settings. Based on availability theory, we also hypothesized that greater cannabis dispensary density controlling for urbanicity would be associated with higher odds of monthly/bimonthly and daily/near-daily cannabis use.

METHODS

Data Sources

Cannabis use and individual level-demographics. Cannabis use data are from the Privatization of Spirits in Washington (PSW) Surveys. The PSW survey comprised six cross-sectional waves conducted between January 2014 and December 2016: January-April 2014 (Wave 1, N = 1,202), September-October 2014 (Wave 2, N = 805), March-May 2015 (Wave 3, N = 824), August-October 2015 (Wave 4, N = 663), March-April 2016 (Wave 5, N = 611), and September-December 2016 (Wave 6, N = 1,392).

During all waves, random digit dialing recruited adult respondents (aged 18+ years). Approximately half of the sample involved landline interviews, and the other half were cell phone interviews. The AAPOR2 cooperation rate ; landline, cell) were: Wave 1 (50.8%, 59.5%), Wave 2 (45.8%, 62.4%), Wave 3 (43.7%, 61.5%), Wave 4

(41.7%, 59.6%), Wave 5 (49.4%, 60.9%) and Wave 6 (45.3%, 63.0%). Wave 1 occurred before non-medical cannabis sales began in WA; therefore, we restricted the analysis to waves 2 through 6 (*n* = 4,295). Respondents received a $10 dollar gift card on completion to thank them for their time. Surveys lasted about half an hour on average. The Public Health Institute Institutional Review Board approved the PSW study protocol.

Respondents provided their residential address, nearest intersection, or ZIP Code. We geocoded the respondents' street address or closest intersection. Street address data were cleaned in Excel and then geocoded and re-matched in ArcMap, requiring a minimum match score and spelling sensitivity score of 80. We excluded respondents who only provided a ZIP Code (*n* = 1,844) or did not provide any geographic information (*n* = 287). We would have had to use a ZIP Code centroid for these respondents, and they may live long distances from those centroids, particularly in rural/suburban areas. In these instances, density measures may not validly measure their retail exposures; therefore, we excluded these respondents.

Cannabis dispensaries. Cannabis dispensary licensing data were obtained from the Washington State Liquor and Cannabis Board by month and year. In WA, dispensaries are licensed for non-medical cannabis sales, and most also possess permissions to sell medical cannabis. We lagged the dispensary data one month before the start of each data collection wave: July 2014 (Wave 2), February 2015 (Wave 3), July 2015 (Wave 4), February 2016 (Wave 5), and August 2016 (Wave 6). The cannabis dispensary locations were matched to coordinates with 99% accuracy. Finally, the coordinates of the respondents' and cannabis dispensaries' locations were spatially joined to a WA census tract (CT) shapefile to determine the CT in which the respondent resided.

Urbancitiy. The US Department of Agriculture Economic Research Service provided 2013 Rural-Urban Commuting Areas (RUCA). These RUCA codes are based on the Office of Management and Budget metropolitan and non-metropolitan categories and were calculated by combining data from 2010 and 2013 (University of Washington Rural Health Research Center.).

Covariates. The American Community Survey 5-Year Estimates provided area-level demographic covariates by year (US Census Bureau, 2015, 2016, 2020). The CT identifier was used to match American Community Survey CT-level data to the respondents' location.

Measures

Dependant variables. There were two cannabis use outcomes: cannabis use at least monthly ("monthly/bimonthly use") and daily/near-daily use. These variables dichotomized responses from the survey question: *How often have you used marijuana, hash or pot during the last twelve months? Monthly or bimonthly cannabis use* was defined as cannabis consumption that occurred at least every month or two and was measured as yes (combined every month or two, once every 2 or 3 weeks, about once a week, and every day or nearly every day) or no (reference group; combined never last year and less often than bimonthly). *Daily or near-daily use* was defined as cannabis consumption that occurred every day or nearly every day and was measured as yes (every day or nearly every day) vs. no (combined all other responses; reference group). The dependent cannabis use variables did not include CBD use.

Independent variables: Cannabis dispensary density. We compared six *cannabis dispensary density* variables. Three were measured at the CT level: 1) *crude count:* number of cannabis dispensaries in the CT, 2) *population exposure:* number of cannabis dispensaries in the CT divided by population, and 3) *dispensary density:* number of cannabis dispensaries in the CT divided by land area. The other three were anchored to the respondent's address: 1) *count per buffer,* which was measured as the number of cannabis dispensaries in a 3- (urban) or 5-mile buffer (suburban/rural). We selected the 3- and 5-mile buffer radii by rounding the median distance for urban (3.03 miles) and suburban/rural (5.33 miles) respondents to the nearest mile. 2) *proximity,* defined as the network distance to the nearest cannabis dispensary. 3) *Clustering,* calculated as a spatial accessibility index for the seven dispensaries closest to the respondent's address using network distance. Spatial accessibility indices sum a set of *n* inverse distances from reference point, $\sum_1^n \frac{1}{distance}$. The proximity and clustering variables were transformed using the natural logarithm because they were highly skewed.

