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Primary crime-related outcome indicators associated with recreational cannabis legalization: a comprehensive literature and data review

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Abstract

Cannabis policies are increasingly being liberalized, including the implementation of formal legalization policies of non-medical use and supply in multiple jurisdictions (initially in the Americas) towards improved public health and safety objectives. While focus on health indicators has shown mixed or adverse outcomes, less attention has been given to social-legal – and specifically crime-related – outcomes of legalization. We conducted a comprehensive literature and data review of key crime-related outcomes associated with non-medical cannabis legalization in four main domains, based on targeted searches of recent academic (e.g., journal publication) and 'grey' English-language literature sources: 1) cannabis-related crimes and enforcement, and other crimes; 2) cannabis-impaired driving and related motor-vehicle-crashes; 3) cannabis sourcing by consumers; and 4) cannabis market evolution and dynamics. The data identified were extracted, organized and narratively summarized by topic. The data reviewed suggest that cannabis-related crimes and enforcement have substantially decreased, yet arbitrary (e.g., racialized) enforcement patterns – involving both adults and youths – commonly persist in legalization settings; evidence for ecological effects on other (e.g., property, violent) crimes is mixed. The prevalence of cannabis-impaired driving does appear to be steady or decreasing, while levels of cannabis involved in motor-vehicle-crashes, and overall motor-vehicle-crash fatality levels appear to have increased. In North American legalization settings, the legal sourcing of cannabis has gradually increased to involve 50–70% or more of consumers alongside expanding legal retail market proliferation, while found to be influenced by multiple factors (e.g., product characteristics, price, use intensity). Conversely, legal cannabis sourcing remains much more limited in Uruguay's restrictive settings. Data on the evolution of illegal cannabis markets is very limited, suggesting some evidence for reductions of illegal production but also shifts or displacement effects (e.g., towards production for or distribution in non-legalization settings), leaving open questions as to the impacts of legalization in these domains. Overall, legalization appears to be meeting some of its socio-legal and specifically crime-reduction goals, yet while key data indicators are mixed or lacking. Focused and expanded research on

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crime-related outcomes of legalization policies is needed, also given limited benefits to date evidenced for health outcomes.

Keywords Cannabis · Legalization · Crime · Socio-legal outcomes · Public Safety · Markets · Policy · Sourcing · Evaluation · Literature review

Introduction

Cannabis use is common, with an estimated > 4% (> 200 million) of the world's adult population (ages 15–64) involved in current use (UNODC, 2022. Cannabis is typically categorized as the most widely used illegal drug, given its predominantly criminal status and control – based on pertinent international drug control treaties (e.g., 1961 'Single Convention') and corresponding national drug laws defining related enforcement frameworks – in most countries for decades (*TNI*, 2023; INCB, 2022; Room, Fischer et al., 2010).

While there have been numerous proposals over time to reform or soften criminal control approaches for cannabis, the post-2000 years have seen major policy revisions that have moved cannabis access and use towards formally 'legal' status in a growing number of jurisdictions. These have included 'medical cannabis legalization' (MCL) policies or programs, which grant individuals with certain defined medical conditions legal cannabis access and/or use for 'therapeutic' usage (Blanchette et al., 2022; Fischer et al., 2020a, 2020b; Shover & Humphreys, 2019). More recently, several jurisdictions have implemented formal ('*de jure*') legalization and regulation policies of non-medical ('recreational') cannabis use and supply (RCL) for adults, specifically providing for legal and regulated availability, distribution, and use of cannabis generally similar to other, legal substances used for non-medical purposes (e.g., alcohol or tobacco) (Decorte et al., 2020; Kilmer & Pérez-Dávila, 2023; Spithoff et al., 2015; UNODC, 2022. RCL policies have been implemented, while within rather heterogeneous regulatory frameworks (e.g., concerning age restrictions, place of use, legal product and source options), in Uruguay (2013), Canada (2018), about half of US states (2012 onward), Malta, Germany and Luxembourg; they have been proposed or explored in several other countries (e.g., Switzerland, the Netherlands)(Boury et al., 2022; Hall & Lynskey, 2020; Kilmer & Pérez-Dávila, 2023; UNODC, 2022. RCL provisions in some (but not all) of those jurisdictions include legal and regulated cannabis production and distribution/sales through commercial producers and/or retail systems, whereas elsewhere the supply relies mainly on (legal) self-production (e.g., 'home cultivation') by consumers and/or collective and regulated self-production (e.g., 'cannabis clubs') (INCB, 2022).

RCL frameworks have been considered major, while controversial policy reforms or 'experiments' in the psychoactive substance control realm. They have been implemented based on different rationales or objectives (including improved health, safety and/or economic outcomes), and different processes (e.g., some as executive policy reforms, others by referendum). The literature on outcomes associated with RCL policies has been growing rapidly. To date, most assessments of impacts has focused on

'health' (e.g., cannabis consumers' and/or public's health) outcomes. For this, evidence has been mixed overall, with a substantive body of studies showing, for example, select increases in cannabis use levels in general and key sub-populations (e.g., youth) and/or risky (e.g., frequent use and/or high-THC products) use patterns, clinical problems (e.g., cannabis dependence) and related hospitalizations/emergency department (ED) visits for various cannabis-related indications (e.g., mental health, poisonings, injuries) associated with RCL implementation (Athanassiou et al., 2023; Farrelly et al., 2023; Fischer et al., 2023; Hall & Lynskey, 2020; Myran et al., 2023a, 2023b, 2023c). Hence, overarching questions remain as to whether RCL implementation has produced overall net benefits or burdens for health outcomes.

Another important area of RCL-related impacts that has received less empirical attention are social, and specifically crime-related, outcomes. Assessments of crime-related RCL-outcomes are relevant for several different reasons. First, RCL policies render elementary cannabis-related behaviors (e.g., adult possession/use or supply) legal – while with regulatory restrictions (e.g., for age, place, quantities, distribution to consumers, etc.) – and so aim to reduce related criminalization and/or related crime and enforcement burdens (Boury et al., 2022; Decorte et al., 2020; UNODC, 2022. In addition, cannabis-related enforcement has been shown to be erratic and/or arbitrary (e.g., racialized) while consuming extensive socio-economic resources, with RCL policies aiming for improved social justice and/or efficiency (Adinoff & Reiman, 2019; Auriol et al., 2023; Owusu-Bempah & Luscombe, 2021; Room, Fischer, et al. 2010). Second, cannabis' legal status may – through various, for example, behavioral or environmental mechanisms – affect other crimes, such as cannabis-impaired driving and related crashes as well as other (e.g., violent/property) crime types (French et al., 2022). Third, many RCL initiatives feature the replacement and reduction of illegal cannabis production, distribution, and sourcing – or cannabis 'black' markets and related crimes – through legal supply and distribution mechanisms as a primary goal (Auriol et al., 2023; Decorte et al., 2020; French et al., 2022). Overall, these crime-related impact aspects present an emerging while major and important outcome domain of RCL-policies for policy assessment and evaluation.

In these contexts, the present paper aims to provide a comprehensive overview of available evidence for primary crime-related outcome indicators associated with *'de jure'*-type RCL policy implementation. Our examination loosely follows a set of previously identified main indicator categories regarding crime-related outcomes for cannabis legalization policies as informed by a 'post-legalization criminology' (Fischer et al., 2021). Informed by the overview of available data indicators, it discusses select basic implications from the evidence for RCL-related research and policy, as well as knowledge gaps that need addressing.

Methods

Given the relatively novel, while wide ranging and heterogeneous nature of the literature available regarding crime-related outcomes as related to RCL policy, we conducted a comprehensive (while non-systematic) literature and data review with the aim of identifying and synthesizing related selected indicator data (Grant & Booth,

2009). This review in general scope and approach focused on four, previously defined primary categories of criminological 'post-legalization' indicators associated with formal, '*de jure*'-type RCL policies and settings (Fischer et al., 2021): 1) Cannabis- and other crime-related outcomes; this subsumes both outcomes specifically for cannabis-related crimes and enforcement, as well as other types of crimes affected by or related to cannabis; 2) cannabis-impaired driving and related motor-vehicle crashes/fatalities; 3) cannabis sourcing behaviors by consumers; and 4) cannabis (legal and illegal) market evolution and dynamics. We undertook targeted searches for related, selected key literature and data indicators in pertinent social and health sciences (e.g., PsychInfo, Criminal Justice Abstracts, Web of Science, Google Scholar) databases, based on relevant search terms (e.g., cannabis/marijuana, crime, offenses, enforcement, impaired driving, motor-vehicle-crashes, sourcing, markets, production, supply) fitted and applied for the indicators of interest. Sources of potentially relevant grey literature (e.g., government, survey or other data reports or websites) were also identified through electronic searches. Where available, data from recent systematic or other types of review articles were given priority for consideration. Alternatively and/or in addition, we considered pertinent, quality primary studies and reports containing data on one or more of the four topic-related indicators for inclusion. Moreover, we focused on studies/data that presented primary empirical information on changes in relevant outcomes as defined from before to after the implementation of RCL policy in a given jurisdiction. Furthermore, our search concentrated on recent (i.e., post-2016 with search results up to mid-2023), English-language literature or data sources. Relevant empirical data were extracted, organized, and narratively summarized and presented according to the four pre-defined topical domains, and related sub-topical categories.

