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# Current trends in Finnish drug abuse: Wastewater based epidemiology combined with other national indicators

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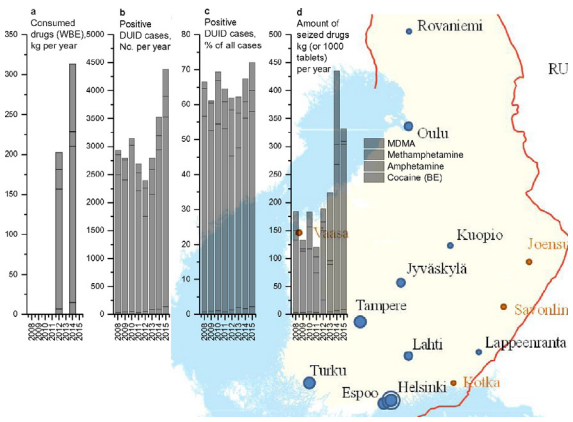
## HIGHLIGHTS

- Wastewater-based epidemiology was combined with other indicators of drug use for joint interpretation of the data
- Regional drug use trends with extensive geographical coverage of 45% of the Finnish population
- The use of amphetamine, MDMA and cocaine has increased from 2012 to 2014 in Finland
- Amphetamine continues to dominate the Finnish stimulant-drug market in all parts of the country
- Market size estimates and estimates for a comparison of confiscated drugs to drugs consumed by users were performed

## GRAPHICAL ABSTRACT

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## ABSTRACT

No single measure is able to provide a complete picture of population- or community-level drug abuse and its current trends. Therefore, a multi-indicator approach is needed. The aim of this study was to combine wastewater-based epidemiology (WBE) with data from other national indicators, namely driving under the influence of drugs (DUID) statistics, drug seizures, and drug use surveys. Furthermore, drug market size estimates and a comparison of confiscated drugs to drugs actually consumed by users were performed using the WBE approach. Samples for wastewater analysis were collected during one-week sampling periods in 2012, 2014 and 2015, with a maximum of 14 cities participating. The samples were analysed with a validated ultra-high-performance liquid chromatography-mass spectrometric (UHPLC-MS/MS) methodology for various common drugs of abuse. The results were then compared with data from other national indicators available. Joint interpretation of the data shows that the use of amphetamine and MDMA has increased in Finland from 2012 to 2014. A similar trend was also observed for cocaine, although its use remains at a very low level compared to many other European countries. Heroin was practically absent from the Finnish drug market during the study period. The retail market for the most common stimulant drugs were estimated to have been worth EUR 70 million for amphetamine and around EUR 10 million for both methamphetamine and cocaine, in 2014 in Finland.



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## 1. Introduction

In 2001 Daughton first proposed the idea of untreated municipal wastewater as a highly diluted urine sample from the population residing in the area (Daughton, 2001). Despite its short history, wastewater-based epidemiology (WBE) has become an established discipline to monitor regional use trends of illegal drugs, with >40 publications in 2014 (Castiglioni and Vandam, 2016). In addition to the endeavors of the scientific community, a crucial factor in the rapid recognition of the concept in Europe has been the interest and support of the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA), which also hosts an interactive website presenting the results of an ongoing European multi-city study now covering 80 cities, including 14 Finnish cities today (EMCDDA, 2016).

Most of the earlier WBE studies were focused on drug use in major cities, but lately, more extensive studies that include both bigger and smaller cities have also been carried out, as exemplified by the study of Nefau et al. (2013) that included 25 cities in France. We started systematic, nationwide monitoring of the Finnish drug situation by means of wastewater analysis initially in 2012, with ten cities participating (Kankaanpää et al., 2014). In 2014, to further improve the geographical coverage of the study, four additional towns situated in previously uncovered parts of Finland were invited to participate. These 14 cities and neighbouring areas covered approximately 45% of the Finnish population. To the authors' knowledge, this is the widest coverage in national drug abuse studies based on WBE. However, a multi-indicator approach and joint interpretation of complementary data from various sources is still likely to give a better image of the current drug situation and its past development.

On the other hand, the WBE approach is completely different from various other methodologies for estimating drug prevalence and related issues, and therefore WBE can be used innovatively and complementary to other approaches. For example, estimates and calculations of the size of a drug market are challenging, since the nature of the drug market is largely hidden and criminal. For the first time EMCDDA and Europol estimated that the size of Europe's drug market is worth at least EUR 24 billion in 2013 (EMCDDA and Europol, 2016). Nevertheless, it was admitted that these new estimates were based on very limited data, with many gaps, which has necessitated some very broad assumptions. Wastewater analysis data was not used in these calculations and may at least complement other approaches.

The main aim of the study was to assess community-level drug abuse by combining WBE with driving under the influence of drugs (DUID) statistics, drug seizure data from the Police and Finnish Customs authorities, and drug use survey data. Furthermore, since the WBE approach allows unique possibilities for estimating the size of the drug market, in terms of quantity and value, we combined data from different sources to perform these novel types of estimates for a few main drugs. The WBE approach was also applied for comparing confiscated drugs to drugs actually consumed by users.

Wastewater samples were collected during two one-week sampling campaigns in 2012 and again in 2014, with 10 and 14 cities participating per year respectively. The sampling campaign of 2015 was more limited, with the four biggest cities participating only. The analytes included in this part of the study were amphetamine, methamphetamine, 3.4-methylenedioxymethamphetamine (MDMA, 'Ecstasy'), cocaine and its metabolite benzoylecgonine (BE), and the heroin marker 6-monoacetylmorphine (6-MAM), as well as methadone and its metabolite EDDP. Cannabis was not included in the study, since its biomarker carboxytetrahydrocannabinol may suffer from some sampling and analytical challenges, and therefore the authors do not consider its results adequately accurate in wastewater.

