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MICROBIOLOGICAL POLLUTION OF THE SOUTHERN BALTIC SEA FROM SMALL URBAN CATCHMENTS FOLLOWING RAIN EVENTS OF DIFFERENT INTENSITIES

Mikrobiologiska föroreningar av södra Östersjön från små urbana avrinningsområden vid olika regnintensiteter

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Abstract

The microbiological quality of storm water runoff was monitored at four traffic-related sites in Trelleborg, Sweden to assess how microbiological pollution depends on rain intensity. Flow proportional storm water runoff samples were collected during the initial runoff and analyzed for total coliform bacteria, *Escherichia coli, Clostridium perfringens,* and intestinal enterococci. Microbiological pollution in storm water runoff was not proportionally related to traffic intensity. Intense rain events produced runoff that was substantially more polluted with indicator bacteria compared to less intense events. The average concentration of intestinal enterococci in storm water at all sites exceeded the requirement for good quality bathing water (2006/7/EC) by 5 to 55 fold suggesting that storm water discharged from even relatively small urban areas has the potential to pollute the southern Baltic Sea, or any, water reservoir with potentially pathogenic microbes. The results can be used as reference in assessment of potential impacts on human health of the release of storm water into the southern Baltic Sea, and other reservoirs, from the relatively small traffic-related catchments found in smaller cities.

Key words – microbiological pollution, rain intensity, runoff quality, storm water

Sammanfattning

Den mikrobiologiska kvalitén av vägdagvatten mättes på fyra ställen i Trelleborg för att undersöka hur mikrobiologiska föroreningar beror på regnintensitet. Flödesproportionella dagvattenprover togs under avrinningens start och analyserades *Escherichia coli, Clostridium perfringens,* och enterokocker. Mikrobiologiska föroreningar i dagvattnet var inte proportionell mot trafikintensiteten. De mest intensiva regnen genererade dagvatten som var mer förorenade jämfört med regn med lägre intensitet. Medelvärdet av halten av enterokocker i dagvattnet var 5 till 55 gånger högre än de rekommenderade värdet för badvatten (2006/7/EC). detta visar att även små urbana områden potentiellt kan förorena Östersjön eller andra recipienter med patogena mikrober. Resultaten kan användas som referensvärden vid effektstudier av hälsoeffekter av utsläpp av vägdagvatten från små urbana områden.

Introduction

While a current trend is to incorporate storm water into urban design as a visible component of a sustainable urban environment, little is known about how the microbiological quality of this water, with its proximity to humans in their everyday environment, could impact the health of urban populations. Storm water runoff is polluted with different indicator bacteria which contribute to the microbiological pollution of surface waters;

however, the understanding of factors and parameters influencing the contamination and distribution of bacteria in storm water is limited. In addition the significance of the relationship between specific combinations of commonly used indicator organisms detected in the storm water, and other factors related to a catchment site or specific event, is not well understood.

When examining water for contamination by bacteria many different types of organisms can be of interest, depending on the suspected source of contamination. For detection of fecal pollution, counting of total coliforms gives an idea of the amount of bacteria in a sample but does not necessarily indicate fecal pollution. Coliform bacteria can originate from nutrient-rich waters, soil or decaying plant material, and thus a high number of total coliform bacteria present in untreated water is not in itself a cause for alarm unless other indicators, such as pathogenic coliforms, are detected (WHO 2003). Detection of intestinal enterococci, *E. coli* and *C. perfringens* are regarded as more specific indicators of fecal and/or pathogen contamination. Intestinal enterococci are specifically regarded as indicators of fecal pollution originating from warm blooded animals and humans (WHO 2008), while a recent study has suggested that detection of *C. perfringens* is a conservative indicator specifically for contamination of water with feces from non-herbivorous animals (i.e. wild boar, dogs, cats) and human-associated sewage (Vierheilig et al., 2013). *E.coli* is a broad indicator of fecal contamination from humans, animals and agricultural activities. Of these three more specific indicators of fecal contamination, detection of each provides different information based on the distinct microbiological properties of the organisms. *C. perfringens* is a spore-forming bacterium, remaining for long periods of time in the environment following the original contamination event and is unable to reproduce in water. The detection of *E. coli* can indicate a recent contamination as it is less persistent than *C. perfringens* (Vierheilig et al., 2013). Enterrococci are somewhat resistant to drying, sodium chloride and alkaline pH and are used to complement counts of *E. coli*, particularly in tropical climates, where Enterococci have been positively associated with the presence of a number of bacterial pathogens including *Salmonella* and *Campylobacter* (Viau et al., 2011). A series of epidemiological studies demonstrated that the numbers of *E. coli* and enterococci correlated best with bather illness, while total coliform counts were less reliable (Noble et al., 2003).