Results

Effects on crimes and enforcement

In most existing policy frameworks, cannabis and related behaviors (e.g., possession/use, production, distribution) are defined and prohibited as *per se* crimes; their enforcement has commonly been found to be arbitrary or biased (e.g., racialized) and to consume substantial criminal justice resources (Fischer et al., 2021; Owusu-Bempah & Luscombe, 2021; Room, Fischer, et al. 2010). In addition, through different (e.g., psycho-behavioral or ecological) mechanisms, RCL implementation may result in effects on other (i.e., non-drug) types of crimes. Most RCL initiatives have been implemented with the aim of reducing the cannabis-related crime and enforcement burden, as well as to improve social justice or equity outcomes (Adinoff & Reiman, 2019; Auriol et al., 2023; Kilmer & Pérez-Dávila, 2023).

Cannabis crimes and enforcement

Cross-sectional analysis of Uniform Crime Reporting (UCR; 2010–2019) data found that in four US states with RCL policies without prior decriminalization, legalization

was associated with a 76.3% decrease (95% Confidence Interval [CI]: − 81.2% to − 69.9%) in arrest rates among adults; in five RCL states with prior decriminalization, it was associated with a smaller but still substantial decrease in adult arrests (− 40.0%; 95% CI, − 55.1% to − 19.8%); however, no association was observed with changes in arrest rates among youths (-31.6%; $p < 0.10$) in either cluster (Gunadi & Shi, 2022). A quasi-experimental UCR data-based study (2000–2016) examining cannabis possession arrests in 38 US states, found that in the four RCL states identified, the adult (≥ 18 years) arrest rate decreased by 168.50 (95%CI: 158.64–229.65) per 100,000 population post-RCL, while, the arrest rate for youth (> 18 years) did not significantly change (7/100,000 population; 95%CI: − 15 to 30) (Plunk et al., 2019). Analyses of National Incident Based Reporting System (NIBRS)-based data on cannabis possession arrests in Washington state (2012–2015) showed that among adults (21 + years), arrest rates significantly decreased (87%: $p < 0.001$) after RCL (2012), yet did not change ($p = 0.73$) after retail market implementation (2014). Among youth (18–20 years) overall, cannabis arrest rates also dropped significantly (46%; $p < 0.001$) but less substantially than for adults, and non-significantly increased ($p = 0.10$) after legal market implementation (Firth et al., 2019). Analysis of changes in cannabis-related arrest rates for juveniles (ages 10–17; 2012–2018) in Oregon, with RCL implemented in 2015, found that pre-RCL, the number of cannabis allegations declined from 3,762 (2012) to 2,631 (2014); however, this decline ceased post-legalization (2,709 in 2016). Most allegations were for small amounts (< 1 oz) of cannabis possession. Notably, the total rate of juvenile cannabis allegations in Oregon increased by 28% (RR = 1.28; 95%CI = 1.14, 1.44) post-RCL, while the decline in allegations/month observed prior (RR = 0.99; 95%CI = 0.98, 0.99) flattened following RCL (RR = 1.01; 95%CI = 1.01, 1.02) (Firth, Davenport, et al., 2020). Time-series (SARIMA) analysis of UCR data-based police-reported cannabis offenses in Canada (2015–2021; n = 247,249), documented that RCL implementation (2018) was associated with significant decreases in total cannabis offenses among adults (18 + years from the pre-RCL [2015–2018] to the post-RCL [2018–2021] periods: [adult females: 37,481 to 5,254; estimated step effect change [SE]: -73.9% [30.6%]; $p < 0.0001$]; adult males: 185,997 to 18,518; -83.2% [21.2%]; $p < 0.0001$] (Callaghan et al., 2023a). Among both adult males and females, the relative decreases in actually observed crime incidents across the two periods were markedly more substantial for cannabis possession (males: 155,222 to 4,200; females: 30,091 to 679) than for other types of (e.g., supply-related) cannabis offenses (males: 30,775 to 14,317; females: 7,390 to 4,575). Corresponding data analyses showed that RCL was also associated with significant reductions in enforced cannabis offenses among underage (i.e. 12–17 years) youth: (female youth: 8,971 [2015–2018] to 558 [2018–2021]; -62.1% [34.3%]; $p < 0.0001$; male youth: 32,000 to 2,508; -53.0% [22.7%]; $p < 0.0001$). While the absolute numbers of cannabis possession incidents among youth also decreased substantially (female youth: 8,377/367; male youth: 29,015/1,603), this particular type of offenses -- different from adults -- remained as the respective relative majorities of cannabis-offenses observed among underage youth following RCL in Canada (Callaghan, Sanches, Hathaway, Asbridge, MacDonald, et al., 2023b).

Cannabis-related enforcement patterns and disparities

Case–control analysis of state-based UCR data (2000–2019) for cannabis possession arrests among adults and youths in 43 US states, including nine which implemented RCL, found that when comparing absolute differences in arrests (before policy changes) from 2008 to 2019, RCL implementation was associated with 561/100,000 and 195/100,000 fewer arrests for Black and White adults, respectively, and with 131.1 and 131.2 fewer arrests for Black and White individuals among youths. For both age groups, these reductions were similar to states that implemented decriminalization, yet multifold those in states without cannabis policy changes. However, trend analyses of the arrest ratios from 2000 to 2019 suggested racial disparities remained over time (Sheehan et al., 2021). Analysis of NIBRS-based cannabis possession arrest data from Washington state (2012–2015) showed marked variation in cannabis arrest rate changes by race post-RCL; specifically, arrest rates for African Americans declined substantially and absolute disparities decreased, but the relative disparities, compared with Whites, increased from a 2.5-times elevated arrest rate to a 5-times elevated rate following legal market opening (2014). Correspondingly, cannabis arrest rates for African-American youth dropped post-RCL and the absolute disparities decreased, but remained almost twice as high as for Whites (Firth et al., 2019). Another NIBRS data-based analysis (2010–2016) for Colorado documented that post-RCL, the total cannabis arrest rate for adult women decreased markedly (-2.53; $p < 0.001$), while with disproportionate trends and disparities across racial sub-groups. Specifically, while arrest rates declined across all groups following RCL (2013–2016), African-American women (2.0/100,000) were arrested at twice the rate than Latina (0.95/100,000) and White (0.73/100,000) women; these discrepancies extended to arrests for cannabis possession only (1.48/100,000; 0.67/100,000; 0.58/100,000) (Meize et al., 2022). A study examining cannabis arrest data for multiple incident types (e.g., possession, distribution, and public consumption) at the municipal level in Los Angeles (2010–2019) following 'decriminalization' (2011) and 'legalization' (2016) policy changes found that following decriminalization, there were 19.8 (SD = 0.9) per 100,000 cannabis-related arrests for Black individuals and 2.9 (SD = 0.9) arrests for Whites, with a Black-White difference of 17.0 (SD = 7.2) and a Black/White ratio of 6.9 (SD = 0.3), respectively. Following RCL, the cannabis arrest rates reduced to 3.2 (SD = 1.6) for Blacks and 0.3 (SD = 0.2) for Whites, resulting in a Black-White difference of 3.0 (SD = 1.6) and a Black/White arrest ratio of 12.7 (SD = 2.0), While the absolute numbers and differences for inter-racial cannabis arrest outcomes declined, there was an increase in relative disparities post-RCL, which included an emergence of arrests for public cannabis consumption – a non-existent offense pre-RCL – with Black individuals arrested at a 6.7 (SD = 2.0) times higher rate compared to Whites (Joshi et al., 2023). Another UCR data-based analysis of cannabis-related arrests in Colorado and Washington (2009–2016) showed significant declines in cannabis arrests for most, but not all racial sub-groups post-RCL. Specifically, RCL was associated with a 19.075/100,000 decrease in cannabis possession arrest rates for Black and a 9.032/100,000 decrease for White, but not for Asian or Native-American individuals in Colorado. In comparison, cannabis arrest rates declined by a predicted value of

2.528/100,000 for Asians, 26.432/100,000 for Blacks, and 6.534/100,000 for Whites (but not Native-Americans) in Washington. When comparing pre- with post-RCL trends for cannabis arrests, there was no enhanced decline post-RCL for any group in Colorado; in Washington, the decline in arrests for Blacks tapered off, while the trends for Native-Americans reversed from upward to downward, suggesting that RCL produced a net protective effect for overrepresented populations by decreasing criminal justice contact, but only a limited disparity reduction effect (Willits et al., 2022). Cannabis-related arrest rates for juveniles in Oregon (2012–2018) post-RCL indicated substantive variations by race/ethnicity: While most cannabis allegations (72%) involved White youth, the highest rates of cannabis allegations occurred among Native-American, followed by Black and White youth. Native-American youth, compared with White youth, were 264% more likely to receive a cannabis allegation pre-RCL; this disparity did not significantly change post-RCL. Correspondingly, Black youth were 88% more likely to receive a cannabis-related allegation than White youth; this disparity significantly decreased to 23% post-RCL; Latinx and Asian/Pacific Islander youth had lower cannabis allegation rates than Whites both pre- and post-RCL (Firth, Davenport, et al., 2020).

