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Profiles of illicit drug use during annual key holiday and control periods in Australia: wastewater analysis in an urban, a semi-rural and a vacation area

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Abstract

Aims

To examine changes in illicit drug consumption between peak holiday season (23 December–3 January) in Australia and a control period two months later in a coastal urban area, an inland semi-rural area and an island populated predominantly by vacationers during holidays.

Design

Analysis of representative daily composite wastewater samples collected from the inlet of the major wastewater treatment plant in each area.

Setting

Three wastewater treatment plants.

Participants

Wastewater treatment plants serviced approximately 350 000 persons in the urban area, 120 000 in the semi-rural area and 1100–2400 on the island.

Measurements

Drug residues were analysed using liquid chromatography coupled to a tandem mass spectrometer. Per capita drug consumption was estimated. Changes in drug use were quantified using Hedges' g.

Findings

During the holidays, cannabis consumption in the semi-rural area declined (g = −2.8) as did methamphetamine (−0.8), whereas cocaine (+1.5) and ecstasy (+1.6) use increased. In the urban area, consumption of all drugs increased during holidays (cannabis +1.6, cocaine +1.2, ecstasy +0.8 and methamphetamine +0.3). In the vacation area, methamphetamine (+0.7), ecstasy (+0.7) and cocaine (+1.1) use increased, but cannabis (−0.5) use decreased during holiday periods.

Conclusions

While the peak holiday season in Australia is perceived as a period of increased drug use, this is not uniform across all drugs and areas. Substantial declines in drug use in the semi-rural area contrasted with substantial increases in urban and vacation areas. Per capita drug consumption in the vacation area was equivalent to that in the urban area, implying that these locations merit particular attention for drug use monitoring and harm minimisation measures.

Keywords: Australia; cannabis; cocaine; drug epidemiology; ecstasy; LC-MSMS; methamphetamine;

Queensland

Illicit drug use can result in negative consequences for public health and social order [1]. The prevalence of illicit drug use has been traditionally monitored using self-report data, such as household surveys [2-4]. Accurate surveillance of clandestine illicit drug use is difficult, but essential, for the strategic development and evaluation of the effectiveness of public health and law enforcement schemes.

One alternative method of estimating illicit drug use within a population is wastewater analysis, measuring mass loads of excreted drug metabolites from wastewater [5, 6]. Wastewater analysis can provide complementary information to survey methods for monitoring population drug use [7-9]. For example, while wastewater analysis cannot provide information such as users' behaviour and demographics, it can provide near-real-time objective data on quantities and types of drugs consumed within a catchment {one example of particular relevance is ecstasy use because tablets sold as 'ecstasy' sometimes do not actually contain 3,4-methylenedioxymethamphetamine (MDMA) [10-12]} and minimises ethical issues as the pooled data collection supports anonymity [13].

Wastewater analysis has been used to measure geographical variations in illicit drug use within and between cities at a given time point. For example, Zuccato *et al*. [8] demonstrated that cannabis use was more prevalent, but cocaine was less prevalent, in Lugano and London than in Milan, while methamphetamine use was similar. Irvine *et al*. [14] and Lai *et al*. [15] have recently demonstrated higher MDMA and methamphetamine consumption in Australian than European cities. Greater drug use in metropolitan versus rural settings within Oregon (USA) and across Belgium has been also reported [16, 17]. Recently, Thomas *et al*. showed higher cocaine use in European cities located in the west and central than those in the north and east [18].

Furthermore, the approach has described temporal trends in drug use, such as a decline in cocaine use in Milan after the global financial crisis [9]. Importantly, wastewater monitoring can provide a high temporal resolution, with, for instance, a number of studies demonstrating a higher drug use on weekends than weekdays for most illicit drugs (e.g. [18-21]). While there is substantial evidence demonstrating weekly variations in substance use [18, 22-24] and variations in use while on personal holidays [25], information on seasonal variations in drug use prevalence is sparse as traditional prevalence surveys typically enquire about users' behaviour over a number of months. Limited data from ambulance, hospitals and targeted surveys indicate that the Christmas/New Year holiday season is a time when sub stance use becomes more common [22, 25, 26]. Similarly, higher drug loads have been detected in urban wastewater samples between December and January [27, 28]. These previous studies show a change in drug use associated with holidays, but no data are available on whether such changes are restricted to metropolitan areas or whether drug preferences change during specific 'party' periods. Spatial assessment of variations in substance use is crucial as drug use patterns in urban areas may not be the same as that in other communities across a state or country [29]. Comprehensive analyses of drug use on weekends or holiday seasons across regions would potentially be useful in allowing health agencies to strategically manage intervention schemes.

