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Aberg, Dan; Chaplin, Daniel; Freeman, Chris; Paizs, Bela; Dunn, Christian

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The environmental release and ecosystem risks of illicit drugs during Glastonbury Festival.

Authors; **Dan Aberg[a]**, Daniel Chaplin[b], Chris Freeman[a], Bela Piaz[b,c], Christian Dunn[a]

[a]Wolfson Carbon Capture Lab, Bangor University, Bangor, Wales

[b]Centre for Environmental Biotechnology, Bangor University, Deiniol Rd, Bangor, LL57 2UW, UK

[c] Current address: Rosalind Franklin Institute,

Dan Aberg is corresponding author.

Dan Aberg: dan.abergx@googlemail.com

Daniel Chaplin: d.chaplin@bangor.ac.uk

Chris Freeman: c.freeman@bangor.ac.uk

Christian Dunn: c.dunn@bangor.ac.uk

Abstract

Reported high drug use at music festivals coupled with factors such as public urination can lead to the direct release of illicit drugs into the environment. Glastonbury Festival 2019 had 203,000 attendees, its site is intercepted by the Whitelake River providing a direct route for illicit drug pollution into the local environment. We tested for popular illicit drugs such as cocaine and MDMA in the river upstream and downstream of the festival site as well as in the neighbouring Redlake River. Both rivers were sampled the weeks before, during and after the festival. Cocaine, benzoylecgonine and MDMA were found at all sample sites; concentrations, and mass loads (mass carried by the river per unit of time) were significantly higher in the Whitelake site, downstream of the festival. MDMA mass loads were 104 times greater downstream in comparison to upstream sites (1.1-61.0 mg/hr vs 114.7 mg/hr; $p<0.01$). Cocaine and benzoylecgonine mass loads were also 40 times higher downstream of the festival (1.3-4.2 mg/hr vs 50.4 mg/hr; $p<0.01$) (22.7-81.4 mg/hr vs 854.6 mg/hr; $p<0.01$). MDMA reached its highest level during the weekend after the festival with a concentration of 322 ng/L. This concentration is deemed harmful to aquatic life using Risk Quotient assessment (RQ) and provides evidence of continuous release after the festival due to leaching of MDMA from the site. Cocaine and benzoylecgonine concentrations were not at levels deemed harmful to aquatic life according to RQ assessment yet were 3 times higher than MDMA concentrations. Redlake River experienced no significant changes ($p > 0.05$) in any illicit drug levels, further confirming that drug release was likely dependent on the festival site. The release of environmentally damaging levels of illicit drugs into Whitelake River during the period of Glastonbury Festival suggests an underreported potential source of environmental contamination from greenfield festival sites.

Keywords

Illicit drugs, Environmental pollution, Music festivals, cocaine, MDMA.

Highlights

- Illicit drugs were found in the river running through the Glastonbury Festival.
- MDMA was found at environmentally damaging levels in the local aquatic ecosystem.
- MDMA release was delayed suggesting sorption and subsequent leaching from the site.
- Levels of cocaine were high enough to disrupt the lifecyle of the European eel.
- Use of treatment wetlands and preventing public urination could reduce the issue.

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Abbreviations

WWTP: Wastewater Treatment Plant, WL: Whitelake River, RL: Redlake River, SM: Supportive Materials, UPLC: Ultra Performance Liquid Chromatography, HPLC: High Performance Liquid Chromatography, PPCP: Pharmaceutical and Personal Care Products.

1.Introduction

Through the use of liquid chromatography methods such as UPLC and HPLC, illicit drugs have been found in surface waters across the world at concentrations ranging from 0.2 - 183 ng/L in rivers such as the Thames (UK), Po (Italy), Ebro (Spain), Beiyunhe (China) and Liberia (Costa Rica) (Zuccato *et al.*, 2008; Postigo, de Alda and Barcelo, 2010; Causanilles *et al.*, 2017; Hu *et al.*, 2019). Illicit drugs found range from class A to C with cocaine, methamphetamine, amphetamines and opiates being common occurrences at the ng/L level in rivers; higher concentrations of the metabolites for these compounds are often found alongside their parent compounds.

Illicit drugs, once taken are excreted in urine and faeces, both as unaltered and metabolic forms. These forms then travel through the sewage system, entering WWTPs where they are then released into the environment, due to poor removal (Castiglioni *et al.*, 2008; Baker and Kasprzyk-Hordern, 2013).

Monitoring drug concentrations in WWTP influent allows trends in drug use for nearby populations to be observed in almost real-time (Zuccato *et al.*, 2008; van Nuijs *et al.*, 2011). This is best exemplified by the spikes in drug concentration found in sewage during large social events such as The Superbowl, Independence Day and music festivals (Gerrity, Trenholm and Snyder, 2011; Bijlsma *et al.*, 2014; Foppe, Hammond-Weinberger and Subedi, 2018).

Music festivals are large social events where drug use is significantly higher than average with large quantities of "party drugs" such as MDMA, ketamine and methamphetamine based drugs being consumed (Lai *et al.*, 2013; Bijlsma *et al.*, 2014; Jiang *et al.*, 2015). A large increase of drug concentrations in influent has been shown to reduce the effectiveness of WWTPs resulting in higher quantities of drugs being released into the environment.

Illicit drugs have only been found at low concentrations in surface waters, yet due to the psychoactive nature and harmful effect of these compounds in humans, the impact on aquatic ecosystems is severe. Exposure to 20 ng/L cocaine concentrations for 30 days disrupted the endocrine system of the European eel (*Anguilla anguilla*) which then has the potential to delay sexual maturation of this critically endangered species (Gay *et al.*, 2013). Cocaine and its main metabolite benzoylecgonine have also been shown to cause DNA fragmentation and cytotoxicity in Zebrafish embryos, oxidative stress in zebra mussels and an inhibitory effect on mitochondrial activity on fern spores (Binelli *et al.*, 2012; García-Cambero *et al.*, 2015; Parolini *et al.*, 2017). Zebra mussels, a common ecological test model species, also experience cytotoxicity when exposed to MDMA (Parolini, Magni and Binelli, 2014). Environmental pollution from illicit drugs is rarely limited to a single substance and is often a cocktail of illicit compounds, when exposed to multiple substances at a time Zebra mussels experience higher genotoxic and oxidative effects (Parolini *et al.*, 2015, 2016).