Effects on enforcement of other drugs/in other jurisdictions

Time-series-based analysis of UCR data (2007–2019), showed a decrease in cannabis possession offences of 5,523 offences per 100,000 population ($p < 0.01$) for the first month of RCL (December 2012) in Washington state relative to the non-RCL control states. No corresponding changes were detected for possession offense rates of other types of drugs, while the cannabis retail sales implementation (2014) was associated with significant differences in heroin/cocaine ($p < 0.05$) and other nonnarcotic drug possession ($p < 0.01$) rates between Washington and the control states (Wu & Cullenbine, 2022). In contrast, RCL implementation in Colorado and Washington states was associated with apparent 'spillover effects', where border counties, relative to non-border counties of neighboring states experienced substantial increases in cannabis possession arrests; these effects, however, were mostly concentrated in a few states and concerned adult (but not juvenile) arrests (Hao & Cowan, 2020). Another UCR data-based analysis found that RCL implementation in US states was associated with significant decreases of 20.7%-31.5% in drug arrests (or 1–2 arrests/100,000 population) over a post-legalization period of 3–4 years, with over two-in-five of these arrests being cannabis-related. In comparison, no changes in arrests for other (e.g., property, violence) types of crimes were observed (Sabia, 2021).

Effects on other crimes

A variety of studies, based on a multiplicity of methods, have examined possible associations of RCL implementation with other types of crimes (mostly for local or state-based settings) with rather inconsistent findings. For example, Freisthler and colleagues based on 16,354 space–time unit observations over 34 months, found that the density of RCL-dispensaries was positively associated with property crime rates in

spatially adjacent areas in Denver, Colorado, though the effects were not local (Freisthler et al., 2017). Another study also focusing on neighborhood levels (3,981 grid cells; 2012–2015) found that the presence of RCL- (and MCL-) dispensaries was associated with significant increases in the rates of different crime- and disorder-outcomes in Denver (Hughes et al., 2020). Based on difference-in-differences analysis of UCR data (2007–2017), substantial increases in multiple crime type rates, including overall property and violent crime as well as burglary, motor vehicle theft, larceny and aggravated assault crimes, were associated with RCL implementation in Oregon (2014) relative to non-RCL states (Wu et al., 2021). In addition, quasi-experimental analysis of UCR data (2007–2017) showed increases in simple assault rates in Oregon counties post-RCL, relative to non-RCL states (Wu & Willits, 2022).

In contrast to studies suggesting positive associations between RCL implementation and other crime outcomes, others indicate crime-neutral or -reducing effects associated with RCL. For example, the presence of one additional neighborhood-based dispensary under RCL conditions in Denver was found to be associated with a significant reduction of 17 crimes per month/10,000 residents (19% decline relative to average crime rate) in the local area; no such reductions were observed for adjacent neighborhoods (Brinkman & Mok-Lamme, 2019). RCL-implementation in Washington state (2012) was found to be associated with significant decreases in within-state rape and property crimes post-legalization (201–2014) compared with the pre-legalization period (2010–2012) and relative to the Oregon state-side (Dragone et al., 2019). Difference-in-differences analysis of UCR data (2003–2017) suggested some evidence for a protective RCL-related 'spillover effect' on crime in Colorado, expressed by significant reductions in property crime, larceny, and simple assault in border counties of neighboring states (Wu et al., 2020). A quasi-experimental study utilizing multi-spatial units in Washington (DC) found that, with some exceptions, violent/non-violent crime levels decreased or remained constant in areas following the opening of a MCL-dispensary (Zakrzewski et al., 2020). Synthetic control method-based analysis of US state-level data (2000–2019) found that RCL in Colorado and Washington states was generally not associated with variations in index crime rates; there were select, short-term exceptions (e.g., larceny/theft and motor-vehicle theft in Colorado; burglary in Washington) (Harper & Jorgensen, 2023). Similarly, time-series-based analysis of UCR data (1999–2016) for the two states found that RCL and related cannabis sales implementation had no significant, long-term effects on rates of violent or property crime in these settings (Lu et al., 2021). Difference-in-differences analysis of UCR data showed that that the introduction of MCL was associated with significant decreases in violent crimes (overall: -12.5%; robberies: -19%, homicides: -10%; assaults: -9%) in US states (California, New Mexico, Arizona) that border Mexico. This reduction was strongest for counties near the border (< 350 kms) and specifically for drug trafficking-related crimes. The effects were absent for inland states, while border states saw a significant crime reduction when a neighbor state implements MCL (Gavrilova et al., 2019).

Both the time-series-based analyses of UCR data for adults and youth populations (2015–2021) did not show evidence of significant changes in respective rates of national property crimes (estimated step effect change [SE]: youth-females: 1.6% [7.1%]; $p = 0.82$/youth-males: 1.0% [8.3%]; $p = 0.90$; adult-females: 1.0% [2.4%];

p = 0.69/adult-males: 1.0% (2.4%); p = 0.78) or violent crimes (youth-females: 6.0% [6.9%]; p = 0.88/ youth-males: -0.2% [8.7%]; p = 0.98/adult-females: 0.5% (3.9%); p = 0.90/adult-males: 1.9% (2.5%); p = 0.45) from before to after RCL implementation in Canada (2018) (Callaghan et al., 2023a, 2023b; Callaghan, Sanches, Hathaway, Asbridge, MacDonald, et al., 2023b). Based on a difference-in-differences approach analysis of related enforcement data 2002–2019, RCL-implementation in Uruguay was found to result in a 'spillover effect' involving an increase of 19.31/100,000 (standard deviation [SD]: 0.26) in drug possession and 9.35/100,000 in drug trafficking offense rates, in addition to significant increases in drug seizure rates for cannabis, cocaine and crack-cocaine, in Brazilian municipalities located near the border with Uruguay. There was no significant decrease in violent crimes (Vicente, 2022).

A few studies examined effects of RCL on crime clearance rates, considering possible dynamics of RCL freeing up enforcement resources that may allow for the more effective investigation of other crimes. For example, one time-series-based analysis of UCR data (2010–2015) found that RCL was associated with mostly steady, but selectively increasing crime clearance rates of certain crime types in Colorado and Washington states (Makin et al., 2019). Based on difference-in-difference and synthetic control methods (SCM)-analysis of UCR-data (2007–2017), significant increases in the clearance rate for overall violent crimes, and specifically for aggravated assault were found in Oregon state post-RCL implementation relative to non-RCL states; however, clearance rates for violent crimes decreased over time (Wu et al., 2022).

Overall, evidence suggests that RCL implementation is associated with substantial reductions in cannabis-related enforcement and arrests, and particularly cannabis use-related offenses, also in comparison to other drug crimes or enforcement, in RCL jurisdictions. Conversely, arbitrary or racially selective patterns of cannabis enforcement have been shown to continue in some places, and there have been 'spillover' effects on cannabis enforcement in RCL-adjacent jurisdictions. Evidence of effects of RCL on other types of (e.g., property/violent) crimes is markedly mixed, and may also involve 'spillover' effects on neighboring jurisdictions, while improvements for police clearance rates seem to exist.

Cannabis-impaired driving, motor-vehicle-crashes and fatalities

Cannabis-impaired driving, and potential motor-vehicle-crash (MVC) involvement is a major indicator of importance for both cannabis-related health and crime outcomes (Fischer et al., 2021). Acute cannabis exposure impairs essential driving skills, and elevates the risk for consequential MVC involvement and related injury/fatalities (Cohen et al., 2019; Fischer et al., 2022; Manetti et al., 2023). In many jurisdictions, cannabis-impaired driving is prohibited by per se/THC-threshold laws which render it a criminal offense, and thus relies on enforcement and deterrence-related effects. At the same time, changing cannabis use, availability and/or risk perceptions as possibly associated with RCL may influence cannabis-impaired driving and related adverse outcomes (Razaghizad et al., 2021; Windle et al., 2021).