## 2. Material and methods

### 2.1. Chemicals, reagents and materials

Amphetamine sulphate, cocaine hydrochloride and MDMA hydrochloride were purchased from Sigma-Aldrich (St. Louis, MO, USA). Methamphetamine hydrochloride and methylenedioxyamphetamine (MDA) hydrochloride, and 6-MAM were donated by the UN Narcotics Laboratory (Vienna, Austria). The cocaine metabolite BE and the methadone metabolite EDDP, as well as the deuterated drug analogues amphetamine-$d_6$, cocaine-$d_3$, MDMA-$d_5$, methamphetamine-$d_{14}$ and benzoylecgonine-$d_3$, were purchased from Cerilliant (Round Rock, TX, USA) at concentrations of 1 mg/mL, or 100 μg/mL in methanol or acetonitrile. Carbon 13-labelled internal standards $^{13}C_6$-amphetamine sulphate, $^{13}C_6$-methamphetamine hydrochloride and $^{13}C_6$-MDMA hydrochloride were purchased from Chiron AS (Trondheim, Norway). All of the reagents used were of the highest quality. Water was purified to a UHQ grade using a Millipore Direct-Q system from EMD Millipore Corporation (Billerica, MA, USA) equipped with an LC-Pak™ (Millipore), $C_{18}$ reverse-phase silica cartridge to minimize interference from organic impurities in the mobile phase. The Oasis MCX Vac RC (60 mg) SPE cartridges were from Waters (Milford, MA, USA).

### 2.2. Sample collection and storage conditions

For the nation-wide studies of 2012 and 2014, composite 24-h samples of untreated wastewater were collected twice a year during one-week sampling periods from the inlets of fourteen wastewater treatment plants (WWTPs) located in the cities of Espoo, Helsinki, Joensuu (since 2014), Jyväskylä, Kotka (since 2014), Kuopio, Lahti, Lappeenranta, Oulu, Rovaniemi, Savonlinna (since 2014), Tampere, Turku, and Vaasa (since 2014). The geographical locations of the cities are shown in Fig. 1, with cities participating since 2014 printed in yellow. The number of inhabitants served by each WWTP ranged from 800,000 to <30.000, and they are listed in detail in the left panel of Fig. 4. In addition, a more limited sample collection was carried out in 2015, with the biggest WWTPs of Helsinki, Espoo, Turku and Tampere participating only.

Using the equipment available at each WWTP, five to seven consecutive 24-h composite raw wastewater samples were collected in either a volume- or time-proportional mode. A volume-proportional sampling mode was used in all WWTPs except Lappeenranta, Savonlinna, Joensuu, Oulu and Rovaniemi, where samples were collected in a time-proportional mode. From the sampling device, samples were immediately transferred to glass bottles and acidified (pH 2 with hydrochloric acid) to prevent the degradation of compounds prior to analyses (Gheorghe et al., 2008; Baker and Kasprzyk-Hordern, 2011). The samples were stored in a refrigerator until dispatched in coolers to the National Institute for Health and Welfare (THL), Helsinki, where they were stored in a deep-freeze state (at −18 °C) until analysed. The sampling campaigns were carried out as follows: 1) May 19 to 28, 2012; 2) November 25 to December 1, 2012; 3) March 11 to 17, 2014; 4) November 25 to December 1, 2014, and 5) March 11 to 17, 2015.

### 2.3. Sample pre-treatment, instrumentation, and analytical conditions

Sample pre-treatment was carried out with Oasis MCX cartridges, and instrumental analyses with a triple quadrupole UHPLC-MS/MS system as described earlier (Kankaanpää et al., 2014). However, in 2013 deuterated drug analogues were replaced as internal standards by $^{13}C$ analogues where available prior to the analysis of the national samples from 2014 and 2015.

The analytical methodology was validated prior to the first sample collection periods in 2012. A detailed description of the validation

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**Fig. 1.** Geographical location and size of population served by the 14 wastewater treatment plants (WWTPs) included in the study.

experiments is found in the supplementary material of our previous publication (Kankaanpää et al., 2014).

### 2.4. Complementary data sets to the WBE approach

The data gathered from the WBE approach were compared to DUID statistics and drug seizure data from the Police and Finnish Customs authorities (National Bureau of Investigation, 2013-2016, 2016). The DUID data is presented both as the total number of cases positive for each drug per year, as well as the percentage of positive cases as calculated from the number of cases that were suspected of DUID in Finland during the years 2008–2015. All the analytes discussed in this paper were routinely screened and undeniably confirmed (if positive) by chromatographic mass spectrometric methods in whole blood for each case suspected of DUID in Finland. The amount of seized drugs was examined for each drug per year during the same time period. The drug seizure data included the summary of all drugs confiscated in Finland and data from both Police and Finnish Customs (National Bureau of Investigation, 2016). The average purity of each drug was available as a yearly average of all purity measurements performed by the Police without taking into account the size of the drug seizure. A more detailed analysis was performed for amphetamine, methamphetamine and cocaine purity in 2014, where all individual seizures were examined to calculate the weighted average purity of these drugs (see Section 2.5). Retail prices for illicit drugs were gathered from different police districts in Finland (Finnish Police, National Bureau of Investigation, 2016) and were used for estimating the retail drug market size in monetary value for amphetamine, methamphetamine and cocaine.

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### 2.5. Calculations

Daily drug consumptions were calculated from measured concentrations of the drugs or their metabolites in wastewater, with correction factors for drug excretion applied as described earlier (Kankaanpää et al., 2014). It must be noted that the need for improvements in corrections for drug excretion is an issue that is subject to ongoing discussion in the scientific community. However, since there is as yet no consensus or guidelines on the recommended correction factors (Castiglioni and Gracia Lor, 2016), we continued with the factors proposed by van Nuijs et al. (2011), that is, 3.0 for cocaine (measured as BE), 3.3 for amphetamine, 5.0 for MDMA, 2.3 for methamphetamine and 4.8 for methadone (measured as EDDP).

The yearly national-level consumptions of the stimulant drugs were calculated from averaged drug loads measured in wastewater from 10 Finnish cities during two (spring and autumn/winter) one-week sampling campaigns per study year. The four cities that participated in 2014 only were omitted from these calculations to ensure comparability between the years.

In order to include more recent data from 2015 in the evaluation of drug use trends, separate calculations of yearly drug consumptions were carried out using wastewater drug loads from spring campaigns carried out in the four biggest cities, namely Helsinki, Espoo, Tampere, and Turku.