Urban storm water serves as a source of bacterial contamination to waters receiving the storm run-off, with the poorest quality storm water associated with street markets and poorly maintained residential locations (Ellis, 1993). The principal sources of indicator organisms generally are animal faeces, litter, refuse, vegetation, and street dirt, but in some cases can also include illegal connections to storm sewers. Bacterial water quality in Silk Stream (London, UK), and associated downstream waters receiving urban storm runoff and combined sewer overflows (CSO), showed that amounts of total coliforms, fecal coliforms, fecal streptococci and *Salmonella* exceeded those specified by EEC guidelines throughout the study area, particularly following severe storm events (Jacobs and Ellis, 1991). Gastroenteritis, skin, and respiratory diseases have been reported following contact with contaminated storm water in urban detention ponds (Nascimento et al., 1999). Young and Thackston (1999) investigated urban streams receiving urban storm runoff in Nashville – Davidson County, TN, USA and showed that counts of *E. coli,* fecal coliforms, and fecal streptococci were much higher in sewered basins than in the nonsewered basins and that fecal bacteria densities were related to the density of housing, population, development, percent impervious area, and domestic animal density. Malin et al. (2009) investigated the impact of storm water runoff on water quality of an urban, a suburban, and a rural stream and observed that excessive coliform abundance frequently occurred in the most urbanized catchments. Tiefenthaler et al. (2011) investigated the relative levels and flux patterns of *E. coli*, enterococci, and total coliforms from different land use types in Los Angeles, USA. They found that bacterial concentrations in storm water varied based on the contributing land use, with recreational areas having the highest concentrations followed by agricultural land and urban space with the lowest concentrations contributed from open space. The higher amounts of discharged sediments associated with recreational and agricultural areas are cited as partial explanations for the high numbers of bacteria associated with these types of land use. The rate of change of concentration and the strength of the first flush of both *E. coli* and total suspended solids where both shown to be influenced by catchment size, drainage infrastructure complexity and land use (McCarthy et al., 2012). As bacteria, particularly Gram negative bacteria such as *E. coli,* are able to attach to surfaces as biofilms, it is perhaps not surprising that findings related to sediment or suspended solids parallel those of bacterial contamination.

In addition to urban variables, weather and climate phenomena have been associated with greater contamination of storm water with indicator bacteria. Given that bacteria, particularly pathogenic bacteria and others of human origin prefer growth temperatures close to that of the human body, it is not surprising that both Young and Thackston (1999) and Hathaway et al. (2010) observed that counts of fecal bacteria were higher in summer than in winter. Hathaway showed that numbers of *E. coli* and fecal coliforms were significantly lower during winter than other seasons, although interestingly, it was more difficult to associate temporal climate with numbers of enterococcus. Coliform abundance was significantly higher during rain events than during dry periods with fecal coliform bacteria in water receiving storm runoff positively correlated with the total rainfall preceding the sampling (Mallin et al., 2009). Higher concentrations and fluxes of bacteria occurred early in storms and preceded peak flows in runoff of storm water (Tiefenthaler et al., 2011). Antecedent climate data has been shown to explain variability of indicator bacteria concentrations in storm water, with temperature, and the moisture of the soil and atmosphere as the most important variables to be considered (Hathaway et al., 2010, McCarthy et al., 2012). McCarthy et al. (2012) showed that numbers of *E. coli* were correlated to antecedent climate parameters, as opposed to hydrological parameters such as rainfall intensity; an effect that they explain could be linked to permissive weather conditions enhancing the growth and/or persistence of bacteria within a catchment.