Driving under the influence of *cannabis*

A number of studies provide data on the prevalence and changes in driving under the influence of cannabis (DUIC) in RCL-policy contexts (Windle et al., 2022). In the national Canadian Cannabis Survey (CCS), among respondents self-reporting cannabis use (in the last 12 months) the proportion indicating that they had driven a vehicle within 2–4 h of either smoking or ingesting cannabis (includes item variation, depending on survey year) initially varied but then gradually decreased, from 29% in 2017 [pre-RCL], 27% in 2018, and 24% in 2019 to 19% in 2020 and 18% in 2022 (Boury et al., 2022; Government of Canada, 2023). In Ontario's general adult population (18 +), the annual prevalence of self-reported DUIC within one hour of use remained largely steady, from 2.6% in 2017 to 2.4% in 2020 and 2.5% in 2022 (Boury et al., 2022; Nigatu & Hamilton, 2022); given observed increases in cannabis use prevalence through this period, these rates suggest a likely decline of rates of driving under the influence cannabis among cannabis users. Drivers in US states (2013–2017) that had implemented MCL but not RCL had marginally higher odds of self-reporting DUIC compared to drivers in states where cannabis remained illegal (adjusted odds ratio [AOR]:1.29; 95%CI: 0.98, 1.70). No evidence was found that drivers in US states that implemented both MCL and RCL had higher odds of DUIC compared to states where both non-medical and medical cannabis use were illegal (AOR:1.06; 95%CI:0.71, 1.56) (Benedetti et al., 2021). *Per-se* or THC-threshold laws were significantly associated with lower self-reported driving after marijuana use (AOR 0.74; 95%CI: 0.57, 0.95) (Benedetti et al., 2021). In an international online survey of youth (ages 16–19 years), 15.4% of respondents in Canada (just pre-RCL) implementation, 9.9% in England (no RCL), and 27.7% in the US (RCL partially implemented) reported that they had driven a car within two hours of cannabis use in 2017 (Wadsworth & Hammond, 2019). A recent systematic review identified a total of three studies that indicated increases in the prevalence of DUIC associated with MCL, whereas another systematic review comprising 12 studies concluded that evidence specifically for DUIC-related effects associated with RCL was "inconsistent" (French et al., 2022; Windle et al., 2022).

Cannabis exposure among MVC-injured drivers

A series of epidemiological studies have examined possible changes in cannabis exposure levels among MVC-related trauma/injury patient samples as related to RCL-implementation. The review by Windle and colleagues (2022) identified a total of 15 related studies with trauma patient samples involving cannabis-positivity tests in different US states. The majority (nine studies) found an increase in cannabis positivity in MVC-patients associated with RCL or related retail sales specifically in the states of Colorado and Washington; Colorado and Washington combined; or Alaska, Colorado, Oregon, and Washington combined, whereas five studies found no differences in Colorado or Washington, and one study found a decrease in the latter two states (Windle et al., 2022). For higher-quality individual studies, Vogler (2017) found a pooled increase of 31.4% in the proportion of MVC fatalities in which the driver was tested positive for cannabis and alcohol was not

involved, in Alaska, Colorado, Oregon, and Washington states, compared with that in control states (Vogler, 2017). Hansen et al., (2020a, 2020b) estimated that, when compared with synthetic controls, MVC fatalities in which at least one driver was found to be cannabis-positive increased by 92% in Colorado and 28% in Washington (2013–2016), with 45% − 60% of the increase attributable to RCL implementation, although state-specific estimates were imprecise (Hansen et al., 2020a). A study of MVC-injured and hospitalized individuals (n = 4,339) in four Vancouver hospitals (2013 to 2020) found increased prevalence levels of blood THC levels among drivers of > 0 ng/milliliter (adjusted prevalence ratio (APR): 1.33 (95%CI: 1.05–1.68), > 2 ng/milliliter (APR: 2.29, 95%CI: 1.52–3.45), and > 5 ng/milliliter (APR: 2.05, 95%CI: 1.00–4.18) from the years before to after RCL implementation in Canada (Brubacher et al., 2022). In a more recent study not considered in the above reviews, a total of 426 cases of cannabis-involved traffic injury-related ED visits in Ontario's population (16 years and older) between 2010 and 2021 were identified (Myran et al., 2023b). Annual rates of cannabis-involved traffic injury-related ED visits increased by 475.3% over the study period (0.18 visits/1,000 total traffic injury-related ED visits in 2010 to 1.01/1,000 in 2021). Over the same period, alcohol-involved traffic injury ED visits increased by only 9.4% (8.03/1,000 in 2010 to 8.79/1,000 in 2021). More specifically, initial RCL implementation with restrictions (October 2018-February 2020) was associated with a 94% increase in the quarterly rate of cannabis-involved traffic injury-related ED visits relative to pre-legalization (ARR:1.94; 95%CI: 1.37–2.75), while subsequent commercialization (March 2020-December 2021) was associated with a 223% increase (ARR:3.23; 95%CI: 2.42–4.33) (Myran et al., 2023b).

Changes in population-level MVC-fatalities

Other types of epidemiological studies have examined possible changes in overall rates of MVCs and related driver fatalities associated with RCL. Windle and colleagues' review found that, overall, the majorities of studies focusing on data from Colorado, Washington or Oregon reported increases in MVCs or related outcomes associated with RCL (Windle et al., 2022). Similarly, another review found that 15 studies reported RCL/RML implementation to be associated with changes in MVC rates, whereas 5 studies found no such relationship (González-Sala et al., 2023). More specifically, in higher quality studies, fatal collisions or MVC-fatalities were estimated to have increased 3.6%-5.9% in Colorado, 1.4%-3.6% in Washington, and 1.5%-20.5% in Oregon following RCL implementation (Windle et al., 2022). Among higher-quality studies that pooled data from > 2 US states, virtually all found point estimates suggesting an increase in MVCs or related outcomes associated with RCL implementation (1.4%-7.8%) and legal sales (1.4%-6.0%), respectively, with only one study presenting inconclusive results (Farmer et al., 2022; Leung & Dutra, 2021; Vogler, 2017). Importantly, these effects were also commonly associated with select 'spillover' effects on neighboring (non-RCL) US state jurisdictions where similar, but heterogeneous increases in MVC-fatalities were observed as in RCL-states (Lane & Hall, 2019). A study focusing on urban and rural regions of Uruguay (2012–2017) found that RCL implementation was associated with an overall

52.4% (95%CI:11.6, 93.3) increase in light motor-vehicle drivers' fatality rates; however, this effect was not observed for motorcyclists (Nazif-Munoz et al., 2020). More specifically, the increase in MVCs was significant in Montevideo, Uruguay's capital and major urban area, but not in rural areas. A study assessing weekly traffic injury-related emergency department presentations (2015–2019) from before to shortly into RCL implementation in select provinces in Canada found no significant associations in Alberta for all drivers (+9.17 visits; p = 0.52) or youth drivers (-0.66 visits; p = 0.42) nor in Ontario (+28.93 visits; p = 0.30 and +0.09 visits; p = 0.98), respectively with RCL implementation (2018) (Callaghan et al., 2021).

Substantive minorities of current cannabis users engage in cannabis-impaired driving, but there is inconsistent evidence as to whether related prevalence levels have increased with RCL implementation. Conversely, respective studies show that the levels of cannabis exposure among MVC-related trauma/injury patients and the overall rates of MVC-related fatalities have shown slight while commonly significant increases in association with RCL implementation. These data suggest for potentially conflicting dynamics, where limited enforcement and deterrence mechanisms in conjunction with increases in cannabis use, product potency and availability, and lowered risk perceptions may add to cannabis-impaired driving-related harm in RCL setting, for example, by making those prone to driving under the influence of cannabis use more likely to take greater risks and consequently be involved in MVC.

Cannabis sourcing

A core element of most, while not all RCL frameworks are provisions for the establishment of legal cannabis distribution and supply and related product sourcing (e.g., retail stores) for consumers. The policy-based objectives behind this aim both to provide consumers with regulated, and thereby safer and/or healthier cannabis products, as well as to reduce illegal cannabis market activities and related crime (Auriol et al., 2023; Rehm & Fischer, 2015). Several different types of legal cannabis supply provisions have been established in RCL environments, including legal/licensed retail storefronts, 'cannabis social clubs', internet-sales and home-/self-cultivation (Decorte et al., 2020). Given that illegal cannabis markets have long and viably existed prior to RCL implementation, a primary question is to which extent consumers would switch to obtaining their cannabis from legal sources and what main factors influence such transitions in RCL environments.