The current study monitored the consumption of the four most commonly used illicit drugs (cannabis, cocaine, ecstasy and methamphetamine) in Australia [2] during the Australian peak summer holiday period, which includes Christmas and New Year. Per 1000 capita drug consumption was compared with control periods in three different locations: a large coastal urban area; an inland semi-rural area; and an island with a small resident population predominantly populated by vacationers during holiday times. We examined changes in consumption patterns of the four illicit substances during holiday times in each of these locations.

Methods

Wastewater sampling

Wastewater sampling was conducted at the major wastewater treatment plant (WWTP) of each of the three study locations in south-east Queensland (Australia) (Table 1). Two sampling campaigns were conducted, one during the peak holiday period (Christmas to New Year: 23 December 2010–3 January 2011) and one as a comparative control period (26 February–3 March 2011).

Catchment	Inland semi-rural	Coast urban	Vacation island
Population	120 000[a]	350 000[a]	1100–2400[b]
Index of relative socioeconomic advantage and disadvantage (Aust %ile)[c]	973 (71)	1023 (86)	1028 (87)
Index of education and occupation (Aust %ile)[d]	977 (70)	980 (72)	978 (70)
Daily flow[e] (mL/day)	40 (50)[f]; 30 (15)[g]	120 (30)[f]; 70 (9)[g]	0.57 (20)[f]; 0.25 (25)[g]
Sampling mode	Volume proportional[h]	Continuous flow-proportional[i]	Flow-/time-proport
Sampling day	10[f]; 5[g]	8[f]; 5[g]	11[f]; 4[g]

Table 1. Information of each study location.

1. aRegional council data. Changes in the population size during holiday periods are unknown. bEstimated by dividing total wastewat flow by a typical daily per capita water consumption. cIndex of Relative Socio-economic Advantage and Disadvantage: a continuum of advar (high values) to disadvantage (low values) derived from Australian 2006 Census variables, like households with low income and people with tertiary education [52]. dIndex of Education and Occupation: includes Australian 2006 Census variables relating to the educational and occupational characteristics of communities, such as the proportion of people with a higher qualification or those employed in a skilled occupation. Lower scores indicate an area with a high proportion of people without qualifications, without jobs and/or with low skilled jobs [52]. eAverage (relative standard deviation %). fHoliday period. gControl period. h7am–7am for a daily composite sample (every 200 m3 grab sample; approx. 165 grab samples per day, ΔTequivalent for one grab sample = 9 minutes). i6am–6am for a daily composite sample.j10 10am for a daily composite sample; time-proportional hourly composite samples (ΔT = 3 minutes), flow-proportionally manually mixed acco to hourly flows to form daily 24-hour composite sample.

Samples (24-hour composites) were collected from the inlet of the WWTP at each site using high-frequency sampling modes following best practice recommendations [30, 31]. Sampling modes are summarised in Table 1: briefly, $WWTP_{urban}$ used continuous flow-proportional sampling and $WWTP_{semi\text{-}rural}$ used volume-proportional sampling. For the

WWTP $_{island}$, hourly time-proportional (ΔT = 3 minutes) composite samples were collected, and hourly samples were flow-proportionally mixed (manually, according to hourly flow data) to obtain a 24-hour composite sample. All sampling modes herein were evaluated with previously published methods [30, 31] to guarantee the collection of representative 24-hour composite samples considering the different local boundary conditions. All samples were refrigerated during collection, acidified on site after subsampling and frozen until analysis. This method of sample conservation has been demonstrated to maintain target chemical stability in wastewater [32-34].