Effect measure modifier: Urbancity. RUCA codes classified the respondent's CT as urban (metropolitan areas) vs. suburban or rural (reference group; includes micropolitan areas, small towns, and rural areas). The most recent RUCA Codes available used the 2010 decennial Census and measured population density, urbanization, and commuting patterns (Economic Research Service, 2020).

Demographic covariates. At the individual level, we adjusted for age, sex, race, ethnicity, income, educational attainment, employment, and alcohol use. *Age* in years was continuous. *Sex* was a dichotomous variable (female [reference group] vs. male) and included because cannabis use is more prevalent among males (Carliner et al., 2017; Substance Abuse and Mental Health Services Administration [SAMHSA], 2022). The *race* variable had four categories: Black, White (reference group), 2+ racial or ethnic groups, and other racial groups or unknown. Black adults and adults who identify with two or more races have higher odds of monthly and weekly cannabis use (Wu et al., 2016). *Ethnicity* was measured using a dichotomous variable (not Hispanic/Latinx [reference group] vs. Hispanic/Latinx), as cannabis use rates are lower among Hispanic/Latinx people (Mitchell et al., 2020). Cannabis use is more common among those with lower incomes (Mitchell et al., 2020). Respondent's self-reported annual *income* was measured using four categories: <$20,000, $20,001-$60,000 or missing, $60,001-$100,000, and $100,001+ (reference group). *Educational attainment* was measured using a three-category variable that indicated whether the respondent reported a high school degree or less (reference group), some college, or a college degree or more. *Employment* was a four-category variable measured as employed (reference group), unemployed, retired, or other statuses (combined disabled, never worked, homemaker, and student). Finally, we adjusted for *current (past-year) drinking status* (yes vs. no [reference group]), as more than 75% of current cannabis users also drink alcohol (Pape et al., 2009).

At the CT level, we included a measure of *material deprivation* because cannabis dispensary densities are higher in places with economic deprivation (Amiri et al., 2019). We calculated material deprivation using the Townsend Deprivation Index, which sums z-scores of four indicators: household crowding, unemployment, renter-occupied households, and households without a car (Townsend et al., 1988). Higher values of the index indicate greater levels of material deprivation.

We included the *data collection wave* as a final covariate to adjust for any temporal trends. The reference group was wave 2 (September-October 2014).

Analysis and Analytic Sample

We first graphed the dispensary density variables by urbanicity to assess whether mean density was higher in urban or suburban/rural areas. All graphs were made in Microsoft® Excel® (Microsoft Corporation, 2018). The graphs used two analytic samples, depending on whether the dispensary density measurement method was calculated at the CT level (n = 1,445 CTs) or anchored to respondents' residential address (n = 2,162 adults).

Next, logistic regressions tested whether cannabis dispensary density was associated with adult cannabis use patterns. The regressions used the same analytic sample as the second set of graphs. Table S-1 in the supplemental appendix compares characteristics of respondents excluded (vs. included) because they did not provide a street address or intersection. Briefly, a larger percentage of respondents who provided their address were current drinkers (74.4% vs. 66.6%, $p < .01$), and respondents with and without street-level geographic information differed by CT-level material deprivation ($p < .01$).

We tested whether the outcomes clustered in CTs by calculating the intraclass correlation coefficient (ICC). The ICC for daily/near-daily cannabis use was greater than 0.1 ($ICC = 0.12$), so we clustered standard errors within CTs.

We forced age, sex, race, ethnicity, and data collection wave into the models based on previous research (Carliner et al., 2017; Hasin et al., 2019; Mitchell et al., 2020). We then selected additional covariates as variables that were significant in at least one adjusted regression. Adjusted logistic regressions tested whether cannabis dispensary density was associated with cannabis use patterns (i.e., monthly/bimonthly and daily/near-daily cannabis use). We ran each regression three times to test the association between different dimensions of dispensary density: availability (counts of dispensaries), accessibility (proximity), and clustering. Based on the graphs and ease of interpretation, we measured availability using the number of cannabis dispensaries in the buffer around the respondent's home. We also assessed whether urbanicity modified the association between cannabis dispensary density and cannabis use via stratification. Descriptive and regression analyses were performed in Stata v.16.1 (StataCorp, 2019). We reported simplified results for the key independent variables to aid interpretation, but full tables including covariates appear in the supplemental appendix (Table S-2 and S-3).