To compare confiscated drugs by the Finnish authorities to drugs actually consumed by users using wastewater analysis (2014) results, the average purity of amphetamine, methamphetamine and cocaine was calculated in a detailed analysis of all seizures in Finland in 2014. The average purity of each drug was calculated as the weighted average by taking into account the size of the seizure and the purity of each seizure (larger seizures being, on average, of higher purity compared to small doses). Since these drugs are confiscated as their sulphate and hydrochloride salts, the seized drugs were corrected for their salt content. For very small seizures, purity information was unavailable, though they represented a minor portion of all seizures and so the potential effect for calculations of the weighted average purity was quite negligible. In the calculations, the following variables were used: 1) the reported drug seizures in Finland (in 2014), 2) the weighted average purity of amphetamine (32.0%), methamphetamine (27.4%) and cocaine (67.0%) calculated from the data provided by the National Bureau of Investigation and Finnish Customs authorities (in 2014), 3) the minor contribution of licit drug loads (Khan and Nicell, 2012) corrected by the latest sales figures (Finnish Medicines Agency, 2015), 4) the back-calculated wastewater results to consumption figures (2014) of 14 cities and their neighbouring areas covering approximately 45% for the Finnish population, and 5) extrapolation of these wastewater results for the whole Finnish population (5.46 million in 2014; Statistics Finland, 2016).

For retail market size estimates of amphetamine, methamphetamine and cocaine in Finland, in terms of both quantity and value, wastewater analysis (2014) results were back-calculated to consumption figures and combined with 1) the average purity of laboratory analytically confirmed results for each drug in 2014 (National Bureau of Investigation, 2016) and 2) retail prices for amphetamine, methamphetamine and cocaine in Finland (Finnish Police, National Bureau of Investigation, 2016). Wastewater results of approximately 45% of the whole Finnish population were extrapolated to the whole Finnish population for each of the drugs consumed.

### 2.6. Statistical analysis

Statistical evaluations of changes in national-level yearly drug consumption, as calculated from drug loads measured in wastewater from 10 cities, were performed with Mann–Whitney *U* test. In order to include more recent data from 2015, a separate statistical evaluation was performed with Kruskall-Wallis nonparametric ANOVA, followed by a Mann–Whitney *U* test with Bonferroni protectionfor multiple comparisons. To ensure comparability with 2015 data, the latter statistical evaluations were made in a sample consisting of spring campaigns from the four biggest cities only.

## 3. Results and discussion

### 3.1. National drug situation

This WBE study shows that during the study period, amphetamine continuously dominated the Finnish drug scene, while the use of the other stimulants MDMA, methamphetamine and especially cocaine was less common. In addition to the stimulant drugs, the incidence of heroin in the Finnish drug scene was also examined. The heroin metabolite 6-monoacetylmorphine (6-MAM) remained undetected with a LOQ of 2 ng $L^{-1}$ in wastewater analysis, indicating no use or very low level use.

The big picture of the Finnish amphetamine-dominated stimulant drug abuse is uniformly revealed by WBE, DUID and seizure data, as shown in Fig. 2. WBE results from the ten cities that participated already in 2012 were used for calculating drug consumption. National-level consumption of amphetamine ($P < 0.05$, Mann–Whitney *U* test), MDMA ($P < 0.05$, Mann–Whitney *U* test) and cocaine ($P < 0.05$, Mann–Whitney *U* test) increased statistically significantly from 2012 to 2014, while the change in metamphetamine use did not reach statistical significance. These cities represent geographical areas throughout Finland, and cover approximately 40% of the Finnish population, and can therefore be considered to represent national-level drug consumption. It must be noted, however, that this approach may overestimate drug consumption to some extent, since areas of less drug use, namely rural areas and small cities, are underrepresented in the study.

Fig. 3a–d show the consumption of each drug during the period 2012–2015, calculated from wastewater drug loads from the four biggest cities, in comparison with DUID cases, seizure data, and also the mean purity of the seized drug.

According to the WBE data in Fig. 3a, the use of amphetamine has increased statistically significantly from 2012 to 2014 ($P < 0.05$, Mann–Whitney *U* test), and even more from 2014 to 2015 ($P < 0.05$, Mann–Whitney *U* test). When examining the DUID data, similar increases can be seen. An interesting finding from the years before WBE was initiated in Finland is that according to the DUID data, there was a decreasing trend in the number of apprehended drivers who were amphetamine-positive from the year 2008, reaching the lowest level in 2012, followed by an increasing trend that still continues. Seizure data is not as unambiguous; however, a recent increase in trafficking of amphetamine is suggested, as the amounts of seized amphetamine during the period 2014–2015 were higher than ever. Fig. 3a also shows that the pattern of mean purity of amphetamine seized by the police is strikingly similar to the pattern of drivers apprehended who were amphetamine positive as seen in the DUID data. The mean purity was at its lowest, 15%, in 2012, while in the period 2014–2015 the mean purity increased to around 25%, reaching the level of 2008. According to Police sources, a marked increase in mean purity is a strong signal of increased availability of a drug (National Bureau of Investigation, 2016). Therefore, it seems safe to conclude that the availability, and consequently the use of amphetamine, has increased in Finland since 2012. This interpretation is also in line with the results of the Finnish drug survey conducted in 2014, where lifetime prevalence of amphetamine showed a tendency to increase, from 2.1% in 2010 to 3.0% in 2014 (Hakkarainen et al., 2015). The register-based study conducted in 2012 estimated the number of problem amphetamine users in Finland at 11,000 to 18,000 (Ollgren et al., 2014), which is unchanged from earlier studies (Partanen et al., 2004). Unfortunately, there is no such register-based estimate that yet covers the years 2014 and 2015.

In contrast to amphetamine, the use of methamphetamine (Fig. 3b) has decreased ($P < 0.05$, Mann–Whitney *U* test) from 2012 to 2014 in

