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# Long term development of Bathing Water Quality at the German Baltic coast: spatial patterns, problems and model simulations

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ABSTRACT

Bathing water quality plays a key role for public health, is highly important for recreational tourism and therefore monitored in the EU-Directive 2006/7/EC. To identify pollution hot spots, sources and impacts of the directive-change in 2006, including a change of indicator organisms, we evaluated monitoring data of the past 15 years, collected own data, determined survival rates of indicator organisms and applied hydrodynamic modelling in a micro-tidal-system.

Due to higher survival rates under turbid conditions and restricted water exchange, shallow, eutrophic bays and lagoons are hot spots of microbial pollution. Rain events cause high microbial emission and distribution. Based on different decay rates, the ratio of *E. coli* to Enterococci can hint towards a pollution source. Including rain predictions, currents and winds, hydrodynamic models can then assess the daily risk of microbial pollution at each bathing site. They are an important tool to modify beach management and event-based monitoring.

## 1. Introduction

Tourism is extremely important for the economy of communities. Especially at the coasts, it is highly dependent on the bathing water quality (BWQ) wherefore regular monitoring was first defined 1975 in the EU Bathing Water Directive 76/160/EEC (EU, 1976). This was modified in 2006 by the EU Directive 2006/7/EC (EU, 2006) towards more specific indicator organisms from total and faecal coliforms to *E. coli* and Enterococci. Concentrations of these are positively correlated to swimming-related illnesses (Cabelli et al., 1982; Wade et al., 2010; Pinto et al., 1999; WHO, 2001). Nonetheless, problems still occur on a regional basis where microbial pollution hampers tourism because of bathing bans or beach closures. When the General German Automobile Association (ADAC) conducted additional sampling in the German seaside resort Kühlungsborn, they found high indicator concentrations although official monitoring by the State Agency for Health and Social Affairs of Mecklenburg Western-Pomerania (LAGuS MV) categorized the same bathing waters in excellent quality. Results where highly discussed by the media and the European wide monitoring methods set by the Directive were questioned. After the LAGuS took position and the ADAC backed down, a negative effect on Kühlungsborn and the question about adequate EU monitoring of bathing water quality still remains.

Since monitoring data are limited to a certain sampling site, we combine additional microbial sampling in Kühlungsborn area, at the Barther Bodden, within the Szczecin Lagoon and the Warnow Estuary, with official monitoring data to evaluate overall suitability of the recent Directive. Case study sites are chosen based on their relevance to bathing water quality: Kühlungsborn is under public pressure due to high indicator concentrations found by the ADAC. Barth at the Barther Bodden aims to be a coastal resort and to attract tourists with several bathing sites, but the only one so far exceeds thresholds regularly. Towns around the Szczecin Lagoon also aim for a stronger economy based on tourism and therefore would like to promote especially family-friendly bathing in this shallow lagoon but irregular occurring threshold exceedances interfere. Hydrodynamic models for Szczecin Lagoon have been used in Schernewski et al. (2010) and Schippmann et al. (2013) but sources were only assumed and not validated. The Warnow Estuary ends into a highly touristic place (Warnemünde) and at the same time is densely populated by the city Rostock. We investigate if these pollution sources pose a risk for bathing within and outside the estuary using a validated model. Furthermore, we assess how monitoring data can be used to backtrack sources as well as to predict microbial pollution. Therefore, we i) provide a long-term

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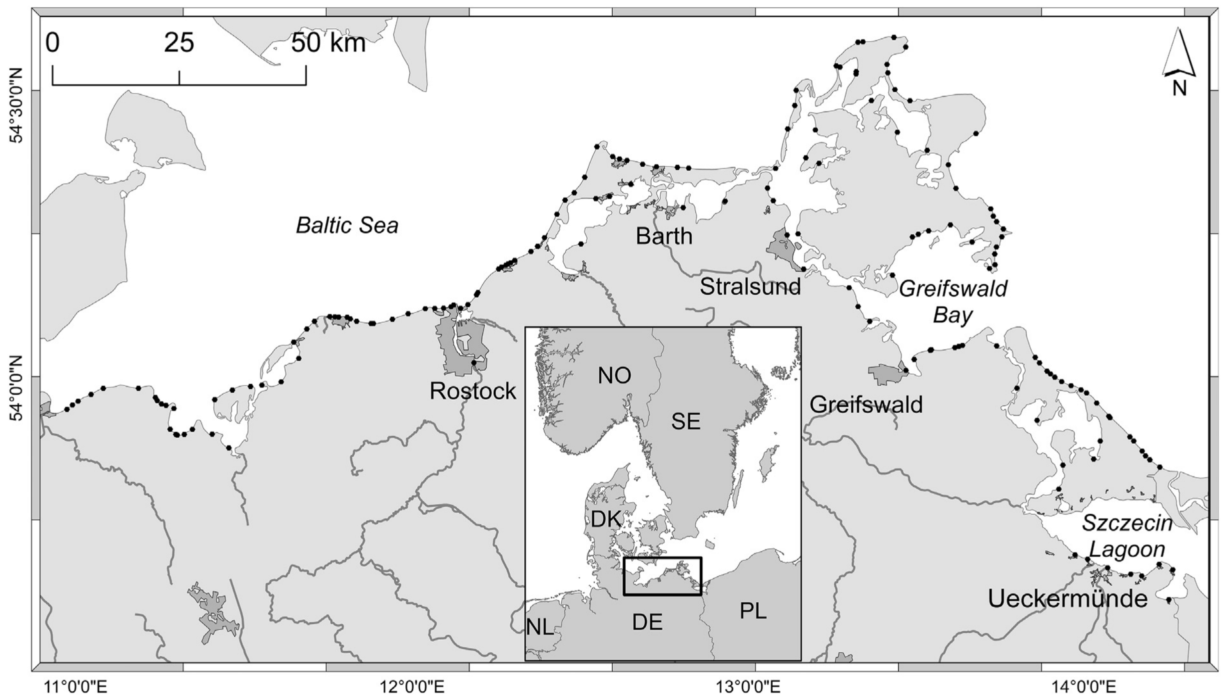