Many festivals in the UK are "greenfield festivals"; situated in the countryside with temporary toilet facilities installed for festival-goers. Due to these often-poor toilet conditions, public urination is a widespread issue and pools of urine at festival sites have been found to contain cocaine and MDMA (Mardal *et al.*, 2017). Public urination at a music festival adjacent to Lake Belaton in Hungary, caused the release of illicit drugs into the nearby lake at levels high enough to cause acute effects on the aquatic life (Maasz *et al.*, 2021). Glastonbury Festival is a world-renowned, five-day, music and arts festival in Pilton, Somerset that has been running since 1970; the 2019 festival had a total of 203,000 visitors (Digital, 2020). The festival site is intersected by a tributary of the Whitelake River which then continues through the surrounding farmland, towards the Shapwick Heath and Westhay Moor NNRs. This study hypothesises that the high level of drug use and public urination common at music festivals, coupled with proximity to a river, will cause the direct release of illicit drugs into the nearby ecosystem with potentially harmful effects downstream.

2.Methods

2.1. Sample collection

Whitelake River, as shown in Figure 1 consists of two tributaries that converge below the festival site; both tributaries were sampled upstream from the festival (WLUP1(SM.1) and WLUP2(SM.2)) and one site was sampled downstream (WLDWN(SM.3)). The neighbouring river (Redlake) was sampled up and downstream, (RLUP(SM.4) and RLDWN(SM.5)) to allow a comparison between a river directly in contact with the festival and one in a neighbouring valley.

At each site four 1 litre grab samples were collected in 1 L amber glass bottles, acidified to pH 2.0 and kept at 5°C (Gheorghe *et al.*, 2008). Before sample collection each bottle was consecutively washed with tap water, 5% decon 90 solution, 5% HCl, distilled water, MeOH and ultra-pure water. Each site was sampled on the weekend before, during and after the festival (22/06/19, 29/06/19, 06/07/19). Samples were transported in ice boxes to the laboratory at Bangor University within 24hrs and then filtered through a GF/C glass fibre filter paper and a 0.45 µm Nalgene filter paper before being stored at 5°C in the dark to minimise photolytic and microbial degradation. Cocaine and benzoylecgonine experience minimal degradation at 4°C in pH 2.0 acidified water after 6 days with no degradation in the first 3 days (Gheorghe *et al.*, 2008).

The literature on this topic typically focusses on the sampling of WWTPs where the use of 24hr composite samples is preferable (Ort *et al.*, 2010). Ideally a refrigerated autosampler would have taken a 24hr composite sample at each site however due to non-existent electrical supply grab sampling was opted for. The utilisation of grab sampling instead of composite sampling due to degradation concerns has been reported in other papers (Baker and Kasprzyk-Hordern, 2013). Samples are also typically 2.5L for surface water sampling but due to the anticipated higher concentrations than normal, 1L bottles were used (Gheorghe *et al.*, 2008; Kasprzyk-Hordern, Dinsdale and Guwy, 2009; van Nuijs *et al.*, 2009).

River temperature, conductivity, flow velocity and cross-sectional area were measured at each site. All field techniques and river calculations (river discharge) were conducted following the WHO guidelines (Bartram *et al.*, 1996).

The mass load of the river at each sample site was calculated to provide a fairer comparison between sites as river flow rate/volume varies throughout the watercourse. Mass load is calculated by multiplying the concentration(ng/L) by the flow rate of the river (L/hr). Sewage epidemiology studies typically measure by gram per day but due to the grab sampling method, any 24-hour estimates would be under the poor assumption that the site measured would not experience any significant changes (Ort *et al.*, 2010).

2.2. Sample preparation method

Samples were concentrated and filtered via a solid phase extraction (SPE) method using Oasis MCX PRIME (150mg, 6cc) cartridges. Each cartridge was primed with 2 mL of MeOH and 2 mL of pH 2.0 water, with each priming solution flowed through via gravity. Each sample (1 L) was then vacuum pulled through at a rate of 2 mL per minute (SM.6a,b). Cartridges were cleaned with 2 mL of pH 2.0 water and then washed with 1 mL of MeOH via vacuum filtering (SM.7). Each cartridge was eluted 3X with 2 mL of ACN:5% NH_3 MeOH at a 60:40 ratio via gravity (SM.8). Each elution had a 300 µl aliquot extracted and filtered using a 0.2 µm PTFE syringe filter. The Aliquot was stored in an Acquity I-Class sample manager at 10°C in preparation for injection.

2.3. Target Analytes

Illicit drugs were selected based on their popularity with festival users with the focus on cocaine and MDMA. Target analytes were cocaine, benzoylecgonine and MDMA. Internal standards were not used in this study; instead an average percentage recovery was calculated for the SPE method for each compound with the results presented in SM.9.

2.4. Analytical Method

The analytical analysis was conducted using the methodology outlined in the Waters application notes for analysis of drugs of abuse (Danaceau, Freeto and Calton, no date). UPLC-TQMS experiments were carried out on an Acquity I Class UPLC coupled to a Xevo TQ-XS triple quadrupole mass spectrometer. An Acquity UPLC BEH C_8 column (75 mm × 2.1 mm, 1.7 µm) from Waters Corporation (Wilmslow, UK) was used in the UPLC separation. The column was kept at a constant temperature of 40°C with the aid of an oven and preheater connected before the column. The Mobile Phase consisted of MilliQ water with 0.1% formic acid (A) and Acetonitrile with 0.1% formic acid (B). The gradient program was as follows: 98% A at 0 min, 50% A at 3.33 min, 10% A at 3.50 min, 98% A at 3.60 min, 98%A at 4 min. The flow rate was set at 0.6 mL min^{-1}. The injection volume was 1 µL and the autosampler was cooled to 15°C. Analytes were ionized with an ESI source in positive ion mode under the following conditions: Desolvation gas 1000 L/hr, Collision gas 0.15 mL/min, cone gas 150 L/hr; Ion spray nebulizer gas 7.0 bar; Capillary voltage 2.57 kV; Detector voltage 0.56 kV; Cone voltage 53 V; Entrance Potential -1.7 V; Exit Potential -2.1 V. Additional parameters were fixed as for the tuning file. MRM conditions are detailed in SM.10.