Chemical analyses

Six drug residues of the parent drug and/or its major metabolite were measured. These included MDMA, amphetamine, benzoylecgonine, cocaine, methamphetamine and tetrahydrocannabinol carboxylic acid (THC-COOH). Validated analytical methods were applied (detailed in Lai *et al.* [15]). Briefly, for all compounds, except THC-COOH, filtered wastewater samples (1 mL) were spiked with mass-labelled internal standards and analysed without extraction process. THC-COOH in the filtered samples (50 mL) was enriched onto solid-phase extraction cartridges (Oasis MCX®, Waters, Milford, MA, USA), and then eluted in methanol and concentrated (0.3 mL) under a stream of nitrogen at 30°C. All samples were analysed together with calibration standards by high-performance liquid chromatography (Shimadzu Nexera UHPLC system, Kyoto, Japan) coupled to a triple quadrupole tandem mass spectrometer (AB SCIEX QTRAP®5500, Ontario, Canada).

Back estimation of illicit drug consumption

This study applied the back-calculation method for estimating illicit drug consumption (mg/day/1000 people) reported previously in the literature (e.g. [8, 17]). The following formula was used:

$$\frac{Drug\ residue\ concentration\left(\frac{ng}{L}\right) \times Waterwater\ flow\ rate\left(\frac{L}{day}\right) \times Correction\ factor}{Estimated\ number\ of\ people\ in\ a\ given\ area}$$

A correction factor, that relates to average excretion rate of a given drug residue and the molecular mass ratio of a parent drug to its metabolite, was calculated based on published values (Table S1). For example, when residue levels of benzoylecgonine are used to back-estimate parent cocaine consumption, a correction factor of 3.1 (1.1/0.35) is calculated based on an average excretion rate of 35% [35-37]and molar mass ratio of 1.1 (cocaine to benzoylecgonine). The estimated number of people in the catchment area was based on the most recent census data of the regional council for urban and semi-rural areas [38]. Given the population volatility in the vacation area, the number of people in this area was estimated by dividing daily wastewater flow by typical individual water consumption (230 L/day/person, based on historical WWTP data. Note: This area is drained by a separate sewer system, which collects wastewater from households in one pipe system and stormwater runoff in another pipe system. Investigations by the local sewer operators reveal that infiltration of groundwater is unlikely, and there are no industrial activities contributing to wastewater. Consequently, changes in wastewater flows on the vacation island predominantly reflect changes in number of people in the drained catchment.). Where analytically possible, two residue measurements were used to back-calculate consumption in order to improve reliability of estimates [15]. For example, both cocaine itself and its major metabolite, benzoylecgonine, were used to back-calculate average cocaine consumption (Table S1). Amphetamine and methamphetamine found in wastewater may originate from illicit sources and also from certain prescription medications. These include selegiline (for Parkinson's disease) which metabolises to methamphetamine, and dexamphetamine (primarily for attention deficit hyperactivity disorder), which metabolises to amphetamine. To estimate illicit methamphetamine consumption, we estimated the average daily excreted load of amphetamine and methamphetamine that may have arisen from these medical sources using official prescription data [39] (amphetamine from dexamphetamine: 780, 270 and 3.8 mg/day; methamphetamine from selegiline: 22, 10 and 0.11 mg/day, for urban, semi-rural and vacation areas respectively). We then subtracted these estimates from the load of amphetamine and methamphetamine measured in each sample. As police seizure data suggest that illicit amphetamine production is negligible in Australia [40], the small amount of amphetamine measured in samples was assumed to be due to illicit methamphetamine consumption. Methamphetamine consumption was back-estimated from both the levels of methamphetamine and amphetamine measured in samples. For MDMA and cannabis, only one drug residue for each (MDMA and THC-COOH respectively) was analysed and used for back calculating consumption, as per current literature (e.g. [8, 41]).

Drug dosage was calculated by dividing estimated consumption with the reference dose recently reported in Australia: 20 mg for cannabis, 30.5 mg for methamphetamine, 145 mg for cocaine and 80 mg for MDMA [40, 42-45]. It should be noted that the reference dose is corrected for purity information (for methamphetamine and cocaine), and in the case of MDMA, purity and typical content recorded in the jurisdiction under study (see Prichard *et al*. [20] for more details). Cannabis dose is not assessed in any Australian national drug reports. Instead, we adopted literature values for the mean dose of cannabis which resulted in psychological effect [45, 46].

