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CHANGES IN DRIVER CANNABINOID PREVALENCE ASSOCIATED WITH IMPLEMENTING MEDICAL MARIJUANA LAWS IN 14 U.S. STATES

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14. ABSTRACT

This study's objective was to investigate whether implementing medical marijuana laws was associated with changes in cannabinoid prevalence among drivers involved in fatal crashes in California and 13 other states with medical marijuana laws implemented before 2010. Time series ARIMA analyses were used to calculate state-by-state estimates of the percentage-point change in cannabinoid prevalence among fatal-crash-involved drivers associated with implementation or modification of medical marijuana laws. The implementation of medical marijuana laws was found to be reliably associated with increased cannabinoid prevalence in only three states: California, with a 2.1 percentage-point increase in the percentage of all fatal-crash-involved drivers who tested positive for cannabinoids (1.1% pre vs. 3.2% post, which represents a 196% increase in cannabinoid prevalence relative to the pre-law level) and a 5.7 percentage-point increase (1.8% vs. 7.5%, or a 315% increase) among fatally-injured drivers; Hawaii, with a 6.0 percentage-point increase (2.5 vs. 8.5, or a 235% increase) for all drivers and a 9.6 percentage-point increase (4.9% vs. 14.4%, or a 196% increase) among fatally-injured drivers; and Washington, with a 3.4 percentage-point increase (0.7% vs. 4.1%, or a 455% increase) for all drivers and a 4.6 percentage-point increase (1.1% vs. 5.7%, or a 432% increase) among fatally-injured drivers. The increases in all three states were stable step increases, meaning that the prevalence increased to a new level in these states and remained relatively flat subsequently. No relation between the post-law cannabinoid prevalence change estimates and the ease of marijuana access rankings was found.

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PREFACE

This report is the final product of a project comparing the prevalence of cannabis among fatal-crash-involved drivers before-and-after 14 states implemented medical marijuana laws. This project was funded by the National Highway Traffic Safety Administration through a grant administered by the California Office of Traffic Safety (Grant 20738). This report was prepared by the Research and Development Branch of the California Department of Motor Vehicles under the administrative direction of David J. DeYoung, Chief. The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the State of California or the National Highway Traffic Safety Administration.

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EXECUTIVE SUMMARY

Background

In 1996, Californians passed the first medicinal marijuana law in the U.S. (Proposition 215; the Compassionate Use Act of 1996), which allows patients with certain medical conditions or symptoms to get a recommendation from a medical doctor permitting them under state law to use and cultivate limited amounts of marijuana for symptom relief. The initial law was subsequently operationalized by a legislative bill implemented in 2004 (Senate Bill 420) that imposed statewide guidelines outlining how much marijuana could be grown and possessed by patients, and that granted state-level legal protections to physicians recommending marijuana and dispensaries selling marijuana. Eighteen other U.S. jurisdictions have subsequently passed some form of medicinal marijuana law.

Recent use of marijuana is associated with higher risk of crashing and there is mounting evidence that implementing medical marijuana laws is associated with increased marijuana use in general among some adults. Therefore, the objective of this study was to determine whether implementing medical marijuana laws was associated with changes in cannabinoid prevalence among drivers involved in fatal crashes in California and 13 other states with medical marijuana laws implemented before 2010. This was determined after adjusting for potential confounding associated with changes in drug testing frequency of crash-involved drivers and the national trend towards higher driver cannabinoid prevalence. A potential dose-response relationship between changes in cannabinoid prevalence in these states and the degree of regulation and/or ease of access to medical marijuana afforded by the laws was also explored.

Methods

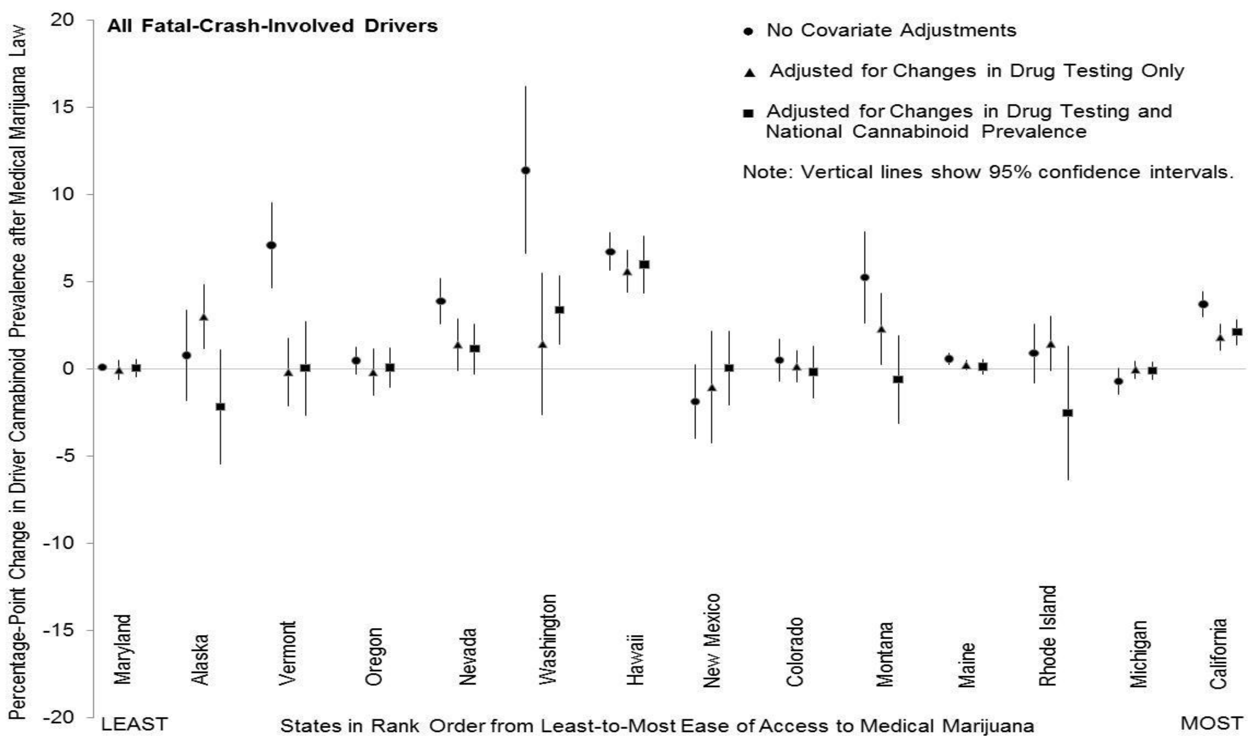
Of the 19 U.S. jurisdictions that enacted some form of medicinal marijuana law by December 31, 2012, 14 implemented the law before 2010 and were included in this study as medical marijuana states (i.e., AK, CA, CO, HI, MD, ME, MI, MT, NM, NV, OR, RI, VT, and WA). Time series analyses were used to calculate state-by-state estimates of the percentage-point change in cannabinoid prevalence among fatal-crash-involved drivers associated with implementation or modification of medical marijuana laws, after adjustments to remove trend towards increased U.S. marijuana use in general and variation in driver drug testing regularity. Separate models for all drivers and only fatally-injured drivers were calculated for each state. The models were run with and without the adjustments for potential sources of confounding. The resulting percentage-point changes in driver cannabinoid prevalence resulting from the time series models were plotted as a function of ranks representing ease of patient access to medical marijuana afforded by the laws.

Results

After adjustments were made for both driver drug testing frequency in each state and national trend in driver cannabinoid prevalence among states without medical marijuana laws (Figure 1), the implementation of medical marijuana laws was found to be reliably associated with increased cannabinoid prevalence in only three states: California, with a 2.1 percentage-point increase in the percentage of all fatal-crash-involved drivers who tested positive for cannabinoids (1.1% pre vs. 3.2% post, which represents a 196% increase in cannabinoid prevalence relative to the pre-law level) and a 5.7 percentage-point increase (1.8% vs. 7.5%, or a 315% increase) among fatally-injured drivers; Hawaii, with a 6.0 percentage-point increase (2.5 vs. 8.5, or a 235% increase) for all drivers and a 9.6 percentage-point increase (4.9% vs. 14.4%, or a 196% increase) among fatally-injured drivers; and Washington, with a 3.4 percentage-point increase (0.7% vs. 4.1%, or a 455% increase) for all drivers and a 4.6 percentage-point increase (1.1% vs. 5.7%, or a 432% increase) among fatally-injured drivers. The increases in all three states were stable step increases, meaning that the prevalence increased to a new level in these states and remained relatively flat subsequent. No relation between the post-law cannabinoid prevalence change estimates and the ease of marijuana access rankings was found.

Discussion

The implementation of medical marijuana laws was associated with increased prevalence of cannabinoids among drivers involved in fatal crashes in only a minority of the states that implemented these laws. The observed increases were one-time changes in the prevalence levels, rather than upward trends, suggesting that these laws result in stable increases in driver marijuana prevalence. The reasons that some states experienced changes in prevalence while others did not are unknown, but one factor appears to be differences between states in drug testing practices and regularity. Ease of patient access to marijuana was not found to be related to changes in post-law cannabinoid prevalence.



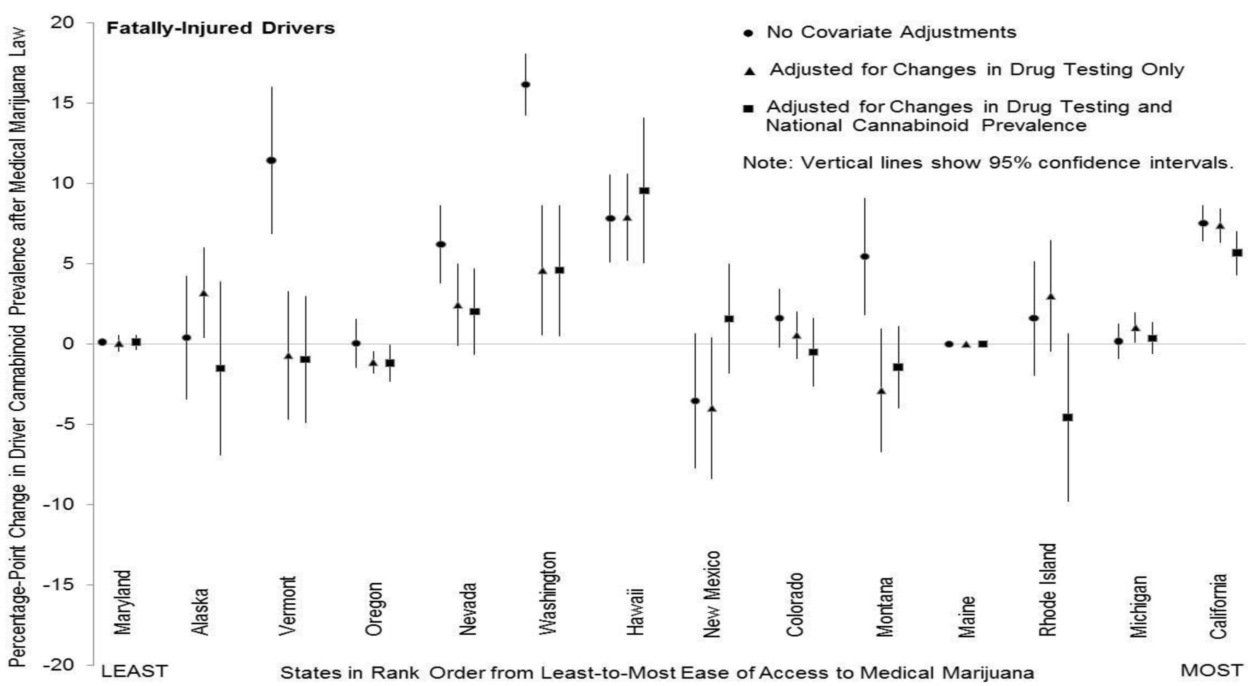


Figure 1. Percent-point change in cannabinoid prevalence among all fatal-crash-involved drivers (upper) and fatally-injured drivers (lower) after medical marijuana law implementation by state rank order of least-to-most access to medical marijuana provided by the law, 1992-2009.

These results support the effort by the California Department of Motor Vehicles to begin receiving information on drug influence or the combined influence of drugs and alcohol among drivers involved in crashes from the California Highway Patrol's Statewide Integrated Traffic Records System (SWITRS). Further, given the increased prevalence of cannabinoids among fatal crashes in California, these results support the recent law change (Assembly Bill 2552, Chapter 753, Statutes of 2012) that will create separate *California Vehicle Code* subsections to distinguish convictions for driving under the influence of alcohol alone, drugs alone, or a combination of alcohol and drugs. This law change will become operative January 1, 2014.

Recommendations

1. It is recommended that nationwide standardization of drug testing procedures and criteria be considered to improve the consistency of testing both between and within jurisdictions, which concurs with a prior recommendation by the National Transportation Safety Board.

2. A survey could be conducted of the various county and private laboratories that perform drug tests of crash-involved drivers in California to characterize the variations in drug testing practices and procedures within the state and assist in developing standardized statewide drug testing practices and procedures.

3. Additional research is needed to determine whether the increases in cannabinoid prevalence found in California, Hawaii, and Washington resulted in marijuana use among drivers being a more prevalent factor in causing crashes in those states.

4. The California medical marijuana law has been implemented for over a decade, yet little is actually known about the crash risk of drivers with medical marijuana recommendations. Comparisons of the traffic safety records of a cohort of drivers with medical marijuana recommendations to a matched cohort of drivers in general could help establish whether those with recommendations are at increased actuarial risk for crashing.

5. Finally, given the increased cannabinoid prevalence among drivers in some states after medical marijuana laws are implemented, along with the recent legalization of marijuana for recreational purposes in Colorado and Washington, a comprehensive research effort is needed to empirically determine the concentrations of cannabinoids that impair driving

ability, alone or in combination with alcohol, to aid in crafting laws that establish per se limits for driving under the influence of cannabinoids.

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INTRODUCTION

Marijuana Use, Effects on Driving Ability, and Crash Risk

Marijuana is a plant that is rich in cannabinoids, which are chemicals that have effects on perception, concentration, decision making, attention, reaction time, and coordination; all of which are involved in driving motor vehicles (Ashton, 2001; Bramness, Khiabani, & Mørland, 2010; Crean, Crane, & Mason, 2011; Mann, Brands, MacDonald, & Stoduto, 2003). Hence, there has been a longstanding concern that marijuana use by drivers may be associated with increased risk of crashing (Lenné, Triggs, & Regan, 2004; Sewell, Poling, & Sofuoglu, 2009). This concern is supported by epidemiological studies, which suggest the recent use of marijuana is associated with 2 to 6 times higher risk of crashing (dependent on the dose) compared to driving unimpaired (Asbridge, Hayden, & Cartwright, 2012; Baldock, 2008; Bates & Blakely, 1999; Beirness, Simpson, & Williams, 2006; Li, Brady, DiMaggio, Lusardi, Tzong, & Li, 2012; Ramaekers, Berghaus, van Laar, & Drummer, 2004).

The Advent of Medicinal Marijuana Laws

In 1996, Californians passed the first medicinal marijuana law in the U.S. (Proposition 215; the Compassionate Use Act of 1996), which allows patients with certain medical conditions or symptoms to get a recommendation from a medical doctor permitting them under state law to use and cultivate limited amounts of marijuana for symptom relief. The initial law was subsequently operationalized by a legislative bill implemented in 2004 (Senate Bill 420) that imposed statewide guidelines outlining how much marijuana could be grown and possessed by patients, and that granted state-level legal protections to physicians recommending marijuana and dispensaries selling marijuana. Persons who obtain medical marijuana recommendations in California do so most often for pain, insomnia, or anxiety, and typical patients are age 35 or older, male, White, college educated, and employed (Reinarman, Nunberg, Lanthier, & Huddleston, 2011). Eighteen other U.S. jurisdictions have subsequently passed some form of medicinal marijuana law (Table 1), many of which have been later amended or had other supplementary laws or regulations enacted to operationalize or modify the medical marijuana programs.

Table 1

19 U.S. Jurisdictions with Medical Marijuana Laws as of December 2012, Dates of Initial Enactment or Significant Modification, and Effective Dates

Jurisdiction	Initial enactment and significant modifications	Effective date
1. Alaska	Ballot Measure 8 (Nov 3, 1998)	Mar 4, 1999
	Senate Bill 94 (Jun 1, 1999)	Jun 2, 1999
2. Arizona	Ballot Proposition 203 (Nov 2, 2010)	Apr 14, 2011
3. California	Proposition 215 (Nov 5, 1996)	Nov 6, 1996
	Senate Bill 420 (Oct 12 ,2003)	Jan 1, 2004
4. Colorado	Ballot Amendment 20 (Nov 7, 2000)	Jun 1, 2001
	House Bill 1284 & Senate Bill 109 (Jun 7, 2010)	Jul 1, 2010
5. Connecticut	House Bill 5389 (May 31, 2012)	Oct 1, 2012
6. Delaware	Senate Bill 17 (May 13, 2011)	Jul 1, 2011
7. District of Columbia	Amendment Act B18-622 (May 21, 2010)	Jul 27, 2010
	Emergency Amendment to Title 22 (Apr 14, 2011)	Apr 14, 2011
8. Hawaii	Senate Bill 862 (Jun 14, 2000)	Dec 28, 2000
9. Maine	Ballot Question 2 (Nov 2, 1999)	Dec 22, 1999
	Senate Bill 611 (Apr 2, 2002)	Jul 25, 2002
	Question 5/Legislative Document 1811 (Nov 3, 2009/Apr 9, 2010)	Dec 23, 2009
	Legislative Document 1296 (Jun 24, 2011)	Sep 22, 2011
10. Maryland	Senate Bill 502 (May 22, 2003)	Oct 1, 2003
	Senate Bill 308 (May 10, 2011)	Jun 1, 2011
11. Michigan	Proposal 1 (Nov 4, 2008)	Dec 4, 2008
	Administrative Regulations (Apr 4, 2009)	Apr 6, 2009
12. Montana	Initiative 148 (Nov 2, 2004)	Nov 2, 2004
	Senate Bill 423 (May 14, 2011)	Jul 1, 2011
13. Nevada	Ballot Question 9 (Nov 7, 2000)	Oct 1, 2001
	Assembly Bill 453/Assembly Bill 519 (Jun 15, 2001)	Oct 1, 2001
14. New Jersey	Senate Bill 119 (Jan 18, 2010)	Oct 1, 2010
	Administrative Regulations (Nov 23, 2011)	Dec 19, 2011
15. New Mexico	Senate Bill 523 (Apr 2, 2007)	Jul 1, 2007
	Administrative Regulations (Dec 1, 2008)	Dec 15, 2008
	Revised Administrative Regulations (Dec 15, 2010)	Dec 30, 2010
	Senate Bill 240 (Mar 5, 2012)	Jul 1, 2012
16. Oregon	Ballot Measure 67 (Nov 3, 1998)	Dec 3, 1998
	House Bill 3052 (Jul 21, 1999)	Jul 21, 1999
	Senate Bill 1085 (Sep 8, 2005)	Jan 1, 2006
17. Rhode Island	Senate Bill 0710 (Jan 3, 2006)	Jan 3, 2006
	Senate Bill 0791 (Jun 21, 2007)	Jun 21, 2007
	House Bill 5359 (Jun 16, 2009)	Jun 16, 2009
	House Bill 8172 (Jun 22, 2010)	Jun 22, 2010
	Senate Bill 2555/House Bill 7888 (May 22, 2012)	May 22, 2012
18. Vermont	Senate Bill 76/House Bill 645 (May 26, 2004)	Jul 1, 2004
	Senate Bill 00007 (May 30, 2007)	Jul 1, 2007
	Senate Bill 17 (Jun 2, 2011)	Jun 2, 2011
19. Washington	Initiative 692 (Nov 3, 1998)	Nov 3, 1998
	Senate Bill 6032/Administrative Regulations (May 8, 2007)	Jul 22, 2007/Nov 2, 2008
	Senate Bill 5798 (Apr 1, 2010)	Jun 10, 2010

Note. This information was compiled from ProCon.org (2012), NORML (2012), state legislative web sites, and correspondence with state personnel.

The medical marijuana laws vary greatly across the 19 jurisdictions in terms of the access to medicinal marijuana they provide to patients. Specifically, the laws differ with regard to recommendation-qualifying conditions or symptoms, legal protections, possession limits, dispensary availability, allowance for and protection of caregivers, sanctioning of home marijuana cultivation, registration requirements, and recognition of out-of-state patients (Marijuana Policy Project, 2011). Most laws, including California's, provide both legal protections and means to legally access marijuana, whereas others, like Maryland's, provide some protection from criminal prosecution, but no routes to legally access marijuana.

Medicinal Marijuana Laws and Cannabinoid Prevalence in General

It may seem intuitive that the implementation of medicinal marijuana laws would increase marijuana availability, resulting in increased prevalence of cannabinoid use in general. While marijuana use does tend to be higher in states with medical marijuana laws, there is controversy regarding whether the laws actually lead to more marijuana use or whether the higher prevalence and passage of medical marijuana laws are both a reflection of more accepting norms regarding marijuana use in those jurisdictions (Anderson, Hansen, & Rees, 2012; Cerdá, Wall, Keyes, Galea, & Hasin, 2012; Gorman & Huber, 2007; Harper, Strumpf, & Kaufman, 2012; Wall, Poh, Cerdá, Keyes, Galea, Hasin, 2011). Another possibility is that users are more likely to divulge their practices after medical marijuana laws are passed, assuming that they may be less fearful of prosecution or penalty for these admissions. However, there is evidence that marijuana use in general increased among California adults after the operational guidelines for the medical marijuana law were implemented in 2004. Specifically, about 32% of adults ages 18–25 and 9% of adults ages 26 or older reported having used marijuana during the past year in 2008-2009, compared to 28% and 8%, respectively, during 2002-2003 (U.S. Department of Health and Human Services [DHHS], 2010). The 4 percentage-point increase in marijuana prevalence found among California 18-25 year olds is comparable to 3 percentage-point increases found for recent marijuana use after medical marijuana laws were implemented in Montana and Rhode Island, though no change in prevalence was found following the Vermont law (Anderson & Rees, 2011).

Medicinal Marijuana Laws and Cannabinoid Prevalence among California Drivers

Whether the apparent increase in adult marijuana use in general among California adults after implementation of the medical marijuana law translated into increased prevalence among drivers—and hence is a potential concern for traffic safety—is less clear. Evidence from oral fluid samples taken from a random sample of weekend nighttime drivers in four California jurisdictions in 2010 suggest that the prevalence of cannabinoids among these drivers was higher (8%) than was the case in these same jurisdictions in 2007 (5%) (Johnson, Kelley-Baker, Voas, & Lacey, 2012). A similar roadside sample of California drivers in 2012 found the prevalence of cannabinoids to be about 7% (Lacey, Kelley-Baker, Romano, Brainard, & Ramirez, 2012). However, these estimates reflect changes in prevalence between samples that were all taken several years after California's medical marijuana law was operationalized in 2004, so it is questionable whether this increase is an effect of the medical marijuana law. Also noteworthy is that the 2007 cannabinoid prevalence estimate for California—though it was taken 3-years after the medical marijuana law was operationalized—was lower than the national average of 8%, and that the higher 2010 and 2012 estimates—taken 6 and 8 years after the medical marijuana law was operationalized—were merely consistent with the national prevalence estimate.