With complexities surrounding the necessary parameters governing both growth and persistence of bacteria within a catchment area, it is an established observation that is difficult to compare results between different studies involving bacteria and storm water. In addition, the available knowledge may be based on grab samples taken in storm water receiving bodies or from stormwater outfalls and data collected within streams and estuaries (McCarthy et al., 2007; Hathaway et al., 2010). Data gathered from specific event-based monitoring of urban storm water runoff that incorporates information regarding climatic variables, different catchment characteristics, and land use is required to better understand factors influencing the microbiological quality of storm water.

The understanding of factors influencing microbiological pollution of storm water is crucial to plan for local storm water management not least with regard to type and use of the waters receiving the storm runoff. Microbiological storm water quality may be of great concern if the discharge point is situated close to bathing and recreational areas, or into water used as a source reservoir for drinking water: the microbiological pollution of drinking water reservoirs by storm water is not well investigated (Åström and Petersson, 2009). In Sweden most municipalities discharge storm water from urban areas to the recipient body of water through separated sewers; however, there is no binding legal regulation in Sweden regarding monitoring or standards for minimal quality of released storm water. While the compilation of guideline values for storm water quality discharged from urban areas is ongoing in Sweden, these guidelines do not currently include any consideration of microbiological parameters (Riktvärdesgruppen, 2009). In addition, few studies address the influence of microbial pollution from storm water runoff on the water quality in the southern Baltic Sea (Schippmann et al., 2013a, 2013b).

This study investigates the microbiological runoff quality at four traffic-related urban catchments in a small city in southern Sweden. These catchments have no storm water flow during dry weather conditions and provide direct runoff from an urban paved surface, limiting possible uncertainties related to the origin of water being sampled. The commonly used indicators for monitoring microbiological quality of water in reservoirs were used to investigate the storm water samples with numbers determined for: total coliform bacteria; *Escherichia coli* (*E. coli*); presumptive *Clostridium perfringens*; and intestinal enterococci. The choice of studied indicator organisms was made to support assessment of fecal pollution and related risks associated with storm water.

Methods

Study site

Four storm water catchment areas (Fig 1; Table 1) were selected in Trelleborg, a small city of 26 000 inhabitants and situated in the south of Sweden. The storm water from the city is discharged to the southern Baltic Sea in the vicinity of public bathing areas. Normal annual precipitation in the region is 491 mm (Falsterbo station, SMHI 2010) and the climate is temperate with occasional snow in winter. Precipitation at the study site was monitored throughout the study period, from May 2009 to April 2010.

Runoff water sampling and analyses

The interior of all storm water pipes in the studied catchments was investigated prior to the sampling campaign using a camera to ensure that there were no leakages from wastewater pipes or drainage water. The selection of storm water sampling points, the preparatory work prior to the sampling campaign, and the sampling method are described in detail by Czemiel Berndtsson (2014).

Only the first-flush portion of runoff water was sampled: this portion was equalized at each site and at each event to minimize the effect of different depths of the sampled runoff on results. Flow proportional sampling was used to collect a sample volume of storm water runoff at each site equivalent to approximately 1 mm of precipitation on the impermeable area of the respective catchment. Depending on the character and intensity of