Data analysis

To quantify the degree of change in drug use between monitoring periods, the Hedges' g effect size measure was applied. Hedges' g is an adjusted measurement of the magnitude of the difference by taking pooled variability into account [47] (see equations in Supporting Information). A ‘g’ of 0.2 is considered a small change, 0.5 is medium and 0.8 or more is large [48]. Analysis was conducted using Comprehensive Meta-Analysis 2.2.

Results

Cannabis was the most common drug used during the control period (~80–90% of total estimated drug consumption), with estimated consumption at 1000–2000 mg/day/1000 people in all three areas (Fig. 1a, c, f). Methamphetamine was the next most commonly consumed drug across the three areas, with levels approximately one order of magnitude lower than cannabis. Cannabis and methamphetamine use in semi-rural and urban areas remained relatively stable throughout the week. Cocaine and MDMA consumption was relatively low in the semi-rural area, but higher in the urban and vocation areas. Use clustered around the weekends in the three areas at a range of about 20–200 mg/day/1000 people for cocaine and 5–50 mg/day/1000 people for MDMA.

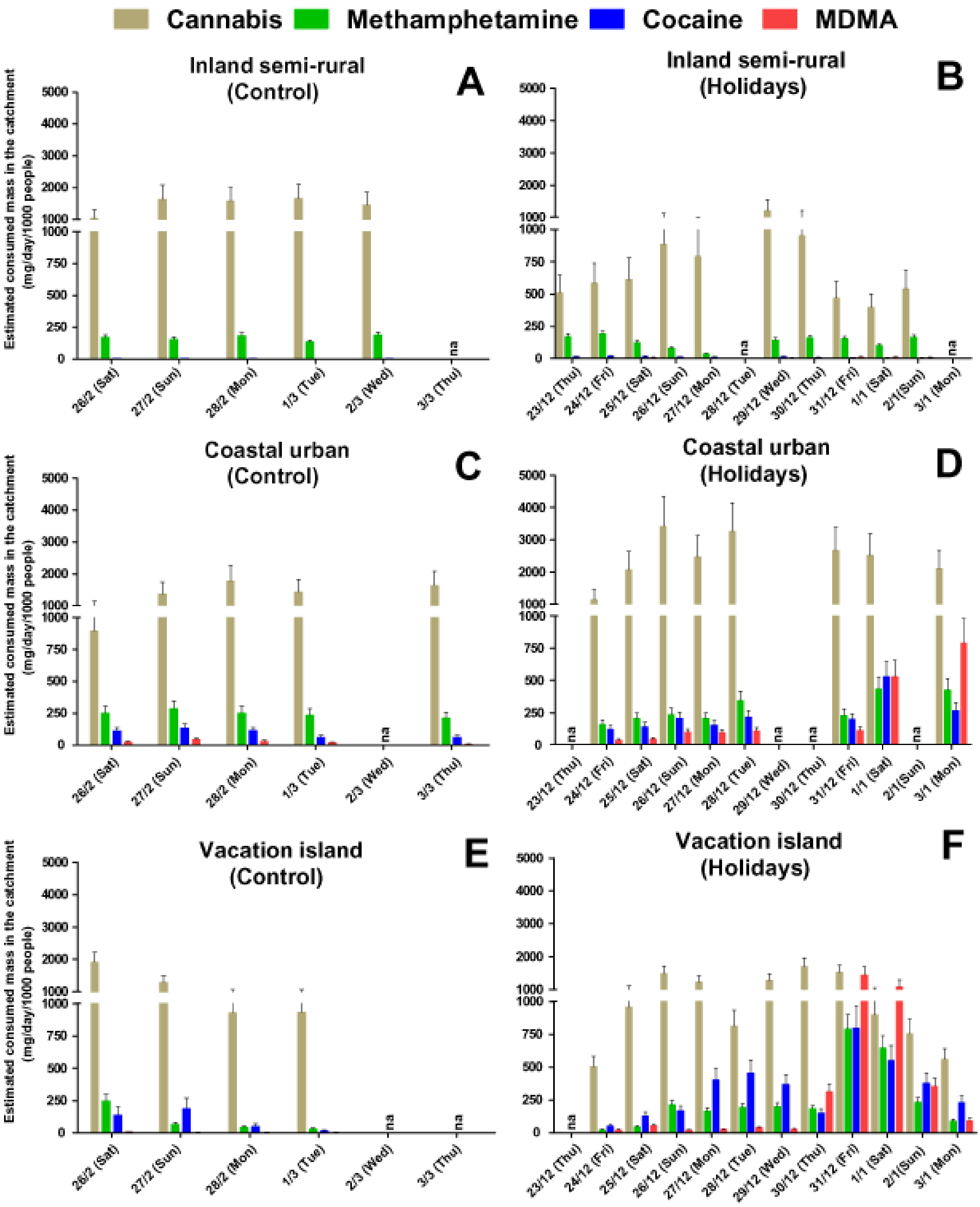

Figure 1. Estimated daily consumption (mg/day/1000 people) of cannabis, methamphetamine, cocaine and 3,4-methylenedioxymethamphetamine (MDMA) during the control (left column) and holiday (right column) periods in the three study locations (Table S3). 'na' means that no sample was collected on that day. As described in Lai *et al.* [15], error bars combined the uncertainty of sampling, flow measurement, chemical analysis and excretion fraction (Table S2)

In the semi-rural area levels of drug use during the holiday period did not differ dramatically from those in the control period. Most notably, cannabis use declined, approximately halving in the holiday period overall, and was lower during the New Year period and in the lead up to the Christmas holiday (Fig. 1b). Methamphetamine use remained relatively unchanged between these periods. Cocaine and MDMA use increased during the holiday period (at least doubling), but still remained an order of magnitude lower than that of the other two drugs.