Nonetheless, the crude evidence based on California fatal crashes suggests that cannabinoid prevalence among fatal-crash-involved drivers may have increased following the medical marijuana law. In 2009, about 5% of all California drivers involved in fatal crashes were known to have had cannabinoids in their system; in 1995, the year before Proposition 215 was enacted, that percentage was only about 1% (National Highway Traffic Safety Administration [NHTSA], 2012). Among drivers who were killed in fatal crashes in California—who tend to be tested for drugs more frequently and consistently—the percentage-point change is even greater: cannabinoids were detected for about 2% in 1995 compared to 9% in 2009.

Confounding of Cannabinoid Prevalence Estimates based on Crash-Involved-Drivers

Attributing crude increases in cannabinoid prevalence among California fatal-crash-involved drivers solely to the medical marijuana law is naïve. The nationwide prevalence of cannabinoids among drivers involved in fatal crashes has increased slowly over the past 2 decades, and even in states without medicinal marijuana laws. Across all states, the percentage of drivers involved in fatal crashes and for whom cannabinoids were detected increased from about 1% in 1992 to 4% in 2009; among states that did not enact medicinal marijuana laws, these values were similarly about 1% and 4% (NHTSA, 2012). Hence, some of the crude increase in cannabinoid prevalence among fatal-crash-involved drivers in California could simply be a reflection of slowly upward trending marijuana use among U.S. adults in general (DHHS, 2010).

Furthermore, estimates of changes in driver cannabinoid prevalence based on crash-involved drivers are likely confounded by variations in the frequency of drug testing of drivers.

Cannabinoid detection and drug testing prevalence among drivers are strongly positively correlated; if more drivers are tested, then the numbers of drivers for whom cannabinoids are detected would also be expected to be higher. Across all states, about 18% of fatal-crash-involved drivers were tested for drugs in 1992 compared to 35% in 2009 (NHTSA, 2012). Drug testing of fatal-crash-involved drivers was more consistent across time in California; an average of about 36% of drivers were tested for drugs during the years prior to enactment of the initial medical marijuana law and an average of about 38% were tested subsequently. Among drivers killed in fatal crashes in California, the testing is much more frequent and was also fairly consistent before and after the medical marijuana law was enacted (on average, 80% beforehand and 81% subsequent). Nonetheless, changes from year-to-year in the frequency of drug testing of drivers—if these variations are systematically associated with the implementation of medical marijuana laws—remain a potential explanation for differences in cannabinoid prevalence among fatal-crash-involved drivers before and after medical marijuana laws are implemented, and may explain some of the apparent increase in cannabinoid prevalence among these drivers after California's medical marijuana law was implemented. It is also possible that there were changes in the testing practices and standards among California toxicology laboratories coinciding with the implementation of the medical marijuana law that might account for the higher post-law prevalence. For example, laboratories that had not routinely tested for cannabinoids may have begun to do so after the passage of the medical marijuana law perhaps because marijuana use became a more salient political issue.

Studies of Medicinal Marijuana Laws on Driver Cannabinoid Prevalence

The effect of medicinal marijuana laws on cannabinoid prevalence among drivers has only been formally studied in one U.S. state (California). Operationalizing California's medical marijuana law in 2004 was found to be associated with a 2 percentage-point increase in cannabinoid prevalence among all drivers involved in fatal crashes, and about a 3 percentage-point increase among those killed in single-vehicle crashes (Crancer & Crancer, 2010). However, these estimates may be biased upward due to more vigilant drug testing of drivers after the law was implemented and the general upward trend in marijuana use among U.S. adults discussed earlier, which were not accounted for in the study.

Study Objectives

Recent use of marijuana is associated with higher risk of crashing and there is mounting evidence that implementing medical marijuana laws is associated with increased marijuana use in general among some adults. Therefore, the objective of this study was to determine whether implementing medical marijuana laws was associated with changes in cannabinoid prevalence among drivers involved in fatal crashes in California and 13 other states with medical marijuana laws implemented before 2010. This was determined after adjusting for potential confounding associated with changes in drug testing frequency of crash-involved drivers and the national trend towards higher driver cannabinoid prevalence. A potential dose-response relationship between changes in cannabinoid prevalence in these states and the degree of regulation and/or ease of access to medical marijuana afforded by the laws was also explored.

METHODS

Data Sources and Coding Procedures

Counts of all drivers involved in fatal crashes in the U.S. for the period 1992 to 2009 were extracted from the Fatality Analysis Reporting System (FARS; NHTSA, 2012). FARS contains information on drivers, vehicles, and crash circumstances for all motor vehicle crashes in the U.S. that involve a death of either an occupant of a vehicle or a non-motorist within 30 days of the crash. FARS was used because it is the only nationwide database that contains detailed drug test results for drivers, including whether specific drug classes were detected. The driver crash involvements were aggregated by state and calendar year.

Drivers were classified as having been tested for drugs if one or more of the available drug result fields on their FARS record indicated that they had tested either positive or negative for any drug besides alcohol (codes 1–10 and 98 for 1992; codes 100–996, 998 for 1993–2009); otherwise they were coded as not having been tested for drugs. The drivers were classified as having tested positive for cannabinoids if at least one of the available drug result fields indicated that a cannabinoid or related metabolite was detected in their urine or blood (code 6 for 1992; codes 600–695 for 1993–2009); otherwise they were coded as not having tested positive for cannabinoids. Given that it is likely that there are variations both across and within jurisdictions in drug testing standards and procedures, along with the potential for cannabinoid metabolites to be detected in body fluids for days or even weeks after use (Huestis, 2002; Huestis & Smith, 2006; National Highway Traffic Safety Administration [NHTSA], 2010), being coded as positive for cannabinoids does not necessarily imply that the drivers were impaired or that cannabinoid use was a causal factor in the crashes. Being cannabinoid positive in this study is only suggestive of relatively recent (within a few weeks) cannabinoid use. Hence, the annual percentages of fatal-crash-involved drivers in each state who were positive for cannabinoids, adjusted for changes in drug testing regularity, are only a proxy for cannabinoid prevalence among drivers. The drivers were also classified as to whether or not they were fatally-injured in the crashes.

Description of the Time Series Analyses

Of the 19 U.S. jurisdictions that enacted some form of medicinal marijuana law by December 31, 2012, 14 implemented the law before 2010 and were included in this study as medical marijuana states (i.e., AK, CA, CO, HI, MD, ME, MI, MT, NM, NV, OR, RI, VT, and WA). The 37 jurisdictions without medical marijuana laws implemented before 2010 were aggregated for use as a control series. Because almost all the medical marijuana states require proof of residency in order to qualify for their medical marijuana programs (e.g., state-issued driver licenses or identification cards), the fact that some of the control states border medical marijuana states would not be expected to result in a significant increase in driver cannabinoid prevalence in those control states resulting from patients who cross state borders to obtain marijuana. Additionally, the large number of states included in the control series, most of which do not border medical marijuana states, would minimize any treatment contamination that did occur.

The method used for determining whether there was a reliable change in driver cannabinoid prevalence after the enactment of medical marijuana laws in each state was Auto-Regressive Integrated Moving Average (ARIMA) interrupted time series analysis (Box & Jenkins, 1970; Box & Tiao, 1975). Using this analytic method, the annual percentages of fatal-crash-involved drivers who tested positive for cannabinoids in each state were first statistically adjusted for any preexisting secular trends, autocorrelation, variations in the frequency of drug testing of drivers, and slowly upward trending marijuana use among U.S. adults in general, prior to estimating any changes in prevalence associated with implementing medical marijuana laws or modifications to the laws. The annual percentages of fatal-crash-involved drivers in each state who were tested for drugs were used in the ARIMA analyses to adjust for variations in drug testing frequency over time, which may vary as a function of available funding and other factors (Liu, 2006). The annual driver marijuana prevalence among the 37 jurisdictions that did not implement medical marijuana laws prior to 2010 was used in the ARIMA analyses to model and remove the national upward trend in marijuana use, which could otherwise be mistaken for an intervention effect. Individual ARIMA models were run for each of the 14 states that implemented medical marijuana laws, and the models were conducted with and without the adjustments for changes in drug testing frequency and national driver cannabinoid prevalence. Because drivers who are killed in crashes tend to be drug tested more frequently and consistently than non-fatally-injured drivers, ARIMA analyses were conducted for all fatal-crash-involved drivers and then separately for only fatally-injured drivers.

Although it might be expected that any changes in driver cannabinoid prevalence would occur in a gradual-permanent manner following medical marijuana law implementation, because of the short series lengths and annual aggregation of the data, sudden-permanent interventions were modeled due to the fact that they only require one parameter (ω) to be estimated for each intervention effect (Yaffee, 2000). Up to three different intervention points were allowed for each state, each being modeled as a sudden-permanent impact. The first intervention point was always the date of initial medical marijuana law implementation, followed by up to two more intervention points reflecting significant modifications to the law or the implementation or modification of program regulations (see Table 1). No state implemented more than two potentially meaningful modifications to their medical marijuana law during the study time period that could not be modeled using the allowed number of intervention points. Because annual data were analyzed, the interventions were deemed to have begun during the first year that they were in effect for at least 5 months. For example, because the California medical marijuana law was enacted and implemented in November 1996, the first calendar year during which the law was in effect for at least 5 months was 1997. Therefore, the 1997 calendar year was used to represent the beginning of the California medical marijuana law. The bill operationalizing the California law was enacted in October 2003 with an effective date of January 2004. Because this modification of the California law was in effect for at least 5 months in calendar year 2004, this year was used as the intervention date for this modification. Any second and third intervention points were removed from the final ARIMA models if they were not found to be statistically reliable using a .05 alpha level. Twelve of the final models for fatal-crash-involved drivers and twelve for fatally-injured drivers included only a single intervention point. For two of the final fatal-crash-involved driver models (CA and RI) and two of the final fatally-injured driver models (CA and ME) two intervention points were retained. For 13 of the states, the 18-year study period provided from 5 to 15 years of pre-medical marijuana law data (M = 9.8 years), and 3 to 13 years of post-law data (M = 8.2 years). For one state (MI) only, 1 year of post-law data was available. Therefore, the results for this state should be considered as tentative.

For sake of brevity, the ARIMA model parameters (e.g., moving average terms) are not presented. All the final models had fairly simple non-seasonal ARIMA structures involving at most only a single first-order moving average or auto-regressive term. All auto-regressive and moving average terms in the final models were within the bounds of stationarity and invertibility, meaning that they had absolute values less than 1.0 and were mathematically stable (Yaffee, 2000). Joint estimation of model parameters and outlier effects was used during the analyses to reduce the impact of outliers (Chen & Liu, 1993). The final models were those that best represented the underlying prevalence of cannabinoids among the drivers in each state as determined by the best-fitting auto-correlation and partial-auto-correlation functions of the series residuals (Liu, 2006). The results of the ARIMA analyses provided state-by-state estimates of the percentage-point change in driver cannabinoid prevalence associated with implementation or modification of the medical marijuana laws, after adjustments to remove trend towards increased marijuana use in general and variation in driver drug testing regularity. Percentage change estimates relative to the pre-intervention series were also calculated for descriptive purposes.

Ease of Medical Marijuana Access/Degree of Regulation Rankings

To explore whether the changes in driver cannabinoid prevalence in the 14 medical marijuana states were associated in a dose-response manner with the ease of patient access to medical marijuana afforded by the laws, each state's medical marijuana law was scored for eight access/regulation dimensions: (a) protection from criminal charges/civil penalties, (b) qualifying conditions, (c) possession limits, (d) dispensary availability, (e) caregiver availability and protection, (f) home cultivation, (g) identification card requirements, and (h) out-of-state portability (Marijuana Policy Project, 2011). Each law was given one score for each of the eight dimensions, which were weighted to reflect the relative importance given to each dimension by a small sample of California medical marijuana users. The protection from criminal charges/civil penalties dimension was given the most weight, followed by the qualifying conditions and dispensary availability dimensions, then the possession limits and home cultivation dimensions, and finally the identification card requirement, caregiver availability/protection, and out-of-state portability dimensions. Composite scores were created by summing the scores across the eight dimensions and could range from 17 to 80 with higher values indicating weaker regulation by the state, more protections for patients, and overall easier patient access to marijuana. The states were ranked based on the composite scores as providing 1 (least) to 14 (most) patient access to marijuana. The percentage-point changes in driver cannabinoid prevalence resulting from the ARIMA models were plotted as a function of these ranks. The dimension coding criteria and point scores, total composite scores, and state rankings are shown in Appendix A.

RESULTS

Coding Outcomes and Description of Nationwide Drug Testing and Marijuana Prevalence

A total of 1,000,864 fatal-crash-involved drivers, of whom 452,144 were fatally-injured, were identified nationwide from the 18 years of FARS data (1992–2009). Of these, 24.5% (*n* = 245,495) were tested for drugs. Drivers were more frequently tested for drugs in medical marijuana states (30.3%) than in other jurisdictions (22.9%). About 2.0% (*n* = 19,977) of drivers were found to be positive for cannabinoids, with higher overall prevalence in medical marijuana states (2.7%) than the other jurisdictions (1.8%). Of only drivers tested, 8.1% (*n* = 19,977) nationwide were found to be positive for cannabinoids, again with higher prevalence among those tested in medical marijuana states (8.9%) than in other jurisdictions (7.9%). Among those fatally injured, 42.4% (*n* = 191,787) were tested for drugs; again testing was more frequent in the medical marijuana states (59.1%) than in other jurisdictions (38.1%). About 3.2% (*n* = 14,297) of the fatally-injured drivers were found to be positive for cannabinoids, with higher overall prevalence in the medical marijuana states (4.6%) than states without medical marijuana laws (2.8%). Of only tested fatally-injured drivers, 7.5% (*n* = 14,297) nationwide were found to be positive for cannabinoids, with similar prevalence among those tested in medical marijuana states (7.7%) and other jurisdictions (7.4%).

Substantiation of Confounders for Inclusion in the Time Series Analyses

Two potential confounders were considered for inclusion in the time series models: (a) variations across time in the percentages of fatal-crash-involved drivers who were tested for drugs in each medical marijuana state; and (b) trend in marijuana use among U.S. drivers in general, as represented by the percentages of fatal-crash-involved drivers who tested positive for cannabinoids in the aggregated non-medical marijuana states during the study time period. There was wide variation across states in the percentages of drivers tested for drugs both before and after the laws were implemented. In all but five medical marijuana states (AK, CO, ME, OR and RI), the percentages of fatal-crash-involved drivers tested for drugs were higher after the laws were implemented (Table 2), with increases ranging from 3.1 to 41.7 percentage-points. The percentages of fatally-injured drivers tested for drugs were only higher following the laws in six of the medical marijuana states (MD, MT, NV, NM, VT, and WA), with increases ranging from 17.1 to 73.1 percentage-points. Higher post-law percentages of drivers tested would be expected to bias the crude cannabinoid prevalence estimates towards higher values in the states that increased drug testing. The percentages of drivers tested before and after the laws were implemented were particularly low for Oregon and Maine, making any crash-based cannabinoid prevalence estimates in these states to be of questionable validity. Drug testing also increased 7.6 percentage-points for all fatal-crash-involved drivers and 9.6 percentage-points among fatally-injured drivers in the aggregated non-medical marijuana states.

Table 2

Average Percentages of Fatal-Crash-Involved Drivers and Fatally-Injured Drivers Tested for Drugs in 14 U.S. States Enacting Medical Marijuana Laws before 2010 and 37 Aggregated Comparison Jurisdictions that did not Enact Medical Marijuana Laws before 2010, 1992-2009

State	Intervention year(s)	All fatal-crash-involved drivers				Fatally-injured drivers			
		$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$	$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$
Alaska	1999	39.5	26.7	-12.7	-32.2	46.4	29.0	-17.4	-37.6
California	1997, 2004	35.2	38.3	3.1*	8.8	79.1	81.8	2.8	3.5
Colorado	2001	31.3	33.8	2.5	8.0	57.7	67.1	9.4	16.3
Hawaii	2001	41.8	59.8	18.0*	43.1	91.9	90.7	-1.2	-1.3
Maine	2000, 2002	0.8	1.7	0.8	100.5	0.3	0.7	0.4	131.2
Maryland	2004	2.1	35.6	33.5*	1566.2	5.2	78.4	73.1*	1393.1
Michigan	2009	13.2	29.3	16.1*	121.2	27.2	47.4	20.3	74.7
Montana	2005	44.8	70.0	25.2*	56.2	54.8	78.9	24.1*	44.0
Nevada	2002	16.1	41.2	25.0*	155.1	28.1	65.6	37.4*	133.0
New Mexico	2007, 2009	39.8	80.1	40.3*	101.4	78.5	95.5	17.1*	21.7
Oregon	1999, 2006	14.0	20.9	6.9	49.0	9.5	14.5	5.0	52.1
Rhode Island	2006, 2007, 2009	44.3	33.4	-10.9	-24.6	93.4	65.3	-28.1	-30.1
Vermont	2004, 2007	11.2	52.9	41.7*	370.7	22.1	92.0	69.9*	315.6
Washington	1999, 2007, 2009	24.4	43.8	19.4*	79.4	52.5	82.7	30.2*	57.5
Jurisdictions without medical marijuana laws	None[a]	17.5	25.1	7.6*	43.6	31.0	40.6	9.6*	30.9

Note. $\%_{Pre}$ = average annual percentage of drivers tested for drugs prior to initial medical marijuana law. $\%_{Post}$ = average annual percentage of drivers tested for drugs after initial medical marijuana law. Δ_{PP} = percentage-point difference in drug testing. $\Delta_{\%}$ = percentage change in drug testing relative to the pre-law time period. The percentage-point difference and percentage change estimates are not exact in some cases due to rounding.

[a]Because there is no 'intervention' date from which to compute pre-post values for the control states, for descriptive purposes these figures represent a comparison before and after the first medical marijuana law was implemented in California.

*$p < .05$. two-tailed *t* test.

Note that the table presents differences between the pre-law and post-law testing percentages (i.e., percentage-point differences defined as $\%_{Post} - \%_{Pre}$ and labeled as Δ_{PP} in the table) and also the percentages that those differences represent compared to the pre-law testing levels (i.e., percentage change defined as $[(\%_{Post} - \%_{Pre}) / \%_{Pre}] \times 100$ and labeled as $\Delta_{\%}$ in the table). These estimates sometimes appear to be widely different, particularly in cases where the pre-law percentages were low and the post-law percentages were much higher. For example, in

Maryland only 2.1% of fatal-crash-involved drivers were tested for drugs before the medical marijuana law was implemented, but 35.6% were tested subsequently. The percentage-point difference in testing was 33.5 (35.6 – 2.1 = 33.5). Because this was a large percentage-point increase in testing and the pre-law percentage was very low, this represents about a 1,566% increase ([(35.6 – 2.1) / 2.1] × 100)) in driver drug testing compared to the pre-law level.

To formally establish that drug testing regularity and national marijuana prevalence were associated with both the cannabinoid prevalence in the medical marijuana states (i.e., the percentage of drivers in those states who tested positive for cannabinoids) and the implementation of medical marijuana laws—and therefore were potential confounders— Pearson correlations were examined (Table 3). The correlations were calculated individually for each medical marijuana state and also combined across all 14 medical marijuana states. Separate estimates were calculated for all fatal-crash-involved drivers and for fatally-injured drivers only.

Table 3

Correlations of Potential Covariates with the Implementation of Medical Marijuana Laws and Driver Marijuana Prevalence in Medical Marijuana States, 1992-2009

Covariate	Implementation of MM laws[c]			MM state marijuana prevalence[d]		
	All MM states combined	Individual MM state estimates: Minimum	Individual MM state estimates: Maximum	All MM states combined	Individual MM state estimates: Minimum	Individual MM state estimates: Maximum
All fatal-crash-involved drivers						
Drug testing regularity[a]	.29*	.21	.97*	.61*	.06	.98*
National marijuana prevalence[b]	.72*	.53*	.84*	.44*	.27	.96*
Fatally-injured drivers						
Drug testing regularity[a]	.19*	-.09	.96*	.55*	.04	.96*
National marijuana prevalence[b]	.71*	.55*	.85*	.38*	.04	.95*

Note. MM = Medical marijuana.

[a]Annual percentages of drivers tested for drugs in each MM state. [b]Annual percentages of drivers found to be positive for cannabinoids in the 37 U.S. jurisdictions that did not pass medical marijuana laws before 2010. [c]Coded as 1 if the medical marijuana law had been implemented in the state during a given year and 0 otherwise. [d]Annual percentages of drivers found to be positive for cannabinoids in the medical marijuana states.

*$p < .05$, two-tailed Pearson correlation.

Drivers tended to be drug tested more often in medical marijuana states after the medical marijuana laws were implemented ($r = .29$) and higher testing in medical marijuana states tended to be associated with higher cannabinoid prevalence in these states ($r = .61$). Driver cannabinoid prevalence in non-medical marijuana states tended to be higher after medical marijuana laws were passed in the other 14 states (r = .72) and higher cannabinoid prevalence in non-medical marijuana states was also associated with higher prevalence in medical marijuana states (r = .44). These results were similar when only fatally-injured drivers were considered. There was variation among the medical marijuana states in terms of the strength of these relationships; in some cases the relations were negligible, whereas in others the correlations were extremely high. Overall these results suggest that both variation in drug testing and national trend in driver marijuana use are potential confounders for many states, which substantiated the need to adjust for these factors in the time series analyses.

Crude (Unadjusted) Changes in Driver Cannabinoid Prevalence after Medical Marijuana Laws

The crude, or unadjusted, annual 1992–2009 cannabinoid prevalence estimates among all fatal-crash-involved drivers in California (Figure 1) and fatally-injured drivers in California (Figure 2) are presented below for illustrative purposes. The corresponding figures for the other 13 medical marijuana states are shown in alphabetical order in Appendix B. The series labeled "State Cannabinoid Prevalence" in the figures shows the cannabinoid prevalence among the drivers (the percentage of all drivers found to be positive for cannabinoids). The vertical lines in the figures indicate the initial implementation date of the medical marijuana law in each state and any significant modifications to the law that were used as intervention points in the time series models. Also shown in the figures are the corresponding annual percentages of drivers in each state who were tested for drugs, which are labeled as "State Drug Testing" in the figures, and the cannabinoid prevalence of drivers in the aggregated jurisdictions that did not implement medical marijuana laws before 2010, which is labeled "National Cannabinoid Prevalence" in the figures.

The crude average prevalence of cannabinoids among all fatal-crash-involved drivers was higher in seven of the 14 medical marijuana states (CA, HI, MI, MT, NV, VT, WA) after the laws were implemented (Table 4), with increases ranging from 2.2 to 8.2 percentage-points. The crude average prevalence of cannabinoids among fatally-injured drivers in these same seven states increased 3.5 to 15.1 percentage points after the laws were implemented. Crude average marijuana prevalence in the aggregated jurisdictions that did not implement medical marijuana laws also increased 1.3 percentage-points among all fatal-crash-involved drivers and 1.9 percentage-points among fatally-injured drivers. Given the increased prevalence in jurisdictions that did not implement medical marijuana laws, and the fact that drug testing in many states was higher after the laws were passed, these crude changes in cannabinoid prevalence probably do not accurately reflect the actual impact of implementing medical marijuana laws in these states.