Fisher Scientific Optima Grade acetonitrile, water and formic acid were purchased from Fisher Scientific UK. Standard compounds were purchased from Sigma Aldrich UK and used without further purification.

2.5. Environmental risk characterisation

An estimate of the harmful effect of illicit drugs can be calculated through comparison of aquatic toxicology data to the maximum measured environmental concentration (MEC). The ratio of the MEC to a predicted no effect concentration (PNEC) results in a risk quotient (RQ). The resulting RQ once compared with a level of concern (LOC), determines the level of potential risk to organisms (US Environmental Protection Agency., 1997, 2015; Maasz *et al.*, 2021). Literature sources provide toxicity data (LC50, median effect concentration (EC50), for algae, cladocerans and fish) for the targeted drugs and are presented in table 2 (Zhou *et al.*, 2019; Maasz *et al.*, 2021). Some values in literature have used predicted toxicity values sourced from the Ecological Structure Activity Relationships Program (ECOSAR) when laboratory data was unavailable. Due to unreliable datasets, the recommended assessment factor of 1000 was applied (Zhang *et al.*, 2017; Zhou *et al.*, 2019).

3. Results

3.1 Concentrations of Illicit drugs

All samples had values above the limit of detection showing that the illicit drugs are present even in small streams and tributaries. The concentrations found are shown in Figure 2; the concentrations of benzoylecgonine were below the limit of quantification for the RLUP site on the weekends before and after the festival (LOQ; 0.1 ng/L). All other sites were above the LOQ.

Whitelake River (WL) had higher concentrations than the Redlake River (RL) at every site for all tested drugs. Sites on the river RL rarely exceeded 1 ng/L whereas the river WL had concentrations ranging from 10-998 ng/L. Benzoylecgonine was the most abundant compound found with concentrations above >100 ng/L for all sites during and after the festival, with a peak of almost 1 µg/L for WLUP1 after the festival. MDMA concentrations were highest on the weekend after the festival for all sites except WLUP2, which experienced its highest concentration during the weekend of the festival. WL sites all had higher concentrations than the RL sites for the weekend before the festival.

3.2. Mass loads

3.2.1 Cocaine

Cocaine levels, as shown in figure 3 were highest at the Whitelake downstream (WLDWN) site for all weekends with the highest recorded value of 50mg/hr during the weekend of the festival. WL had significant levels of cocaine at both upstream sites for all weekends sampled with a gradual increase in levels as the festival period came and passed. The WLDWN site had significantly higher levels for all weekends in comparison to the upstream sites. Samples taken during the festival weekend had over six times the amount of cocaine when compared those taken during the weekend before the festival.

An ANOVA test showed a statistically significant difference in cocaine levels between the sites $F(14, 57) = 99.44$, $P = <.001$. A Post-Hoc Tukey test showed a significant difference between the WLDWN site during the festival and every other sample site and day $P < .05$. The WLDWN site showed no significant difference for the weekends before and after the festival suggesting a return to the rivers base level $P > .05$. The WLDWN lowest cocaine load was still twice as high as the highest for Redlake downstream site (RLDWN) when comparing sample days differences of up to 128X were recorded for the weekend of the festival.

3.2.2 Benzoylecgonine

Benzoylecgonine was found at much higher levels than cocaine with every site, except RLUP, having a minimum of 10X the mass. Figure 4 shows the mass load of benzoylecgonine for all sites in mg/hr. Figure 4 follows a similar trend to the levels found for cocaine (fig.3) with WLDWN during the festival having the highest values of around 850mg/hr. A one way ANOVA test showed a significant difference in the levels of benzoylecgonine between sites $F(14, 58) = 334.16$, $P = <.001$. A Post-Hoc Tukey test showed the WLDWN site had significantly higher levels of benzoylecgonine during and after the festival when compared with the other sites ($P < .05$). The WLUP sites during and after the festival had a significant increase in drug levels with both sample days having a higher mass load than WLDWN before the festival. All values for WL after the festival were at least three times higher than those before at their respective sites, with WLUP1 being fourteen times higher. RL sites had significantly lower mass loads than WL ($P > .05$) with no significant variation between sample days ($P > .05$).

3.2.3 MDMA

MDMA was found at higher levels than cocaine for all WL sites during and after the festival, with mass loads being up to twenty-six times higher. Figure 5 shows the hourly load of MDMA for all sites. MDMA trends differed from cocaine with levels after the festival being the highest. An ANOVA showed a significant difference in levels of MDMA between sites $F(14, 59) = 422.06$, $P = <.001$. A post hoc Tukey test showed a significant difference between WLDWN during and after the festival with every site. The WLUP2 site was unique in being the only site with its highest level during the festival rather than afterwards. During the festival, the WLUP2 site showed a statistically significant difference between itself and every other site ($P < .05$). The RLDWN site had a higher level after the festival than every other site, except WLDWN. However, a Tukey test showed RLDWN was not significantly different from the other sites ($P > .05$). RLUP showed no significant variation between weekends $P(> .05)$.