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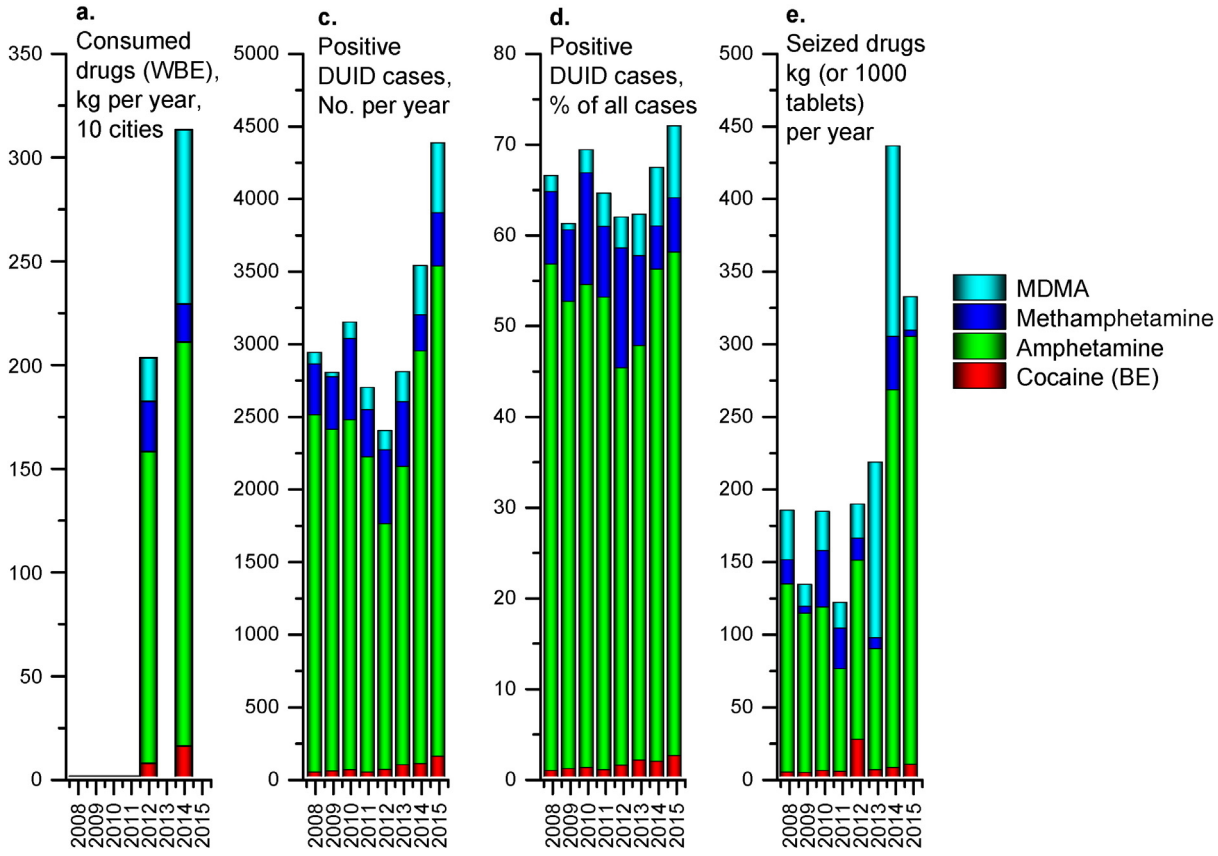


**Fig. 2.** Comparison of different indicators of the drug situation in Finland: panel a) Yearly drug consumption (kg/year) back-calculated from wastewater analyses from ten cities participating in the study both in 2012 and 2014. Panel b) Total number of positive driving under influence of drugs (DUID) cases. Panel c) Number of positive driving under influence of drugs cases calculated as percentages of all cases. Panel d) Amount of drugs seized by the Police or Finnish Customs authorities. The amount of MDMA is presented as 1000 tablets per year, the other drugs as kg per year.

the WBE data from spring campaigns in the four biggest cities. In contrast, when examining the average yearly WBE data from 10 cities in Fig. 2, this phenomenon is absent, since the inclusion of more cities and two sampling campaigns per year levels the sporadic temporal and spatial incidence that seem to be characteristic of Finnish methamphetamine use. Also DUID and seizure data exhibit random-like variations, suggesting that availability of methamphetamine has been more occasional than that of amphetamine, leading to marked yearly fluctuation.

Fig. 3c shows that the consumption of MDMA in the four biggest cities has increased both in the period 2012 to 2014 ($P < 0.05$, Mann–Whitney *U* test) and 2014 to 2015 ($P < 0.05$, Mann–Whitney *U* test), apparently even more than amphetamine use. This trend is evident in both the WBE and DUID data. The seizure data is, again, more ambiguous, with very high numbers of seized tablets in 2013 and 2014, followed by a return to a markedly lower level in 2015, a drop that cannot be seen in the DUID data. The MDMA seizure data include tablets only, while the amount of MDMA smuggled in powder form is increasing (National Bureau of Investigation, 2016), which may partly account for the apparently low amount of MDMA seizures reported in 2015. According to the drug survey of 2014, there has been an increase in the use of ecstasy since 2010 (Hakkarainen et al., 2015), with the lifetime prevalence increasing from 1.7 to 2.6% of the population.

The use of cocaine (Fig. 3d), although at a very low level when compared to amphetamine or MDMA, is also gaining more popularity according to both the WBE and DUID data. The amount of consumed cocaine in the four big cities increased statistically significantly both from 2012 to 2014 ($p < 0.05$, Mann–Whitney *U* test), and from 2014 to 2015 ($P < 0.05$, Mann–Whitney *U* test). Further, the amount of seized cocaine is seen to have increased very steadily if the aforementioned exceptional seizure of 2012 is omitted from the data. In contrast, in the drug survey of 2014 the life-time prevalence of cocaine has shown less of an increase, being 1.5% in 2010 and 1.7% in 2014 (Hakkarainen et al., 2015).

When comparing these three types of data, the advantage of the WBE data is evident: it represents the whole population residing in the catchment area of the WWTPs participating in the study. With over 40% of the population of Finland included, this data can confidently be considered to represent the whole population, although there is certain overweight of the urban population. In contrast, the DUID data does not represent the general population, but is rather selected in a manner that contains many random elements, including among others the effect of the drugs on driving ability, local police activity, bias caused by the limitations of road-side testing. When assessing the seizure data, there are several issues that must be taken into account. First, the data are strongly dependent on the activity and operational success of the Police and Customs authorities. In addition, one exceptional seizure may impact the data markedly, which is most clearly seen in the cocaine data of 2012, which is dominated by a large 20 kg seizure of the drug that was in transit to a third country. Similarly, in 2014 there was a single amphetamine seizure of 51 kg (The Finnish Customs, 2015), and in 2015, a single seizure of >100 kg, of amphetamine accounting for the third of amphetamine seized during the whole year (National Bureau of Investigation, 2016).