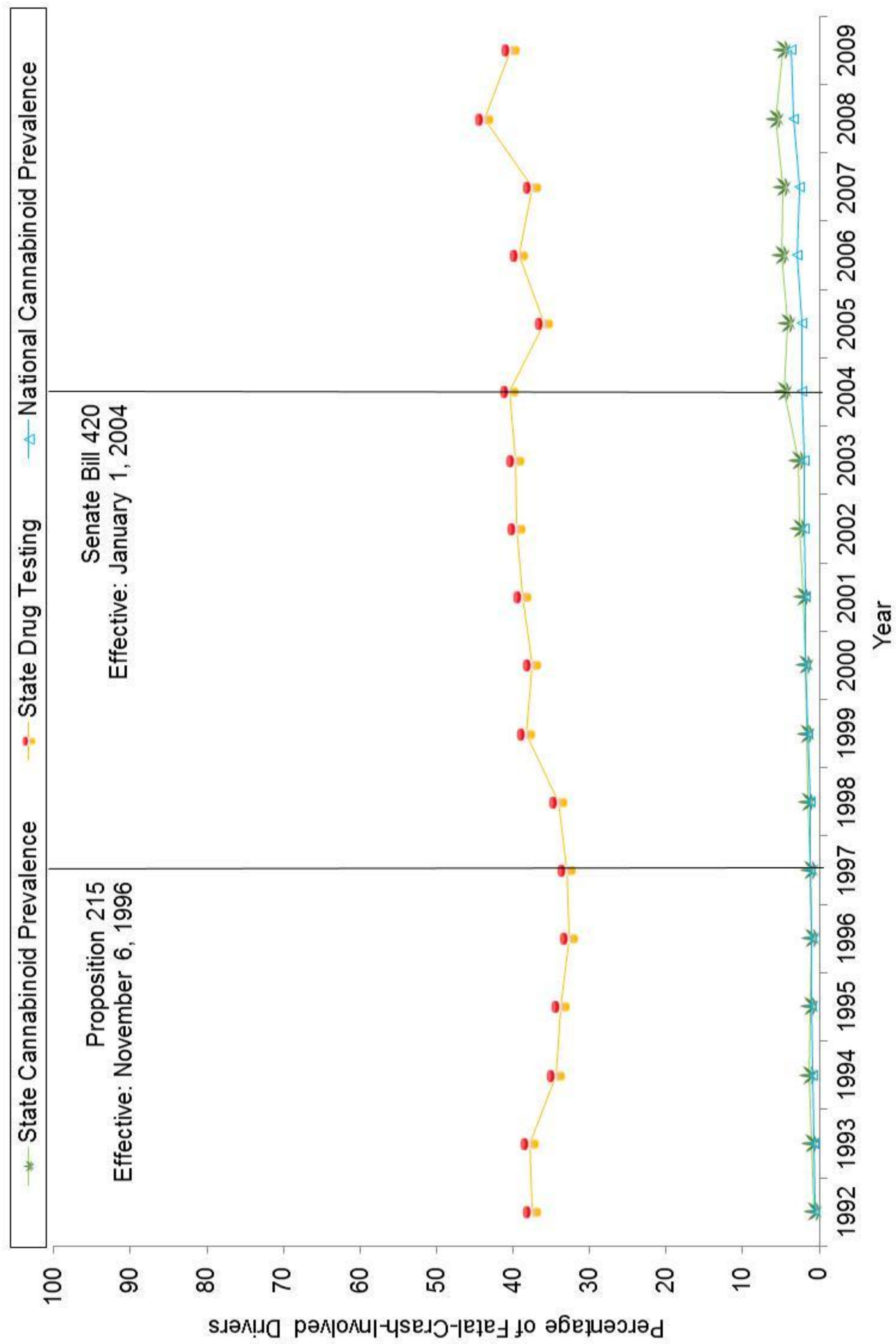

Figure 1. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in California, 1992–2009.

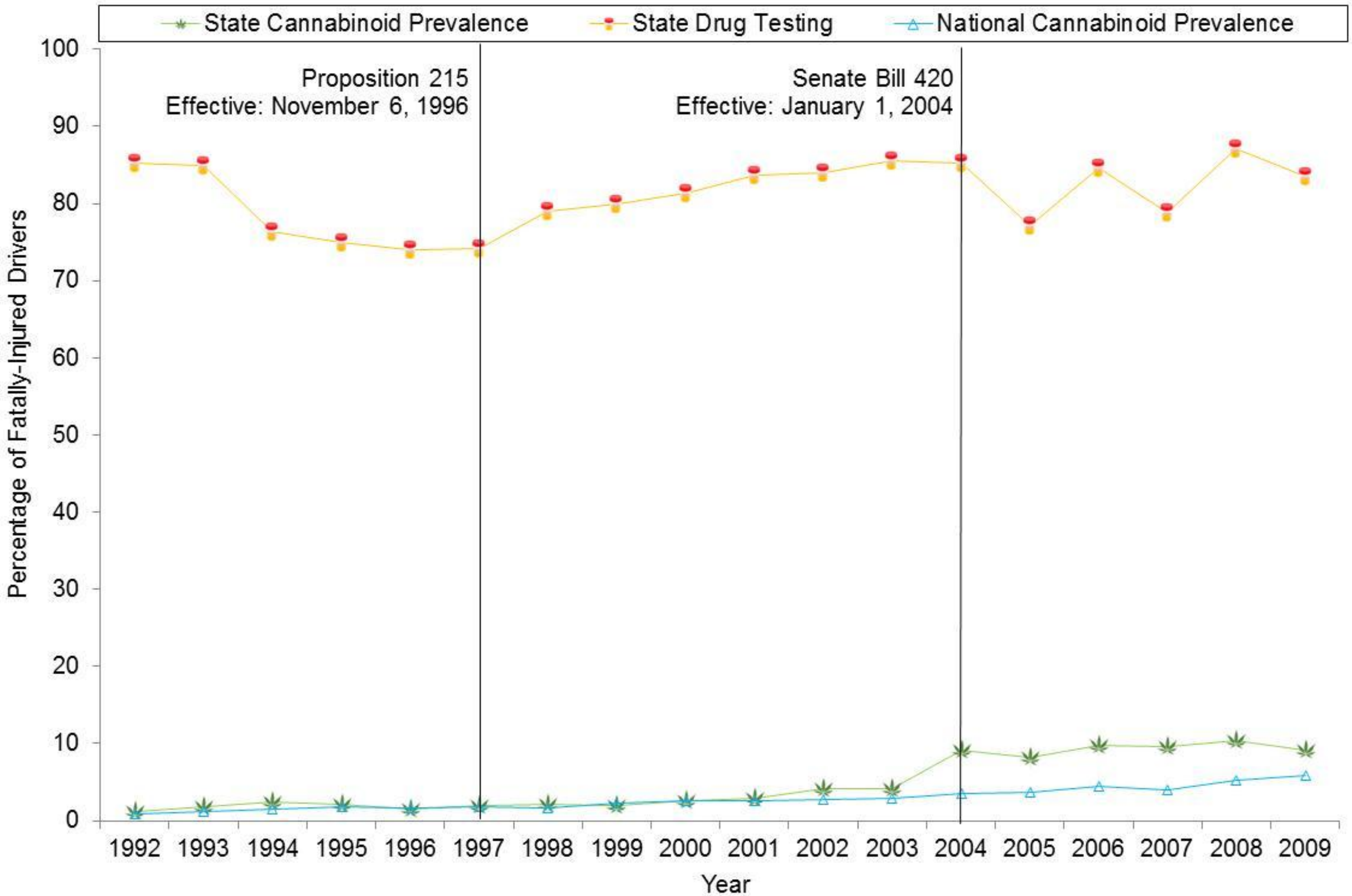

Figure 2. Cannabinoid prevalence and drug testing among fatally-injured drivers in California, 1992–2009.

Table 4

Crude Average Percentages of Fatal-Crash-Involved Drivers and Fatally-Injured Drivers with Positive Cannabinoid Test Results, Crude Percentage-Point Differences, and Crude Percentage Changes in 14 U.S. States Enacting Medical Marijuana Laws before 2010 and 37 Aggregated Comparison Jurisdictions that did not Enact Medical Marijuana Laws before 2010, 1992-2009

State	Intervention year(s)	All fatal-crash-involved drivers				Fatally-injured drivers			
		$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$	$\%_{Pre}$	$\%_{Post}$	Δ_{PP}	$\Delta_{\%}$
Alaska	1999	5.5	6.3	0.8	14.3	6.3	6.7	0.4	6.9
California	1997, 2004	1.1	3.3	2.2*	200.3	1.8	5.8	4.0*	223.3
Colorado	2001	3.7	4.2	0.5	13.9	6.1	7.7	1.6	26.5
Hawaii	2001	2.5	9.3	6.7*	264.5	4.9	12.7	7.8*	160.4
Maine	2000, 2002	0.3	0.6	0.3	123.6	0.0	0.0	0.0	0.0
Maryland	2004	0.1	0.2	0.1	148.3	0.1	0.1	0.1	122.6
Michigan	2009	1.4	3.7	2.3*	165.7	2.5	6.0	3.5*	140.0
Montana	2005	4.5	9.8	5.3*	116.6	5.5	11.0	5.5*	99.0
Nevada	2002	2.0	5.9	3.9*	197.0	2.8	9.0	6.2*	223.9
New Mexico	2007, 2009	2.0	0.1	-1.9	-93.0	4.2	0.2	-4.0	-96.1
Oregon	1999, 2006	2.5	2.9	0.5	19.8	2.0	1.2	-0.8	-40.9
Rhode Island	2006, 2007, 2009	2.2	3.1	0.9	40.2	4.3	5.9	1.6	37.2
Vermont	2004, 2007	2.3	9.5	7.1*	303.2	4.6	16.1	11.4*	248.6
Washington	1999, 2007, 2009	0.7	8.9	8.2*	1102.9	1.1	16.2	15.1*	1421.1
Jurisdictions without medical marijuana laws	None[a]	0.9	2.2	1.3*	148.6	1.4	3.3	1.9*	142.0

Note. The table figures are not adjusted for trend, seasonality, or autocorrelation. $\%_{Pre}$ = average annual cannabinoid prevalence prior to initial medical marijuana law. $\%_{Post}$ = average annual cannabinoid prevalence after initial medical marijuana law. Δ_{PP} = crude percentage point difference in cannabinoid prevalence. $\Delta_{\%}$ = crude percentage change in cannabinoid prevalence relative to the pre-law time period. The percentage-point difference and percentage change estimates are not exact in some cases due to rounding.

[a]Because there is no ‘intervention’ date from which to compute pre-post values for the control states, for descriptive purposes these figures represent a comparison before and after the first medical marijuana law was implemented in California.

*$p < .05$. two-tailed *t* test.

Analyses of Changes in Driver Cannabinoid Prevalence after Medical Marijuana Laws

The estimates of change in driver cannabinoid prevalence resulting from the ARIMA time series models, with and without adjustments for confounders, are shown in Table 5. Based on models that did not include adjustments for changes in drug testing or national cannabinoid prevalence, the implementations of medical marijuana laws in seven states (CA, HI, ME, MT, NV, VT, and WA) were found to be associated with reliable increases in cannabinoid prevalence ranging from 0.6 to 11.4 percentage-points among all fatal-crash-involved drivers. In six of these states (excluding ME), cannabinoid prevalence also reliably increased among fatally-injured drivers, ranging from 5.5 to 16.2 percentage points. However, these estimates are probably confounded by changes in drug testing and the national trend towards higher driver cannabinoid prevalence.

After adjusting the prevalence estimates for changes in the percentages of drivers tested for drugs within each medical marijuana state (Table 5), reliable increases in cannabinoid prevalence after the laws were implemented ranging from 1.8 to 5.6 percentage-points were found for four states (AK, CA, HI, and MT) among all fatal-crash-involved drivers. Among fatally-injured drivers, reliable increases in cannabinoid prevalence ranging from 1.0 to 7.9 percentage-points were found for five states (AK, CA, HI, MI, and WA), along with a reliable decrease of 1.1 percentage points in one state (OR). However, these estimates are likely still confounded by the national trend towards higher driver cannabinoid prevalence.

After adjustments were made in the models for both driver drug testing frequency in each state and national trend in driver cannabinoid prevalence among states without medical marijuana laws (Table 5), the implementation of medical marijuana laws was found to be reliably associated with increased cannabinoid prevalence in only three states (CA, HI, WA). The increases in all three states were stable step increases (see Figures 1-2, B5-B6, and B25-B26), meaning that the prevalence increased to a new level in these states and remained relatively flat subsequently. Interestingly, the initial implementation of the California medical marijuana law in 1996 was not reliably associated with a change in driver cannabinoid prevalence. However, after the medical marijuana law was operationalized by the California Legislature under Senate Bill 420 in 2004, cannabinoid prevalence increased 2.1 percentage-points (95% confidence interval [CI], 1.4–2.9) among all fatal-crash-involved drivers and 5.7 percentage-points (CI, 4.3–7.0) among fatally-injured drivers. Relative to the time period before the California law was implemented, these seemingly small percentage-point increases correspond to subsequent cannabinoid prevalence being about 196% higher among all fatal-crash-involved drivers and 315% higher among fatally-injured drivers in California.

Table 5

ARIMA Results for Fatal-Crash-Involved Drivers and Fatally-Injured Drivers with Positive Cannabinoid Test Results Showing Adjusted Percentage-Point Differences and Percentage Changes in 14 U.S. States Enacting Medical Marijuana Laws before 2010, 1992-2009

State	No covariate adjustments			Adjusted for changes in drug testing only			Adjusted for changes in drug testing and national cannabinoid prevalence		
	Δ_{PP}	95% CI	$\Delta_{\%}$	Δ_{PPadj}	95% CI	$\Delta_{\%adj}$	Δ_{PPadj}	95% CI	$\Delta_{\%adj}$
	All fatal-crash-involved drivers								
Alaska	0.8	-1.8, 3.4	14.3	3.0*	1.1, 4.9	54.3	-2.2	-5.5, 1.1	-39.2
California	3.7*	3.0, 4.4	343.3	1.8*	1.0, 2.6	168.0	2.1*	1.4, 2.9	195.8
Colorado	0.5	-0.7, 1.7	13.9	0.1	-0.8, 1.1	4.0	-0.2	-1.7, 1.3	-4.8
Hawaii	6.7*	5.6, 7.8	264.5	5.6*	4.4, 6.8	220.3	6.0*	4.4, 7.6	235.3
Maine	0.6*	0.3, 0.9	223.7	0.2	-0.1, 0.5	85.8	0.1	-0.3, 0.6	50.0
Maryland	0.1	-0.0, 0.3	148.4	-0.1	-0.6, 0.5	-77.6	0.1	-0.4, 0.6	86.3
Michigan	-0.7	-1.5, 0.0	-51.2	0.0	-0.5, 0.5	-2.3	-0.1	-0.6, 0.4	-8.0
Montana	5.3*	2.6, 7.9	116.6	2.3*	0.3, 4.4	51.2	-0.6	-3.1, 1.9	-13.3
Nevada	3.9*	2.6, 5.2	197.0	1.4	-0.1, 2.9	70.8	1.2	-0.3, 2.6	58.8
New Mexico	-1.9	-4.0, 0.2	-93.0	-1.0	-4.2, 2.2	-51.6	0.1	-2.0, 2.2	3.0
Oregon	0.5	-0.3, 1.3	19.8	-0.2	-1.5, 1.2	-7.7	0.1	-1.0, 1.2	3.3
Rhode Island	0.9	-0.8, 2.6	40.2	1.4	-0.1, 3.0	64.6	-2.5	-6.4, 1.3	-112.0
Vermont	7.1*	4.7, 9.5	303.2	-0.2	-2.1, 1.8	-7.7	0.0	-2.7, 2.8	1.7
Washington	11.4*	6.6, 16.2	1535.9	1.4	-2.6, 5.5	193.8	3.4*	1.4, 5.3	454.9
	Fatally-injured drivers								
Alaska	0.4	-3.4, 4.3	6.6	3.2*	0.4, 6.0	51.1	-1.5	-6.9, 3.9	-24.0
California	7.5*	6.4, 8.6	417.8	7.4*	6.3, 8.5	410.9	5.7*	4.3, 7.0	315.2
Colorado	1.6	-0.2, 3.5	26.5	0.6	-0.9, 2.0	9.1	-0.5	-2.6, 1.6	-8.4
Hawaii	7.8*	5.1, 10.6	160.4	7.9*	5.2, 10.6	162.1	9.6*	5.0, 14.1	195.8
Maine	0.0	0.0, 0.0	0.0	0.0	0.0, 0.0	0.0	0.0	0.0, 0.0	0.0
Maryland	0.1	-0.0, 0.3	222.6	0.0	-0.4, 0.5	78.6	0.1	-0.3, 0.6	203.4
Michigan	0.2	-0.9, 1.3	6.8	1.0*	0.1, 2.0	41.0	0.4	-0.6, 1.4	14.6
Montana	5.5*	1.8, 9.1	98.9	-2.9	-6.7, 0.9	-52.3	-1.4	-4.0, 1.1	-25.9
Nevada	6.2*	3.8, 8.7	223.9	2.4	-0.1, 5.0	87.9	2.0	-0.6, 4.7	73.4
New Mexico	-3.5	-7.7, 0.7	-84.7	-4.0	-8.4, 0.4	-95.8	1.6	-1.8, 5.0	37.9
Oregon	0.1	-1.4, 1.6	3.1	-1.1*	-1.8, -0.5	-57.5	-1.2*	-2.3, -0.0	-59.8
Rhode Island	1.6	-1.9, 5.2	37.2	3.0	-0.4, 6.5	69.4	-4.6	-9.8, 0.7	-105.6
Vermont	11.4*	6.9, 16.0	248.0	-0.7	-4.7, 3.3	-15.3	-1.0	-4.9, 3.0	-21.0
Washington	16.2*	14.2, 18.1	1521.1	4.6*	0.5, 8.7	432.7	4.6*	0.5, 8.7	432.4

Note. Δ_{PPadj} = adjusted percentage-point difference in annual cannabinoid prevalence subsequent to the medical marijuana law implementation. 95% CI = 95% confidence interval for the adjusted percentage-point difference. $\Delta_{\%adj}$ = adjusted percentage change in annual cannabinoid prevalence relative to the pre-law period. All estimates are based on sudden-permanent ARIMA models. The percentage-point difference and percentage change estimates are not exact in some cases due to rounding.

*$p < .05$, two-tailed from ARIMA model.

Taking into account changes in drug testing frequency and trend in national driver cannabinoid prevalence, cannabinoid prevalence increased 6.0 percentage-points (CI, 4.4–7.6) among all fatal-crash-involved drivers and 9.6 percentage-points (CI, 5.0–14.1) among fatally-injured drivers after the Hawaii medical marijuana law was implemented in 2001. Relative to the time period before the Hawaii law was implemented, these percentage-point increases correspond to subsequent cannabinoid prevalence being about 235% higher among all fatal-crash-involved drivers and 196% higher among fatally-injured drivers in Hawaii. After the implementation of the Washington medical marijuana law in 1999, and again taking both confounders into account, driver cannabinoid prevalence increased 3.4 percentage-points (CI, 1.4–5.3) among all fatal-crash-involved drivers and 4.6 percentage-points (CI, 0.5–8.7) among fatally-injured drivers. Relative to the time period before the Washington law was implemented these percentage-point increases correspond to subsequent cannabinoid prevalence being about 455% higher among all fatal-crash-involved drivers and 432% higher among fatally-injured drivers in Washington. Finally, the implementation of the Oregon medical marijuana law in 1998 was found to be associated with a decrease in cannabinoid prevalence of 1.2 percentage-points (CI, -2.3–-0.03) among fatally-injured drivers, corresponding to about a 60% decrease relative to pre-law prevalence. Note that the drug testing percentages before and after the Oregon law was implemented were low and highly volatile in 2008, so the validity of this result is questionable.

Relation to Ease of Medical Marijuana Access/Degree of Regulation Rankings

To explore whether the post-law changes in driver cannabinoid prevalence in the 14 medical marijuana states were associated in a dose-response manner with the ease of patient access to medical marijuana afforded by the laws, the estimates from the time series models were plotted for all fatal-crash-involved drivers (Figure 3) and fatally-injured drivers (Figure 4) as a function of the state ease of access/degree of regulation rankings. If increases in driver cannabinoid prevalence were positively associated with weaker regulation by the states, more protections for patients, and overall easier patient access to marijuana, then it would be expected that the higher percentage-point increase estimates would tend to cluster near the right side of the figures. However, no relation between the post-law cannabinoid prevalence change estimates and the ease of access rankings is apparent in the figures.

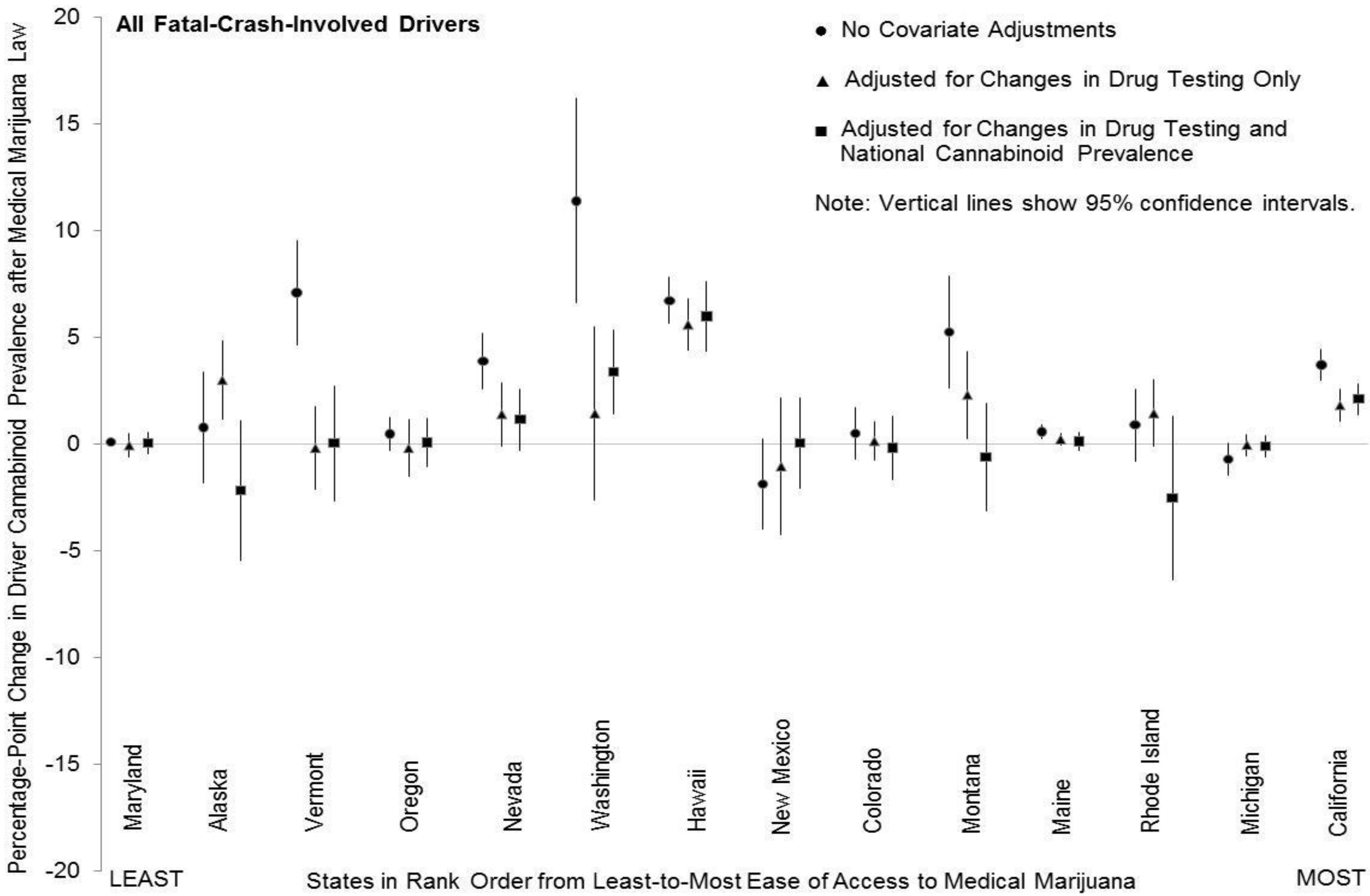

Figure 3. Percent-point change in cannabinoid prevalence among fatal-crash-involved drivers after medical marijuana law implementation by state rank order of least-to-most access to medical marijuana provided by the law, 1992-2009.