Sensitivity Analyses

Later waves. There were relatively few dispensaries open in WA through early 2015, so half (48.99%) of the respondents did not have a cannabis dispensary within 3 or 5 miles of their home during waves 2-6. This may have reduced variability in this predictor, so we conducted a sensitivity analysis that limited the analytic sample to waves 4-6 (Tables S-4 and S-5).

Medical cannabis recommendations. WA legalized medical cannabis in 1998 but did not incorporate medical dispensaries into a formal, licensed regulatory structure until 2015 (Washington State Legislature, 2015). Thus, cannabis dispensary licensing records may have provided an undercount of operational retailers in 2014. Further, adults with a medical recommendation potentially have a longer history of improved access to legal cannabis, which may have resulted in higher access to dispensaries than those who use for exclusively non-medical purposes. To address this limitation, we considered the role of medical cannabis recommendations in the relationship between dispensary density and cannabis use patterns (Tables S-6 and S-7).

RESULTS

Sample Description

Half the respondents (50.1%) were male, and the mean age was 46.7 years (Table 1). Most of the sample was White (77.1%), not Hispanic/Latinx (90.6%), had less than a college degree (68.5%), and/or lived in an urban CT (88.0%). The prevalence of monthly/bimonthly cannabis use differed by age ($p < .001$), sex ($p = .01$), race ($p = .03$), income ($p < .001$), educational attainment ($p < .001$), employment ($p < .001$), and drinking status ($p < .001$). One third of respondents (34.6%) had two or more dispensaries within a buffer 3-/5-mile buffer from their home, 36.7% lived more than 6 miles away from the nearest dispensary, and 32.7% had high levels of dispensary clustering around their home. Post-hoc analyses revealed the prevalence of self-reported monthly/bimonthly cannabis use was higher for respondents with 2+ dispensaries in their 3- to 5-mile buffer (vs. no dispensaries, $p < .01$ and 1 dispensary, $p = .01$) and high (vs. moderate) dispensary clustering ($p = .02$). More respondents who lived within 1.5 miles (vs. 1.5 to 6 miles away, $p = .01$ and 6+ miles away, $p = .03$) of a dispensary reported daily/near-daily cannabis use.

Table 1. *Sample Demographics and Cannabis Dispensary Density Exposure*

Respondent characteristic	Weighted %	Monthly/ bimonthly cannabis use			Daily/ near-daily cannabis use		
		No %	Yes %	*p*-Value	No %	Yes %	*p*-Value
Number of dispensaries in buffer[a]							
0	48.99	51.19	42.36	<.01	49.95	42.69	.11
1	16.43	17.48	13.27		16.89	13.41	
2+	34.58	31.33	44.37		33.16	43.90	
Proximity							
≤1.5 miles	21.05	18.11	29.95	<.001	19.49	31.33	.02
>1.5 miles but <6 miles	42.28	43.65	38.12		43.33	35.33	
≥6 miles	36.67	38.24	31.93		37.17	33.35	
Clustering							
Low	24.11	24.69	22.36	.06	24.29	22.89	.50

Medium	43.20	44.74	38.57		43.81	39.21	
High	32.69	30.57	39.07		31.90	37.90	
Urban CT	88.01	87.97	88.15	.94	88.17	87.01	.71
Medical recommendation	6.64	0.71	24.70	<.001	2.25	36.00	<.001
Age							
18-39 years	40.73	35.97	55.08	<.001	38.22	57.22	<.001
40-59 years	33.37	33.92	31.72		33.60	31.84	
60+ years	25.90	30.11	13.20		28.17	10.94	
Male sex	50.08	47.68	57.33	.01	48.56	60.07	.02
Race							
Black	4.00	4.06	3.81	.03	4.18	2.83	<.001
Other racial and ethnic groups + missing	12.19	10.97	15.87		10.42	23.83	
White	77.09	79.50	69.80		79.91	58.50	
2+ races	6.73	5.47	10.52		5.49	14.85	
Hispanic/Latinx	9.43	8.10	13.46	.06	8.30	16.87	.03
Income							
≤$20,000	21.34	19.10	28.12	<.001	20.21	28.81	<.01
$20,001-$60,000 or missing	42.13	40.73	46.34		40.94	49.93	
$60,001-$100,000	20.62	22.77	14.13		21.83	12.63	
≥$100,001	15.91	17.40	11.40		21.83	12.63	
College degree or more	31.49	34.69	21.80	<.001	33.92	15.45	<.001
Employment							
Employed	60.05	59.86	60.62	<.001	59.97	60.61	.01
Unemployed	5.66	5.16	7.21		5.35	7.75	
Retired	17.64	20.61	8.58		19.03	8.26	
Other statuses	16.65	14.37	23.60		15.65	23.38	
Current drinker	75.10	71.40	86.27	<.001	73.79	83.70	.02
Material deprivation index							
Low deprivation	27.51	28.55	24.36	.11	27.98	24.37	.31
Moderate deprivation	30.68	31.54	28.09		31.24	27.03	
High deprivation	41.81	39.91	47.55		40.78	48.59	
Data collection wave							
Wave 2	20.08	21.10	17.01	.20	20.05	20.31	.41
Wave 3	21.18	22.34	17.71		22.21	14.41	
Wave 4	20.29	20.06	20.99		19.69	24.25	
Wave 5	19.12	18.12	22.13		18.76	21.51	
Wave 6	19.32	18.36	22.15		19.29	19.52	