Cannabis sourcing behaviors in RCL settings

Data from several sources provide basic information on the evolution of cannabis sourcing behaviors in RCL settings. Based on CCS data, 4-in-5 cannabis users in Canada had declared in 2018 (pre-RCL implementation) their intention to obtain their cannabis from legal sources when they became available. The self-reported, subsequent ("usual") use of legal sourcing options for cannabis acquisition following RCL implementation showed a gradual increase from much lower levels, with

24% for cannabis sourcing from a "legal storefront," 13% "legal online" purchases, and 6% "self-growing" in 2019, and subsequent gradual increases to 41%/13%/7% in 2020, 53%/11%/8% in 2021 and 61%/8%/8% in 2022, respectively, for these options (Boury et al., 2022). In 2022, overall about two thirds (63%) of active users reported that they 'always' (48%) or 'mostly' (15%) obtained their cannabis from a legal/licensed source, while 28% 'rarely' or 'never' did so (Government of Canada, 2022). Most of those still acquiring cannabis from non-legal sources did so from 'someone they know' (e.g., family member, friend; 53%), an 'illegal website/online' source (21%), or a 'dealer' (19%). Analysis of multiple data waves of the Canadian National Cannabis Survey (NCS; ages 15 years and older; n = 2,890) collected shortly before (May – September 2018) and after (February – June 2019) RCL implementation in Canada found that the use of a "dealer" among respondents had decreased from 19% to 12% (-37%) within just months into the RCL policy (Hathaway et al., 2021).

The Internet-panel-based International Cannabis Policy Study (ICPS) examined the cannabis sourcing behaviors of Canadian respondents with self-reported cannabis use (2019–2021). The percentage of respondents who sourced "all" (versus "none") of their cannabis products from legal sources (in the past 12 months) significantly increased (AOR: 4.10; 95%CI: 3.35–5.00), but proportions substantially varied by cannabis product type, i.e. from 36.6% for dried flower in 2019; 37.0% (solid concentrates) to 78.0% (oral oils) in 2020; and 48.6% (solids) to 81.6% (drinks) in 2021. In contrast, the percentage of consumers who sourced "none" of their cannabis products legally ranged from 4.4% of consumers of capsules to 31.4% for consumers of hash/kief products (Wadsworth et al., 2023). Similarly divided patterns are reflected for cannabis 'home-cultivation', a cannabis source allowed as part of RCL in most (except for two, Manitoba and Quebec) Canadian provinces. The overall prevalence of home cultivation increased from 5.8% in 2018, to 7.9% in 2019 and to 8.8% in 2020, with 42.3% and 24.5% of self-reported home-cultivators however exceeding the legal maximum of four plants in 2018 and 2020 respectively. While home cultivation was lowest in provinces disallowing it, it proportionally ranged there from 29.5% to 55.7% of national prevalence (depending on province/year) (Wadsworth et al., 2022a, 2022b).

In Uruguay, in early 2022, approximately 69,000 – or less than half—of the estimated 158,000 current users were obtaining cannabis through the legal cannabis market (UNODC, 2022). A Uruguay-based multi-wave survey of frequent cannabis users examined changes in cannabis sourcing at different stages of RCL from 2014 (early RCL stage with restricted legal access) and 2017 (expanded legal access), while considering three possible sourcing categories ('legal': cannabis social clubs (CSC), home cultivation (registered), pharmacy sales (added in 2017); 'gray': sourcing from friends/acquaintances or on their behalf from legal sources; 'illegal': purchases or gifts from illegal sources): In 2014, 'legal' modes of access were preferred by 0.6% (CI: 0.2%–2%), 'gray' by 22% (CI: 13%–33%) and 'illegal' by 78% (CI: 66%–86%) of frequent cannabis user respondents; these source preferences significantly changed to 14% (CI: 9%–21%) for 'legal'; 41% (CI: 29%–55%) for 'gray', and 44% (CI: 34%–56%) for 'illegal' sources by 2017. Increases in 'legal' access modes were mostly related to increased utilization of CSCs and home cultivation. Yet despite multiple legal source options available, still only a minority of frequent

users accessed cannabis legally by 2017, some of which has been explained by substantial restrictions (e.g., registration requirements, limited product range etc.) for the legal acquisition routes available (Queirolo et al., 2023).

Factors influencing legal *cannabis* sourcing

A number of studies have examined factors that influence legal versus illegal cannabis acquisitions by cannabis consumers in the contexts of legal market/sourcing options.

Among Canadian adult respondents in the ICPS (Wave 2, 2019) with any dried flower product purchase in the past year (n = 2506), 47.7% reported their last cannabis purchase to be legal, while with inter-provincial variation (40.5%–81.2%). Legal cannabis purchasing was more likely to occur among those living closer to a legal retail store based on Euclidean distance (< 3 km vs. > 10 km: AOR = 1.56, 95%CI: 1.20–2.02), and with shorter travel time to a retail store (< 5 min vs. > 15 min: AOR = 2.24, 95%CI: 1.56–3.21) (Wadsworth et al., 2021).

In further ICPS-based analyses, the proportion of cannabis consumer respondents who last purchased dried flower product from legal sources increased from 45.7% in 2019 to 58.1% in 2020 (Wadsworth et al., 2022a, 2022b). In addition to provinces reflecting differentials in density and access of legal source options, regression analyses found a significant interaction effect for unit price paid for legal purchasing, likely reflecting overall higher prices for cannabis flower products from legal sources. In addition, frequent (i.e., daily) cannabis consumers were less likely to purchase from a legal source than infrequent users. Furthermore, those respondents purchasing small quantities (1g to 3.49g [AOR = 2.60, 95%CI: 1.85–3.65]) and medium quantities (3.5g to 27.9g [AOR = 2.18, 95%CI:1.62–2.94]) were more likely to purchase cannabis products legally than respondents purchasing large amounts (e.g., > 28g) (Wadsworth et al., 2022a, 2022b). Additional analysis among Canadian respondents of the ICPS (2019–2021) found variations of legal cannabis acquisition associated with frequency of cannabis consumption, with weekly or more frequent consumers being more likely to source 'some' (but not 'all') versus 'none' of their products legally compared with less frequent consumers (Wadsworth et al., 2023).

Another ICPS-based analysis (2019–2020) examined reasons for illegal cannabis purchasing (in the past 12 months) among cannabis consumers in Canada and US-based RCL states (n = 11,659). The most common barriers to legal sourcing among Canadian respondents were: 'higher price' (35.9% in 2019/34.6% in 2020); 'less convenience' (19.8%/16.5%); 'too much distance/none available' (17.7%/10.6%); 'lower product quality' (16.8%/16.9%); 'loyalty to dealer' (14.8%/13.4%); 'desire for anonymity' (13.2%/13.8%); 'no desired product offer' (13.0%/13.9%). Results for US respondents were overall similarly patterned. Canadian respondents, those living in provinces with higher legal cannabis price and/or fewer legal cannabis stores, but also frequent (e.g., daily/almost daily) use patterns were more likely to cite 'price' or 'convenience' factors as barriers to legal cannabis acquisition (Goodman et al., 2022).

An examination of possible co-variates of the choice for illegal purchasing source for cannabis (i.e., 'dealer') among NCS respondents in the months just before and early into RCL implementation in Canada similarly found that, among

other factors, age, price, access and frequency of cannabis use influenced the selection of cannabis source option (Hathaway et al., 2021).

In a systematic review (35 studies) of factors influencing cannabis purchase decisions (e.g., legal versus illegal product/source options) in RCL environments, price aspects were most commonly cited (27 studies) as a consideration in decision-making, with most studies finding demand to be relatively price-inelastic. Among other aspects, 'product quality' was commonly mentioned (Donnan et al., 2022b). Similarly, in a small Canadian qualitative study price -- including price differentials between licensed and non-legal sources -- quality, packaging and warnings, the cannabis source, and social influences emerged as major thematic drivers influencing cannabis purchasing decisions in RCL contexts (Donnan et al., 2022a).

Evidence suggests that in mature RCL environments, there have been gradual, while substantial shifts from illegal to legal cannabis sourcing by consumers, where at points of initial legal retail supply system maturation some half to two-thirds of cannabis acquisitions involve legal cannabis sources/products. These shifts have naturally unfolded in parallel with the extent of available legal supply and sources, yet also seem to further depend on a number of consumer-, system- and other ecological factors, including source convenience/distance, cannabis product quality/characteristics and price, and consumption intensity. Conversely, in Uruguay, highly restricted legal product and source options combined with high access barriers see overall unusually limited legal source utilization.

Cannabis markets

The reduction or elimination of illegal ('black') cannabis markets, and related crime, is a primary objective of most RCL-initiatives (Auriol et al., 2023; Boury et al., 2022; Decorte et al., 2020). In a number of RCL frameworks, this is aimed for by provisions and regulations for legal, including commercial cannabis production and distribution to consumers, while in some RCL environments this happens through the legality of individual or collective cannabis self-production. Especially given that illegal cannabis markets are deeply entrenched, and can operate with distinct (e.g., price or product) advantages in comparison with regulated/legal systems, it is a key question to which extent legal cannabis markets succeed in effectively replacing illegal markets, and what additional factors may influence these impact dynamics.