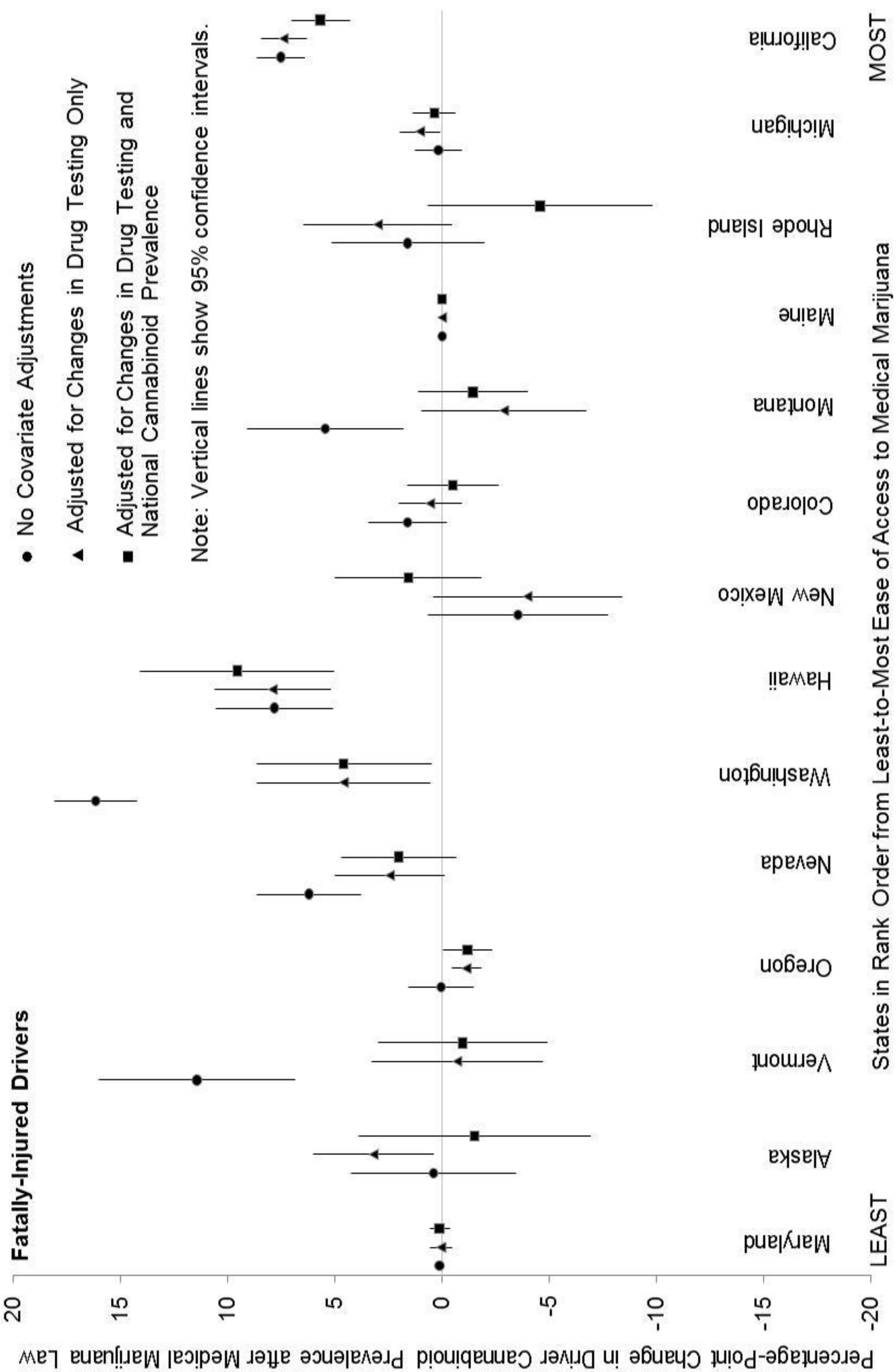

Figure 4. Percent-point change in cannabinoid prevalence among fatally-injured drivers after medical marijuana law implementation by state rank order of least-to-most access to medical marijuana provided by the law, 1992-2009.

DISCUSSION

General Discussion of Findings

After adjustments were made for both driver drug testing frequency in each state and national trend in driver cannabinoid prevalence, the implementation of medical marijuana laws was found to be reliably associated with increased cannabinoid prevalence in only 3 of the 14 states: California, Hawaii, and Washington. The increases in all three states were step increases, meaning that the prevalence increased to a new level in these states and remained relatively flat for long time intervals subsequent: 6 years in California, 9 years in Hawaii, and 10 years in Washington. The increases in cannabinoid prevalence found in these states are certainly concerning if they resulted from driver marijuana use being a causal factor in the fatal crashes. Making this causal determination was not the intent of the present study; it requires a different study design. However, finding that all three states experienced step increases in cannabinoid prevalence, rather than upward trends, suggests that medical marijuana laws may indeed provide marijuana access to a stable population of patients as intended, without increasing the numbers of new users over time (Johnson et al., 2012). Alternatively, medical marijuana laws may increase the numbers of users, but they are less likely to drive, less likely to be involved in a fatal crash, or both. The findings are consistent with recent evidence from oral fluid results taken from roadside samples of California drivers indicating that cannabinoid prevalence was relatively stable between 2010 and 2012 (Lacey, et al., 2012).

The increase in cannabinoid prevalence found among California fatal-crash-involved drivers in the current study replicated that found in a prior study of the California law, but the increase found among fatally-injured drivers was about twice as high (Crancer & Crancer, 2010). This difference may be due to the fact that the current study included fatally-injured drivers from a wider range of crash types (e.g., those involving multiple vehicles) or other disparities in methodology, as the methods were crudely documented in that study. The prevalence estimates from the studies based on California fatal crashes are lower than those from the roadside surveys of California drivers using oral fluid samples (Johnson et al., 2012; Lacey, et al., 2012). The reasons for the differences are unknown, but may be due to the fact that the estimates emanating from fatal crashes are based on a broader sample of times and days of the week, whereas the oral samples were taken on nighttime weekends, when cannabinoids are more prevalent among drivers (Lacey et al., 2009). Another possibility is that differences in drug testing practices and procedures across California labs (e.g., different screening levels for cannabinoids or some labs not regularly testing for cannabinoids), result in lower prevalence estimates based on fatal crashes.

Reliable increases in cannabinoid prevalence were not found in the other 11 states that implemented medical marijuana laws before 2010. In some cases this may be due to low statistical power related to lower numbers of observations over time in the smaller states, and hence large year-to-year variability in cannabinoid prevalence and testing (e.g., AK). Testing higher percentages of drivers for drugs was associated with increased prevalence, and drug testing tended to be higher in many states coinciding with the implementation of medical marijuana laws. Hence, the increases in the crude prevalence estimates in several states were apparently the result of confounding due to increased testing of drivers after the laws were implemented. While changes over time in the frequency of driver drug testing were adjusted within each state, the low levels of testing before and after the laws in some states (e.g., ME and OR), dramatic fluctuations in testing often corresponding with implementation of the laws (e.g., VT and MD), and erratic testing over time in other states (e.g., AK and NV) may have made it difficult to detect changes in prevalence in these states. Nonetheless, some of the states had relatively high levels of testing during the study time period (e.g., CO and NM), yet no increase in prevalence was detected. Given that only 1 year of post-law data was available for Michigan, the finding of no increase in cannabinoid prevalence in this state should be considered preliminary.

One factor that was explored to explain the differences between states in post-law cannabinoid prevalence was the degree of regulation and/or ease of access to medical marijuana afforded by the different laws. However, no relation between the post-law cannabinoid prevalence change estimates and the ease of marijuana access rankings was found. Although the scoring criteria used to create these ranks were based on factors deemed important by marijuana legalization advocates (Marijuana Policy Project, 2011), and the weighting scheme was created based on responses from medical marijuana patients, the ranks may not have been valid reflections of the intended construct. Alternatively, ease of access to marijuana afforded by the laws may simply not be related to changes in cannabinoid prevalence among drivers involved in fatal crashes.

Study Limitations

There are several limitations of this study besides the inconsistent and sometimes meager drug testing of drivers in some states. The estimates are based on fatal crashes, which are only a small subset of all crashes. The causes of fatal crashes differ from less serious crashes; for example, fatal crashes are more likely to involve risky behaviors such as driver alcohol use or excessive speeding (Lam, 2003). Consequently, the cannabinoid prevalence estimates likely do not reflect prevalence among drivers in general. Unfortunately, no national database of less severe crashes exists that contains detailed information about drug testing results. Still, changes in prevalence among these crashes likely reflect some underlying change in prevalence among drivers in general.

The drug test results reported in FARS are poorly documented and there are likely variations both across and within jurisdictions in drug testing standards and procedures, such as different concentration thresholds for deeming results to be positive (Huestis, 2002; NHTSA, 2010). Some laboratories may not even routinely test for cannabinoids, or they may have only routinely begun such testing after medical marijuana laws were implemented. There are also differences among state laws concerning implied consent and other aspects of drug testing when crashes occur (Office of National Drug Control Policy [ONDCP], 2011). Some laboratories may not report tests with negative results and drivers with unavailable test results may be systematically biased in a positive or negative direction (NHTSA, 2010). The factors that increase the likelihood of drivers being tested for drugs are also not known. Tested drivers may not be representative of all fatal-crash-involved drivers, especially in the states that test a minority of their drivers, and prevalence estimates based on such drivers may be higher or lower than that among drivers in general. While there are many unknowns about the reliability and validity of drug test results in FARS, they represent the only national source for data on drugged driving, and hence have been used by other researchers to estimate the prevalence of various drugs among U.S. drivers (e.g., NHTSA, 2010; ONDCP, 2011). Nonetheless, testing-related factors that changed over time within states could bias the prevalence estimates, and therefore the conclusions based on changes in those estimates. The extent to which changes occurred and the impact of any resulting bias are unknown. If there was no such bias in reality, changes in prevalence based on fatal crashes is a reasonable proxy to determine whether relatively recent (within a few weeks) marijuana use among drivers changed after medical marijuana laws were implemented, though positive results do not necessarily imply that the driver was impaired or that marijuana was a causal factor in the crashes. Further, the magnitude of the prevalence estimates should not be taken to be representative of all crashes or all drivers in these states.

Conclusion

In summary, the implementation of medical marijuana laws was associated with increased prevalence of cannabinoids among drivers involved in fatal crashes in only a minority of the states that implemented these laws. The observed increases were one-time changes in the prevalence levels, rather than upward trends, suggesting that these laws result in stable increases in driver marijuana prevalence. The reasons that some states experienced changes in prevalence while others did not are unknown, but one factor appears to be differences between states in drug testing practices and regularity. Ease of patient access to marijuana was not found to be related to changes in post-law cannabinoid prevalence.

These results support the effort by the California Department of Motor Vehicles to begin receiving information on drug influence or the combined influence of drugs and alcohol among drivers involved in crashes from the California Highway Patrol’s Statewide Integrated Traffic Records System (SWITRS). Further, given the increased prevalence of cannabinoids among fatal crashes in California, these results support the recent law change (Assembly Bill 2552, Chapter 753, Statutes of 2012) that will create separate *California Vehicle Code* subsections to distinguish convictions for driving under the influence of alcohol alone, drugs alone, or a combination of alcohol and drugs. This law change will become operative January 1, 2014.

RECOMMENDATIONS

1. It is recommended that nationwide standardization of drug testing procedures and criteria be considered to improve the consistency of testing both between and within jurisdictions, which concurs with a prior recommendation by the National Transportation Safety Board (2012).

2. A survey could be conducted of the various county and private laboratories that perform drug tests of crash-involved drivers in California to characterize the variations in drug testing practices and procedures within the state and assist in developing standardized statewide drug testing practices and procedures.

3. Additional research is needed to determine whether the increases in cannabinoid prevalence found in California, Hawaii, and Washington resulted in marijuana use among drivers being a more prevalent factor in causing crashes in those states.

4. The California medical marijuana law has been implemented for over a decade, yet little is actually known about the crash risk of drivers with medical marijuana recommendations. Comparisons of the traffic safety records of a cohort of drivers with medical marijuana recommendations to a matched cohort of drivers in general could help establish whether those with recommendations are at increased actuarial risk for crashing.

5. Finally, given the increased cannabinoid prevalence among drivers in some states after medical marijuana laws are implemented, along with the recent legalization of marijuana for recreational purposes in Colorado and Washington, a comprehensive research effort is needed to empirically determine the concentrations of cannabinoids that impair driving ability, alone or in combination with alcohol, to aid in crafting laws that establish per se limits for driving under the influence of cannabinoids.

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APPENDICES

Appendix A

State Medical Marijuana Law Ease of Marijuana Access/Degree of Regulation Dimension Coding Criteria and Point Scores, Total Composite Scores, and Rankings

Table A1

State Medical Marijuana Law Ease of Marijuana Access/Degree of Regulation Dimension Point Scores, Total Composite Scores, and Rankings

	Coding dimension point score									
State	Protection from criminal charges/civil penalties	Qualifying conditions	Possession limits	Dispensary availability	Caregiver availability and protection	Home cultivation	Identification card requirements	Out-of-state portability	Total	Rank
Maryland	4	15	2	1	3	2	3	1	31	1
Alaska	8	9	4	2	3	10	1	1	38	2
Vermont	12	3	6	2	6	8	1	1	39	3
Oregon	12	9	10	2	3	4	1	1	42	4
Nevada	12	9	4	4	3	8	1	1	42	5
Washington	8	6	10	2	3	10	3	1	43	6
Hawaii	12	9	6	3	3	10	1	1	45	7
New Mexico	12	12	8	3	6	6	1	1	49	8
Colorado	12	9	6	3	9	10	1	1	51	9
Montana	16	6	4	4	12	8	1	2	53	10
Maine	16	12	6	3	6	8	2	2	55	11
Rhode Island	20	9	6	3	6	8	1	2	55	12
Michigan	20	12	6	3	3	8	1	2	55	13
California	12	15	8	5	15	10	2	1	68	14

Note. Ranks represent lowest (1) to highest (14) ease of access to medical marijuana. When state composite scores were tied, the state with the highest protection from criminal charges/civil penalties score was given the higher ranking. When those scores were tied, the state with the highest qualifying conditions score was given the higher ranking. When those scores were also tied, the state with the highest dispensary availability score was given the higher ranking.

Ease of Medical Marijuana Access/Degree of Regulation Dimension Coding Criteria

To code the degree of regulation and/or ease of access to medical marijuana afforded by the state medical marijuana laws, each state's law was coded for the eight dimensions shown below (Marijuana Policy Project, 2011). Each law was given one score for each of the eight dimensions, which were weighted as shown to reflect the relative importance given to each dimension based on a pilot study of California medical marijuana users. The protection from criminal charges/civil penalties dimension was given the most weight, followed by the qualifying conditions and dispensary availability dimensions, then the possession limits and home cultivation dimensions, and finally the identification card and out-of-state portability dimensions. Composite scores were created by summing the scores across the eight dimensions and could range from 17 to 80 with higher values indicating weaker regulation by the state, more protections for patients, and easier access to marijuana.

Coding dimension	Coding criteria	Point score
1. Protection from criminal charges/civil penalties	Court defense only	4
	Court defense, but less likely to be prosecuted	8
	Protection against arrest and prosecution	12
	Protection against arrest and prosecution; limited civil protections	16
	Protection against arrest and prosecution; explicit civil protections	20
2. Qualifying conditions	Few specific qualifying conditions	3
	Numerous specific qualifying conditions	6
	Few specific qualifying conditions; local authority can increase list	9
	Numerous specific qualifying conditions; local authority can increase list	12
	Health care professional determination of qualifying conditions	15
3. Possession limits	1 ounce or less; no plants allowed	2
	1 ounce; some plants allowed	4
	2 to 3 ounces; some plants allowed	6
	More than 3 ounces but less than 10 ounces; some plants allowed	8
	More than 10 ounces; several plants allowed	10
4. Dispensary availability	Not allowed	3
	A few regulated approved	6
	A larger number regulated approved	9
	Tolerated or loosely regulated, allowing for availability	12
	Non-licensed, as many as the market will hold	15
5. Caregiver availability and protection	No caregiver allowed	1
	One caregiver for one patient	2
	One caregiver for up to 5 patients	3
	No limits for caregivers, but must be registered	4
	No limits for caregivers, voluntary registration	5
6. Home cultivation	Not allowed	2
	Allowed with restrictions	4
	Allowed with permit	6
	Allowed in a locked facility	7
	Allowed unrestricted	10
7. Identification card requirements	Required and mandatory	1
	Optional	2
	None	3
8. Out-of-state portability	Does not allow out-of-state patients	1
	Allows out-of-state patients	2

Appendix B

Figures Showing Annual Crude Cannabinoid Prevalence and Drug Testing for All Fatal-Crash-Involved Drivers and Fatally-Injured Drivers in each Medical Marijuana State, 1992–2009

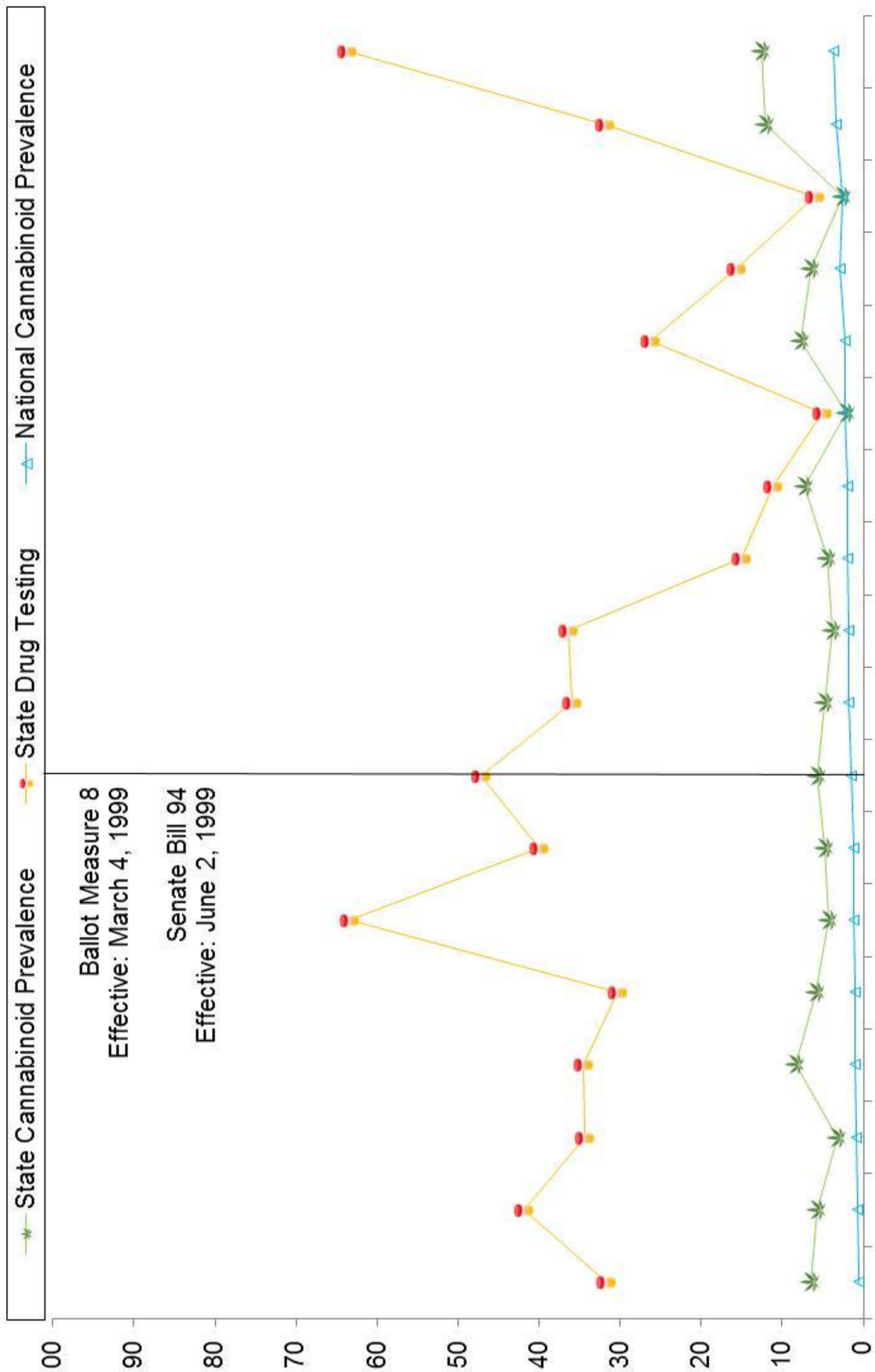

Figure B1. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Alaska, 1992–2009.

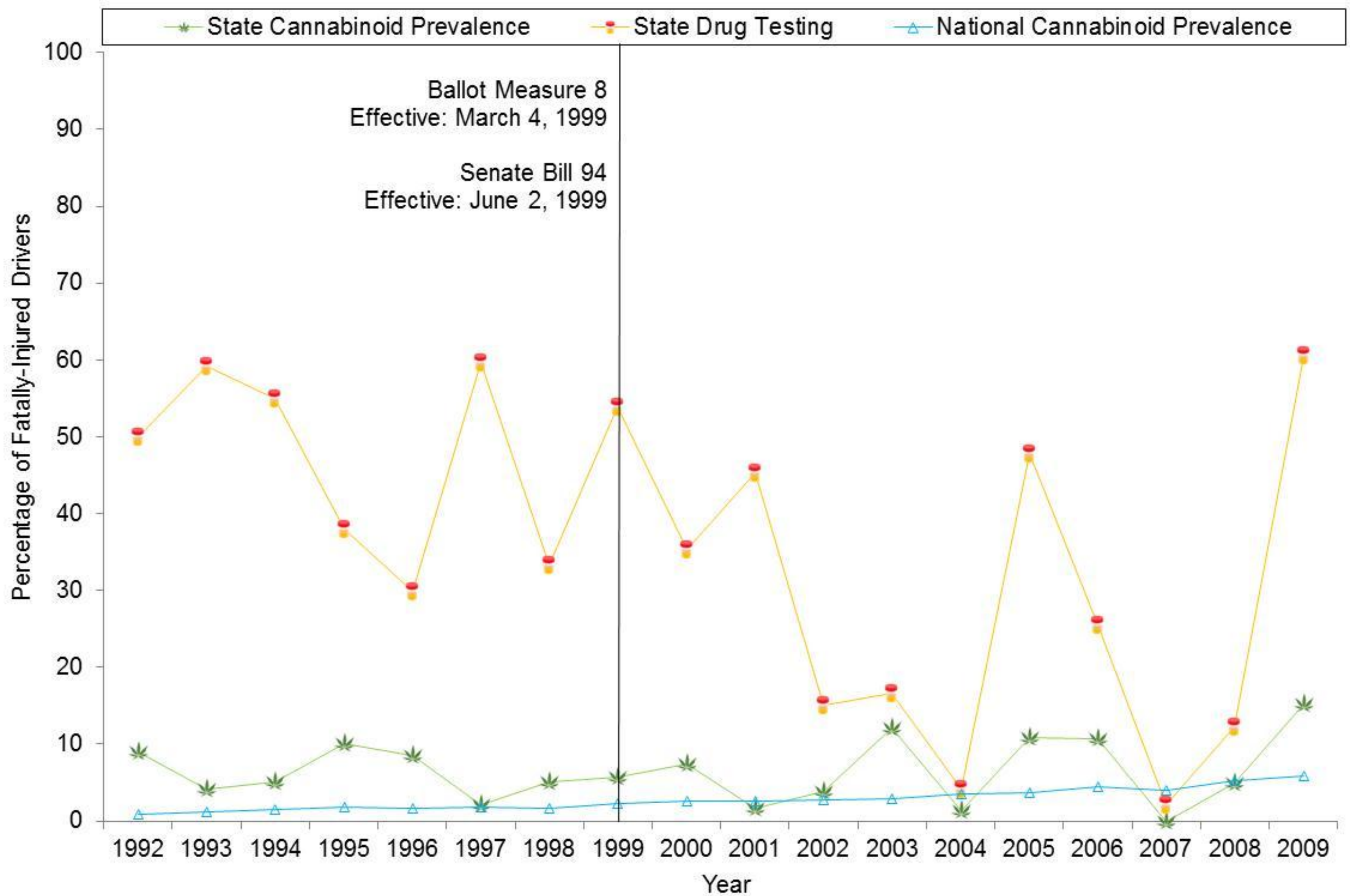

Figure B2. Cannabinoid prevalence and drug testing among fatally-injured drivers in Alaska, 1992–2009.