3.3. Cocaine/benzoylecgonine ratio

Only a small percentage (8%) of consumed cocaine is excreted in urine unchanged, with the majority being excreted as benzoylecgonine (generally 35% of total dose). This can be presented as a metabolic ratio - COC/BE= 0.23 (Ambre *et al.*, 1988; Cone *et al.*, 1998; van Nuijs *et al.*, 2009). The COC/BE ratios for WL (Table 1) ranged from 0.22 to 0.14 before the festival but then decreased to around 0.05 during and after the festival. Degradation of cocaine to benzoylecgonine in surface waters increases with temperature, as shown by Zuccato *et al* (2005) and Van Nuijs *et al* (2009).

Italian rivers had a lower COC/BE ratio (0.05) in comparison to Belgium rivers (0.18); this was attributed to the higher river temperatures in Italy causing a higher rate of degradation.

High degradation rate of cocaine in surface waters is often signified with a lower COC/BE ratio as shown by Van Nuijs *et al* (2009) where ratios increased in winter due to reduced hydrolysis of cocaine in the low-temperature water.

3.4. Summary

Drug levels in WL were significantly higher than the levels found in RL, both in terms of concentration and river load, suggesting high levels of drug usage in the WL River catchment area. WL had significant concentrations in both its upstream and downstream sites which when extrapolated into river load, showed the amount of drugs was higher at the downstream site. All WL sites showed a trend for increased drug presence as the festival came and passed unlike the neighbouring RL. The difference in drug presence between the two watercourses indicates that drug use in the festival causes drug release into the surrounding watercourse. As shown in figure 1, the area between the sites is mainly dominated by the Glastonbury Festival site where drug use rates would be higher than in a rural village, such as Pilton. Benzoylecgonine and MDMA levels were significantly higher the weekend after the festival, compared to the weekend before, suggesting either continued drug use on the festival site or a slow leaching effect from pooled drugs on-site (Yu, Liu and Wu, 2013; Rosi-Marshall *et al.*, 2015).

4. Discussion

4.1. Drug release from the festival

The concentrations found in WL (fig. 2) reached higher levels than expected for a river without a WWTP or urban development nearby. Concentrations for the River Ebro, a non-urban river in Spain are reported in the 25 ng/L range for total drug concentration, whereas WL before the festival and at its lowest had a total drug concentration of 35 ng/L (Postigo, de Alda and Barcelo, 2010). A more accurate comparison can be drawn between WL and RL as they are both similar in size and situated in the same geographical area around the same settlements. When comparing the lowest total drug loads for each river, RL is repeatedly lower with a total drug load of 2 ng/L in comparison to WL with a drug load of 35 ng/L. The higher baseline values for WL are indicative of higher drug use in the catchment area of the river in comparison to RL and the River Ebro. This is of important significance as the 2019 festival was the first festival to take place after the 2018 “fallow year” when the festival did not occur to allow the land to rest. The higher levels of drugs in WL before the festival suggest drug use on-site before the festival begins, possibly by the large number of workers and volunteers present for setting up the site. Another possibility for the higher baseline levels could be long term storage and a slow leaching effect of illicit drugs from the site which will be explored later.

The disparity between RL and WL increases for the weekend during and after the festival, with figure 3,4 and 5 all showing an increased illicit drug load for WL during and after the festival. The mass loads of cocaine and benzoylecgonine for the weekend of the festival were 6.5X and 15X higher than for the weekend before (fig.3,4). MDMA mass loads were 27X and 68X higher for the weekend during and after the festival when compared to the weekend before (fig.5). The massive increases in drug load in the river are indicative of increased drug use and release from the catchment area of WL, which as shown in figure 1, is dominated by the festival site. WWTP’s connected to festivals typically record significantly higher MDMA levels during the festival period, this is due to its popularity at music events (Van Havere *et al.*, 2011; Bijlsma *et al.*, 2014; Jiang *et al.*, 2015). The levels of cocaine and benzoylecgonine in the river WL during and after the festival were significantly higher than those recorded in WWTP’s for festivals in Taiwan and Australia showing higher cocaine use at Glastonbury (Lai *et al.*, 2013; Jiang *et al.*, 2015). Analysis of wastewater from a Spanish festival recorded significantly higher amounts of cocaine and its metabolites than those found in the river WL (Bijlsma *et al.*, 2014). The higher cocaine use at the Spanish music festival and Glastonbury highlights the differences in drug culture between Western Europe and South Asia/Oceania. Western Europe is the second-largest market in the world for cocaine whereas cocaine use in South Asia became more widespread in 2015/16 (Pirona, Matias and Giraudon, 2018).

Benzoylecgonine was the most abundant tested chemical at all sites and had the highest concentration and daily load found (1 μg/L and 850 mg/hr; fig.2, 4). Benzoylecgonine levels were all significantly higher than cocaine levels; this disparity is a regular occurrence in sewage epidemiology analysis (Zuccato *et al.*, 2005, 2008; Castiglioni *et al.*, 2008). The decrease in COC/BE ratio (table. 3) caused by higher degradation was most likely caused by higher water temperatures for the weekends during and after, when surface waters were 2-5°C higher. This further confirms that drug release into the river is through urine and not a direct release of cocaine.

Concentrations and mass loads were found to rise at all sites, including sites upstream of the festival suggesting that the increased population inhabiting the area is releasing drugs at multiple stages of the watercourse. Although this is a possibility as the river WL intersects two major roads that provide access to the festival, the most likely reason for these results is the weather. As shown in SM.12, daily temperatures increased over the sampling period resulting in decreasing river flow (SM.11). The lower dilution factor would exaggerate the levels of drugs in the river resulting in the high concentrations found at WLUP1 after the festival. When converted to mass loads the illicit drug levels are more reasonable but still suggest a wider release into the environment than originally thought.