In the urban area, cannabis consumption almost doubled during the holiday period (Fig. 1d). Methamphetamine consumption remained relatively stable throughout the holiday and control period, but increased around New Year. Use of cocaine and MDMA, which showed a substantial weekend cyclical effect during the control period, at least doubled during the holiday period. Consumption of both of these drugs increased during the New Year period, in particular, with their levels either equalling or exceeding those of methamphetamine.

As anticipated, given the demographic change of the vacation area, there was a very distinctive change in drug use in this area between control and peak summer holiday periods (Fig. 1f). Overall, levels of cannabis remained similar across the two periods. Methamphetamine, cocaine and MDMA consumption, which demonstrated weekend elevations during the control period, all increased in the holiday period, with levels of use at least tripling. In particular, over the New Year public holidays, use of these three drugs increased dramatically, with the estimated per 1000 capita consumed masses being similar to, or exceeding, that of cannabis. The change in MDMA use was particularly notable.

Changes in drug use between the monitoring periods varied among the studied sites, as demonstrated by Hedge's g (Fig. 2). The semi-rural area showed a large reduction in cannabis ($g = -2.8$) and methamphetamine (−0.8) consumption, and a strong increase in both cocaine (+1.5) and MDMA (+1.6) use during the peak summer holiday period. Nonetheless, consumption of the latter two drugs remained very low in comparison to the other areas. All the drugs consumed in the urban area increased markedly during the holiday period, with particularly large increases for cannabis (+1.6) and cocaine (+1.2), and lesser increases in methamphetamine (+0.3) and MDMA (+0.8). In the vacation area, there was a medium-sized decline in cannabis (−0.5) use, but a moderate-to-large increase (+0.7–1.1) in use of the other three drugs.

