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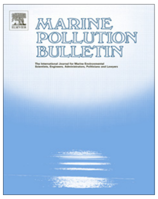

Impact of rainfall on the hygienic quality of blue mussels and water in urban areas in the Inner Oslofjord, Norway

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ABSTRACT

The effects of precipitation on the hygienic quality of water and blue mussels collected from five different localities in the urban areas in the Inner Oslofjord were investigated, with samples analysed for *Escherichia coli*, *Salmonella* spp., pathogenic *Vibrio* spp., Norovirus, Sapovirus, *Cryptosporidium* spp. and *Giardia duodenalis*. The sampling sites were located at varying distances from the outlet of combined sewer overflows (CSO)-impacted rivers/streams. In general, 1–3 $\log_{10}$ increases in fecal indicator bacteria and human pathogens were observed after heavy rainfalls. Blue mussels appeared to be a useful indicator of the impact of sewage at these sites, and generally a good correlation was identified between concentrations of *E. coli* and other human pathogens in the mussels. Provision of general advice to the public of avoiding areas near the outlets of CSO-impacted rivers after heavy rainfall may reduce the risk of gastroenteritis by bathers and others that may swallow water during recreational activities.

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1. Introduction

Oslo, the capital of Norway, is located around the inner part of the Oslofjord, which is best described as an extended inlet from the Skagerrak strait, connecting the North Sea and the Kattegat sea area, which leads to the Baltic Sea. The Inner Oslofjord is a popular area for recreational activities, but it is also a recipient for treated wastewater from the about 900,000 inhabitants living around the Inner Oslofjord. Since the treated wastewater is discharged at about 50 m depth far away from bathing places, the effect on the bathing water quality is limited. The local discharges of untreated wastewater from storm water overflows (called combined sewer overflows, CSOs) and emergency overflows are of more concern for the bathing water quality. A large fraction of the sewer network in the city of Oslo is combined, i.e. the rainwater is collected in the same pipes as the domestic wastewater. During heavy rainfall the capacity of the sewage system may be insufficient to accommodate the greater volume associated with the rainwater-diluted wastewater. Excess volume is then discharged, via CSOs, directly to the Inner Oslofjord or to rivers that flow into the fjord, without treatment in a sewage treatment plant. Similar CSO structures are common assets within the combined urban drainage system in many cities, and discharges during heavy rainfalls may have significant impacts on the quality of receiving waters (Andersen et al., 2013; Mounce et al., 2014).

Historical data from the bathing water surveillance and classification according to the EU bathing water directive show that most of the official beaches in the Inner Oslofjord have excellent or good water quality (Daviknes, 2012). Nevertheless, the water quality at some beaches is classified as poor and these beaches are generally located near the outlet of contaminated rivers. However, water quality at beaches near sources of contamination is not necessarily always poor, but may vary widely. Water quality at beaches may be influenced by discharges from CSOs during heavy rain, other sources of contamination, the location of the beaches relative to contamination sources, the tides and winds which affect the transport in the fjord, and on the solar radiation (Lee and Morgan, 2003; Chan et al., 2013; Zhang et al., 2013).

Several measures, such as increased capacity at the wastewater treatment plants and upgraded pipelines, have been implemented in Oslo in recent years in order to reduce the sewage loads to the fjord. However, external pressures, including increased population in urban areas and more heavy precipitation in recent summers could have counteracted the benefits derived from these measures. Another challenge is the redevelopment of the inner harbor area into residential and recreational areas. The water quality in these areas is historically poor, but politicians and the public expect the relevant authorities to ensure good quality of bathing water within a few years. Measures for reducing the sewage loads to

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the fjord are therefore planned or on-going, and these require large investment costs (Vogelsang et al., 2010; Storhaug et al., 2013).

For localities with highly variable water quality, perhaps due to discharges from CSOs, results from weekly or monthly water samples are of little value for making day-to-day recommendations regarding the hygienic safety of the water. In order to prioritize measures and for better real-time decision-making, including when to advise against recreational activities during short-term pollution events, better understanding about the effect of rainfall events on the water quality at the different locations is necessary.

As shellfish can concentrate contaminants, including pathogenic microorganisms, from the water column during their normal filter-feeding activity, they have previously been suggested to be a useful indicator of water quality. In Ireland a range of different mussel species have been used for biomonitoring of surface inland and coastal waters for human waterborne enteropathogens (Lucy et al., 2008), while in Canada, blue mussels (*Mytilus edulis*) were used for monitoring water quality of Sydney harbor (Nova Scotia) with respect to chemical contaminants during a long-term remediation project (Walker et al., 2013). In contrast with grab samples of water, which provide only a snapshot of the fluctuating water quality at a given time point, results from analysis of molluscan shellfish may reflect the average water quality over a prolonged period.