Note. Percentages may not total to 100 due to rounding.
[a]The buffer radius was 3 miles in urban census tracts and 5 miles in suburban//rural census tracts.

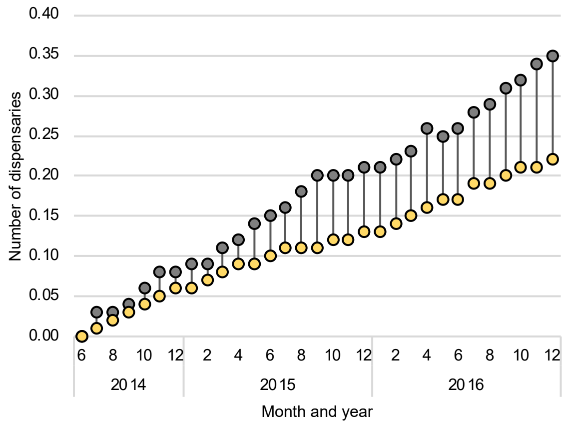
Aim 1: Graphical Comparisons of Cannabis Dispensary Density Measurement Methods

Crude counts (i.e., no denominator) and population exposure (i.e., population denominator) per CT categorized density as higher in suburban/rural CTs (Figure 1).

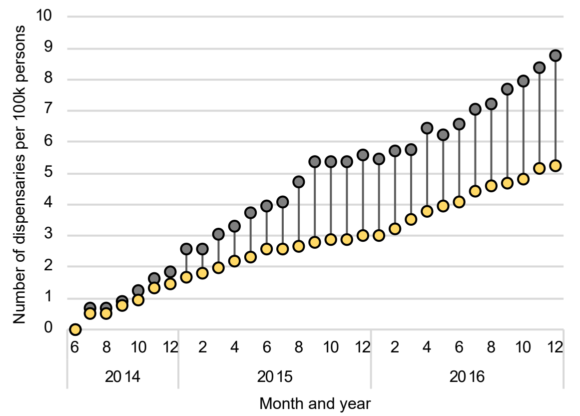
Figure 1. *Average Cannabis Dispensary Density by Month/Survey Wave and Urbanicity*