The issues related to WBE, based on current knowledge, have been discussed in depth in a recent overview on WBE by the EMCDDA (2016). In short, challenges relate to the sampling of wastewater, the stability of drug biomarkers, chemical analysis, back-calculation of drug use, as well as the estimation of population size in the catchment

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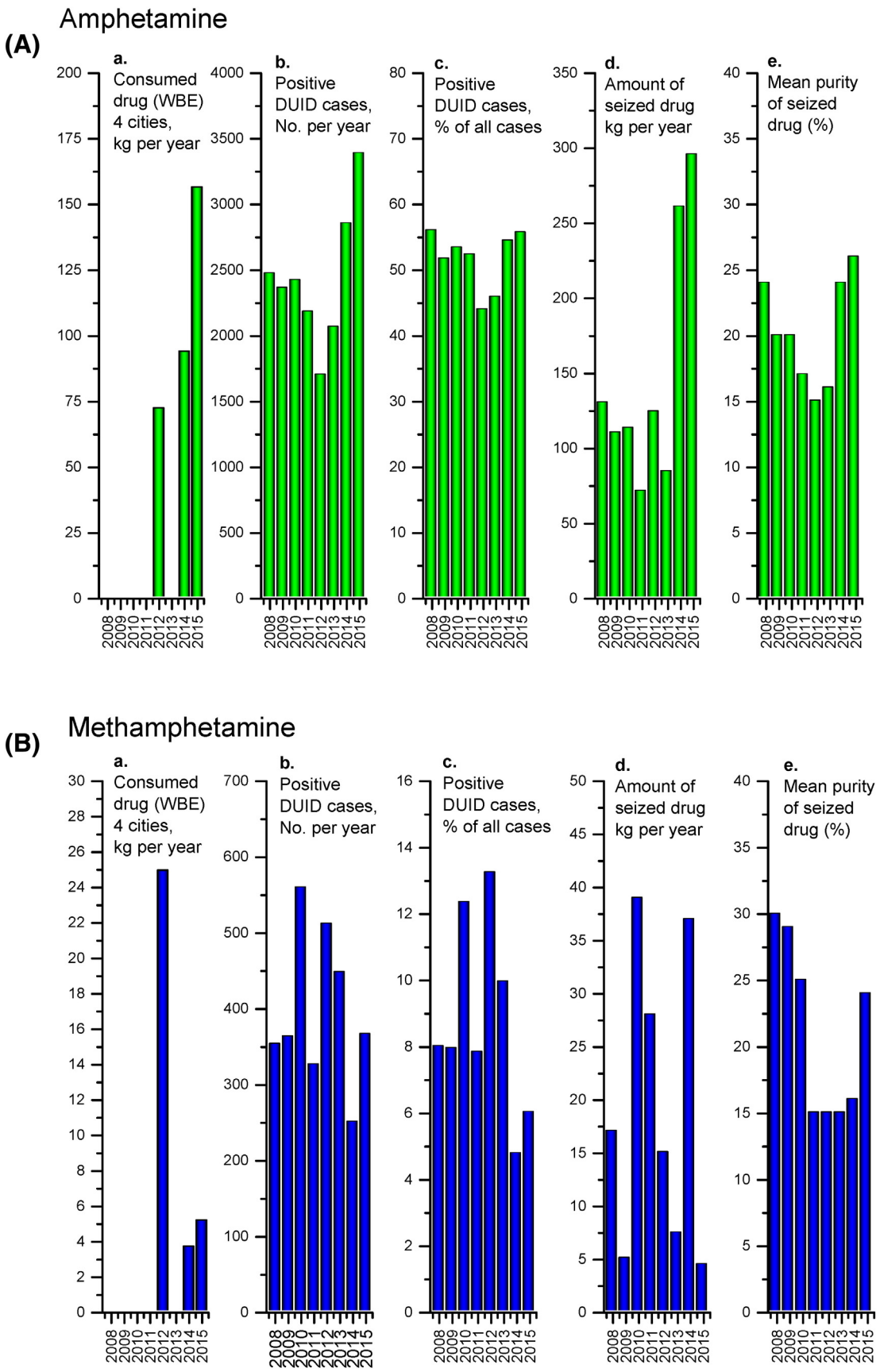


**Fig. 3.** a–d. Temporal trends in drug consumption (back-calculated), number of positive driving under influence of drugs cases and drug seizures together with the mean purity of drugs (as their salt forms) seized by the Police. Yearly drug consumption (kg/year) was calculated from the drug loads from spring sampling campaigns carried out in the four biggest cities (Helsinki, Espoo, Tampere and Turku) to maintain comparability with 2015 data.

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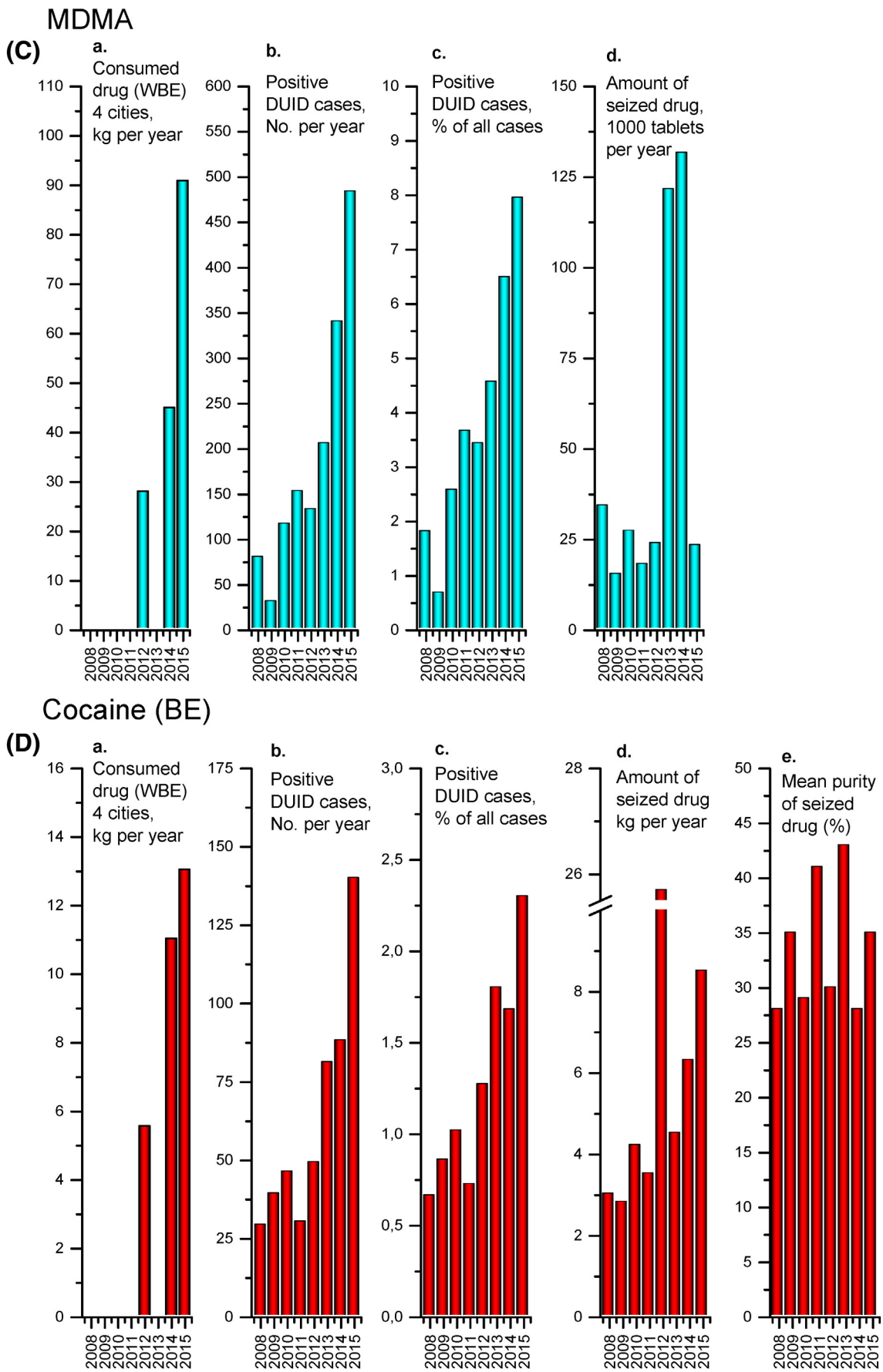