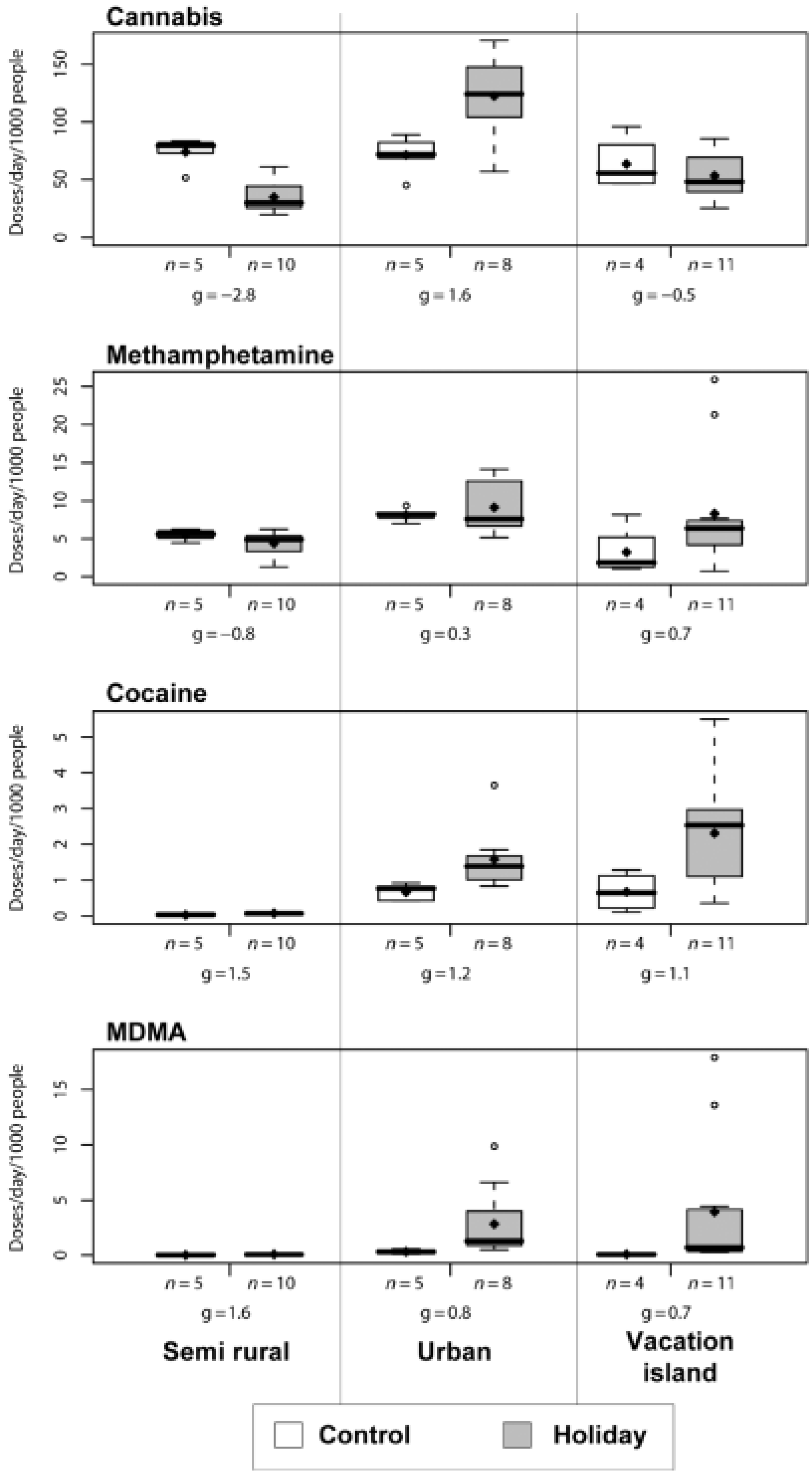

Figure 2. Estimated daily doses (doses/day/1000 people) of cannabis, methamphetamine, cocaine and 3,4-methylenedioxymethamphetamine in the three different communities. White = controls. Grey = holidays. Box = 25–75% interquartile range. Circle = outliers, defined as 1.5 multiplied by interquartile range; the outliers during the holiday period are the data in New Year times (31 December–3 January), while during the control period the outliers are either the data of lower weekday use (26 February) or of weekend effect (27 February). Diamond = mean. *n* = number of available data points. g = Hedges' g. Owing to the small number of data points, missing values and a high variability of drug load both

within and between monitoring periods, Hedges' g, an assessment of the magnitude of change in drug use, was applied [47]. A 'g' of 0.2 is considered a small change, 0.5 is medium and 0.8 or more is large [48]