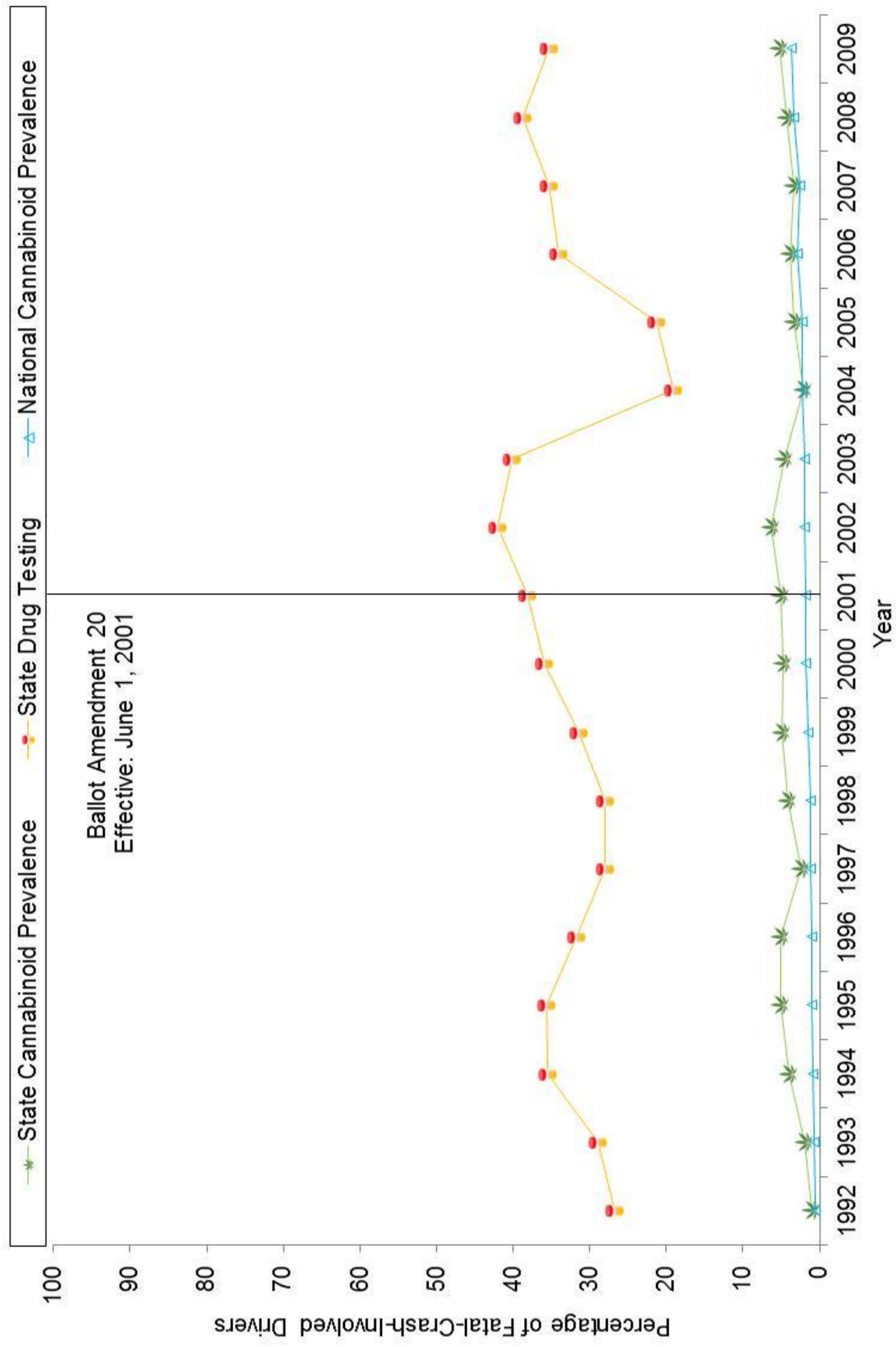

Figure B3. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Colorado, 1992–2009.

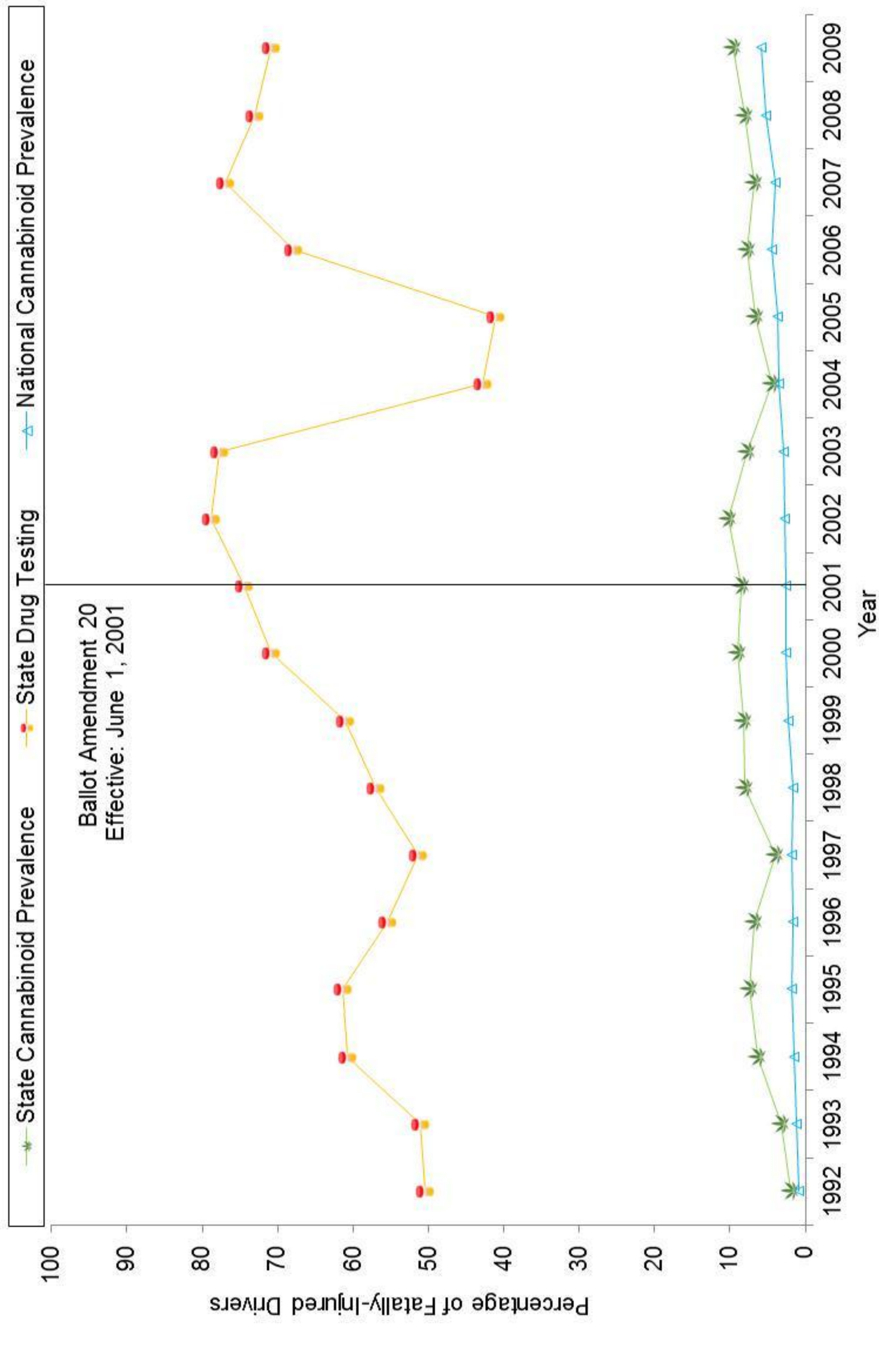

Figure B4. Cannabinoid prevalence and drug testing among fatally-injured drivers in Colorado, 1992–2009.

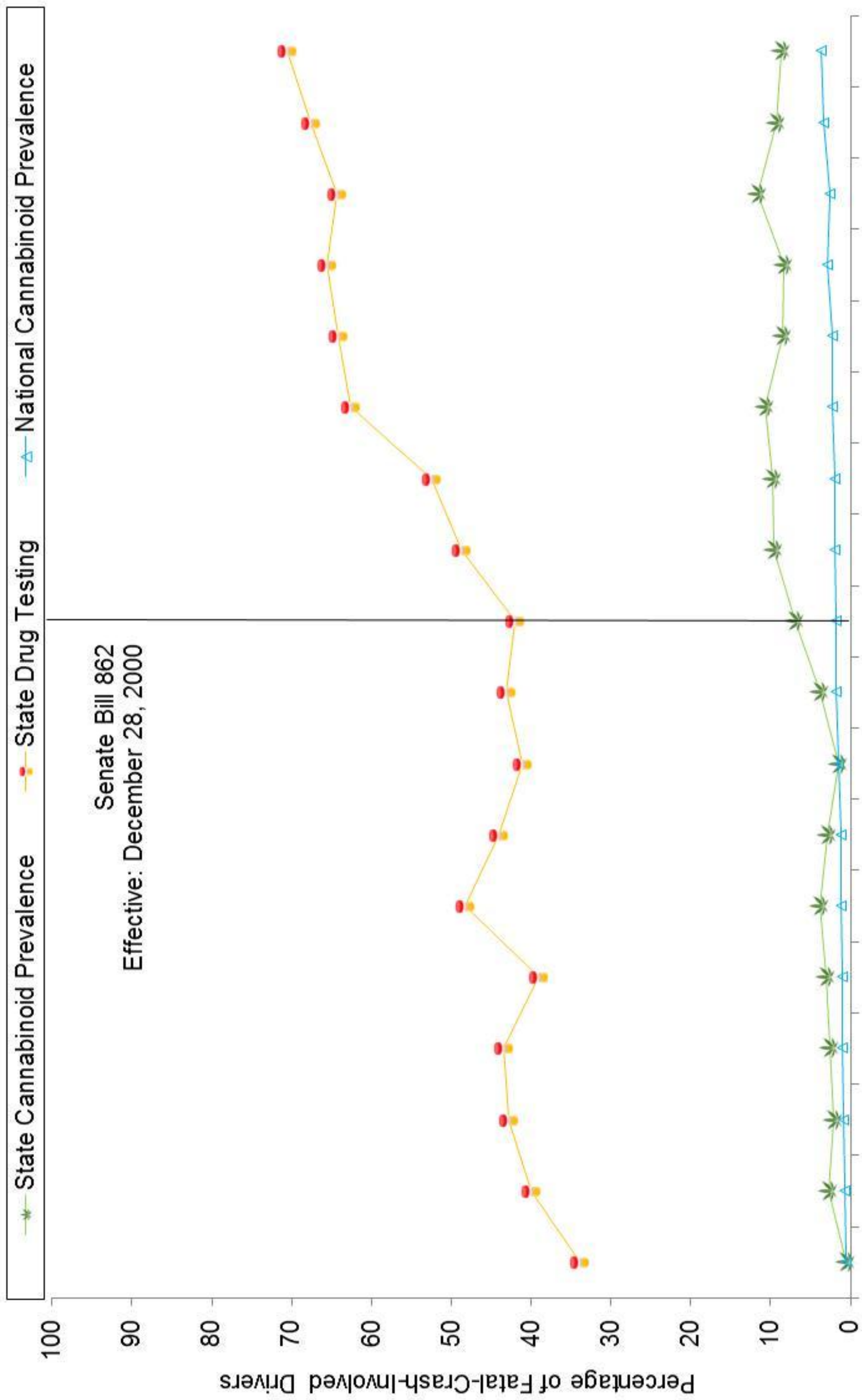

Figure B5. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Hawaii, 1992–2009.

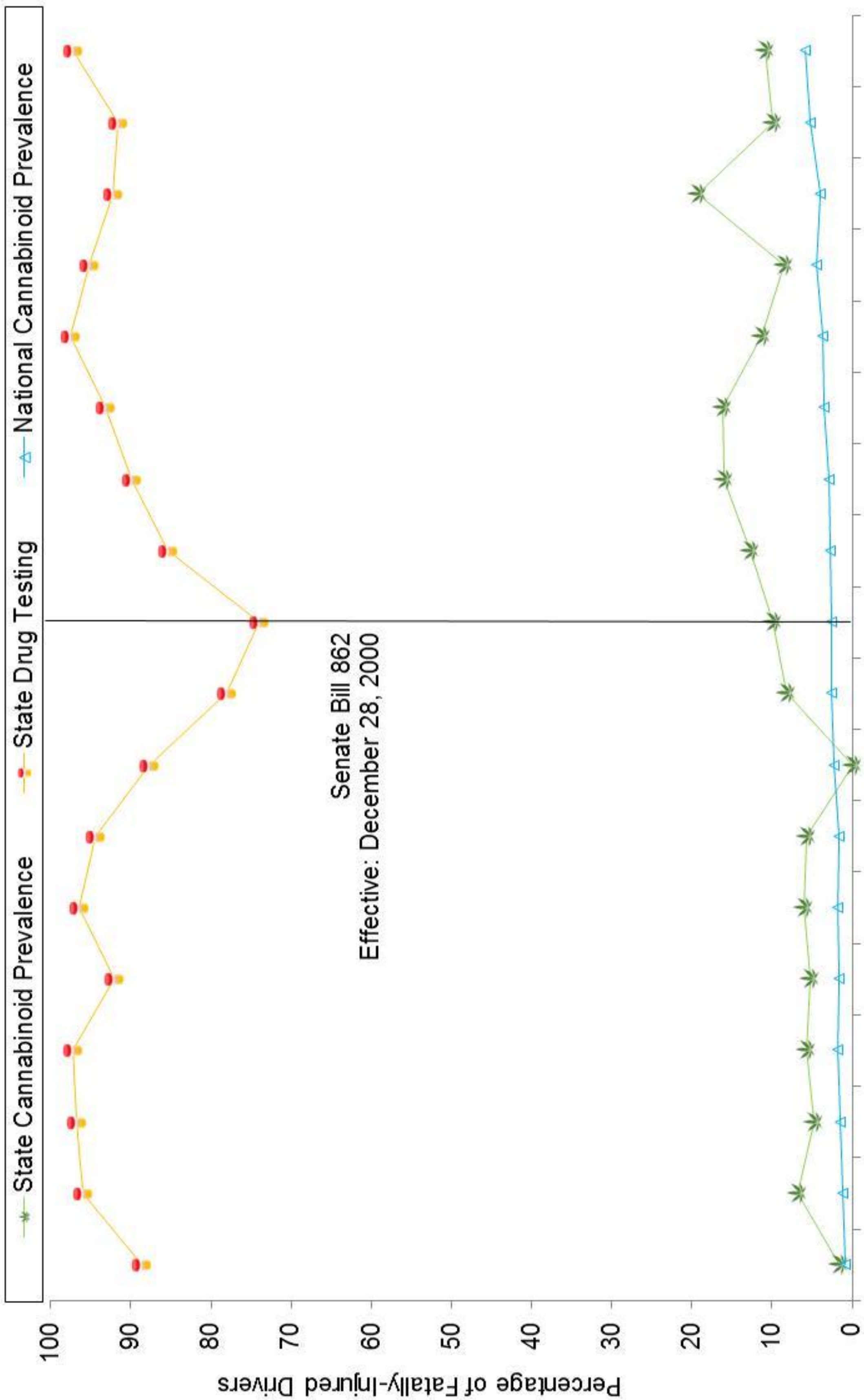

Figure B6. Cannabinoid prevalence and drug testing among fatally-injured drivers in Hawaii, 1992–2009.

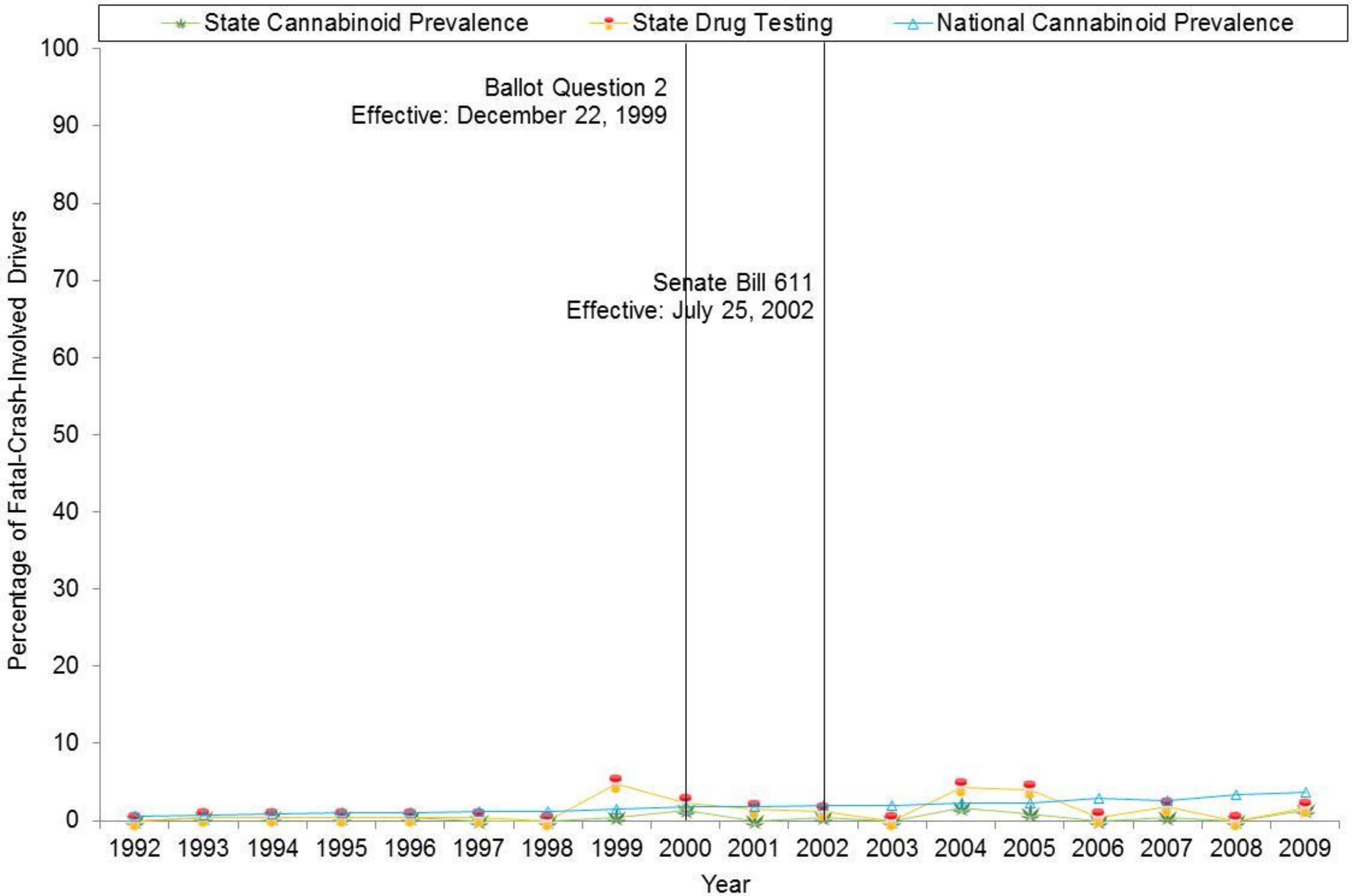

Figure B7. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Maine, 1992–2009.

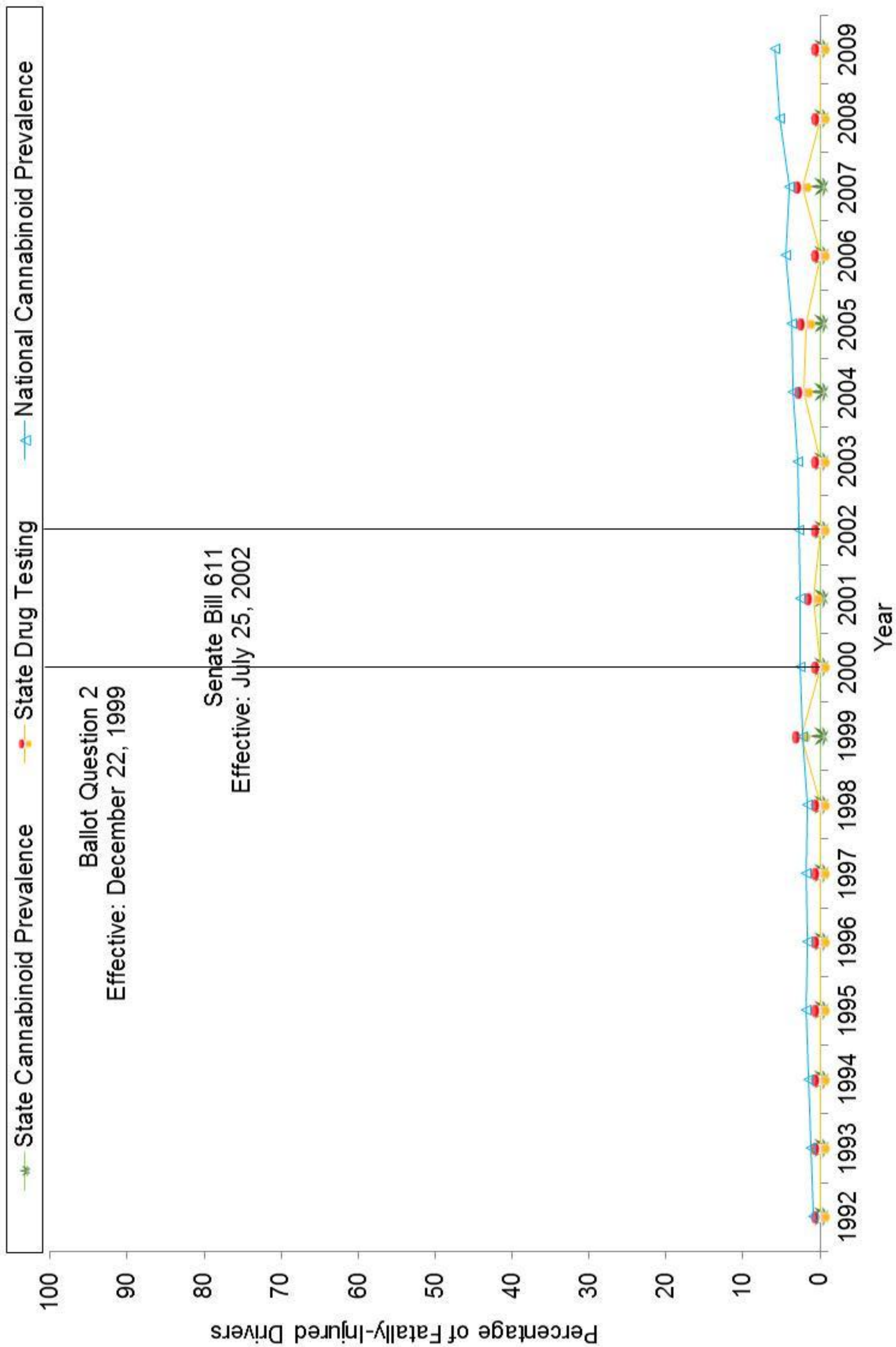

Figure B8. Cannabinoid prevalence and drug testing among fatally-injured drivers in Maine, 1992–2009.