Census tract-level cannabis dispensary density measures

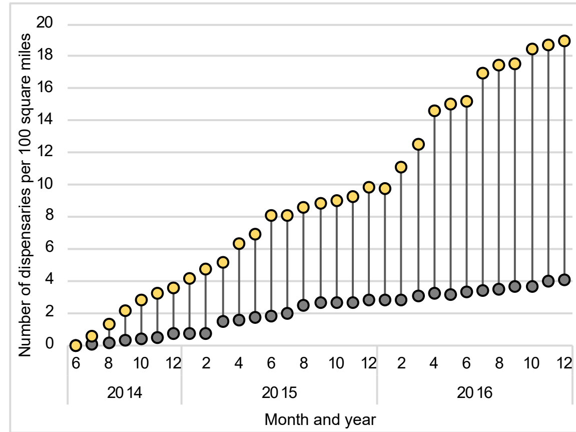
A. Mean dispensaries per census tract



B. Mean dispensaries per 100,000 population

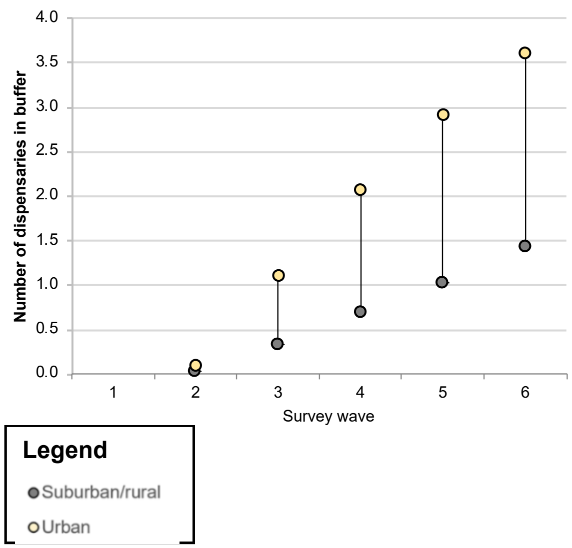


C. Mean dispensaries per 100 square miles

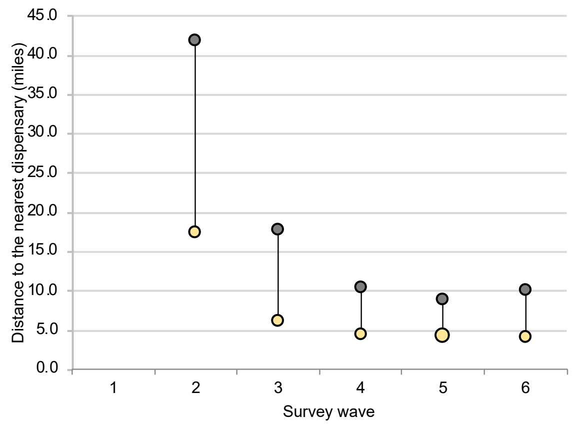


Cannabis dispensary density measures relative to the respondent's address

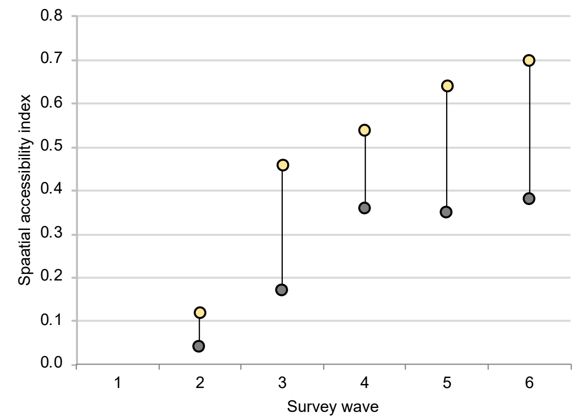
D. Dispensaries in a 3- (urban) or 5-mile (suburban/rural) buffer



E. Distance to the nearest dispensary



F. Spatial accessibility index for 7 nearest dispensaried



This figure shows cannabis dispensary density in urban and suburban/rural census tracts as calculated by six different measures: A) a crude count of the number of dispensaries in the census tract, B) population exposure, measured by dividing the number of dispensaries in the census tract by the population, C) dispensary density, measured by dividing the number of dispensaries by the census tract land area, D) buffer density, measured by counting the number of dispensaries in a 3- (urban) or 5-mile (suburban/rural) buffer, E) proximity, measured as the distance to the nearest dispensary, and F) clustering, measured as a spatial accessibility index to the seven nearest dispensaries. All graphs show that cannabis dispensary density gradually increased from July 2014 through December 2016, although there is an inverse association for proximity because shorter distances indicate higher densities. Suburban/rural density is depicted with grey circles, and yellow circles indicate urban densities. Panels A and B (crude counts and population exposure) show grey circles above the yellow ones, depicting these measures detected higher densities in suburban/rural census tracts. The other panels (density, buffer density, proximity, and clustering) show yellow circles above the grey ones (the reverse is true for proximity, which has an inverse association with availability), indicating that they found higher densities in urban census tracts.

Conversely, counts per buffer, density (i.e., counts per land area), proximity (i.e., distance to the nearest), and clustering showed higher values in urban areas. Post-hoc analyses showed the average population was 21% higher in urban CTs (4,738) than in suburban/rural CTs (3,910). However, average land area was more than ten times higher in suburban/rural CTs (196.15 square miles) than in urban ones (18.54 square miles).

Aim 2: Association Between Cannabis Dispensary Density and Cannabis Use, Adjusting for Urbanicity

Each additional dispensary in the 3- to 5-mile buffer around the respondent's home was associated with 8% higher odds of monthly/bimonthly cannabis use (*aOR* = 1.08, *95% CI* = 1.02, 1.14, p = .01, see Table 2). Every additional mile between the respondent's home and the nearest dispensary was associated with 31% lower odds of daily/near-daily cannabis use (*aOR* = 0.69, *95% CI* = 0.53, 0.91, p = .01, see Table 3). In addition, each 2.7-fold increase in clustering was associated with 2.4 times the odds of daily/near-daily use (*aOR* = 2.4, *95% CI* = 1.32, 4.51, p = .01).