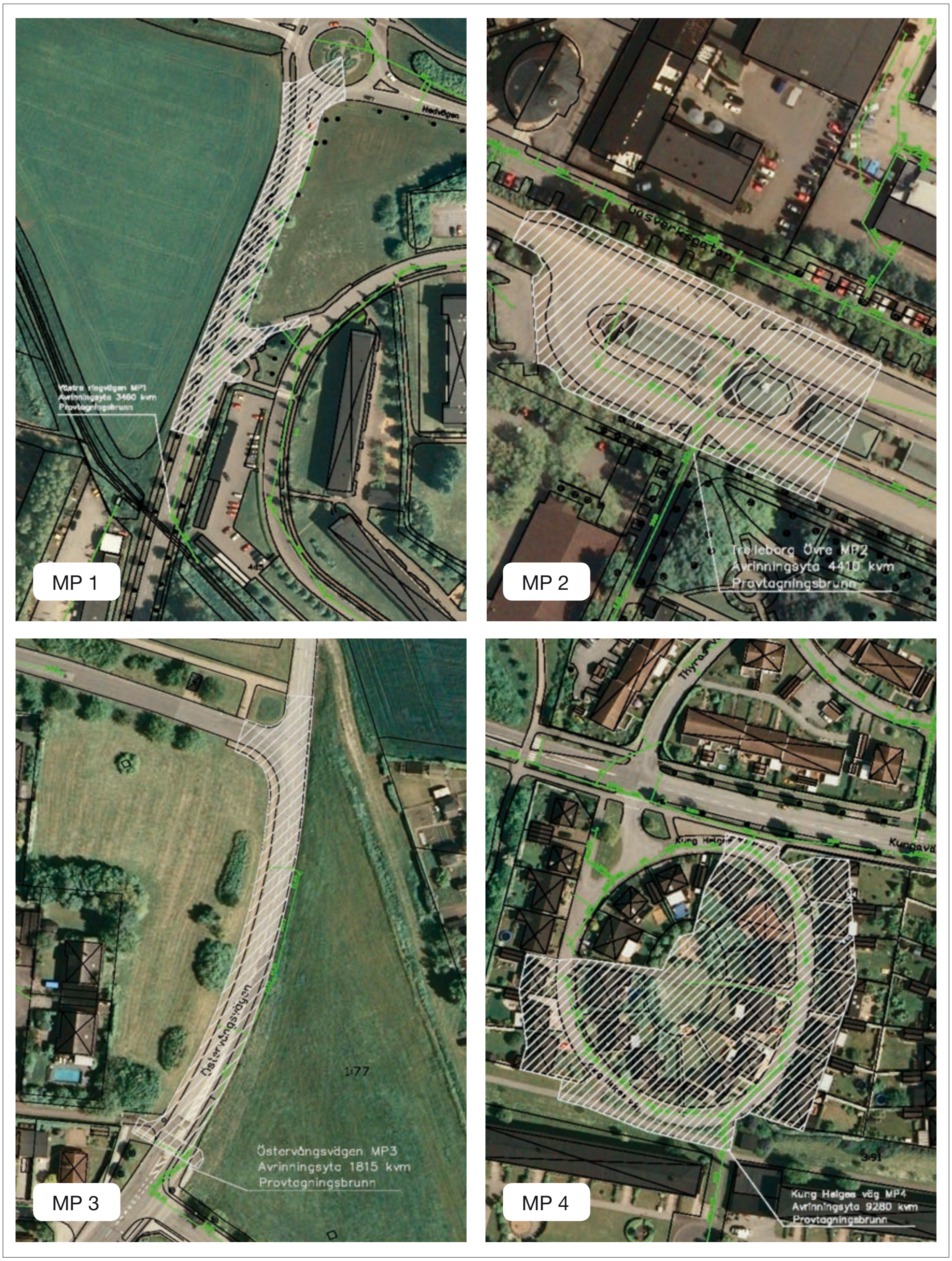

Figure 1. *Storm water catchments and sampling points MP1–MP4.*

Table 1. *Summary of sampling points MP1–MP4 and microbial tests.*

Sampling Point Description					Total coliforms 35°C		*E. coli* 44°C		Pres. *C. perfringens*		Intestinal enterococci	
Name	Description	Traffic intensity[a]	Impermeable catchment material	Size (m^2)	n[b]	Standard deviation (cfu/100ml)	n	Standard deviation (cfu/100ml)	n	Standard deviation (cfu/100ml)	n	Standard deviation (cfu/100ml)
MP1	Västra Ring-vägen, main street	7000	asphalt	3500	5	8954	5	303	5	270	5	3991
MP2	Övre Buss-torget, bus station	100 (95% heavy vehicles)	concrete blocks	4400	6	94082	6	1698	5	1015	6	4890
MP3	Östervångs-vägen, main street	3000	asphalt	1800	4	100256	4	1950	3	337	4	33481
MP4	Kung Helges Väg, residential housing	80	asphalt, concrete, diverse roofing materials	5800[c]	8	33012	8	2324	7	415	8	3006

[a]vehicles per day, annual average
[b]n is number of samples taken
[c]total area of catchment is 9300 m^2, 5800 m^2 is impermeable.

a rainfall event, the precipitation depth until the preset storm water runoff volume passed each sampling site varied in some cases.