Legal *cannabis* market evolution and dynamics

Based on government-sourced sales data, the overall share of legal cannabis products sold in Canada's RCL environment-based market initially started out at 7.8% in October 2018 and grew to 23.7% one year later in September 2019. However, the legal market shares then widely ranged from 13 to 70% across the 10 provinces, with inter-provincial differences in store access, density, and retail prices found to partially explain the variation (Armstrong, 2021a). Further increases in legal store availability explained 46.3% of the variation in provincial sales growth observed

from 2018 to 2020, with each added store estimated to be associated with added quarterly sales of $305 (95%CI: $208-$402) thousand per million residents (ages 15 +) (Armstrong, 2021b).

More recently, four years after RCL implementation (2022), there were 3305 cannabis stores in Canada (10.6 stores/100,000 individuals aged 15 + years) and 59% of neighbourhoods were within a 5-min drive of a cannabis store. However, the number of stores per capita still varied multifold between provinces (e.g., Quebec: 1.2/100,000 vs. Alberta: 20.4/100,000), with overall higher rates in provinces with private/commercial (versus public only) retail system elements. Cannabis sales volumes were $11.85/1,000 residents, with generally greater volumes in private retail systems. Over the four years, per capita stores and sales increased by an annual average of 122.3% and 91.7%, respectively, with larger increases in private versus public systems (4.01 times greater for stores/per capita and 2.46 times for sales/per capita). The annual increase in per capita stores and sales during the first 3 years (2018–2021) was multifold greater (6.0 and 15.5 times respectively) than the increase in the fourth year (2021–2022) post-legalisation, suggesting a retail market plateau or saturation effect (Myran et al., 2022, 2023a, 2023b, 2023c).

A study examining legal cannabis retail market and sales trends from five 'early-adopting' RCL-states (Alaska, Colorado, Massachusetts, Oregon, and Washington) in the US found that Colorado, Oregon and Washington showed distinct trend periods for retail sales. These included an early rapid growth phase immediately following RCL implementation lasting less than one year, subsequent varied growth periods, and then declining sales in subsequent periods (some counteracted by COVID-related effects), whereas sales in Alaska and Massachusetts displayed more stable, consistent growth patterns. The rate of cannabis retail outlets (2022) varied widely inter-state, from 16.8/100,000 population in Oregon to 3.0/100,000 in Massachusetts, similar to the levels of sales per resident, from $382.97 in Alaska to $180.94 in Washington (July 2021-June 2022) (Dilley et al., 2023).

Illegal/black *cannabis* market evolution and dynamics

A primary objective of RCL initiatives has been to reduce or eliminate illegal/black cannabis markets and related crime, and replace these with legal production and distribution markets. There is only very limited, rudimentary evidence to date as to the degree this has effectively occurred, and the extent to which related factors (e.g., market structures, price, enforcement) have influenced these developments.

Hansen et al. (2021) usefully divided cannabis-related 'black market' activities in RCL contexts into three main conceptual categories: 1) ongoing cannabis 'black market' production/sales within RCL environments; 2) illegal production of cannabis in RCL jurisdictions for sale/distribution in other jurisdictions where it remains illegal; 3) consumer travel from jurisdictions where cannabis remains illegal to RCL environments and acquiring cannabis for use back home ('crossborder') (Hansen et al., 2021). Selected, mostly sporadic data illustrate activities or outcomes for each of these categories.

Complementing above-shown data which indicate that acquisitions of cannabis from illegal sources/markets continues among substantive minorities of cannabis

consumers, there is other select system-level evidence that characterizes ongoing 'black markets' activities in established RCL environments. For example, based on comparisons of survey data on cannabis consumption in Washington (2016–2017) with actual amounts sold in the RCL market, Caulkins et al. found that 25% to 40% more cannabis is reportedly consumed than sold, implying a substantial ongoing black market segment for cannabis sourcing (Caulkins et al., 2019). For California, it has been estimated that up to 80% of overall cannabis sold comes from the black or grey market, with much of the latter comprised of California-based but unlicensed producers/sellers that substantially undersell their legal competitors (Meadows, 2019). Following the implementation of MCL/RCL policies in US state jurisdictions, the reported numbers of illicit cultivation sites has been reported to generally have decreased; however related data are rather unspecific (French et al., 2022). Data reports from 111 national forests in the US found a decrease in the number of illegal growing operations located in national forests associated with RCL-policies (Prestemon et al., 2019). Another study found that following RCL-implementation, the number of illegal growing sites significantly decreased in forests in Oregon, but not in Washington state (Klassen & Anthony, 2019). Other studies have examined how RCL in Washington and other states has affected illegal cannabis markets but "methodological challenges make it hard to draw clear conclusions" (Hansen et al., 2021).

There are case studies of factors from US-based RCL states assumed to have helped or exacerbated the viability of black markets. For example, California's regulatory entry thresholds for legal cannabis distributors have been arduous and high; it also asked municipalities to opt in to rather than opt out of legal cannabis sales, which has likely hindered rather than helped the establishment of legal over illegal cannabis source options. Colorado initially allowed extensive home cultivation for cannabis including up to 99 plants; based on a legal loophole individuals could also have it grown by others on their behalf. These rather permissive provisions for legal home cultivation served as the cover for extensive illegal cannabis grow-operations and cross-state export activities. Oregon's RCL regulations did not limit the number of growers' licenses, thus producing a situation of 'oversupply' for legal cannabis production, which drove down prices and resulted in only an estimated one-third of the legally produced cannabis actually being sold to Oregon residents; the rest fuelled illegal domestic and export market activities. Similar 'oversupply' problems and consequences have been reported for other US states (Hansen et al., 2021; Meadows, 2019). For Canada, it has been reported based on national crime intelligence data that of known organized crime entities involved in the cannabis black market, almost all were also involved in other illicit drug markets and were unlikely to be disrupted by RCL implementation, given their alternate streams of revenue. It was suggested that while RCL made it harder for organized crime entities to infiltrate legal cannabis markets, "these groups are […] adapting to changes" and that, especially as long as legal cannabis supply is insufficient to meet demand, illegal sources will continue to fill existing market gaps (Public Safety Canada, 2020; CISC, n.d).

In addition to other factors influencing the interactions between illegal and legal cannabis markets for sales, price levels and dynamics are recognized as an essential variable. Price levels for legal cannabis are influenced in a variety of ways by regulation, including state-set pricing and/or taxation schemes in the US. Taxation

schemes differ by jurisdiction, with retail excise taxes imposed on the price of legal cannabis products in most US states, whereas Uruguay applies a 'variable fee' (rather than a fixed tax rate) and Canada taxes by weight and THC potency for some products (Hansen et al., 2021). In both Washington and Colorado states, the price of legal cannabis products dropped dramatically over the course of RCL implementation in order to compete with illegal market products (Hansen et al., 2021). In Canada, illegal cannabis prices were about 33% lower than prices for legal products when RCL was initially implemented, but dropped further going forward, increasing the competitive advantage of illegal over legal cannabis products.

In a Canada-based study comparing cannabis product/sale characteristics from 185 legal retailers (22 online and 163 storefronts, including 65 government-run stores, 120 private stores) and 944 illegal retailers (791 delivery-only services, 157 storefronts) in the first two months (October–November 2018) of RCL, relative to legal dried cannabis flower ('herb') product, illegal dried herb products were found to be lower in price (e.g., 1g: $10.23 vs. $11.08) and higher in potency (THC: 20.5% vs. 16.1%). Private legal stores had higher prices for dried herb than government-run stores (1 g: $13.08 vs. $10.89; $p<0.05$ for all data comparisons), suggesting competitiveness differentials (Mahamad et al., 2020). Based on pooled crowdsourced and administrative data (2006–2019) for 11 US-based RCL states and 40 non-RCL states, the street price of (non-legal) cannabis decreased by 9.2% [$\beta=-0.092$; 95%CI: −0.15 to –0.03] after RCL implementation, with the largest declines among low-quality purchases ($\beta=-0.195$; 95%CI: –0.282, –0.108). Conversely, street prices for other illegal drug types remained stable (e.g., cocaine) or significantly increased (opioids). Declines in street cannabis prices co-occurred with a 93% ($\beta=-0.93$; 95%CI: –1.51, –0.36) reduction in law enforcement seizures of cannabis in RCL states (Meinhofer & Rubli, 2021). Another Canada-based study compared key characteristics of cannabis offerings from 624 legal and 57 illegal (online) cannabis store sites in 2023. The study found that the products available from illegal sources more likely included herb or extract products (i.e., products easier to produce but also more likely to be high-potency) and were in larger package sizes, and were offered at an average price differential of approximately 20% (e.g., $7.96/g legal cannabis versus $6.24/g illegal cannabis); this suggested a reduction of previously (2019) observed larger pricing differentials of 55%, mainly due to decreases in the price of legal cannabis products (Deloitte Canada, 2023).