Table 2. *Regression Results for the Association Between Cannabis Dispensary Density and Monthly/Bimonthly Consumption Overall and by Urbanicity and Measurement Method, Waves 2-6*

Predictor	Dispensaries in buffer[a]			Proximity			Clustering[b]		
	aOR	95% CI	p-Value	aOR	95% CI	p-Value	aOR	95% CI	p-Value
Full sample (n = 2,162)									
Dispensaries in buffer[a]	1.08	1.02, 1.14	.01	—			—		
Proximity (log-transformed)	—			0.87	0.74, 1.03	.10	—		
Clustering (log-transformed)[b]	—			—			1.69	0.98, 2.89	.06
Suburban/rural CT (vs. urban)	1.54	0.90, 2.63	.11	1.58	0.92, 2.73	.10	1.47	0.87, 2.50	.15
Respondents who live in urban CTs (n = 1,901)									
Dispensaries in buffer[a]	1.08	1.02, 1.14	.01	—			—		
Proximity (log-transformed)	—			0.87	0.73, 1.03	.10	—		
Clustering (log-transformed)[b]	—			—			1.56	0.89, 2.73	.12
Respondents who live in suburban/rural CTs (n = 261)									
Dispensaries in buffer[a]	1.47	0.93, 2.32	.10	—			—		
Proximity (log-transformed)	—			0.77	0.53, 1.11	.17	—		
Clustering (log-transformed)[b]	—			—			7.85	1.31, 47.17	.02

Note. aOR = Adjusted odds ratio, CI = Confidence interval, CT = Census tract, **Bolding** denotes $p < .05$.
[a]The buffer radius was 3 miles in urban census tracts and 5 miles in census tracts.
[b]Clustering was measured using a spatial accessibility index, calculated as the sum of the network (road-based) distances from the respondent's home address to the seven closest cannabis dispensaries. This value was then transformed using the natural logarithm.

Table 3. *Regression Results for the Association Between Cannabis Dispensary Density and Daily/Near-Daily Consumption Overall and by Urbanicity and Measurement Method, Waves 2-6*

Predictor	Dispensaries in buffer[a]			Proximity			Clustering[b]		
	aOR	95% CI	p-Value	aOR	95% CI	p-Value	aOR	95% CI	p-Value
Full sample (n = 2,162)									
Dispensaries in buffer[a]	1.06	0.97, 1.15	.17	—			—		
Proximity (log-transformed)	—			0.69	0.53, 0.91	.01	—		
Clustering (log-transformed)[b]	—			—			2.44	1.32, 4.51	< .01
Suburban/rural CT (vs. urban)	1.48	0.74, 2.96	.27	1.66	0.81, 3.41	.16	1.53	0.76, 3.08	.23
Respondents who live in urban CTs (n = 1,901)									
Dispensaries in buffer[a]	1.05	0.97, 1.14	.21	—			—		
Proximity (log-transformed)	—			0.77	0.62, 0.97	.03	—		

Clustering (log-transformed)[b]	—			—			2.29	1.22, 4.32	.01
Respondents who live in suburban/rural CTs (n = 261)									
Dispensaries in buffer[a]	1.10	0.60, 2.02	.75	—			—		
Proximity (log-transformed)	—			0.66	0.45, 0.97	.03	—		
Clustering (log-transformed)[b]	—			—			11.10	1.55, 79.36	.02

Note. aOR=Adjusted odds ratio, CI = Confidence interval, CT = Census tract, **Bolding** denotes $p < .05$.
[a]The buffer radius was 3 miles in urban census tracts and 5 miles in census tracts.
[b]Clustering was measured using a spatial accessibility index, calculated as the sum of the network (road-based) distances from the respondent's home address to the seven closest cannabis dispensaries. This value was then transformed using the natural logarithm.

Aim 3: Models Stratified by Urbancity

The association between counts of dispensaries per buffer and monthly/bimonthly use persisted in urban settings at the same magnitude (*aOR* = 1.08, *95% CI* = 1.02, 1.14, p = .01). In addition, more clustering was associated with higher odds of monthly/bimonthly cannabis use in suburban/rural settings (*aOR* = 7.85, *95% CI* = 1.31, 47.17, p = .02). Respondents who lived farther away from the nearest cannabis dispensary had lower odds of daily/near-daily cannabis use in both urban (*aOR* = 0.77, *95% CI* = 0.62, 0.97, p = .03) and suburban/rural settings (*aOR* = 0.66, *95% CI* = 0.45, 0.97, p = .03). Similarly, respondents with more dispensary clustering around their home had greater odds of daily/near-daily cannabis use in both urban (*aOR* = 2.29, *95% CI* = 1.22, 4.32, p = .01) and suburban/rural settings (*aOR* = 11.10, *95% CI* = 1.55, 79.36, p = .02).