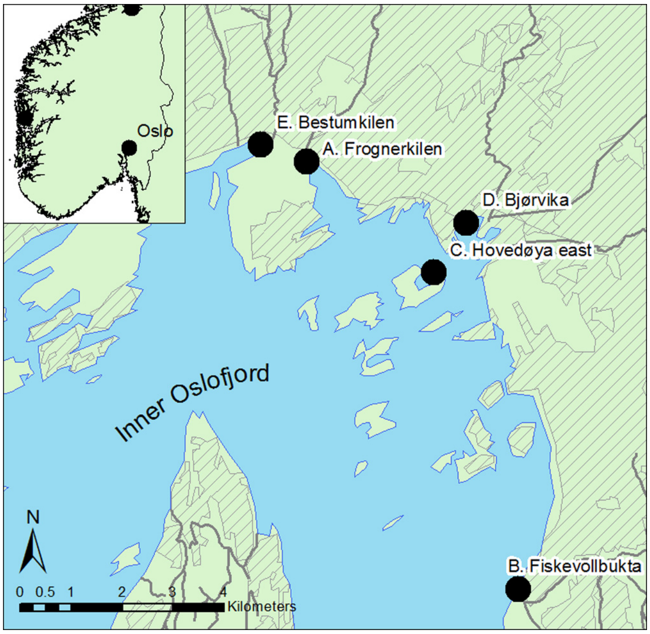

Fig. 1. Location of the 5 sample collection sites in the Inner Oslofjord. Urban areas are shaded and the main rivers/streams are shown.

The purpose of this study was to investigate the impact of precipitation on the occurrence of faecal microorganisms in coastal water (indicator bacteria) and blue mussels (indicator bacteria and human pathogens) at locations close to (i.e. 20–1000 m) the outlets of CSO-impacted rivers in the urban areas of the Inner Oslofjord.

2. Materials and methods

2.1. Study area and sample collection

Five different areas in the Inner Oslofjord, all located in the city of Oslo, were used as sampling sites for blue mussels (Fig. 1). These sites are located at varying distances from the outlets of rivers that are recipients for discharges of CSOs (Table 1).

Samples of native mussels and water from each of the five sites were collected on five different days. The sample collection days were chosen to reflect different rainfall events during the last 48 h prior to sampling; two sampling days were after absence of, or marginal, precipitation (21.05.2013 and 19.06.2013), one sampling day was after some limited precipitation (24.06.2013), and two sampling days were after heavy rainfalls (23.05.2013 and 27.06.2013, Fig. 2).

The mussels were collected from floating pontoons at two of the sampling sites (sites A and C) and a concrete pontoon (site E) 20 to 100 cm below the surface using a metal rake fitted with a net. At site D, the mussels were collected from the boulder wall approximately 50 to 100 cm below the water surface. At site B, the mussels were collected from the mud using the rake. When possible, both small (1 cm length) and large (up to 8 cm) specimens were collected, and a total of 150 to 300 mussels were collected at each site, depending on the average sizes. At site D, only medium to large mussels were found. At each sampling site the mussels were collected into a plastic lidded bucket, and delivered to the laboratory within 6 h. The mussels were stored at 4 °C and analysed the next day.

A 500 ml grab sample of water was also taken at each sampling site and each sampling occasion, with the sample collected from approximately 30 cm below the surface of the water. The water samples were stored with cooling elements and analysed the same day.

2.2. Microbial analysis

2.2.1. E. coli and pathogenic bacteria in the blue mussels

Mussel flesh and intravalvular fluid were aseptically collected into sterile stomacher bags (BagLight PolySilk, Interscience, France). After homogenization in a Stomacher (IUL, Type 0400, IUL s.a. Spain), the samples were analyzed for *Escherichia coli, Salmonella* spp. and pathogenic *Vibrio* spp.

Table 1
Description of the different sample collection sites.

Name	Degree of longitude	Degree of latitude	Blue mussels collected from	Distance from outlet of contaminated river/CSOs
Site A Frognerkilen	010°41.430′	59°54.958′	Floating pontoon	About 200 m from the outlet of the river Frognerelva ($^*Q_m = 0.4$ m^3/s)
Site B Fiskevollbukta	010°46.441′	59°50.592′	Bay mud	About 200 m from the outlet of the river Ljanselva ($^*Q_m = 0.6$ m^3/s)
Site C Hovedøya east	010°44.250′	59°53.877′	Floating pontoon	1 km from river Alna ($^*Q_m = 1.6$ m^3/s) with a main CSO and 1.1 km from Akerselva ($^*Q_m = 3$ m^3/s)
Site D Bjørvika	010°44.864′	59°54.424′	Boulder wall	Inner harbor, about 500 m from the outlet of river Akerselva
Site E Bestumkilen	010°40.431′	59°55.109′	Concrete pontoon	About 20 m from the outlet of the river Hoffselva ($^*Q_m = 0.3$ m^3/s)

[*] Q_m = Average water flow in the river/stream. The concentration of *E. coli* in the rivers may vary from 100/100 ml to > 30 000/100 ml (during heavy rain).

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