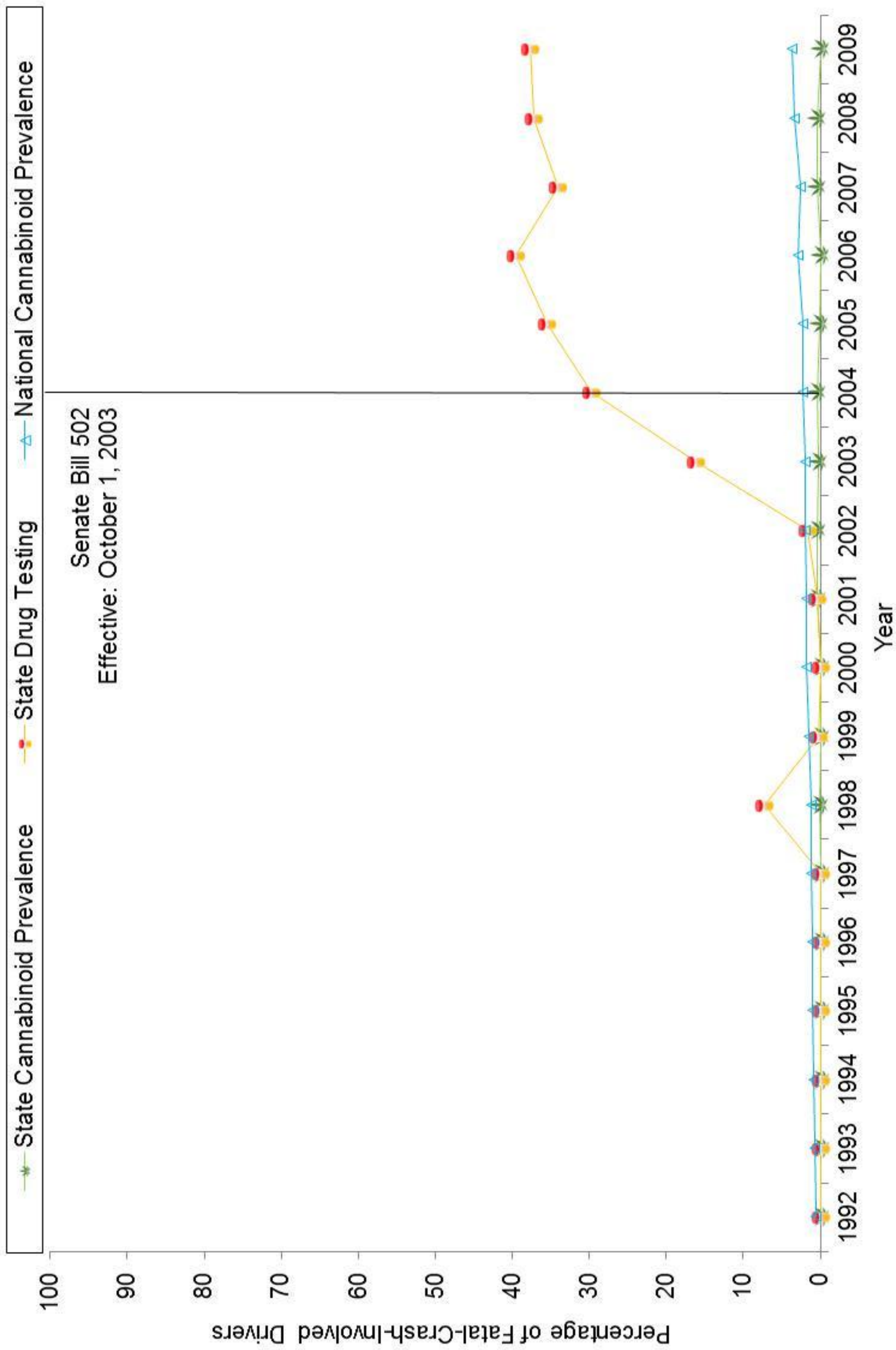

Figure B9. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Maryland, 1992–2009.

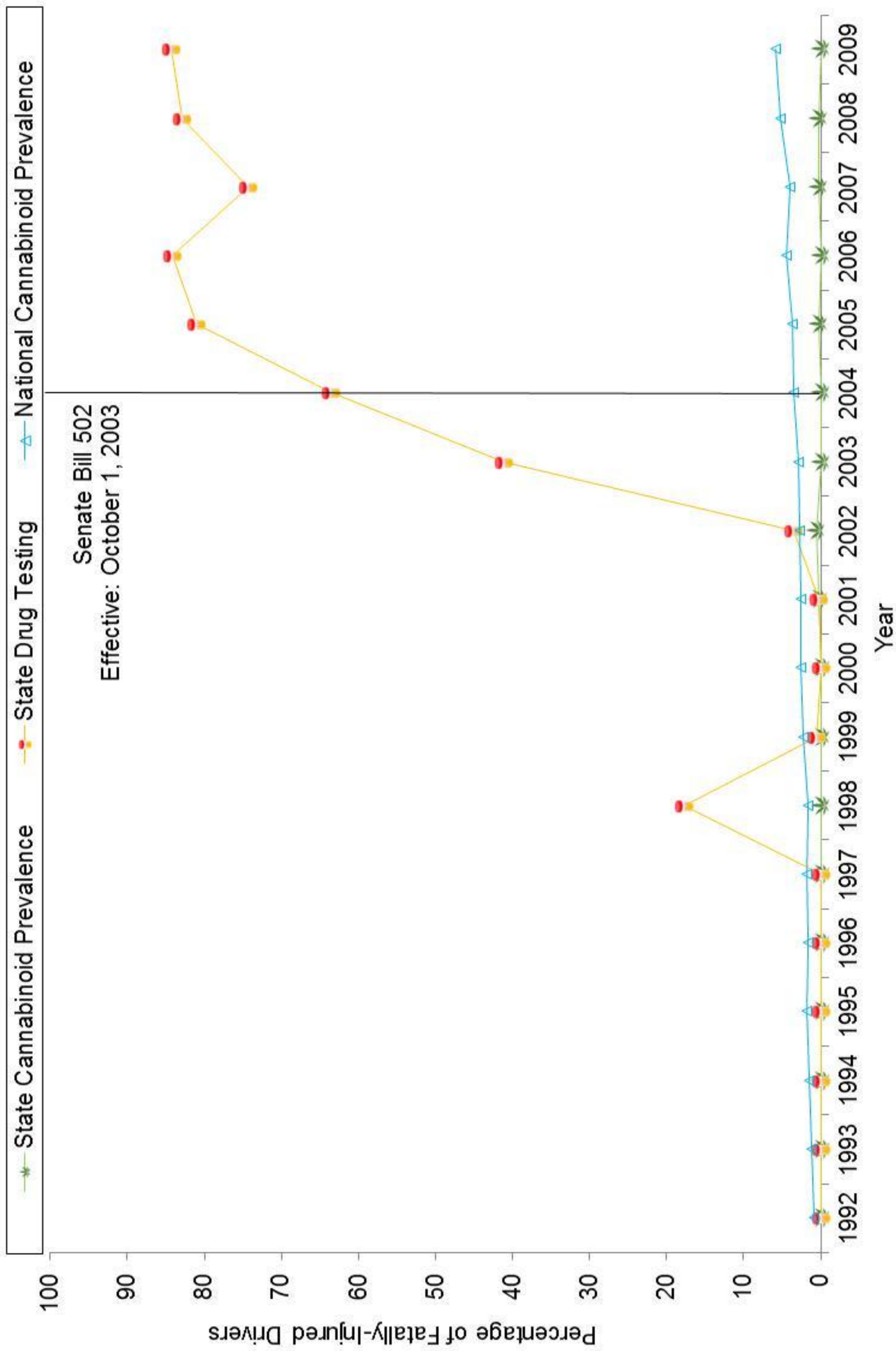

Figure B10. Cannabinoid prevalence and drug testing among fatally-injured drivers in Maryland, 1992–2009.

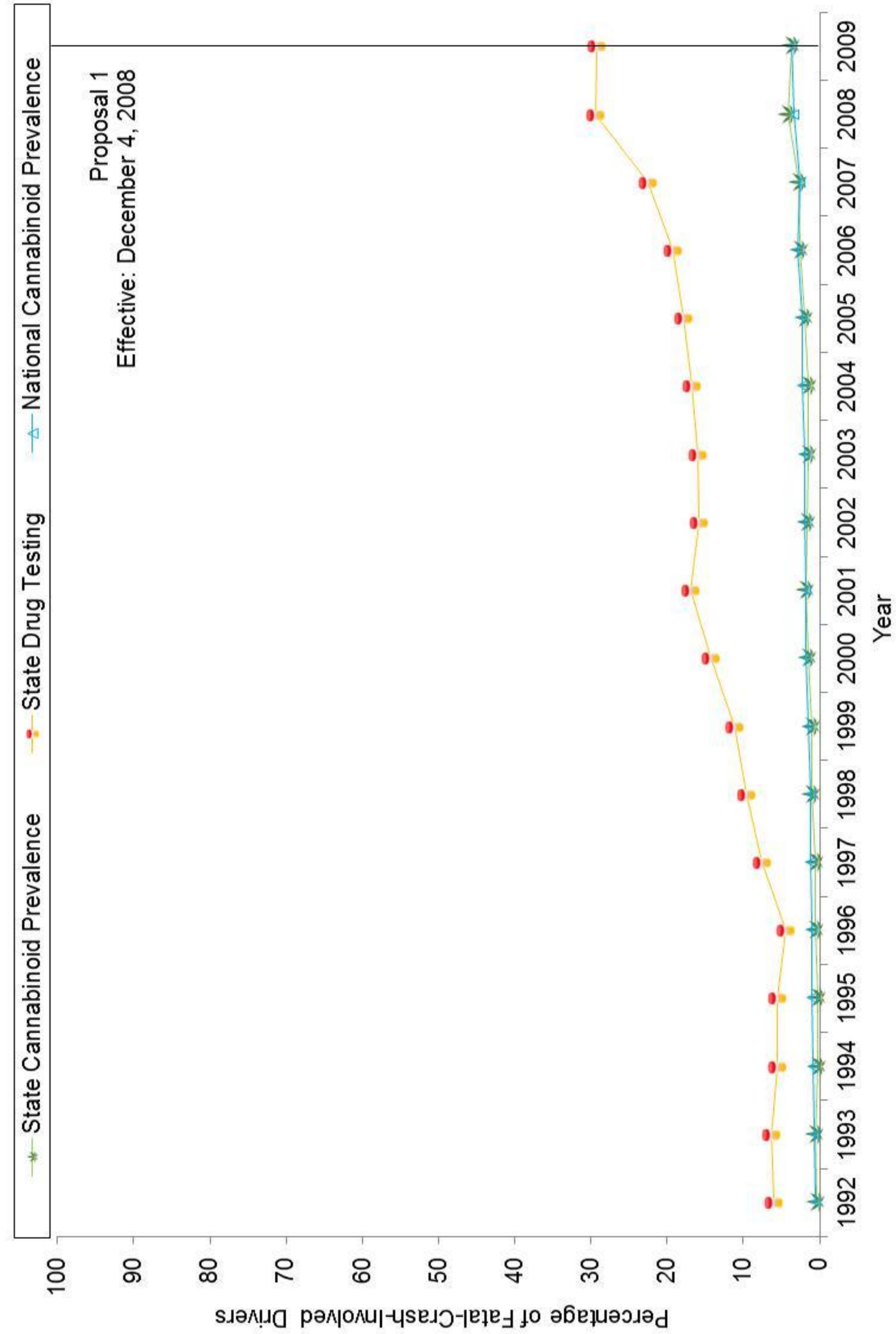

Figure B11. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Michigan, 1992–2009.

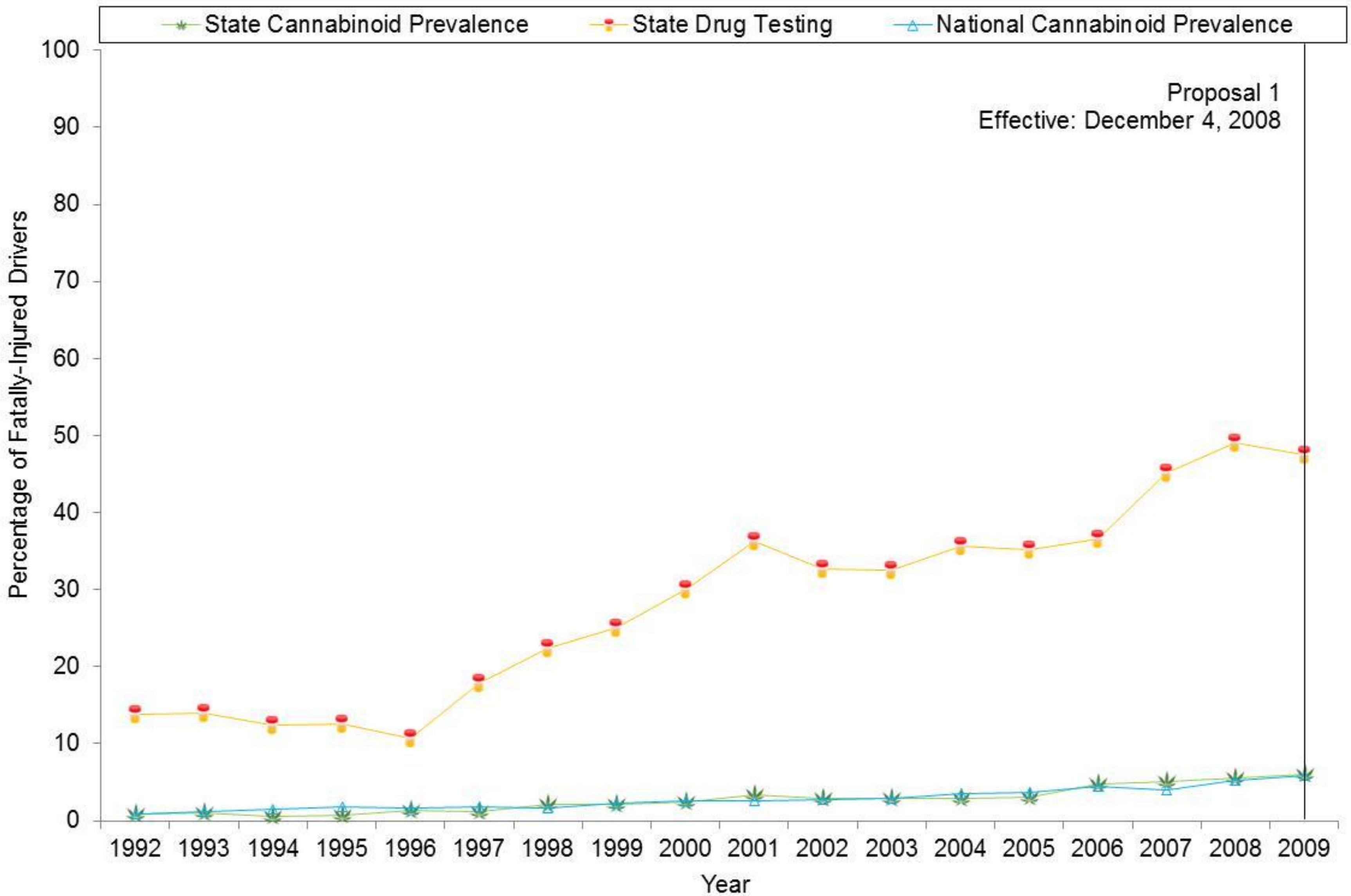

Figure B12. Cannabinoid prevalence and drug testing among fatally-injured drivers in Michigan, 1992–2009.

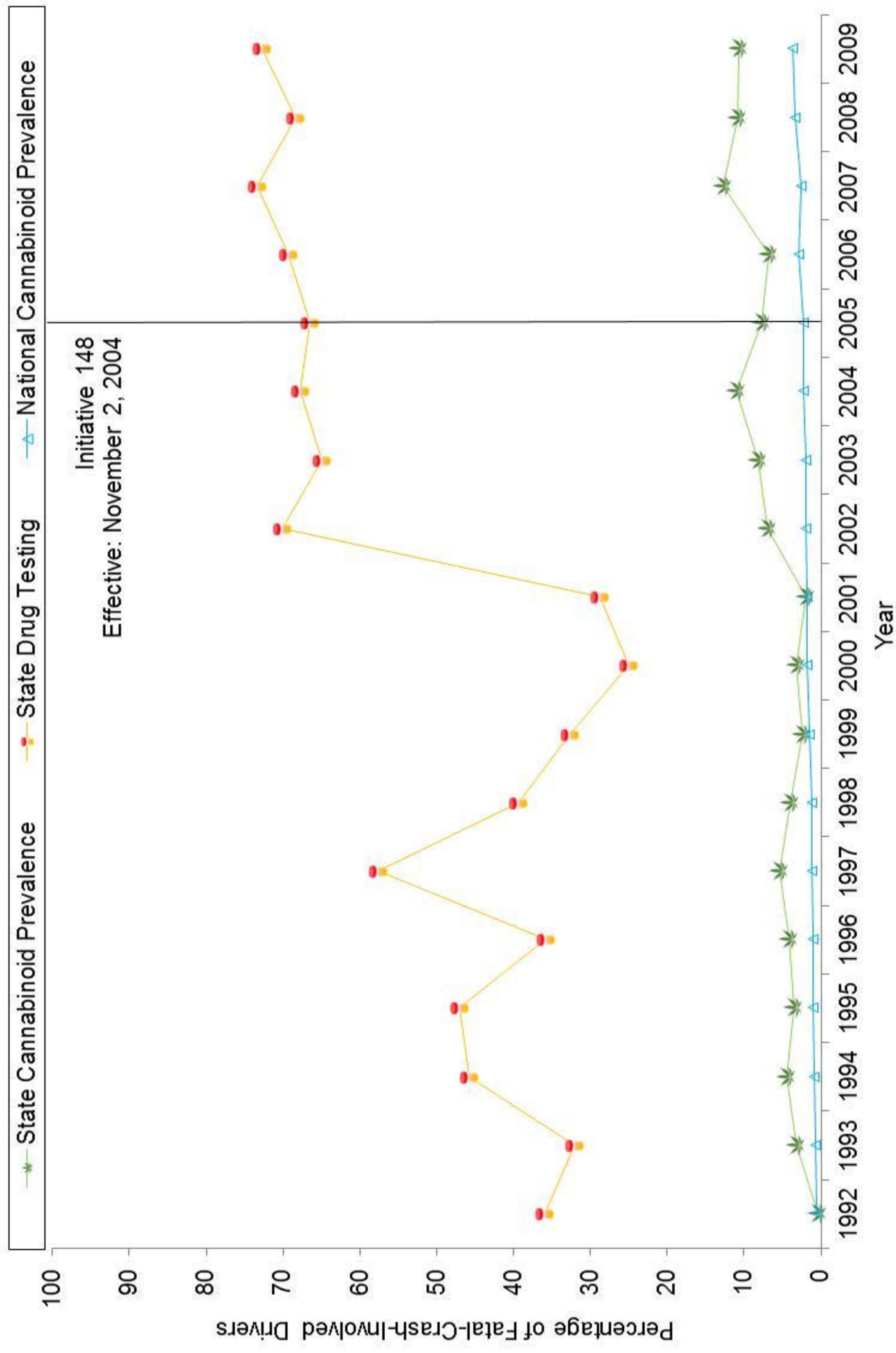

Figure B13. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Montana, 1992–2009.

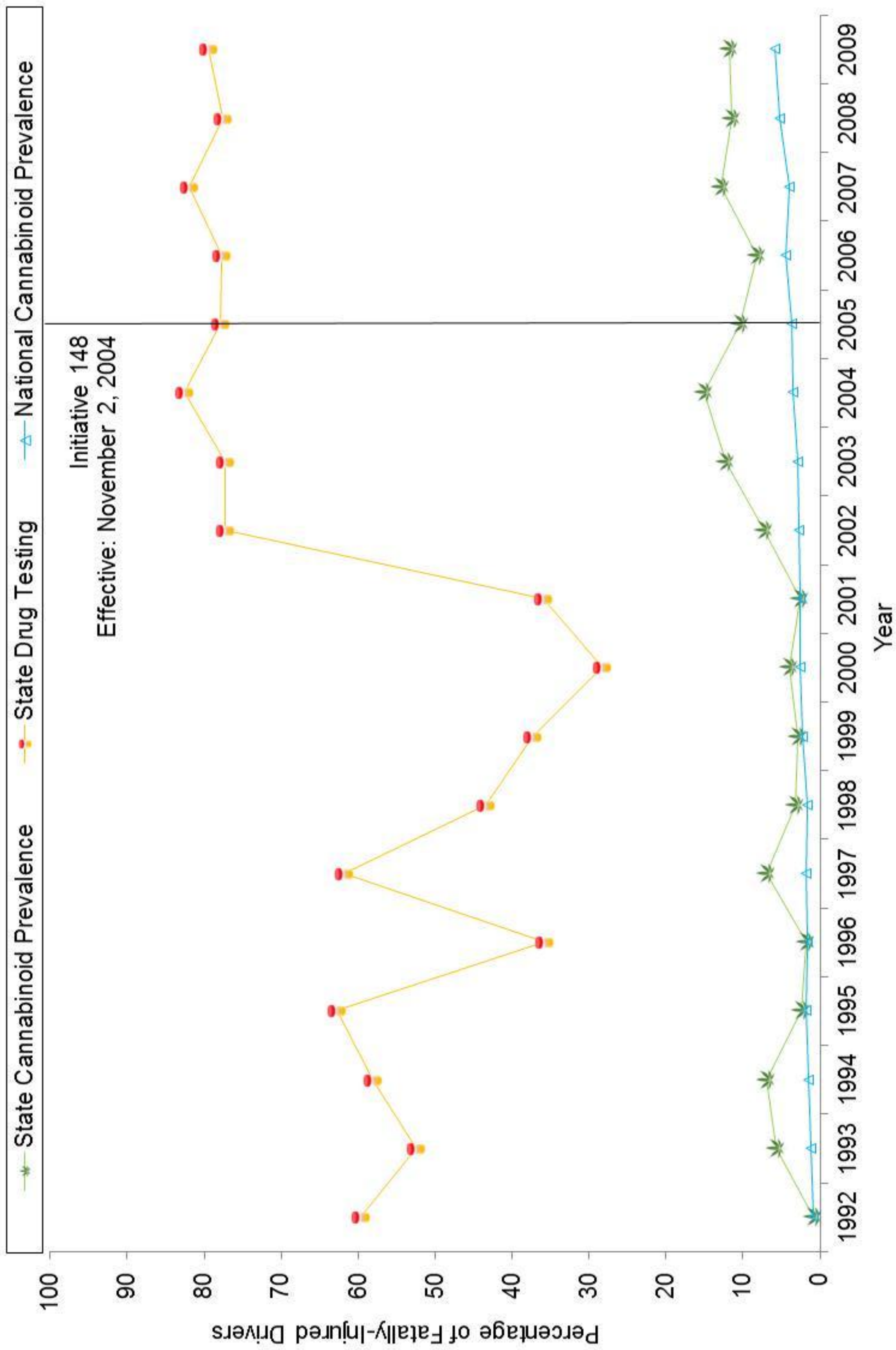

Figure B14. Cannabinoid prevalence and drug testing among fatally-injured drivers in Montana, 1992–2009.