Sensitivity Analysis

In the models restricted to waves 4-6, the results were consistent with the main models except for four differences. First, counts per buffer were associated with monthly use in suburban/rural settings after restricting the data to waves 4-6 (Table S-4). Second, proximity was associated with monthly/bimonthly use in the full sample and urban settings when using waves 4-6. Third, clustering was no longer associated with monthly use in suburban/rural areas but was associated with monthly use overall. Finally, proximity and clustering were no longer associated with daily/near-daily consumption in suburban/rural settings (Table S-5).

Results for the monthly/bimonthly models held after including the medical cannabis recommendation interaction (Table S-6). There was no evidence that the association between cannabis dispensary density and monthly/bimonthly use differed for people with (vs. without) a medical cannabis recommendation. However, having a medical recommendation emerged as a strong predictor of monthly/bimonthly and daily/near-daily use (Table S-7). Proximity and clustering were no longer associated with daily/near-daily use after adjusting for having a medical recommendation. The interaction between medical recommendation and number of dispensaries in a buffer was significant for daily/near-daily use such that the association was only significant for people with a medical recommendation.

DISCISSION

During the first three years of WA's non-medical cannabis market, adults with more cannabis dispensaries near their home had higher odds of monthly/bimonthly cannabis use, and those who lived closer to a cannabis dispensary or in areas with higher dispensary clustering had greater odds of daily/near-daily cannabis use. Dispensary availability was associated with monthly/bimonthly use, while accessibility and clustering were associated with daily/near-daily use. Combining our findings and the conceptual underpinnings of the different cannabis dispensary density measures suggests monthly/bimonthly and daily/near-daily cannabis users may interact with dispensaries differently. Monthly/bimonthly cannabis users may prioritize diversity of product and price options, which would increase with the number of dispensaries. Conversely, daily/near-daily cannabis users may prefer convenience and prices, which shorter travel times and dispensary clustering would facilitate.

Urbanicity appears to play a key role in how cannabis dispensary density measures classify locations. The Washington State Liquor and Cannabis Board store allocation methods resulted in a disproportionate number of dispensaries in urban settings (Caulkins & Dahlkemper, 2013), but only measures that used distance or adjusted for land area – number of dispensaries in a CT per land area, number of dispensaries in a given buffer, distance to the nearest dispensary, and dispensary clustering – detected this distribution. Still, statewide and national analyses of cannabis dispensary density and cannabis use frequently use population denominators (Borodovsky et al., 2016; Everson et al., 2019; Wadsworth et al., 2021). Per capita ratios align with metrics used to quantify dispensary density thresholds in policies and regulations and, thus, are well-suited to research designed to inform such limits. However, future research may also wish to consider the concepts underlying cannabis dispensary density measures to ensure analyses include the most relevant variables and to potentially yield more specific recommendations for substance use prevention.

Our finding that cannabis dispensary availability near adults' homes is associated with monthly/bimonthly cannabis use builds on and is consistent with previous findings that mostly focus on medical cannabis and adolescents/young adults. The number of dispensaries within 4- to 5-miles of a respondents' home was associated with higher odds of past-month cannabis use (Pedersen et al., 2021) and daily use (Shih et al., 2021) among adolescents and young adults. Cannabis-related hospitalizations were higher in California ZIP Codes with more medical dispensaries (Mair et al., 2015), and the prevalence and frequency of WA adult cannabis use rose as the number of dispensaries in a ZIP Code increased (Ambrose et al., 2021). These findings suggest that establishing a threshold for the maximum number or density of cannabis dispensaries may protect against monthly/bimonthly cannabis use.