4.2. Sorption of illicit drugs to soil

Due to their polar nature, PPCPs interact with charged surfaces such as clay minerals found in soils, leading to sorption of PPCPs to soils (Stein *et al.*, 2008; Yu, Liu and Wu, 2013). Illicit drugs such as cocaine and MDMA are also polar and would interact in a similar way with soil (Rosi-Marshall *et al.*, 2015). The sorption/desorption of illicit drugs is reported to be pH-dependent as most illicit drugs gain charge at pH ≥ 8 (Stein *et al.*, 2008; Rosi-Marshall *et al.*, 2015). The polarity of cocaine and MDMA make them highly soluble so they will freely dissolve in surface water which is the main method of transport in the environment (Stein *et al.*, 2008; Rosi-Marshall *et al.*, 2015). Charged surfaces such as clay minerals could reduce polar compound mobility in soil and slow their release into ground and surface waters(Stein *et al.*, 2008; Yu, Liu and Wu, 2013). The area surrounding Pilton is comprised of the Penarth Group shales, a group of impermeable mudstones with lower Lias clays forming the soil on top (Jones *et al.*, 2000; Bristow, 2015). Dry soils, once urinated on, could absorb urine and any illicit drugs in it, which then remain adsorbed to the soil until rainfall causes the drugs to desorb from the soil and dissolve into the water. The Somerset area had no rainfall during the festival and an average temperature of 19.8°C; the area had a total of 11.4mm of rainfall over the ten days before the festival with an average temperature of 14.8°C (SM.11, 12). The low rainfall and high temperature resulted in decreasing water levels in the rivers sampled and drier soils. The low water content in the soil would cause higher adsorption of drugs to soil particles consequently causing the slow release of drugs from the site after the festival (fig. 2, 5).

MDMA is one of the more stable illicit drugs and undergoes little degradation in wastewater with <10% lost after 3 days (van Nuijs *et al.*, 2012; McCall *et al.*, 2016). Research into the stability of illicit drugs in soils has found that once sorbed to soil, MDMA has a half-life of up to 59 days (Pal *et al.*, 2011). The increased stability of MDMA when sorbed to soil, coupled with subsequent desorption during rainfall, could result in the Glastonbury site continually leaching drugs into the nearby surface water and explain the higher concentrations found in WL sites after the festival (fig. 2). The levels found before the festival were probably not from long-term leaching from the site as the stability of illicit drugs, even though prolonged in soil, would not be substantial enough to remain undegraded for an entire year.

4.3. Environmental risk

A brief environmental analysis was done through the calculation of RQs. As shown in Table 2, MDMA concentrations during the weekend after festival calculate to a RQ of 1.49 meaning MDMA concentrations pose an acute high risk to *Daphnia.* MDMA concentrations for the week of the festival are lower resulting in an RQ of 0.34, which still poses a high enough risk for recommended restricted use of the target compound. The high RQ for the week after festival raises concern regarding the potential for long term, environmentally damaging release from the festival site. Cocaine (<0.01) and benzoylecgonine (<0.01) indicate no danger to aquatic ecosystems however, PNEC values do not take into account the impact of long term exposure or the increased toxicity of exposure to illicit drug "cocktails" which cause increased damage (Parolini et al., 2015).

A variety of toxicological experiments conducted on aquatic ecosystems observed negative effects on zebra mussels from cocaine and benzoylecgonine concentrations below the cited PNEC values (Binelli et al., 2012, 2013). The common presumption that benzoylecgonine is less damaging than cocaine has also been refuted with data showing it is more cyto-genotoxic than its parent compound at concentrations of 115 ng/L (Parolini et al., 2017). A 30 day exposure to 20 ng/L concentrations of cocaine disrupted the endocrine system of European eels causing delayed sexual maturity and is hypothesised to be a cause of their environmental decline(Gay et al., 2013). All the aforementioned toxicity studies had concentrations significantly below the PNEC value yet documented a negative impact on aquatic organisms suggesting that the levels found in the Whitelake River are high enough to cause environmental damage. This is of particular concern as the release of illicit drugs has the potential to disrupt the eel population of Westhay Moor NNR situated downstream of the festival.

The continuous release from the catchment of Whitelake River during the festival suggests a need for water treatment at key "bottleneck" areas downstream of the festival to prevent impacts downstream. Constructed treatment wetlands (CTWs) are an environmentally friendly water treatment method with high removal rates for illicit drugs; by mimicking a riparian wetland, a CTW could continuously filter illicit drugs from non-point source pollution (Mitsch, 1992; Petrie *et al.*, 2018). Education of festival attendees on the dangers of public urination should be continued but a failsafe treatment method would provide a second layer of protection for the endangered species downstream.

5. Conclusion

- Sections of the catchment of Whitelake River during Glastonbury festival released environmentally damaging concentrations of the illicit drug MDMA into the local freshwater environment.

- Cocaine was released during the festival period at levels high enough to disrupt the lifecycle of the European eel, potentially derailing conservation efforts to protect this endangered species.

- "Greenfield site" festivals, where high levels of drugs are consumed in a condensed area, can pose a significant risk for the release of illicit drugs into both the freshwater and soil of the site. To minimise the release and subsequent impact of illicit drugs from festivals research into possible treatment via environmentally friendly methods such as CTWs should be conducted. Education on the dangers of public urination on the site should continue to be taught to festival attendees to reduce public urination rates.