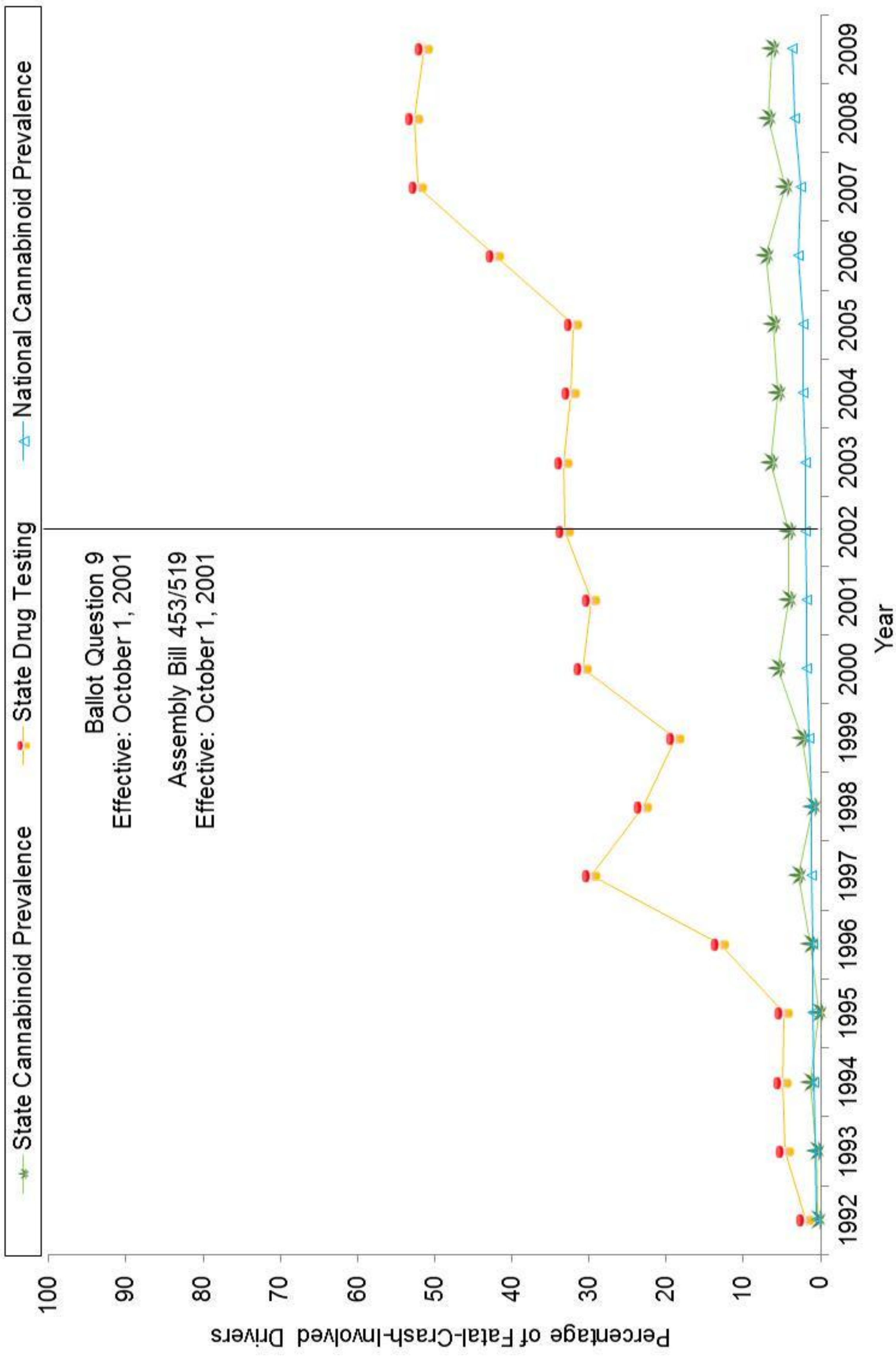

Figure B15. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Nevada, 1992–2009.

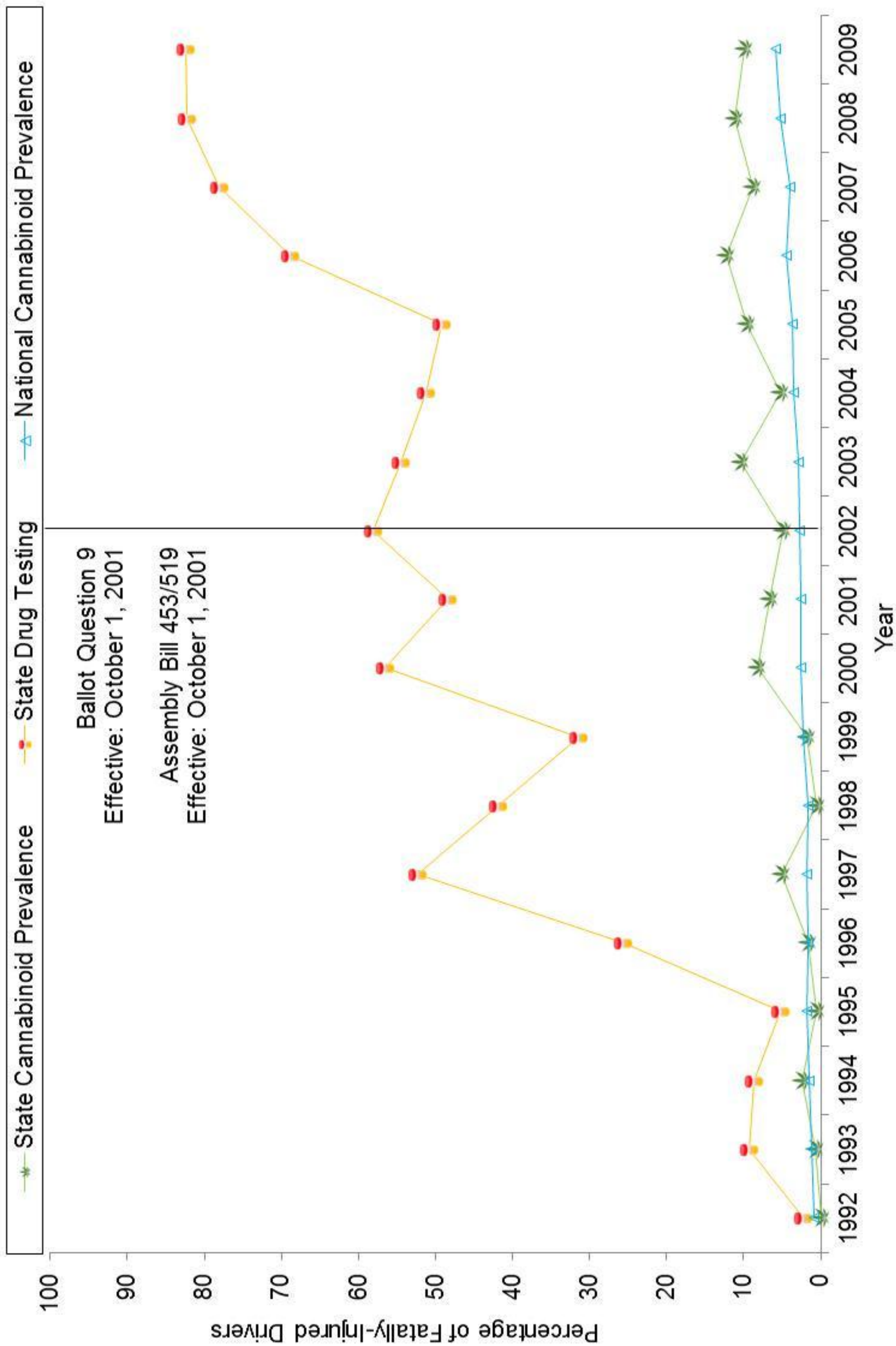

Figure B16. Cannabinoid prevalence and drug testing among fatally-injured drivers in Nevada, 1992–2009.

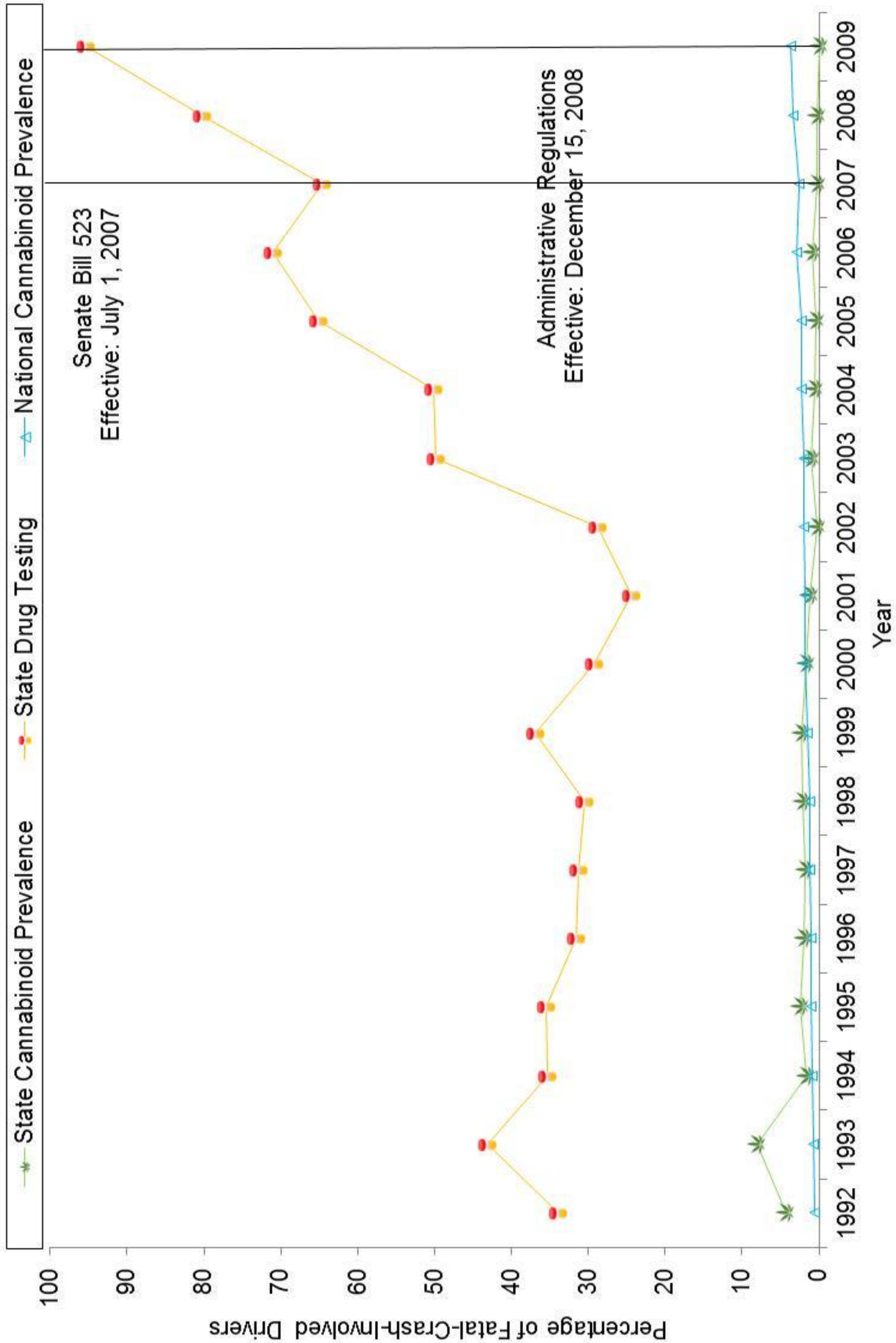

Figure B17. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in New Mexico, 1992–2009.

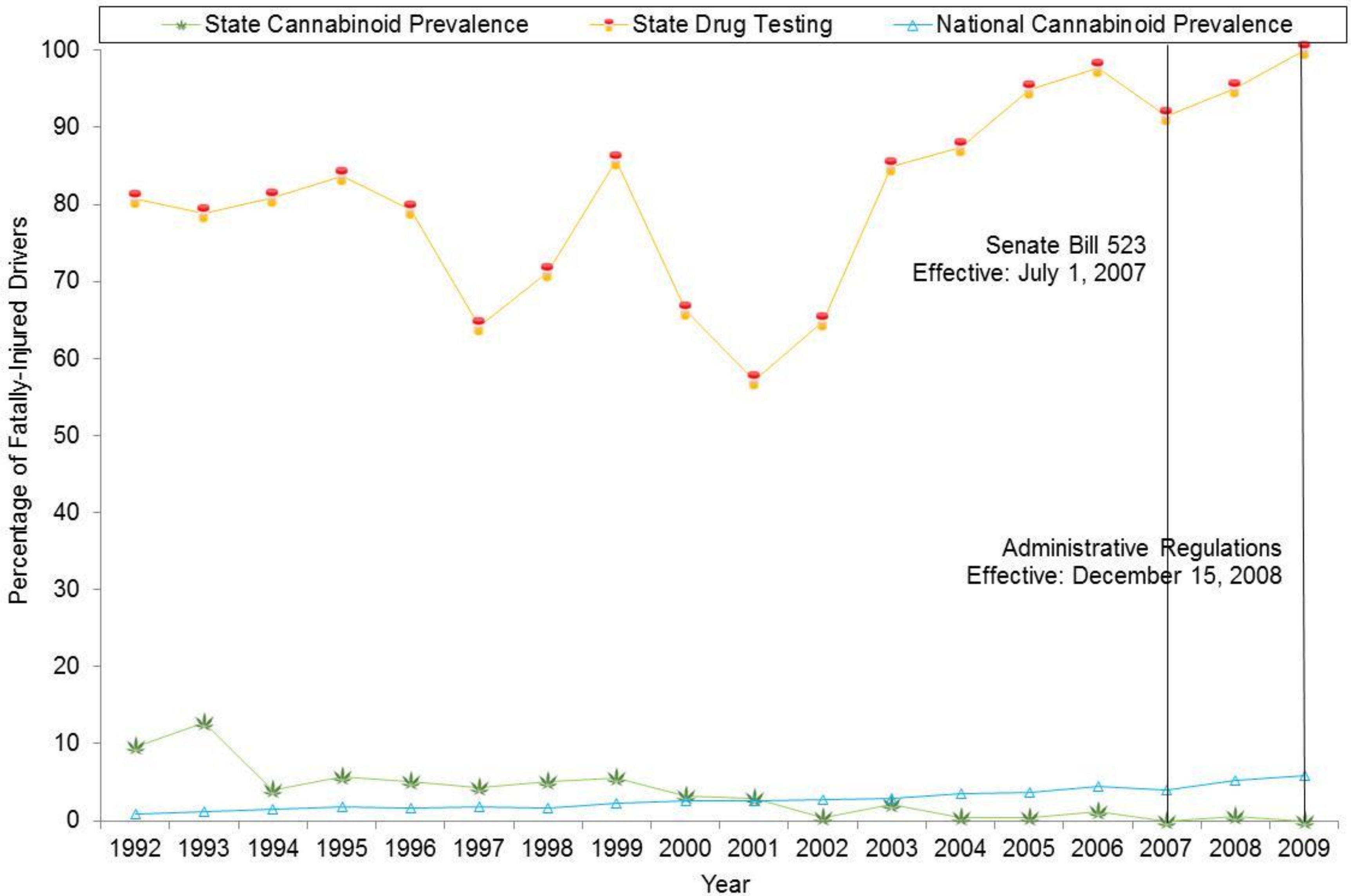

Figure B18. Cannabinoid prevalence and drug testing among fatally-injured drivers in New Mexico, 1992–2009.

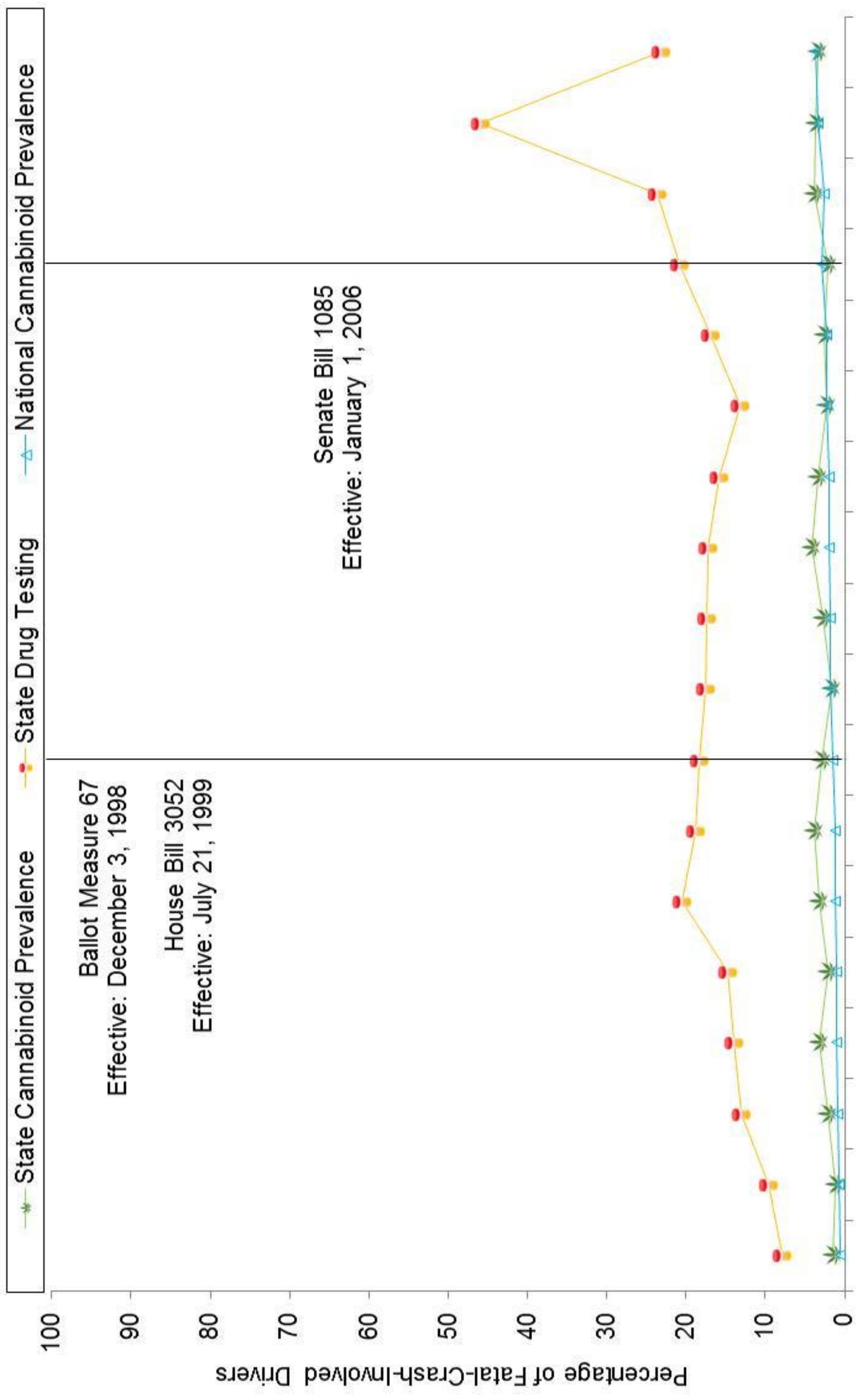

Figure B19. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Oregon, 1992–2009.

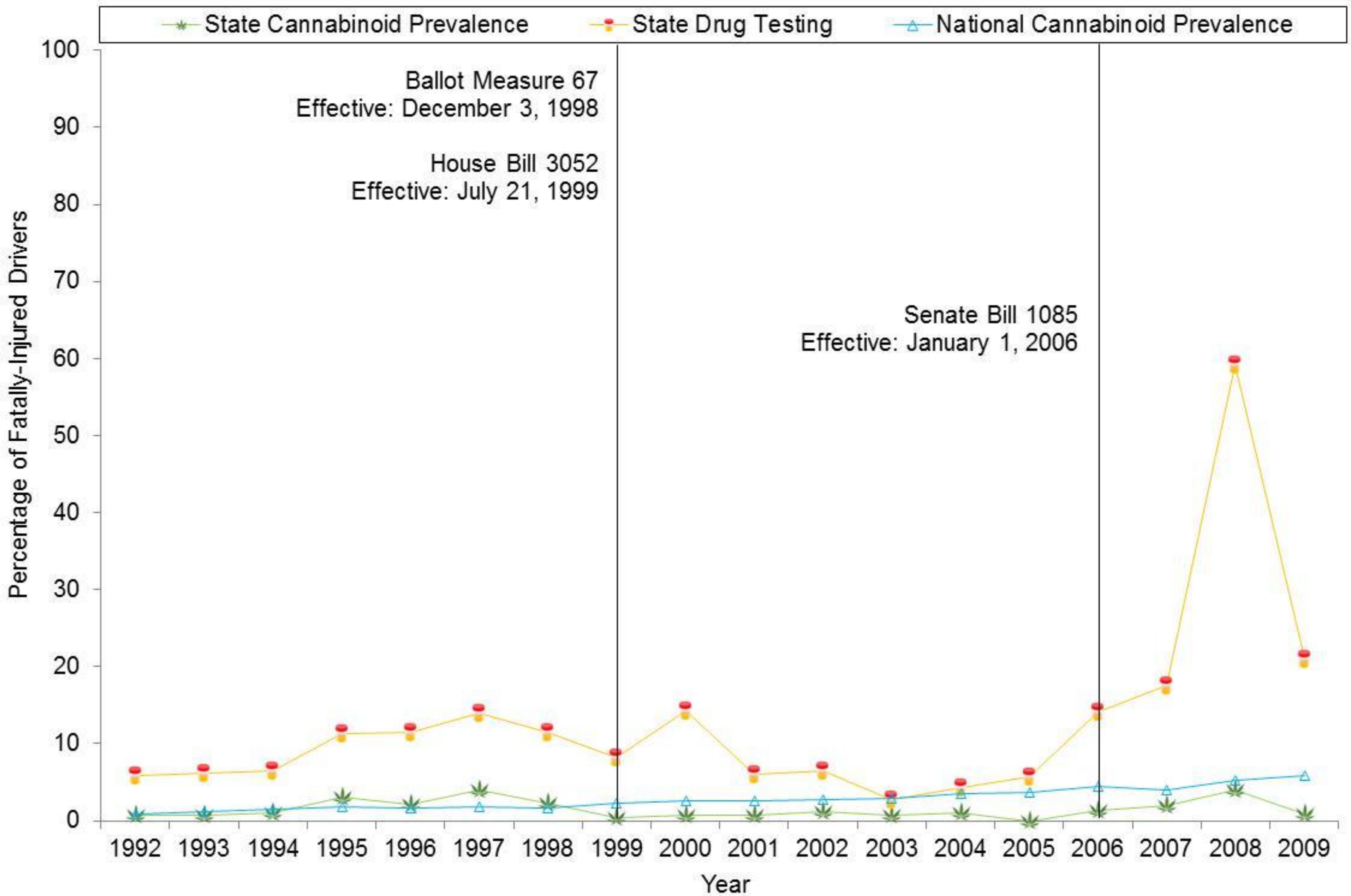

Figure B20. Cannabinoid prevalence and drug testing among fatally-injured drivers in Oregon, 1992–2009.