The likelihood of consumers purchasing cannabis from legal over illegal sources has been found to depend on the relative desirability of legal and illicit cannabis. This involves some degree of a 'premium' on legal cannabis and its related qualities or benefits, including the product's legal status (and avoided related risks concerning illegality) and/or its regulated and 'safer' product quality (e.g., content labeling, contamination). Several studies have demonstrated limited demand elasticities for legal cannabis, and therefore limited substitute potential for illicit cannabis products. For example, aggregate demand elasticities in Washington state's legal market were found to be slightly above negative one. If illegal cannabis was a good substitute, these elasticities would be expected to be substantially higher (Hollenbeck & Uetake, 2021). Amlung et al. (2019) documented that the demand for black market cannabis is lower than legal demand and substantially more elastic to changes in legal markets than the reverse, implying that black market cannabis products are not a good substitute for legal cannabis products

(Amlung et al., 2019). An additionally important factor concerning consumer demand forces is that cannabis consumption patterns are strongly skewed across user populations. Based on national cannabis use data for Canada (2018), those consumers accounting for the upper 10% of relative cannabis consumption amounts accounted for approximately two-thirds of the total cannabis consumption volume in the country (Callaghan et al., 2019). Similarly, based on US survey data, those with near-daily/daily (21 + days/month) cannabis consumption have been estimated to account for 80% of overall cannabis consumption (Caulkins et al., 2020). While these minorities of high-frequency consumers are commonly involved in the use of high-potency/risk products, they are usually found to be more likely to engage in illegal cannabis sourcing within RCL environments (Wadsworth et al., 2021, 2022a, 2022b).

For exemplary evidence of 'cross-border' dynamics between legal and illegal cannabis markets, Oregon had a well-proliferated black cannabis market pre-RCL implementation, with state residents commonly border-crossing to adjacent Washington state to purchase cannabis from legally available retail sources. Following Oregon's own RCL implementation (2015), cannabis sales in Washington along the Oregon border fell by almost 40% (Hansen et al., 2020b). Similar dynamics have been estimated to have occurred in other US states bordering on RCL-states where cannabis remained illegal. Hansen and colleagues estimated this form of cross-border shopping to amount to 'de facto' legalization rates of 72% in Idaho and 45% in the region around Massachusetts (Hansen et al., 2020b). In Colorado, relatively low price levels and larger numbers of dispensaries for legal cannabis have led to decreases in local black market sales, yet extensive ongoing, illegal production is reported for shipments to other states where cannabis remains illegal (Meadows, 2019).

Beyond the available, more detailed data documenting cannabis sourcing behaviors by consumers, there is only very limited and rudimentary data on the effects RCL policies have had on illegal/black cannabis markets (and specifically their actual reduction or replacement). In more mature RCL environments, legal cannabis market structures have been observed to proliferate and expand quickly, but then appear to reach a saturation or plateau point. While some evidence for reductions in illegal cannabis production and distribution markets exists, there is also evidence for ongoing substantial illegal cannabis market activities in RCL environments, commonly operating involving supply activities for competitively lower price levels and/or product advantages over legal markets. Moreover, there appear to have been lateral shifts, where illegal cannabis markets now increasingly focus on cannabis production and supply activities for -- typically illegal -- markets remaining elsewhere, overall suggesting 'displacement' rather than actual elimination effects. Overall, many essential aspects or details of the evolution and dynamics concerning of the legal/illegal cannabis markets in contexts of RCL policy implementation remain empirically unclear or un-examined.

Discussion

RCL policy initiatives have been implemented in a growing number of jurisdictions, with 'pioneer' initiatives in Uruguay, approximately half of US states and Canada; more are being implemented and/or considered elsewhere. RCL initiatives involve

diverse policy objectives, including improvements in public and user health alongside reductions in cannabis-related crime and illegal markets. To date, health-related outcomes for RCL have received the lion share of research attention, suggesting overall that RCL policies have been associated with mixed results, including select increases in key adverse health outcome domains (e.g., cannabis use prevalence, risk behaviors, hospitalizations) (Boury et al., 2022; Farrelly et al., 2023; Hall & Lynskey, 2020; Myran et al., 2023a, 2023b, 2023c). Conversely, 'socio-legal' – and specifically 'crime-related' – RCL policy outcomes have received less empirical attention, and their overall empirical data-base is thinner and more fragmented, while equally important for evaluating the overall impacts of RCL policies (Auriol et al., 2023; Fischer et al., 2023; French et al., 2022). For purposes of our review, we identified and summarized available data on key selected crime-related outcomes associated with RCL policies, generally following a set of four main indicator previously defined as of core importance for this outcome domain (Fischer et al., 2021).

Selected data exist, primarily from North America, on the effects of RCL-policy implementation on cannabis-related crimes, as well as other crimes potentially affected by cannabis use and/or availability. Overall, the levels of cannabis crimes reported or enforced – and especially those for use/possession – have markedly decreased, while not disappeared, in most RCL jurisdictions (Callaghan et al., 2023a, 2023b; Firth et al., 2019; Wu & Cullenbine, 2022). This should not be surprising, given that a main provision of RCL policy involves to formally convert select cannabis-related behaviors (e.g., use, possession and sourcing) into legal behaviors shielded from enforcement at least for legal age adults. At the same time, there is evidence for 'spillover' effects for cannabis enforcement, where related arrest rates have increased (e.g., in select US states) in non-RCL settings bordering on RCL jurisdictions (Hao & Cowan, 2020). In addition, racially biased or arbitrary enforcement patterns and specifically related disparities (e.g., involving disproportionately greater enforcement focus on racial minorities) appear to mostly persist with ongoing cannabis enforcement in RCL contexts where examined, also raising questions to which extent 'social justice' improvements have been achieved in these respects (Adinoff & Reiman, 2019; Firth et al., 2020; Sheehan et al., 2021; Willits et al., 2022). The evidence on effects of RCL policies on other types of (e.g., property, violent) crimes or disorder outcomes is starkly mixed, where some population-level studies finding no effects or decreases while with others finding increases (Dragone et al., 2019; Lu et al., 2021; Wu et al., 2021). These study results pose challenges for direct comparisons, given their rather different methodologies and settings; in addition, the results may be heterogeneous because relevant legal or enforcement frameworks may differ but also since the possible pathways between cannabis use/availability and other crime outcomes concerned are complex and subject to many possibly confounding influencing factors. Notably, these studies also find different kinds of 'spillover' effects from RCL implementation on (e.g., drug-/trafficking-)related crimes in neighboring settings, indicating that related effects are not reliably restricted to local contexts (Gavrilova et al., 2019; Vicente, 2022). As one major gap, rather little data exists on possible changes in or outcomes for cannabis-related crimes or enforcement among under-age (e.g., youth) populations as a distinctly vulnerable group in RCL-settings for whom cannabis activities remain

illegal, yet use typically occurs and remains at high prevalence levels (Callaghan, Sanches, Hathaway, Asbridge, MacDonald, et al., 2023b; Fischer et al., 2020a, 2020b; O'Grady et al., 2022; Plunk et al., 2019). Selected available data show that cannabis-related enforcement focusing on adolescents has markedly decreased in some while remained high in other RCL settings; also on this basis, it remains an empirically and conceptually un-resolved policy challenge as to how to best deal with under-age youth from a cannabis control and enforcement perspective especially in RCL environments (Firth et al., 2020; Fischer et al., 2024; Plunk et al., 2019).

Driving under the influence of cannabis (DUIC) and related MVC injury/fatality involvement is a key crime-related outcome for RCL policies. Given that major possible adverse health (e.g., injuries, deaths) outcomes are involved, DUIC is typically prohibited by *per-se*/threshold laws in RCL settings and as such, involving different detection methods, relies on law enforcement as a main intervention element for control (Pearlson et al., 2021; Turnbull & Hodge, 2017; Watson & Mann, 2016). While there is no clear evidence for major increases and some indications of slightly declining trends of DUIC prevalence, these risk behaviors still remain relatively common among substantive minorities (e.g., 15–30%) of cannabis consumers in RCL settings. There, though, is evidence from several studies that the rates of MVC-related trauma injury patients and/or fatalities with cannabis involvement have increased in RCL environments; in addition, some spillover effects for related increases have also been observed for non-RCL settings (Athanassiou et al., 2023; Farrelly et al., 2023; Lane & Hall, 2019; Windle et al., 2022). It may be assumed that the observed increases in MVC-related injuries and fatalities with cannabis involvement in RCL settings arise from a mix of factors that may involve increases in cannabis availability and related use, but also commonly lowered risk perceptions and limits in DUIC enforcement and related deterrence effects (Carliner et al., 2017; Levy et al., 2021; Watson et al., 2019). Here, targeted research will be crucial to investigate what differentiates cannabis users who make the decision to drive under the influence of cannabis from those who do not, and how to effectively improve both prevention- and deterrence- oriented interventions. Since DUIC-related adverse (e.g., injury and/or death) outcomes are a known major contributor to cannabis-related burden of disease, this ought to be a priority area for improved policy and interventions development; here, lessons especially from the alcohol-impaired driving areas should be valuable for consideration (Babor et al., 2022; Fischer et al., 2016; Imtiaz et al., 2016).