Storm water flow at each selected catchment was monitored during the entire study period with storm water samples taken through manholes after selected rain events. The precipitation was measured with a 0.2 mm tipping bucket rain gauge (Casella CEL Inc, UK). Flow was measured using an AV Portable flow meter (Mainstream Measurements Inc. UK) with water samples obtained using a Lange XIAN 1000 pressure/vacuum transportable sampler (Hach Lange GmbH, Germany). Measuring and sampling equipment was rented from the consulting company (SWECO Environment AB, Växjö, Sweden). During the study period (May 2009 – April 2010), flow proportional storm water samples were taken at each respective site (Table 1) during different storm runoff events. Each sample was comprised of twelve 500 ml volumes of storm water, with 250 dm^3 passing the sampler between each 500 mL volume at MP1 and MP2 (total flow sampled: 3000 dm^3), and 150 dm^3 passing the sampler between each 500 mL volume at MP3 and MP4 (total flow sampled: 1800 dm^3). This sampling setting results in sampled runoff volumes corresponding to approximately 1 mm at MP1, MP2 and MP3 and approximately 0,5 mm at MP4. For this calculation the runoff coefficient was assumed to be 0.8 for all areas.

Runoff water samples were analyzed by VASyd Water Laboratory (Box 191, 201 21 Malmö, Sweden) which holds Swedac accreditation ISO/IEC 17025. The samples were analysed for: total coliform bacteria growing 35°C, thermotolerant *E. coli* (growing at 44 ° C), presumptive. *C. perfringens*, and intestinal enterococci, according to methodologies outlined in ISO/CD 6461-2:2002 and reported as cfu/100ml. Samples more than 24 hours old were not analyzed for microbiological parameters due to possible errors caused by potential bacterial die off or growth.

Results and discussion

Storm water runoff quality

The number of analyzed samples (Table 1) at each sampling point varied due to technical problems occurring occasionally with equipment. For most microbiological parameters the differences between minimum and maximum detected values are large. The sampled runoff volume differed slightly between MP1-3 (1 mm) and MP4 (0.5 mm). While metal concentrations determined for parallel samples to those examined in this study were able to specifically reveal correlations between, for example, traffic intensity and chemical pollution (Czemiel Berndtsson, 2014), the biological nature of the analyses in this study, compounded by known variability associ-

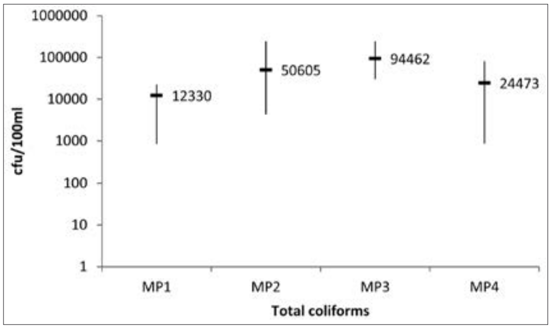

Figure 2. *Average concentrations of total coliforms at MP1–MP4.*

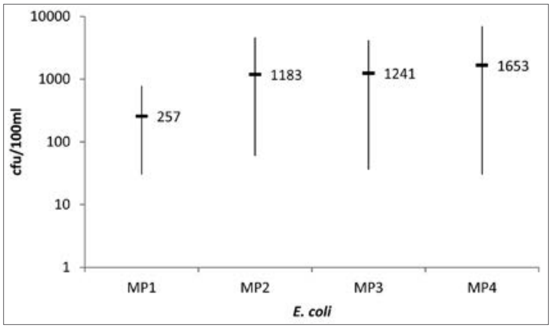

Figure 3. *Average concentrations of E. coli at MP1–MP4.*

ated with storm water (Ledin et al., 2001, McCarthy et al., 2007, Hathaway et al., 2010) have required a more qualitative approach for comparison. Thus, as data series in this study are short, and high values occur which strongly influence the mean value of the series (Table 1), the comparison between sites for microbiological water quality is made using average values of parameters.