**Fig. 3** (*continued*).

area (Zuccato et al., 2008; EMCDDA, 2008; Castiglioni et al., 2013). Although increased knowledge through the efforts of the scientific community has given the means to cope with these uncertainties, WBE is not completely free of challenges and more research is still needed in terms of uncertainties.

Bearing in mind the limitations, these different indicators complement each other, and their joint assessment allows for novel insights into population-level drug abuse. All effort has been made to ensure mutual comparability in each type of data and to avoid misinterpretations. When presenting the big picture of national-level drug abuse, the total drug loads in kilograms per year were calculated from wastewater drug loads measured only in the 10 cities that participated already in 2012, so as to ensure mutual comparability. On the other hand, when presenting the longer time series from 2012 to 2015, WBE data from spring campaigns in those cities that participated also in 2015 were included only. DUID data are presented both as the total number of cases positive for each drug per year, as well as the percentage of positive cases as calculated from the number of cases that were suspected of DUID, to minimize the influence of changes in police activity on the conclusions drawn. In order to eliminate analytical issues, the method was comprehensively validated, and inter-laboratory tests were participated in successfully whenever available.

#### 3.1.1. Comparison of confiscated drugs and consumed drugs

The wastewater-analysis approach provides unique features for estimating the ratio of illicit drugs seized by the authorities to the drugs actually consumed by users. In our previous paper (Kankaanpää et al., 2014), we estimated for the first time by means of WBE approach that 10–20 times more amphetamine, methamphetamine, and cocaine were consumed than were seized in 2012 in Finland. By using a similar approach and variables defined in the paragraph 2.5., we estimate that 5–10 times more amphetamine (calculated 7.9), methamphetamine (4.8) and cocaine (9.5) were consumed than were seized in 2014 in Finland.

It should be noted that this approach may slightly overestimate drug consumption, since rural areas and smaller cities where illicit drug use is generally less frequent than in more urbanized cities are underrepresented in the study, whereas all of the major cities are included. In any case, it indicates that more amphetamine was seized in 2014 in relation to actual drug use when compared to 2012, while the amount of seized methamphetamine was at the same level (5% of use) without a big seizure of 26 kg. Furthermore, based on the results calculated from both the 2012 and 2014 wastewater results, it seems that typically 5–20% of all consumed drugs can be confiscated by the Finnish authorities. Nevertheless, the results are, especially for cocaine and also to methamphetamine, strongly dependent on whether a big seizure or seizures are successfully accomplished for those drugs.

#### 3.1.2. Market size estimates for illicit drugs in Finland

Wastewater analysis allows for interesting prospects to study market size and the financial value of illicit drugs in a given population, when the average purity of drugs and average retail prices of drugs are known. The amphetamine and methamphetamine prices were estimated to be on average EUR 30 (range EUR 25–35) per gram in the most densely populated southern part and EUR 60 (EUR 50–70) per gram in the northern part of Finland (Finnish Police, National Bureau of Investigation, 2016). EUR 35 was used for market size calculations. For cocaine, the price is estimated by the Police as EUR 100 (EUR 80–150) per gram on average. Based on the WBE approach combined with the average purity of drugs and the retail prices for amphetamine, methamphetamine and cocaine in Finland, the retail market size was estimated to have been worth EUR 70 million for amphetamine, and around EUR 10 million for both methamphetamine and cocaine, in 2014 in Finland. These figures exemplify how the stimulant drug market is very different in Finland than in Europe on average. Recently, EMCDDA and Europol estimated that the minimum retail value of the illicit drug market in Europe for amphetamines and cocaine were EUR 1.8 and 5.7 billion, respectively (EMCDDA and Europol, 2016).

Even though the figures obtained through WBE rest on a few assumptions and must be viewed with some caution, they are based on the best information available from national authorities and objective laboratory confirmed data (wastewater results, purity of seized drugs). It can be concluded in general that WBE approaches can complement other approaches in evaluating the size of illicit markets, in terms of both quantity and value, and provide unique perspectives for more accurate estimates.

### 3.2. Local drug use

Mean drug consumptions, as calculated from wastewater drug loads in each WWTP are shown in Fig. 4a and b, with the cities arranged from South to North. Fig. 4a shows the overview of the drug situation across Finland, while Fig. 4b shows amphetamine, methamphetamine, MDMA and cocaine scaled individually. Taking into account the number of inhabitants and cities served by each WWTP shown in the left panel of the picture 4a, it seems that geographical location of the city in the most densely populated part of the country has more impact on a city population's stimulant-drug use than the size of the city. For example, the harbour city of Kotka, which is among the five cities with the highest overall drug use, has <60,000 inhabitants. This is in accord with the register-based study of 2012 that indicated that problem use of amphetamines is somewhat concentrated in southern Finland (Ollgren et al., 2014). The fact that drug abuse is concentrated in the southernmost part of the country may be due to the trafficking routes for the drugs: the substances enter the country mostly via the harbour cities of southern and South-Western Finland, although lately there has been an increase in drug trafficking via the northern land route from Sweden to Finland (National Bureau of Investigation, 2016).