Within the larger goal to reduce illicit cannabis markets in contexts of RCL policies, one main aim is to effectively transition cannabis consumers from illegal to legal sourcing routes and behaviors. For this, depending on setting, a variety of legal and regulated cannabis source types have been established. Data from North America have shown that this has been a gradual and steady, while partially substantively successful process where at initial stages of RCL maturity overall majorities (e.g., 50–70% or more) of cannabis consumers are at least mostly obtaining their cannabis from legal versus sources (Boury et al., 2022; Wadsworth et al., 2023). These rates, naturally, greatly depend on the state and extent of the availability of legal cannabis sourcing systems or ecologies (e.g., number of/access to legal retail stores/other legal sources)

which vary considerably across specific RCL settings (Dilley et al., 2023; Myran et al., 2023a, 2023b, 2023c). In addition, different studies have found cannabis-specific factors to influence choice-making concerning legal sourcing, including product type, price, and quality/availability; moreover, the intensity/frequency of cannabis use behavior appears to be an important factor influencing the proclivity for the choice of cannabis sourcing (Donnan et al., 2022a, 2022b; Goodman et al., 2022; Wadsworth et al., 2021). In contrast to the overall sourcing patterns observed in North America, Uruguay remains an RCL policy setting – despite relative policy maturity—where legal cannabis sourcing is still limited to a minority of users, whereas the majority continue to rely on 'grey' or illegal sources; some of this has been explained with comparably limited product availability, choice and access restrictions/requirements for legal cannabis source options (Decorte et al., 2020; Queirolo et al., 2023). While at least in North America, a majority of cannabis consumers have moved to legal cannabis sourcing, and so have eliminated a substantive extent of local cannabis acquisition crime and related retail markets, a considerable proportion – including high-intensity/-volume consumers (Callaghan et al., 2019; Caulkins et al., 2020; Wadsworth et al., 2022a, 2022b) – appear to still engage in illegal cannabis sourcing and markets. Better and more detailed data are needed to monitor these acquisition behaviors and related dynamics in RCL settings, but also to understand what policy and intervention measures might be effective to further reduce illegal cannabis sourcing by consumers and therefore further contain illegal cannabis retail markets.

The data and information available on the state and evolution of – specifically also illegal – cannabis markets (e.g., including production and/or distribution) in RCL settings is probably the most limited of the main indicator domains examined. For legal cannabis retail markets, data from mostly commercial RCL settings in North America suggest that these quite rapidly ramp up and expand, but then typically reach a sales volume plateau or saturation point after a few years where further expansions, also into continuously existent illegal market segments, appear limited (Dilley et al., 2023; Myran et al., 2023a, 2023b, 2023c). Of note, it is particularly unclear what happens with illegal cannabis production and supply markets under RCL conditions. While the volume and other key parameters of those criminal drug production and distribution ecologies have traditionally been uncertain because they present major challenges for direct/overt data assessments, there is some sporadic information that RCL implementation may have been associated with select reductions in illegal cannabis production activities (French et al., 2022; Hansen et al., 2021; Prestemon et al., 2019). At the same time, different data sources indicate that illegal cannabis market in RCL settings, for example through price and/or product flexibility and related advantages, remain active and competitive with legal products/sources (Hansen et al., 2021; Mahamad et al., 2020; Meadows, 2019; Meinhofer & Rubli, 2021; Deloitte, 2023). Furthermore, there appear to be notable lateral shifts or 'displacement' effects, where illegal cannabis market structures in RCL settings now mainly produce or supply their cannabis products for other markets (e.g. in non-RCL settings), with some data suggesting that they do so by utilizing or exploiting legal production provisions in RCL frameworks (Hansen et al., 2021; Meadows, 2019). At the same time, 'spillover' effects in the other direction have been observed, where RCL jurisdiction–based legal markets have been supplying cannabis consumption demands, for example, in non-RCL border settings (Hansen

et al., 2020b). Overall, there is only very limited evidence tangibly demonstrating clear and consistent reduction effects from RCL implementation on illegal cannabis production and supply activities, which need to be viewed separately from the more substantive shifts observed for consumer-end retail distribution/markets. Rather, related change dynamics may involve more lateral shifts, adaptation and/or displacement-type effects of illegal cannabis production and supply activities in other (e.g., towards specific products and/or for other destinations) directions. Such possible 'displacement' or 'diffusion' effects have been observed to be a common while important phenomenon for general crime control and intervention impacts, and may concretely be acute and relevant for RCL policy effects on illegal cannabis markets (Bowers, 2011; Johnson et al., 2014; Telep et al., 2014). Hence, these possible dynamics concerning illegal cannabis market structures and dynamics require systematic empirical assessment for better understanding these key aspects of crime-related outcomes of RCL policy implementation, also to guide related policy and intervention (e.g., enforcement) efforts.

Limitations

Our literature and data review features some elementary limitations for consideration. First, based on its comprehensive while basic and selective review scope and approach for and within the indicators of interest, and the rather heterogeneous nature of literature and data sources involved, it did not follow a formally 'systematic' (e.g., protocolized) review approach (Grant & Booth, 2009). Therefore, some relevant literature or data may have been missed or omitted, and the search approach and review results may not be categorically reproducible as presented. Given that the aim of this review was not to answer a specific or narrow research question, but rather to provide a general, comprehensively scoping and illustrative overview of available literature and data surrounding RCL and crime-related outcomes, the approach taken and results provided should serve mainly as an initial step identifying both research evidence on and gaps in the topic domains of interest for which future, more in-depth and focused research, for example, including systematic reviews and/or in-depth analyses, should be conducted (Fischer et al., 2021; French et al., 2022). Our review was also limited to English-language studies/data, whereas relevant sources may exist in other languages. Partly also owing to the restricted focus on English-language sources, the data included in the review is predominantly based on outcomes observed in North American settings, with a small share from other jurisdictions (e.g., Uruguay). Additionally, several of the studies identified utilized data from the same sources (e.g., CCS, ICPS, UCR), which may additionally limit their generalizability to other populations.

Conclusions

RCL policies are proliferating globally, with the currently most mature policy initiatives in existence in the Americas. The primary focus of RCL policy evaluation studies to date has been on health outcomes; however, most RCL policies also include

essential socio-legal, and specifically crime-related objectives that have received only comparably limited attention so far, in part also because related data involve illegal behaviors and/or structures, and are therefore commonly more hidden, limited or simply unavailable. We identified and examined available crime-related data for RCL outcomes in four selected, main indicator domains. It appears that RCL policies, to a substantive degree, are meeting some of their objectives in select related crime areas (e.g., reductions in cannabis-related crimes and cannabis sourcing/acquisitions among legal-age consumers), while demonstrable effects appear to be more equivocal, limited and/or absent in others (e.g., DUIC, illegal cannabis production/markets). For most of these areas, substantially more extensive empirical data and overall improved research are needed towards robust outcome assessment efforts, much of which will need to focus with appropriate methods on populations, environments or activities of illegality which present inherent challenges. Importantly, the systematic assessment of socio-legal, and specifically crime-related outcomes of RCL policies are in need of increased attention, also given that assessments of health-related outcomes have indicated rather mixed – including multiple adverse – results. Therefore, the assessment of socio-legal, and specifically including crime-related outcomes ought to be an essential domain for consideration and integration in efforts to evaluate the overall impacts of RCL policies (Auriol et al., 2023; Fischer et al., 2023; French et al., 2022).

Author contributions Professor Fischer developed the concept for, collected and interpreted related data, and conducted the lead writing and editing of the manuscript. Mrs. Robinson and Prof. Albrecht collected and interpretated related data, and contributed to writing and editing of the manuscript. All authors approved the final manuscript version submitted.

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Data availability All data reported in this manuscript are available in the public domain (e.g., in the form of published journal articles, reports, websites).

Declarations

Competing interests Prof. Fischer has held research grants and contracts in the areas of substance use, health and policy from public funding and government organizations (i.e., public-only sources). Prof. Fischer was temporarily employed (2021-2022) as a Research Scientist by Health Canada.

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