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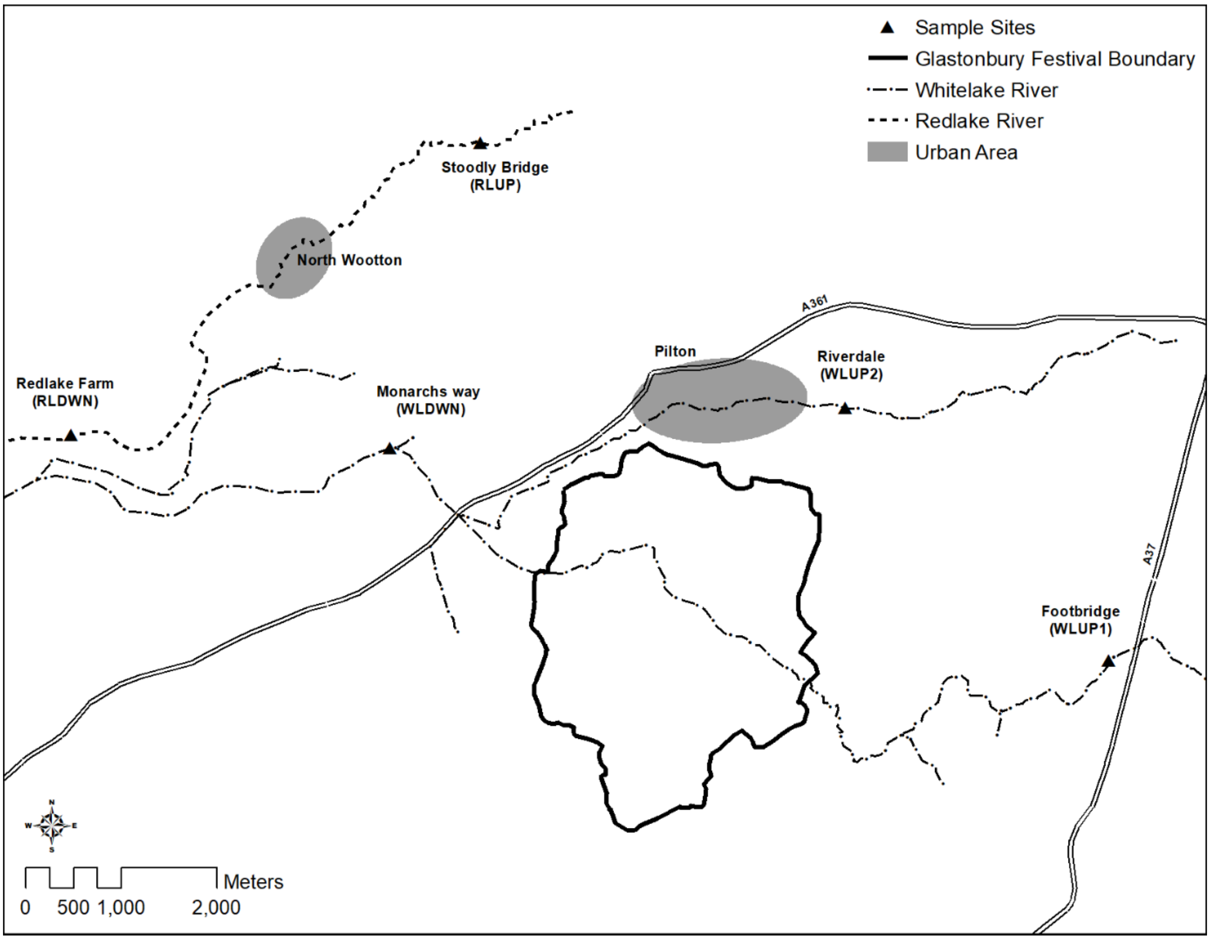

Figure 1: Map of the Pilton area at 1:45.000 with festival boundary and river courses. Position of sample sites along the Whitelake and Redlake Rivers marked by triangles and labelled with geographic and shorthand names. Contains OS data © Crown Copyright and database right (2020)