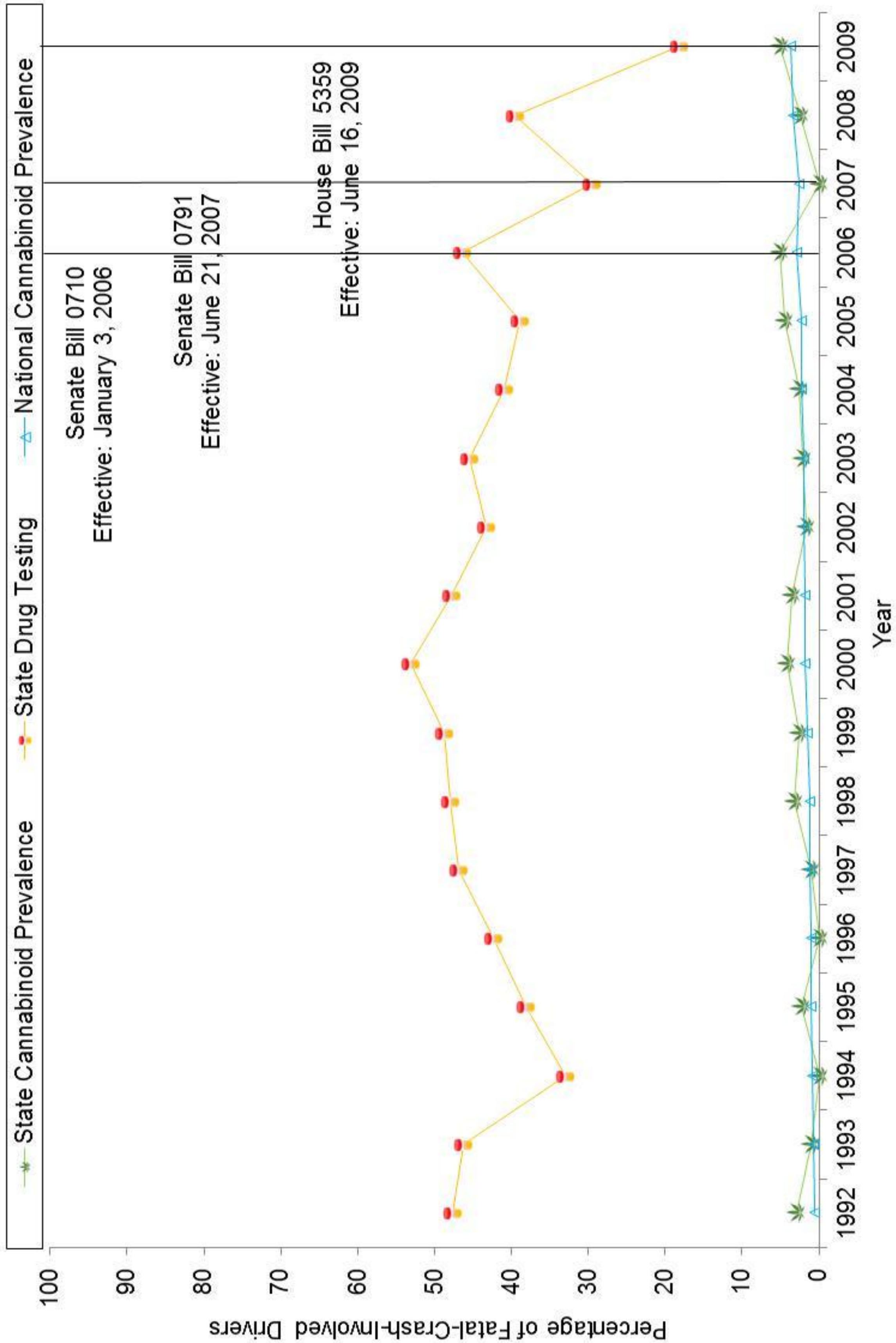

Figure B21. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Rhode Island, 1992–2009.

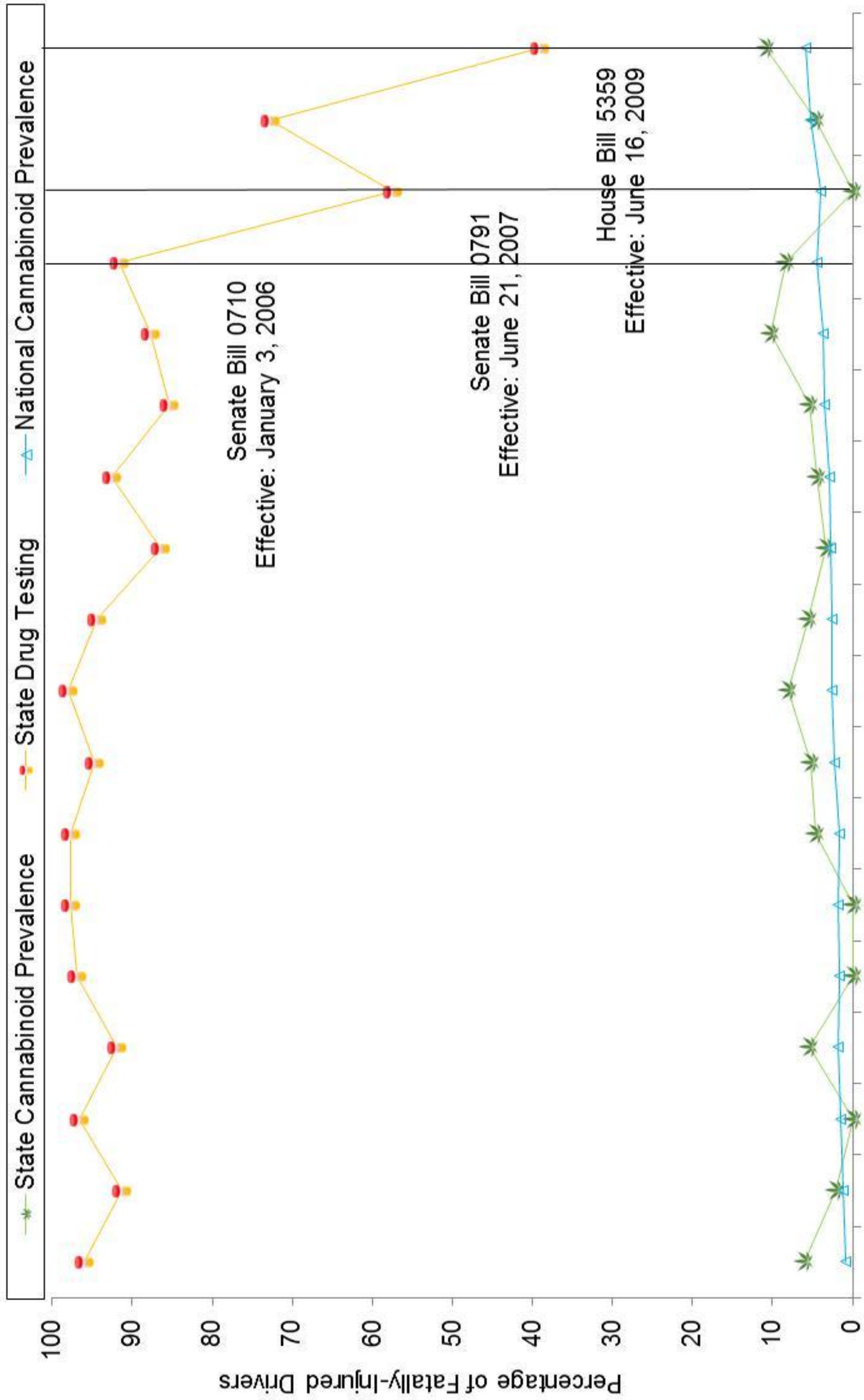

Figure B22. Cannabinoid prevalence and drug testing among fatally-injured drivers in Rhode Island, 1992–2009.

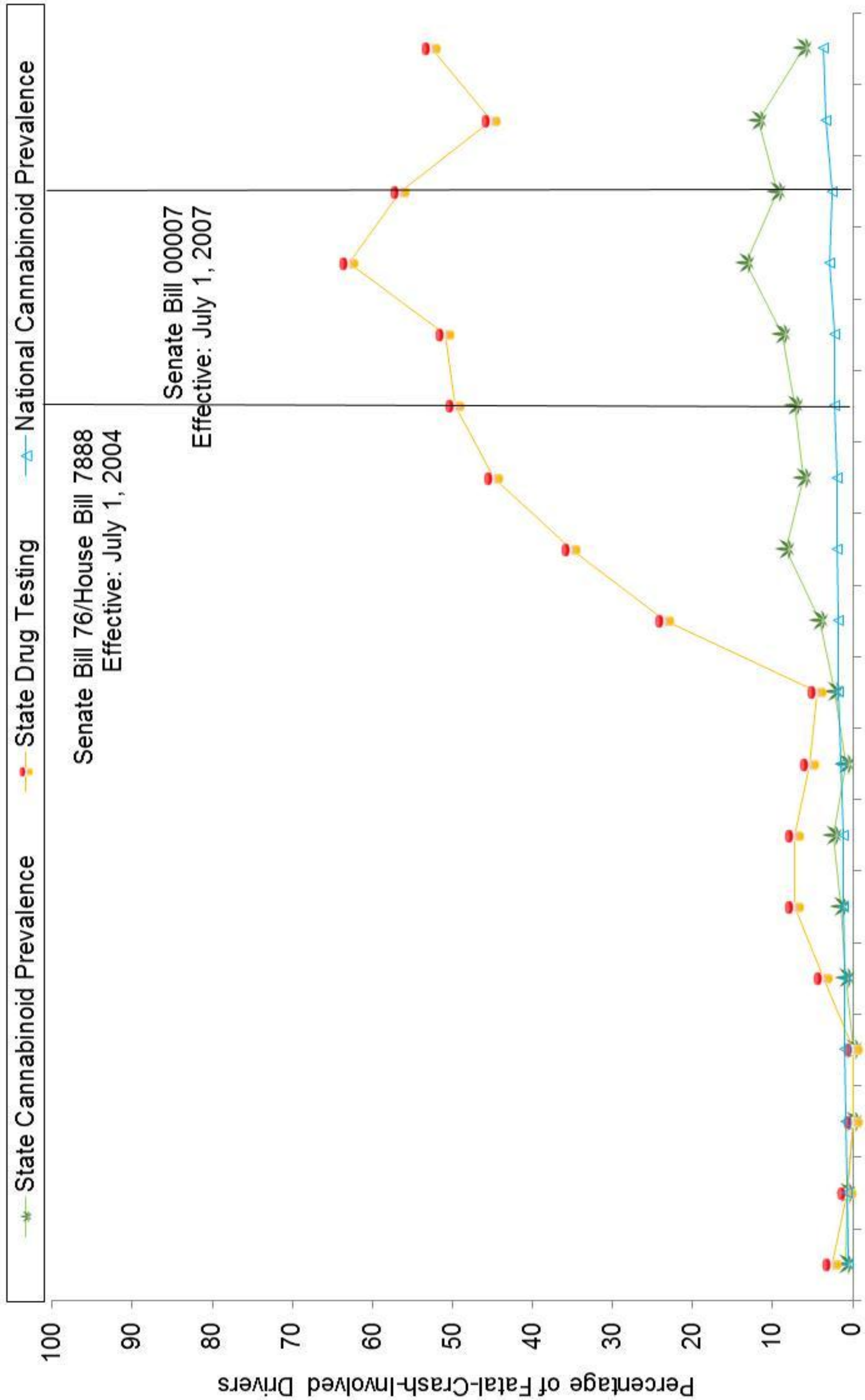

Figure B23. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Vermont, 1992–2009.

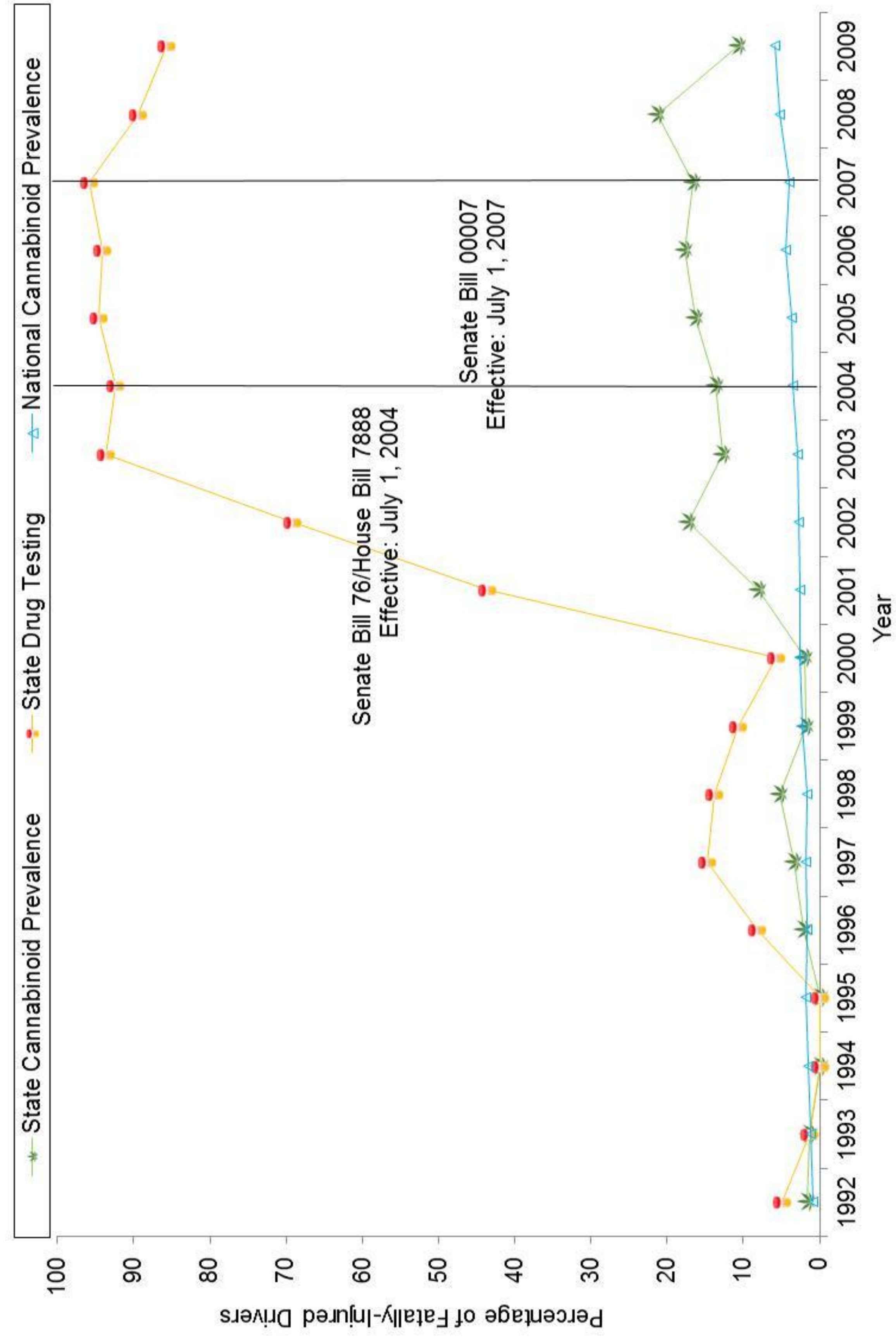

Figure B24. Cannabinoid prevalence and drug testing among fatally-injured drivers in Vermont, 1992–2009.

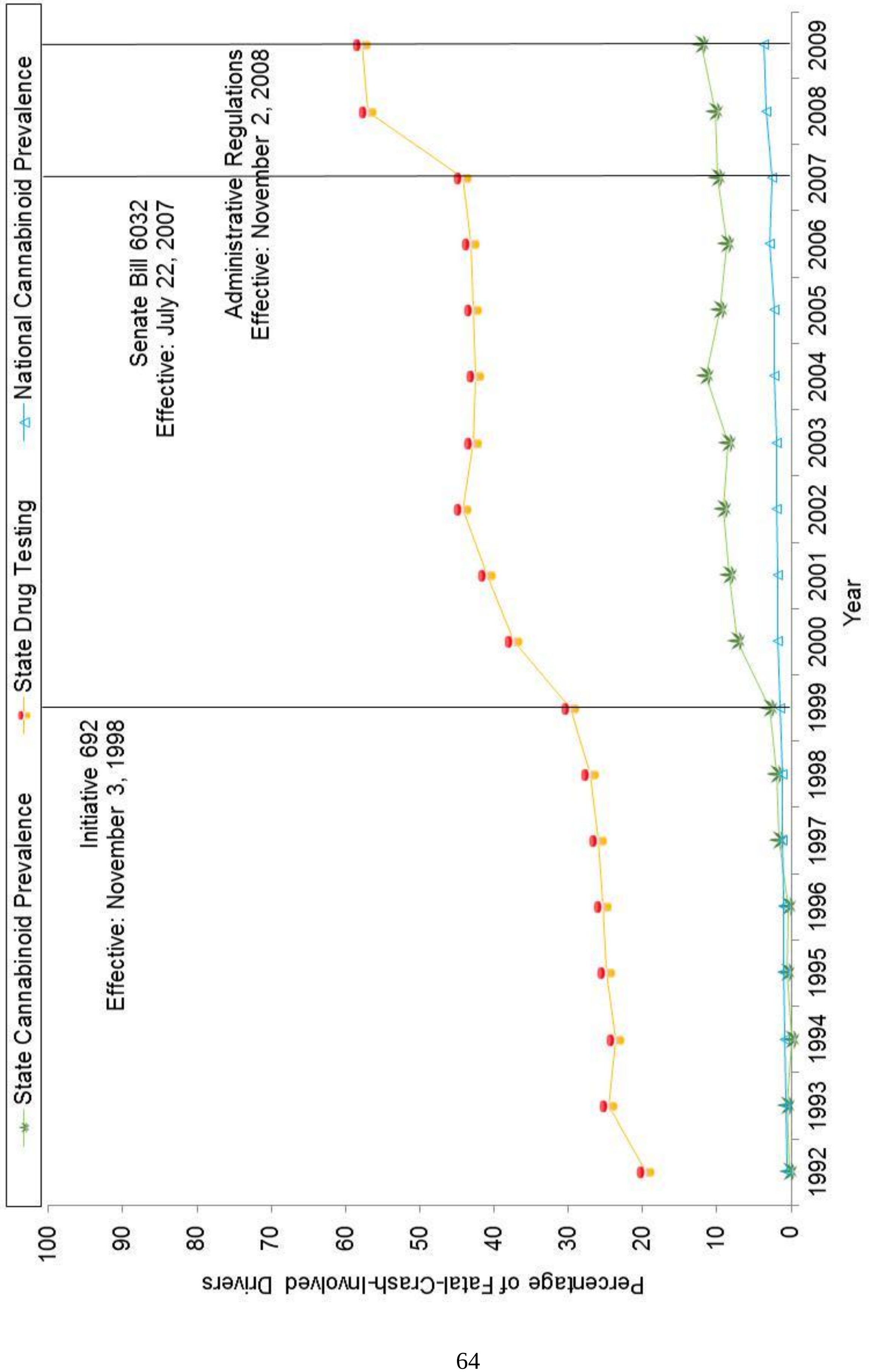

Figure B25. Cannabinoid prevalence and drug testing among fatal-crash-involved drivers in Washington, 1992–2009.

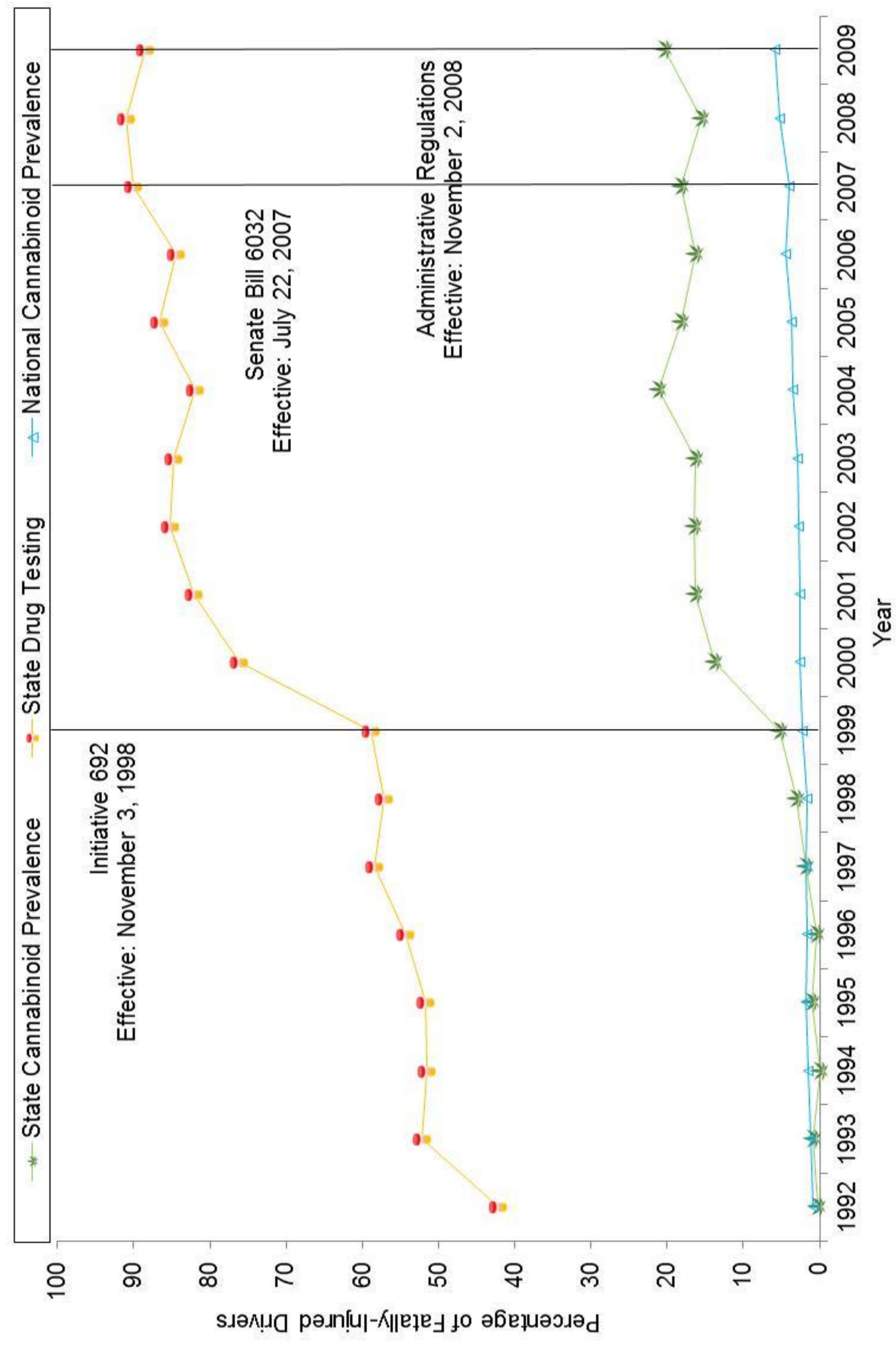

Figure B26. Cannabinoid prevalence and drug testing among fatally-injured drivers in Washington, 1992–2009.