In the semi-rural area, the highest use of cannabis in the peak summer holiday period was estimated at 61 doses/day/1000 people (Fig. 2), marginally below the average of 74 during the control period. In the case of methamphetamine, cocaine and MDMA the maximum levels of use were 6.3, 0.12 and 0.14 doses/day/1000 people respectively. These were higher than the averages of 5.5, 0.032 and 0.015 doses/day/1000 people, respectively, during the control period. In the urban area, the greatest consumption of cannabis, methamphetamine, cocaine and MDMA were of 170, 14, 3.7 and 10 doses/day/1000 people, respectively, during the peak summer holiday. These contrasted with the averages of 70, 8, 0.66 and 0.32 doses, respectively, during the control period. Similarly, in the vacation area, the maximum consumption of cannabis, methamphetamine, cocaine and MDMA, respectively, were 86, 26, 5.5 and 18 doses/day/1000 people during the peak summer holiday. This contrasted with the averages of 63, 3.2, 0.67 and 0.075 doses/day/1000 people in the control period.

Discussion

Our results provide temporally and spatially resolved data on drug use, which complements the triennial National Drug Strategy Household Survey (NDSHS), the main source of data on drug use in the Australian community. Drug consumption differed substantially between areas during the two monitoring periods and different temporal patterns in use of these substances was apparent during the peak summer holiday. Two patterns of illicit drug use were apparent in the study areas. Cannabis and methamphetamine were used in all areas and were less affected by weekend effects. Cocaine and MDMA, by contrast, were more abundant in the urban and vacation areas, and their use increased substantially in all regions during the peak holiday period. This is consistent with self-reports from frequent ecstasy consumers who report that these two drugs are often used in celebratory contexts and at specific events [49].

These patterns appear to confirm, in part, current information regarding drug availability. Cannabis is readily available across Australia because of its easy indoor and outdoor cultivation [40]. Similarly, methamphetamine can be produced locally with limited equipment or precursors, making both of these drugs readily available in rural and regional areas [40]. These factors facilitate their high availability and constant use across regions and time. In the 2010 NDSHS [2] prevalence of daily use is estimated as 1.3% of the total population aged ≥14 years for cannabis and 0.2% for methamphetamine, whereas regular ecstasy use is estimated as 0.1%; the case of cocaine cannot be estimated reliably.

The availability and patterns of cannabis and methamphetamine use contrast with those of MDMA and cocaine. Cocaine is sourced solely via importation so is more dependably available in locations that are closer to importation points, i.e. large urban areas, with populations large enough to support a regular market [29, 40]. MDMA has been reported as being readily available in most Australian urban drug markets [49]. Unlike methamphetamine, MDMA requires precursors that are more difficult to source and more complex to manufacture. Relatively little MDMA manufacture takes place in Australia and there is no evidence to indicate that MDMA manufacture for local consumption takes place in rural Queensland. Drug availability is likely to be driven by consumer demand at specific times. For example, there is more cocaine and ecstasy in the marketplace during holiday periods because such times are when many people are seeking to use these drugs. Although daily or dependent ecstasy consumers are identified rarely [50], use of ecstasy has been tied to specific social contexts, such as nightclubs, live music events, raves and dance parties. This contrasts with the other three drugs, which are usually consumed in homes or at private parties [2, 49]. Drug prices also affect drug preference. On average, cannabis is the cheapest illicit drug ($20–25/g) in Australia, followed by ecstasy ($30–50/dose), methamphetamine ($50/dose) and cocaine ($50–150/dose) [40, 49]. While these factors are likely the most pertinent, multiple other issues may contribute to variations in drug prevalence.

Our wastewater analyses showed that during the peak holiday period, urban and vacation areas had similar drug use profiles that were distinct from the semi-rural area. The urban area has a large nightclub precinct and was also a popular vacation destination for domestic and international tourists. During the summer holiday period, there were many large-scale events, including firework displays, dance parties and entertainment festivals, which attract young adults. As such, in both the urban and vacation areas, holidays increase their population and the number of social activities at which illicit drug use is likely to be more prevalent [49, 51].