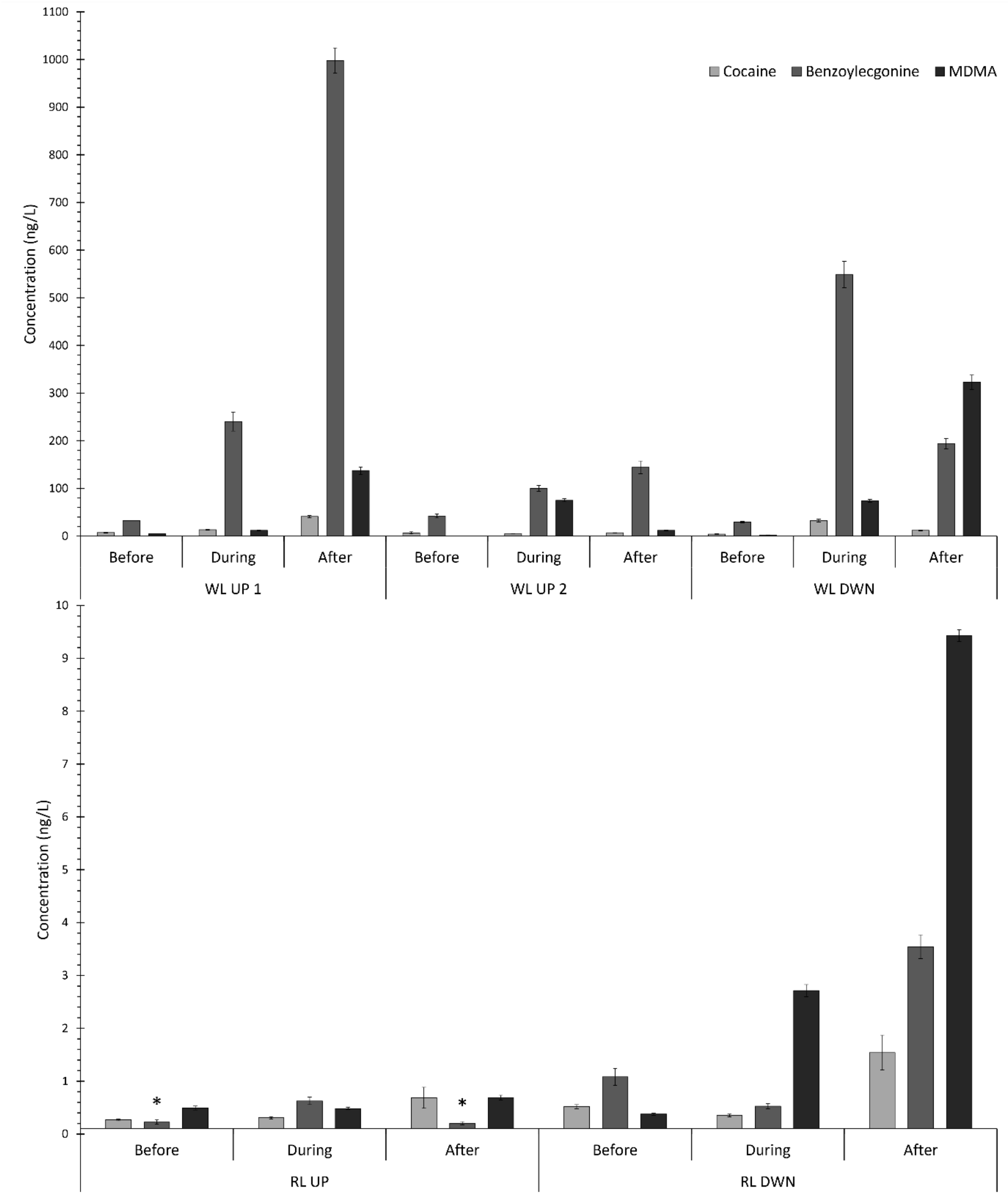

Figure 2: Concentrations of the illicit drugs at each site for the weekend before, during and after Glastonbury Festival in ng/L. Redlake sites are presented in the bottom graph.

* Denotes a result lower than the LOQ.

RL UP: Redlake Upstream, Stoodly Bridge

RL DWN: Redlake Downstream, Redlake Farm

WL UP 1: Whitelake Upstream 1, Footbridge

WL UP 2: Whitelake Upstream 2, Riverdale

WL DWN: Whitelake Downstream, Monarch's way

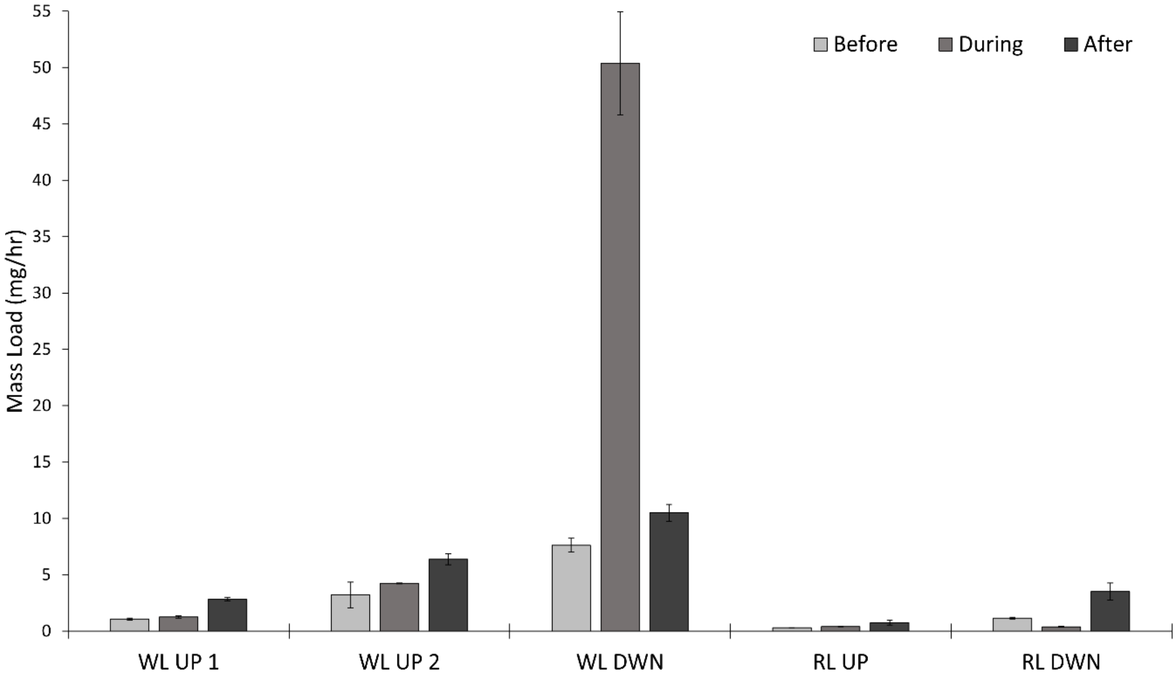

Figure 3: Mass load (mg/hr) of cocaine flowing through each sampling point in the week before, during and after the festival.

