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Anthropogenic impact on marine ecosystem health: A comparative multi-proxy investigation of recent sediments in coastal waters

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ABSTRACT

Hazardous substances entering the sea, and ultimately deposited in bottom sediments, pose a growing threat to marine ecosystems. The present study characterized two coastal areas exposed to significant anthropogenic impact - Gulf of Gdańsk (Poland), and Oslofjord/Drammensfjord (Norway) - by conducting a multi-proxy investigation of recent sediments, and comparing the results in light of different available thresholds for selected contaminants. Sediment samples were analyzed for benzo(*a*)pyrene (B(a)P) and other polycyclic aromatic hydrocarbons (PAHs), nonylphenols (NPs), organotin compounds (OTs), toxic metals (Cd, Hg, Pb), as well as mutagenic, genotoxic and endocrine-disrupting activities (in CALUX bioassays). In general, a declining trend in the deposition of contaminants was observed. Sediments from both basins were not highly contaminated with PAHs, NPs and metals, while OT levels may still give rise to concern in the Norwegian fjords. The results suggest that the contamination of sediments depends also on water/sediment conditions in a given region.

Anthropogenic impact on the health of marine ecosystems is a growing concern in coastal areas, where hazardous substances are more likely to find their way into the sea. An increasing number of such substances are listed by international bodies concerned with environmental protection (HELCOM, 2009; MSFD, 2008; NEA, 2018; OSPAR, 2017a; WFD, 2000). Due to the complexity of anthropogenic releases, potential toxic effects and spreading of chemical contaminants into the marine environment, it is crucial to analyze coastal waters and sediments for a large number of relevant chemical and toxicological variables, which can be assessed in combination to provide information on ecosystem health. Such variables can be termed proxies of environmental health.

Hazardous substances entering the marine environment tend to become associated with suspended particles and are ultimately deposited in bottom sediments. They are persistent and still can be bioavailable as a result of resuspension, diffusion into the water column, decomposition and other transformations. Many indices and/or assessment criteria exist to help classify sediments as contaminated, or subject to ecological risk, or toxic (SQuiRT, 2008; M-608, 2016). However, their use and interpretation are not completely clear, or obvious, and most of them are non-regulatory sediment quality guidelines. Indices and criteria may change depending on the area and the assessment purpose (e.g. environmental management, status screening, health evaluation). Also, different approaches to sediment appraisal may provide significantly different results. In order to contribute to this debate, the present study attempted the characterization of two coastal areas by conducting a multi-proxy investigation of recent sediments, and comparing the results in light of the different available thresholds.

Sediment samples were collected in the Gulf of Gdańsk, in northern Poland, as well as in the Oslofjord/Drammensfjord, in southern Norway (Fig. 1). The sampling took place in the context of a larger Polish-Norwegian Research Programme on “Climate Change Impact on Ecosystem Health – Marine Sediment Indicators” (CLISED, 2014–2017), aiming to study climate change effects in the sedimentary record, and

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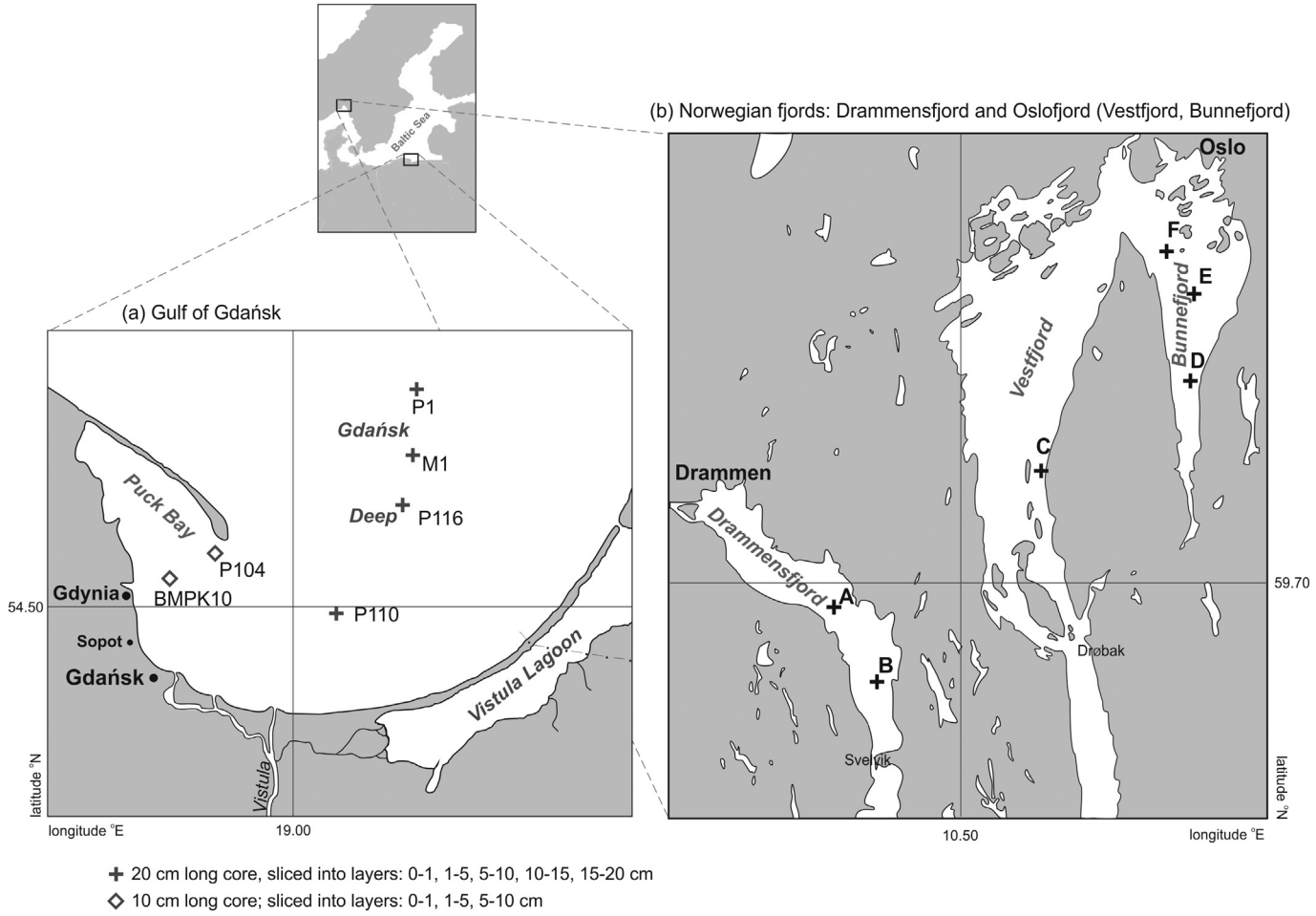