It is clear that amphetamine dominates in every part of the country, with steady and increasing rates of use in most of the cities. In contrast, methamphetamine showed less established use, with transient local hotspots such as Savonlinna in March of 2014, or Lahti and Kuopio in November–December of 2014. Overall, methamphetamine use, in contrast to other stimulants measured, showed no increasing trend, but is rather characterised with randomness. This is probably due to occasional batches of methamphetamine appearing in local clandestine markets as a substitute for amphetamine, rather than a continuous supply of methamphetamine to a specialised user group.

MDMA ('Ecstasy') was used throughout the country, from the big cities of southern Finland to the smaller towns in central and northern Finland to a nearly same extent. The use of MDMA had increasing popularity in various cities (see Fig. 4b). The rate of use of cocaine was low, but increasing, and continuously concentrated in southern Finland. The high price level of up to EUR 150 for 1 g of cocaine in the northern part of Finland (Finnish Police, National Bureau of Investigation, 2016) at least partially explains the low amount of cocaine use.

When comparing data from the years 2012 and 2014, as well as 2015 when available, local use of amphetamine, MDMA and cocaine observed in each city were strikingly similar. This suggests established local user populations for these drugs. It is also likely to reflect relatively stable availability of the drugs, although the fluctuations in the ratios of amphetamine and methamphetamine are likely to be due to temporal and spatial changes in availability, price and quality of the drugs. According to the WBE data from all collection periods, these changes appeared generally more pronounced in smaller cities.

#### 3.2.1. Use patterns

In order to reveal the differences in drug use patterns and whether these patterns remain the same over time, the daily consumptions of the stimulant drugs were plotted from all five sampling campaigns. Fig. 5 shows that amphetamine is rather steadily consumed, though an increasing trend in weekend use as compared to weekday use. The

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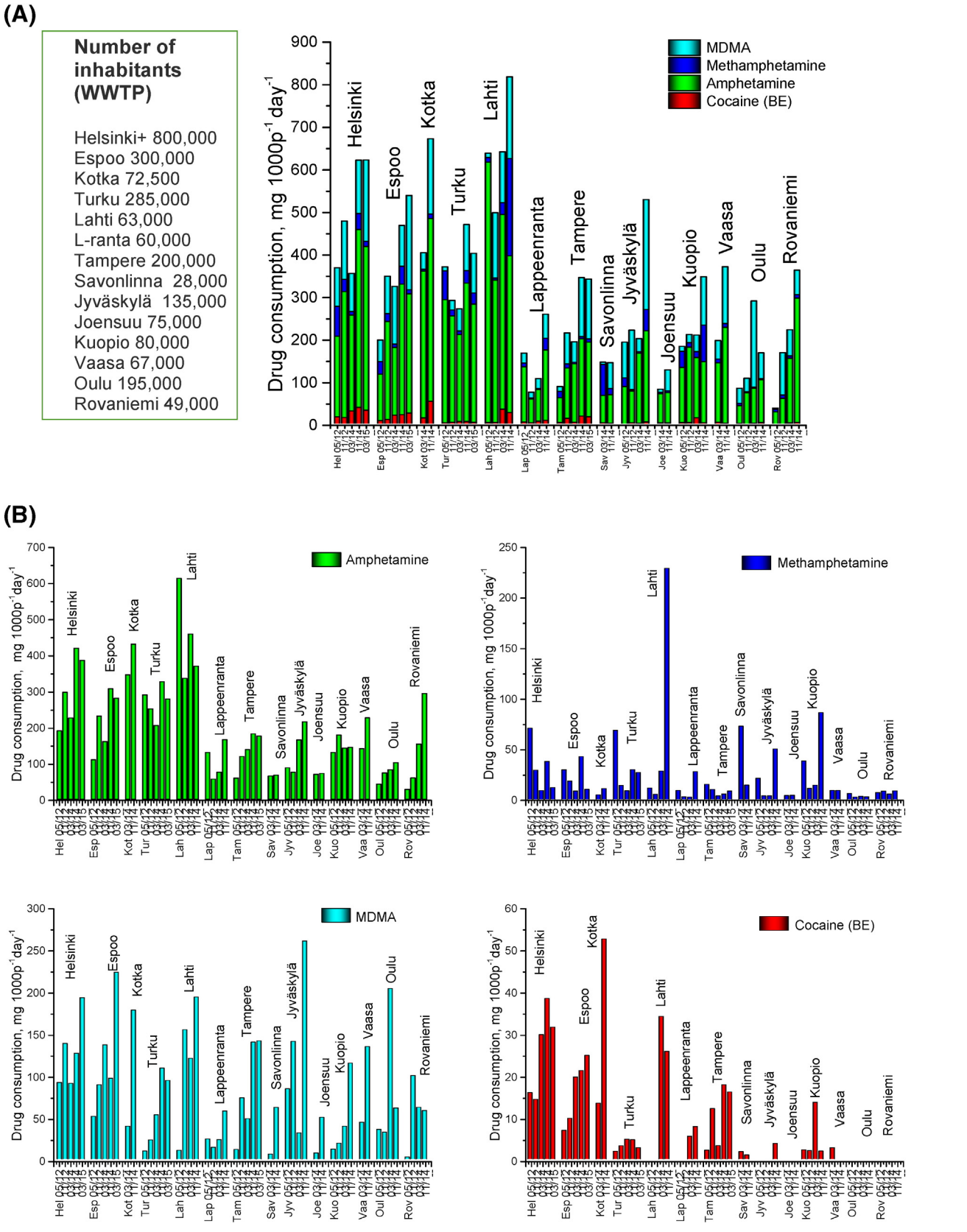


**Fig. 4.** a–b. Local back-calculated drug consumption, as measured by WBE. a) Overview of local mean drug consumptions (mg/1000 persons/day), with the cities arranged from South to North. Left panel of the figure shows the number of inhabitants in each city. b) Local drug consumption with each drug scaled individually.

use of methamphetamine is steadier over different days, and it is only moderately increased during the weekends. Steady consumption of these drugs indicates abuse rather than recreational use. Amphetamines are mostly consumed intravenously by problem drug users in Finland (Varjonen et al., 2014). However, amphetamine especially may have a recreational use as well, as suggested by the somewhat increasing