Influence of catchment area on storm water quality

The microbiological parameters measured in this study to represent storm water quality were compared between the different catchment areas sampled (Fig 2–Fig 6). At each site, total coliforms were the most predominant type of bacteria identified with the highest counts from MP3 (94462), followed by MP2 (50605). This similar trend was also observed for counts of intestinal enterococci, suggesting that samples taken from site MP3, followed by MP2 contained, in general, the most bacteria. Sites MP2 and MP3 also contained similar numbers of *E. coli* and *C. perfringens*, however at sites MP1 and MP4, where fewer total bacteria were observed in the counts, stronger differences could be observed. For MP1 the numbers of *C. perfringens* were approximately double that of *E.coli*, while the trend was reversed for MP4, with 4 times the amount of *E. coli* present in these storm water samples compared to *C. perfringens*.

As total coliform bacteria can be found in nutrient-rich waters, originating from soil or decaying plant material, the high number of total coliform bacteria detected at MP2 and MP3 could perhaps only indicate a high amount of organic matter in the water. Of greater concern, however is that in this study, and particularily at MP3, a high count of total coliforms was combined with significant numbers of intestinal enterococci. While samples from MP3 contained high numbers of intestinal enterococci, these samples also contained the largest numbers of bacteria in total. If the ratio of total coliform bacteria to that of enterococci is compared, MP3 has the lowest ratio (4.2) compared to MP2 (13.9) and MP4 (11.1), with the MP1 ratio at 6.2, suggesting that the concentration of intestinal enterococci is actually low at sites MP1 and MP3. A ratio of total coliforms to enterococci greater than 4 has been proposed to indicate a human origin and while this methods is not recommended for determining the origin of fecal pollution (WHO 2008) it is interesting to note that in this study the resi-

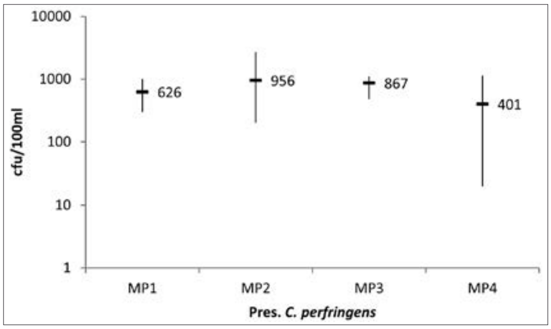

Figure 4. *Average concentrations of presumptive C. perfringens at MP1–MP4.*

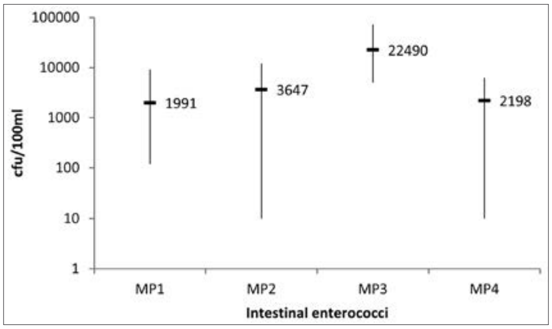

Figure 5. A*verage concentrations of intestinal enterococci at MP1–MP4.*

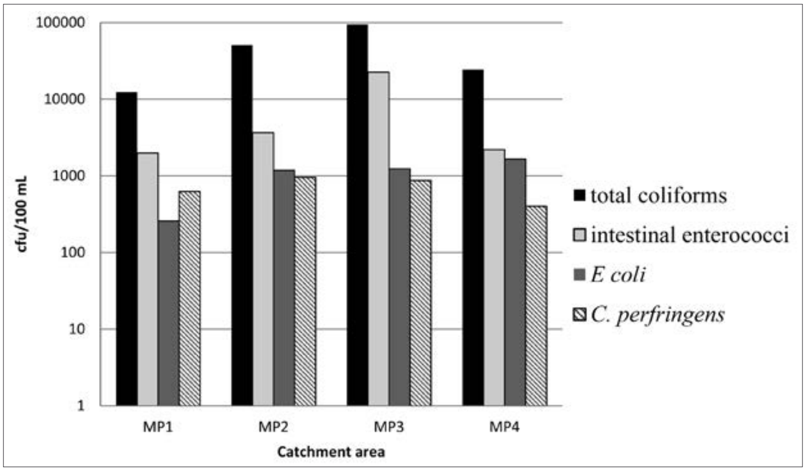

Figure 6. *Total bacterial counts summed for all measured storm events by catchment area (MP1–MP4).* Black bars: total coliforms; light grey bars: intestinal enterococci; dark grey bars: *E. coli*; lined bars: *C. perfringens.*

dential and bus station sites (MP2, MP4) gave ratios consistent with a human origin for bacterial contamination, while the sites frequented largely by motor vehicles had much lower values.