RL UP: Redlake Upstream, Stoodly Bridge

RL DWN: Redlake Downstream, Redlake Farm

WL UP 1: Whitelake Upstream 1, Footbridge

WL UP 2: Whitelake Upstream 2, Riverdale

WL DWN: Whitelake Downstream, Monarch's way

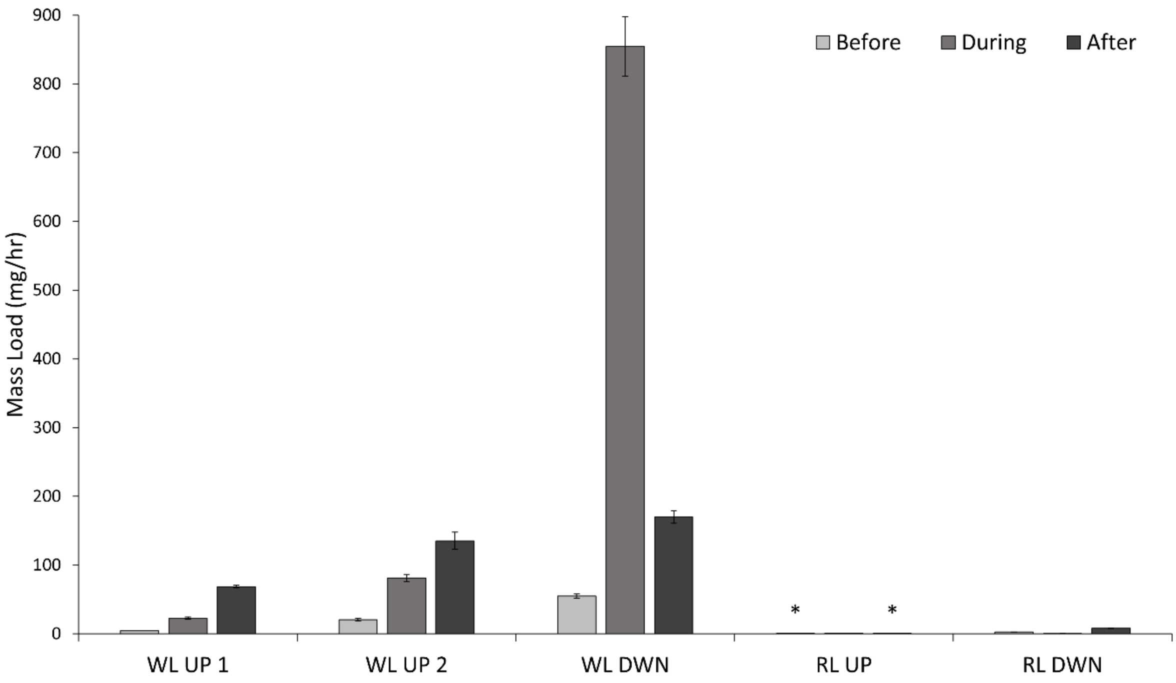

Figure 4: Mass load (mg/hr) of benzoylecgonine flowing through each sampling point in the week before, during and after the festival.

* Denotes a result lower than the LOQ.

RL UP: Redlake Upstream, Stoodly Bridge

RL DWN: Redlake Downstream, Redlake Farm

WL UP 1: Whitelake Upstream 1, Footbridge

WL UP 2: Whitelake Upstream 2, Riverdale

WL DWN: Whitelake Downstream, Monarch’s way

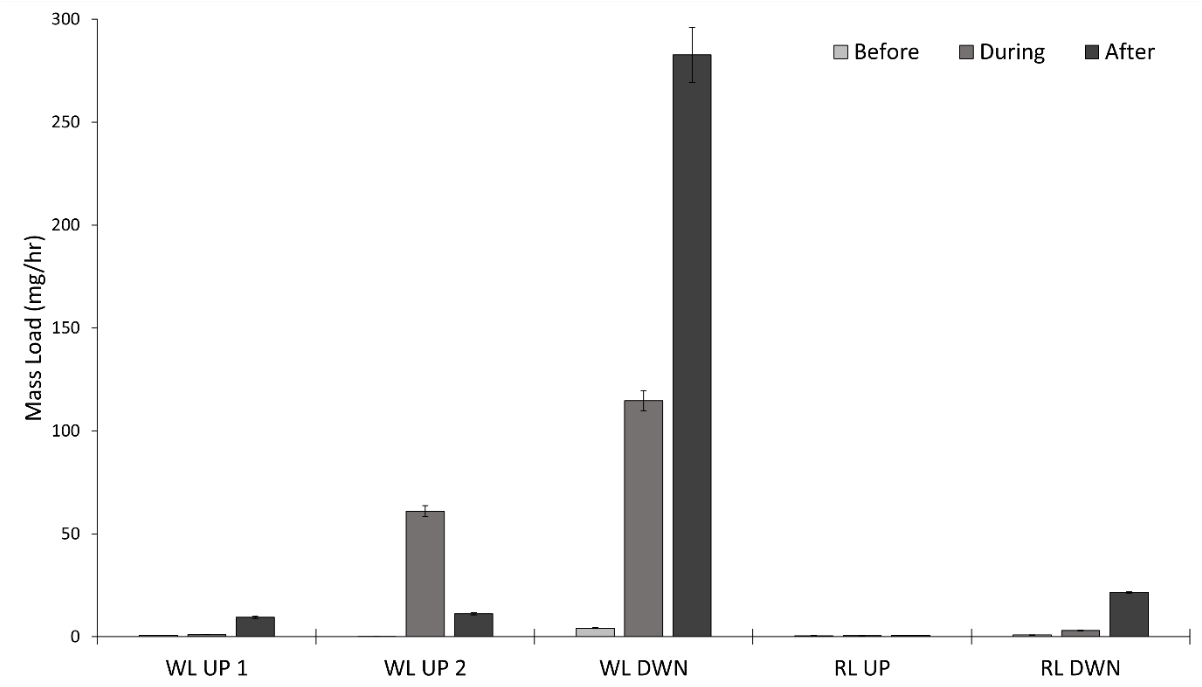

Figure 5: Mass load (mg/hr) flowing through each sample site for the week before, during and after the festival.

RL UP: Redlake Upstream, Stoodly Bridge

RL DWN: Redlake Downstream, Redlake Farm

WL UP 1: Whitelake Upstream 1, Footbridge

WL UP 2: Whitelake Upstream 2, Riverdale

WL DWN: Whitelake Downstream, Monarch's way

Table 1: The ratio of Cocaine to Benzoylecgonine for upstream and downstream sites of the Whitelake River.

Site	**Weekend of sampling in relation to the festival**		
	Before	**During**	**After**
WLUP1	0.22	0.06	0.04
WLUP2	0.16	0.05	0.05
WLDWN	0.14	0.06	0.06

Table 2: Risk quotient (RQ) for detected drugs calculated from maximum environmental concentration (MEC) and the predicted no effect concentration (PNEC) for the lowest available toxicological data. MEC are from the WLDWN site during and after the festival. EC50: Median Effective Concentration, Concentration at which 50% inhibition of a function (e.g. growth rate) was observed.

Compound	MEC (ng/L)	Ecotoxicological data (μg/L)	Experiment information	AF	PNEC (ng/L)	RQ	Risk	Reference
Cocaine	32.33	4,350	EC50 – Green Algae	1,000	4,350	0.007	No risk	*Zhou., et al* 2019
	12.00					0.003	No risk	
Benzoylecgonine	548.41	6,805,000	EC50 – Crustacea	1,000	6.805 E6	8.06E-5	No risk	Zhou., *et al* 2019
	194.22					2.85E-5	No risk	
MDMA	73.6	216	EC50 – Daphnia spp.	1,000	216	0.34	Acute restricted use	Maaz., *et al* 2021
	322.77					1.49	Acute high risk	