Fig. 1. Sampling location.

connect it to indicators of the marine environment health archived in the sediments. Both basins, albeit different in morphology and boundary conditions, are considered representative of situations not uncommon, in the Northern European Seas, where coastal areas have been heavily affected by significant human activities.

The first study area, the Gulf of Gdańsk, is located in the southern Baltic Sea. The depth of this basin increases seawards, to the Gdańsk Deep (max. depth 118 m) in the north, whereas shallower waters are found in Puck Bay (mean depth 3.1 m) located in the west. Its hydrological conditions are determined by large inflows of freshwater from the Vistula River and infrequent inflows of North Sea water through the Danish Straits. Both the Vistula River and the adjacent Gdańsk-Sopot-Gdynia conurbation (region population ~ 1.5 million), exert a significant anthropogenic influence on the Gulf of Gdańsk environment via urban pollution, industrial and agricultural effluents, discharges caused by the ship traffic of two large seaports, nutrient inputs from multiple sources. These factors, together with the variability of salinity (4.5–12.5) and oxygen (from well-oxygenated to hypoxic/anoxic waters) conditions, as well as different sediment grain sizes (from gravels to clay), render the Gulf of Gdańsk a well-suited model basin for studying the fate of contaminants in the marine environment (Lubecki and Kowalewska, 2010).

The second study area, the Oslofjord, is a northward inlet of the Skagerrak, which connects the North Sea with the Kattegat and the Baltic Sea. It is divided into an inner and outer fjord by the sill at Drøbak Sound. The inner Oslofjord consists of two main basins: the Vestfjord and the Bunnefjord (for both max. depth ~ 160 m). The hydrological conditions of these basins are determined by limited deep water exchange and winter renewal. Due to the high population density (the most populated, ~1.5 million, and industrialized area in Norway) and the immediate proximity of the large seaport, the Oslofjord has been exposed to heavy maritime activities and to the input of large amounts of wastewater and nutrients. On the west side, the outer Oslofjord is connected to the Drammensfjord by a sill at Svelvik. For decades, increasing population and intensive agriculture in the drainage area, as well as industrial and sewage discharges, have contributed to high pollution loads and oxygen depletion. However, in recent years the oxygen levels in the Drammensfjord have improved slightly (NGI, 2010). The water masses of all these fjords are stratified, varying from brackish surface water (salinity 1–10) to saline bottom water (salinity 30.5).

The combination of these two test areas provided a chance to sample a significant spectrum of contaminants' origins and impacts in a wide range of environmental conditions. Sediment samples were collected in 2014, during two cruises of the R/V Oceania, at 12 stations, i.e. 6 stations for each of the test areas above (Fig. 1). The locations of the sampling stations were selected so as to represent both different exposures to contaminants and different environmental conditions (see Supplementary materials – Table A for details). The Gulf of Gdańsk samples were collected in Puck Bay (BMPK10, P104) and along the main spread of Vistula waters in this basin, up to the Gdańsk Deep (P110, P116, M1, P1). The Norwegian fjords samples were collected in the Drammensfjord (A, B) and in the inner Oslofjord (Vestfjord - C, Bunnefjord - D, E, F). The sediment cores were 20 or 10 cm long, depending on the location (Fig. 1). The sediments were taken with a Niemistö core sampler (in the Gulf of Gdańsk) and a GEMAX twin-core sampler (in the Oslofjord/Drammensfjord), then sliced, sub-sampled, and stored at −20 °C. The subsamples were analyzed to determine