The detection of *C. perfringens* at all sites is not surprising since spores of this bacteria can originate over a long time scale from fecal contamination by nonherbivorous birds as well as dogs, cats and humans (Vierheilig et al., 2013), all sources that likely frequent the urban areas and streets in the study area. While the numbers of *C. perfringens* and *E. coli* were relatively equal in most samples, the number of *E. coli* was substantially higher than that of *C. perfringens* at MP4, the sampling point located in a villa housing area, consisting of house yards, local road and a grass covered green area. Since detection of *E. coli* requires recent contamination with fecal matter it is not surprising that an area with more live traffic of humans and animals resulted in increased numbers of this organism relative to *C. perfringens.* Comparison of fecal coliform counts in urban, suburban and rural streams following storm water events showed that excessive coliform abundance frequently occurred in the most urbanized catchments (Mallin et al., 2009).

One of the more significant findings is that storm water sampled from all sites failed to meet the requirements for good quality bathing water, of particular concern in this study as storm water is released without treatment into areas used for bathing. EC quality requirement for bathing water stipulate that good quality water must not contain more than 400 cfu/100 mL intestinal enterococci and not more than 1000 cfu/100mL *E. coli.* With respect to intestinal enterococci the limit for good quality bathing water was exceeded at MP1 and MP4 by five times, at MP2 by about ten times and as much as fifty five times at MP3 while amounts of *E coli* were higher than acceptable at MP2, MP3 and MP4. This mirrors observations of numerous other studies examining fecal pollution of recreational waters by storm water runoff suggesting that it could be normally expected that, if untreated, storm water runoff will lower the quality of the water into which it is expelled (McCarthy et al., 2007, Mallin et al., 2009, Hathaway et al., 2010, Parker et al., 2010).

Influence of rain intensity on storm water quality

Bacterial counts (Table 2) and storm characteristics (Table 3) were complete for rain intensity sampling points MP2, MP3 and MP4 for storm events occurring in 2009 on May 20 (Event 1), October 26, (Event 2), November 2 (Event 3), and November 4 (Event 4). All the values are extracted from the data records of measured storm water flow at each sampling site and from precipitation records.

The rain intensity varies much between sampled events and decreases from event 1 (Table 3) through events 2 and 3 until the least intense event 4. The rain volume during a week preceding the sampled event is opposite, increasing from event 1 through events 2 and 3 until reaching the highest value during a week before event 4 (Table 3).

Our results show that Event 1 is characterized by intense rain, the driest period preceding the rain and runoff, and high counts for most of the bacterial indicators, particularly at site MP3 for intestinal enterococci. Samples from Event 1 storm water contained the most *C. perfringens* observed in this study. As *C. perfringens* is considered more resilient for survival compared to coliforms including *E. coli* the high numbers in these bacte-

Table 2. *Concentrations of microbiological indicators in storm water (in cfu/100ml) at MP2–MP4 for Events 1–4.*

Indicator bacteria	Sampling point	Event 1	Event 2	Event 3	Event 4
Total coliforms 35°C	MP2	16260	242000	10920	25130
	MP3	72700	242000	30350	32800
	MP4	6070	81640	12610	15930
E. coli 44 ° C	MP2	4590	890	220	590
	MP3	4150	36	240	540
	MP4	560	6990	2200	1730
pres. *C. perfringens*	MP2	900	No data	300	680
	MP3	1100	No data	480	1020
	MP4	600	No data	20	100
Intestinal enterococci	MP2	12150	3180	10	6450
	MP3	72700	6700	5020	5540
	MP4	5160	6230	10	6040