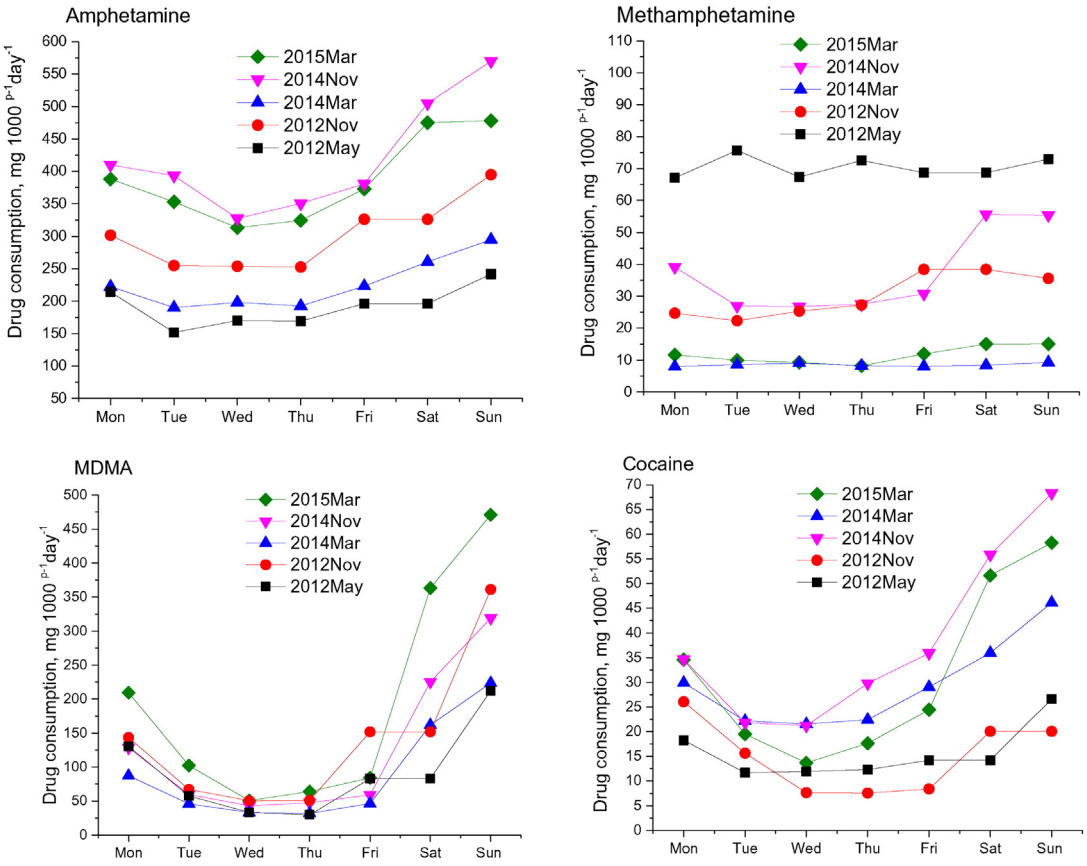


**Fig. 5.** Daily, back-calculated drug consumptions (mg/1000 persons/day) in Helsinki, with data from each sampling campaign plotted individually.

trend during weekends. MDMA, in contrast, is a typical example of a recreational drug with very pronounced weekend use. Cocaine is generally considered a recreational drug in Finland, though it had a much less pronounced weekend-use pattern than MDMA. Fig. 5 also shows that the use patterns for each drug remain relatively unchanged over the course of the different sampling campaigns, suggesting that users have steady habits. For methadone and its metabolite EDDP, a very stable rate of use was observed during both the weekends and weekdays. In Finland, methadone is widely used in opioid maintenance treatments and for pain management that requires constant administration of the drug.

### 3.3. Europe-wide comparisons

When comparing the Finnish national data with global data obtained in a multi-city monitoring project (http://www.emcdda.europa.eu/topics/pods/waste-water-analysis), the Finnish rate of use for amphetamine is mainly above the European average, roughly equalling that of Germany. However, more use is reported in the Netherlands and Belgium, which according to the National Bureau of Investigation (2016), were also the origin of most of amphetamine trafficked to Finland. In contrast, the rate of use of methamphetamine is generally low in Finland, similar to that of many other European countries. There are, however, marked differences between countries, with use concentrated in the Czech Republic, Slovakia, eastern parts of Germany, Norway (Oslo), and in non-European countries, such as Australia. In comparison to other countries participating in the multi-city monitoring project, MDMA is used at an average rate in Finland, equal to that of Germany. In contrast, the Finnish rate of use for cocaine has consistently been very low compared to the European average.

Given the abovementioned uncertainties relating to WBE in general, a question can be raised as to whether wastewater measurements carried out in different laboratories around the world are comparable. The only solution to this issue is the establishment of a simultaneous and uniform study protocol, including inter-laboratory tests, to ensure the production of high-quality data that would allow comparisons of illicit drug use across the participating countries (Thomas et al., 2012; Ort et al., 2014; EMCDDA, 2016). Fortunately, this has been one of the main goals of the multi-city monitoring project, executed by the SCORE group (http://score-cost.eu/).

## 4. Conclusions

Amphetamine dominates the Finnish drug scene, while the use of MDMA, methamphetamine and especially cocaine is less common. This big picture of Finnish stimulant-drug abuse is uniformly revealed by data from WBE, driving under influence of drugs (DUID), and seizure data. A joint interpretation of the wastewater data together with other indicators shows that the use of amphetamine, MDMA and cocaine has increased in the period 2012 to 2014 in Finland. Furthermore, a regional inspection of drug use trends with an extensive geographical coverage of 14 cities and neighbouring areas shows that drug use was more concentrated in the cities of southern Finland, which can partly be explained by drug trafficking routes. However, there are marked differences in the spatial spread of the drugs, with MDMA being the most evenly distributed throughout the country, and cocaine being almost exclusively concentrated in the southern part of the country. The rate of cocaine use was constantly low in comparison with amphetamine use in Finland, and compared with cocaine use in other countries as reported in various studies worldwide. Heroin remained practically absent from the Finnish drug market. Despite some assumptions having to be made in this paper regarding market size estimates and calculations for comparison of confiscated drugs and consumed drugs, the results indicate that the WBE approach can be effectively used to

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perform new types of estimates when combined with other relevant information.

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