**Fig. 1.** Baltic coast of Mecklenburg Western-Pomerania (MV), Germany with official EU coastal bathing sites (●).

comparison of BWQ on 160 sites of the Baltic coast over the last 15 years; ii) compare bathing water directives and methods and evaluate consequences on beach closures and threshold exceedances; iii) identify pollution hot spots and assess possible driving factors using laboratory experiments (decay rates) as well as hydrodynamic transport and behaviour models. This study combines several methods and reflects results of case studies to generate an overall European spatial and temporal picture.

## 2. Methods

### 2.1. Study area

Our study area spreads along the German Baltic coast of MV with around 160 bathing sites (Fig. 1). Tourism in MV increased from 5 million in 2000 to 7.4 million guests in 2015 and in summer months, 40% of the tourists come for bathing pleasure and therefore demand a high bathing water quality (MWAT, 2010).

Case study sites, which serve as example sites for the German coastline are Kühlungsborn, Barther Bodden, Szczecin Lagoon and the Warnow Estuary (Fig. 2).

Kühlungsborn is a seaside resort near Rostock popular by families and elderly people due to sandy beaches, wide promenades and a variety of activity offers. The ADAC found high indicator values here, the small stream *Mühlenbach* discharges 3 km west of here into the sea and the lake *Riedensee* gives shelter for several bird species, which release faecal bacteria (Fig. 2(a)). Salinity in this area ranges between 10 and 13 Practical Salinity Units (PSU). The Barther Bodden (Fig. 2(b)) is a semi-enclosed system belonging to the Darss-Zingst-Bodden-Chain (DZBC) in MV with only a small access to the Baltic Sea. The shallow bodden has an average water depth of 2 m and a maximum of 6 m. Average salinity is 4.5 PSU. The small and flat islands *Kirr* and *Barther Oie* are used by several bird species for breeding and additionally as cattle pasture. Discharges of the river *Barthe* as well as sewages from the city Barth have caused a high eutrophic status of the system (Schiewer, 2001). Similar to the Barther Bodden, the Szczecin Lagoon is a shallow system with an average depth of 3.7 m. Salinity varies between 1 PSU minimum and 2.5 PSU maximum. The lagoon with a total area of 669 km$^2$ is divided into the *Wielki Zalew* on the Polish side and *Kleines Haff* on the German side. The rivers *Peene*, *Zarow* and *Uecker* discharge into the German part of the lagoon (Fig. 2(c)). High nutrient inputs by the Odra river cause heavy eutrophication and poor water transparency. It is connected to the Baltic Sea via three outlets (*Peenestrom, Swina* and *Dziwna*) but Baltic Sea water intrusions are rare and spatially limited (Schernewski et al., 2012). The Warnow river is an eutrophic lowland river in northern Germany, with a total length of 161 km and a catchment area of 3239 km$^2$ intensively used by agriculture. Therefore, the Warnow carries high nutrient loads and particulate organic matter (Bahnwart et al., 1999; Freese et al., 2006; Selig and Schlungbaum, 2002). The city of Rostock with over 200,000 inhabitants borders the Warnow Estuary (Fig. 2(a)). One major sewage treatment plant discharges into the system. Salinity in the Warnow Estuary ranges from 0 to 20 PSU.

### 2.2. Decay rates in laboratory experiments

To determine the decay rates of *E. coli* and Enterococci under different parameters we focused on turbidity, salinity and light as the main drivers along the German Baltic coast and conducted two laboratory experiments. Temperature effects were not further investigated since other studies have already shown a significant inverse relationship between bacterial mortality and temperature (Carlucci and Pramer, 1960; Lessard and Sieburth, 1983; Vasconcelos and Swartz, 1976).

We took water samples in front of a sewage treatment plant outlet (Fig. 2(a)) in April and October 2016 expecting high bacteria concentrations. Samples were stored at 4 °C and processed within 24 h. In triplicate subsamples we i) increased turbidity from an optical density (OD) of 0 to 0.384 at 600 nm by adding autoclaved clay; ii) increased salinity from initially 3 to 11 PSU by adding sea salt; iii) simulated permanent darkness by covering one flask with tin foil. Salinity was adapted to average concentrations along the German Baltic Sea Coast, turbidity was slightly increased to simulate resuspension and gain first impressions on potential changes of the decay. All subsamples were kept at 16 °C under a day-night cycle of 16/8. Over a period of 96 h, aliquots were taken in triplicates after 12 h for the first time step and subsequently in a 24-hour rhythm. Replicas were diluted 1:10 and