rial counts may reflect a collection of fecal pollution over the extended preceding dry period that were collected in the intense runoff event, to produce the counts associated with Event 1. Event 2 is distinguished by the highest counts for total coliforms, paralleled by the highest numbers of *E. coli,* sampled from MP4, observed in this study. Interestingly the trend for numbers of total coliforms for Event 2, with high numbers at MP2 and MP3, is not proportional to the trend observed in *E.coli* counts, supporting the observation in other studies that total coliforms is not necessarily an accurate indicator of fecal contamination. It is perhaps not surprising that MP4 produced the highest counts of *E.coli* due to the residential nature of this catchment, as described in the previous section, although it is interesting to note that large counts of *E. coli* at this catchment do not seem to be related to any distinct characteristic of the rainfall. Seasonal variation is one possible explanation, with numbers of *E. coli* at MP4 showing higher numbers in the fall-winter season. Seasonal variations in the number of *E coli* in the environment have been observed with greater numbers during warmer seasons (Daly et al., 2013), and counts obtained from fall storms (Events 2–4) could reflect multiplication of bacteria within small water or soil pockets within the catchment area during the Swedish summer.

Events 3 and 4 are relatively similar with respect to rain characteristics and most bacterial counts however;

Table 3. *Rain characteristics (intensity, volume until sample is taken, and volume during preceding 7 and 14 days) for catchments MP2–MP4 during Events 1–4.*

Rain Characteristic	Sampling point	Event 1	Event 2	Event 3	Event 4
intensity (l/s,ha)	MP2	340	35	8	2
	MP3	300	35	8	4
	MP4	300	35	8	2
volume until sample taken (mm)	MP2	6,6	2	1,8	1,2
	MP3	5,8	2,4	3,4	3,2
	MP4	6,4	7	1,6	1
volume preceding 7 days (mm)	MP2, MP3, MP4	4.8	9,4	11,6	18,8
volume preceding 14 days (mm)	MP2, MP3, MP4	10,6	10,8	21	34,6

there is a slight increase in *C. perfringens* at all sampling locations between Event 3 and Event 4. Given the short time and similar weather parameters surrounding these two events, it is difficult to account for this specific increase of *C. perfringens* at all sampling locations.

When catchment area is taken into consideration, regardless of overall rain characteristics, more total coliforms, *C. perfringens* and intestinal enterococci are present in the storm water from paved areas while larger counts of *E. coli* are more characteristic of the residential MP4 area. This could reflect the more sensitive biology of *E. coli* which not only is a specific indicator of fecal contamination but which is also not as resilient to harsh survival conditions when compared to *C. perfringens* and intestinal enterococci (Vierheilig et al., 2013). Thus the living nature of the residential area, with foot traffic, green space and animal populations will produce higher numbers of *E. coli,* which if introduced into the more urbanized environments of MP2 and MP3 would have quickly died off and not appeared in the storm water counts. When total counts not related to specific storm events are examined (see above) a predominance of *E. coli* relative to the total coliforms is also observed at MP4.

Taken together, intense rain events together with preceding dry weather can result in greater contamination of storm water runoff, while paved areas are less likely to have *E. coli* as a specific contaminant of the storm water. Interestingly the data appear to show that trends in *E. coli* and intestinal enterococci counts do not follows those for total coliforms at every location, confirming observations that total coliforms may include contamination with bacteria from sources other than fecal pollution (WHO, 2003).

Conclusions

This study finds that microbiological pollution in storm water runoff does not appear related to car traffic intensity but that different types of microbial pollution may enter storm water from different types of catchment areas. Spore forming bacteria such as *C. perfringens* populated storm water from concrete and traffic related catchments, while *E. coli* contamination was more prevalent in storm water originating in residential areas. Given the health risks associated with detection of *E. coli,* and the proximity of the storm water to human and animal traffic in residential areas, additional studies determining the sources of *E. coli* in storm water are necessary. In addition as the levels of bacterial pollution in storm water collected from all sites exceeded requirements for bathing water (2006/7/EC), investigation into sources of storm water contamination in Trelleborg, Sweden will ensure that the recreational waters of the southern Baltic Sea receiving the storm water are suitable for bathing, particularly following intense rain events. Alternatively, it could be required that storm water is treated prior to discharge.

The results indicate that storm water discharged from even relatively small urban areas can be a source of significant microbiological pollution to waters receiving the storm runoff. This should be considered when planning storm water management and assessing risks for human health following exposure to urban storm water runoff for similar urban areas, including both open storm water systems and bodies of water receiving the polluted runoff.

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