The decline in cannabis use in the semi-rural area during the peak holiday season was an unexpected finding. It may reflect the departure of a substantial proportion of cannabis users from these regions during these holidays—possibly moving to areas with a greater population density and more social attractions. Although socio-economic data indicates the resident populations of the three study areas are similar in education and occupational status, residents in the urban and vacation areas had a higher average income than those in the semi-rural area [52]. Residents in the urban area, as well as tourists staying in vacation apartments, may have more disposable income to purchase more expensive illicit drugs, such as cocaine. With wastewater analysis, Zuccato *et al*. [9] showed similar inter-area-related variation in drug loads between two cities over time (Milan and Como) in northern Italy: a significant increase (+40%) in cannabis load from March to September in Milan versus a decrease (−24%) from June to November in Como, with similar findings for methamphetamine (+48% versus −50% respectively). Specific focused studies are required to clarify the reasons behind these effects.

In the urban area we observed higher rates of weekend drug use on New Year's Day versus weekends during the control period: approximately 44 000 versus 16 000 daily doses for cannabis, 5200 versus 3200 for methamphetamine, 1300 versus 270 for cocaine and 2300 versus 110 for MDMA. This was also true in the vacation area, with about 50 versus 10 daily doses for methamphetamine, 10 versus 1 for cocaine and 30 versus 0.1 for MDMA (although daily cannabis doses were similar in each period, at 110). These results indicate that specific holidays increase illicit drug use more than weekends. However, wastewater data cannot determine whether this change reflects an increase average dose per person or an increase in the number of consumers, or some combination of the two.

Our data may be able to provide some guidance on priorities in minimising harm from substance use. For example, given their consistent prevalence across urban and (semi-)rural areas, cannabis and methamphetamine remain a central focus of national drug campaigns. Around peak holiday times, more targeted informational and acute emergency responses associated with MDMA and cocaine could be efficient in urban and high-status vacation areas where use of these drugs seems more sensitive to holiday effects. Targeted harm reduction messages, such as warnings related to appropriate hydration while taking MDMA and binge and poly-drug use, may need to be emphasised in these locations to reduce risk of overdose, injuries or violence during intoxication. It is important to note that even relatively secluded vacation areas are not immune to high per capita drug use during these peak times; acute care workers (e.g. ambulance, first aid and emergency medicine professionals) in such sites may need to prepare appropriate protocols to deal with adverse events during such time.

Several caveats apply to the appropriate interpretation of our results. First, population sizes contributing to wastewater samples in each area, and the change in population between the control and holiday seasons, could not be determined accurately. This may lead to variations in per capita consumption of each substance. Second, some apartments in the vacation area had independent septic systems. As their wastewater was not delivered to the wastewater treatment plant, we may have underestimated the total mass of illicit drugs used in that location. However, any effects on the overall estimation of per capita drug consumption are likely small because we estimated the population in the vacation location based on the daily wastewater flow divided by average water consumption per person. Third, generalisation from the results in the vacation area should be exercised with caution because within such a small population size small changes in the number of drug consumers can strongly affect rates of per capita consumption. Other limitations of wastewater analysis in estimating illicit drug use have been discussed in the literature (e.g. [7, 8]). The most pertinent of these are poly-drug consumption and changes in drug metabolism in chronic users: all calculations necessarily assume the use of a single substance and an 'average' metabolism for each drug under investigation. Additionally, conversion between the mass of a substance quantified in wastewater to the number of doses consumed is complicated by variations in drug purity. In the future, long-term wastewater monitoring can be combined with analyses of substance purity (gathered, e.g., from police seizure data) to better estimate the number of doses consumed per capita.

In conclusion, to our knowledge, this is the first study to apply wastewater analysis to compare illicit drug use profiles between a holiday and a control period across three different types of locations. The pattern of drug use detected broadly conforms to epidemiological expectation and demonstrates the validity of wastewater analysis in detecting changes in rates of use of these drugs. Valid and reliable assessment of illicit drug use in different area types could fill an important data gap for policy makers because most drug epidemiology originates from urban areas, which are unlikely to represent drug use in regional areas and other settings.

Declaration of interest

None.

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