We found that distance and clustering – not the number – of dispensaries was associated with daily/near-daily use. these results demonstrate the importance of considering potential multilevel drivers of daily/near-daily use, particularly when those who use every day or nearly every day have eight times the risk of meeting criteria for CUD when compared to people who use cannabis several times a year (Robinson et al., 2022). These heavy users consume the majority of cannabis sold in legal markets, with the heaviest 10% responsible for over two-thirds of all cannabis sales (Callaghan et al., 2019). Our comparison of cannabis dispensary density measures and their associated conceptual underpinnings suggests potential dynamics that may underplay how different types of cannabis users interact with the cannabis environment. Most states limit non-medical cannabis purchase quantities, which means daily/near-daily users may need to make more frequent trips to dispensaries than others who use cannabis less frequently. Under these conditions, adults may prefer the convenience of dispensaries located closer to their home. Similarly, the competition induced by clustering dispensaries together may result in lower prices that could entice customers who purchase larger volumes of product over time. Future research should investigate how frequent cannabis users select dispensaries to patronize and whether establishing minimum distances between dispensaries could reduce frequent cannabis use.

Results from sensitivity analyses suggested that medical recommendations play an important role in the dynamics of daily/near-daily use. At a minimum, these findings show the importance of multilevel investigations into daily/near-daily use, which may inform tailored or targeted substance use prevention initiatives. In our sample, most (71%) people with a medical recommendation used cannabis daily/near-daily, but only 9% of those without a medical recommendation used cannabis this way. Given its sizable odds ratio and a p-value less than 0.10, it is possible that the association between cannabis dispensary clustering and daily/near-daily use is stronger for those with medical recommendations, but we were underpowered to detect this. We encourage future research that explores the dynamics of cannabis dispensary density, medical recommendations, and cannabis use patterns with larger sample sizes.

To our knowledge, ours is one of the first studies to investigate whether urbanicity modifies the association between cannabis dispensary density and cannabis use. Two differences emerged between urban and suburban/rural settings. First, dispensary availability was not associated with monthly cannabis use in suburban/rural areas even though this association existed in the full sample and urban areas. The count per buffer variable contained more zeroes in suburban/rural settings, as a result of dispensaries primarily opening in urban settings, particularly in the initial stages of the cannabis market. Second, dispensary clustering was associated with monthly cannabis use in suburban/rural areas but not urban areas. As the levels of clustering are lower in suburban/rural settings, this could suggest a saturation model in which the initial levels of clustering may exert a larger effect on monthly cannabis use patterns. If this is the case, then policies and regulations that intentionally aim to more evenly distribute cannabis dispensaries in appropriately zoned areas may be an important tool in reducing and preventing daily/near-daily cannabis use.

Studies that associate dispensary density with consumption assume density affects cannabis purchases and, consequently, use. Thus, cannabis dispensary density measures ought to capture dispensary attributes most relevant to customer purchasing behaviors. When asked to report the attributes relevant to purchase decisions, people ranked product quality, price, and strain availability as most important; on average, they ranked distance 11th (Zhu et al., 2021). We also note that affordability (economic availability) is the fourth dimension of access as conceptualized by Penchansky and Thomas (Penchansky & Thomas, 1981). Given the large literature on the role of price in cannabis purchasing behaviors (Donnan et al., 2022) and the potential role of pricing reduction in cannabis dispensary clustering, research investigating potential additive effects of spatial and economic availability may be warranted. Retail observations may also enhance density analyses by allowing researchers to investigate how dispensary density intersects with their characteristics in shaping purchasing behaviors.

Limitations

The pooled surveys were cross-sectional, so our results should not be interpreted as causal. It is possible that cannabis dispensaries opened in places with higher demand/consumption. Relatedly, unlicensed medical dispensaries operated in WA prior to legalizing adult non-medical use. We were unable to adjust for exposure to medical cannabis prior to their incorporation into the formal, licensed cannabis market (Washington State Legislature, 2015). However, our cannabis dispensary density measures account for the influx of medical cannabis dispensaries when these two systems merged. In addition, our cannabis consumption data were self-reported, so they are limited by possible recall errors and underreporting due to social desirability bias. Cannabis consumption patterns are also shaped by economic availability, and we did not have data on cannabis pricing by dispensary that would allow us to account for this. Further, prices fell sharply as the WA market began to commercialize (Smart et al., 2017). In July 2015, WA raised the retail cannabis excise taxes from 25% to 37%, while eliminating the 25% tax rates on producers and processers, reducing the overall tax burden substantially. These changes may have affected cannabis consumption patterns. Finally, our data generalize to WA, but they may not be representative of other states with non-medical cannabis markets.

Conclusions

Adults who live in areas with higher cannabis dispensary density had higher odds of using cannabis monthly/bimonthly and daily/near-daily during the first three years of WA's non-medical cannabis market. These results suggest that potential public health importance of regulatory agencies limiting the number of retail cannabis dispensaries in support of lower frequency of cannabis use. This may be achieved via the use of density thresholds or by establishing minimum distance requirements between dispensaries to prevent clusters from forming.

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