Oceanological and Hydrobiological Studies
Vol. XXXIV, Supplement 2

Institute of Oceanography (3-10) 2005 University of Gdańsk

UPWELLINGS ALONG THE HEL PENINSULA (THE BALTIC SEA) BIO-PHYSICO-CHEMICAL OBSERVATIONS

Preface

Upwelling is a vertical upward current, which raises the waters from deeper layers to the sea surface. Such phenomenon could occur both on the open oceanic waters and in shallow, coastal sea waters. Although upwelling is characterized by low vertical velocities as compared to the horizontal ones, it results in considerable changes in surface sea layer. Coastal upwellings are usually more intense than those occurring on the open waters since their vertical current velocities are higher (Bowden 1983). The advanced investigations on Atlantic and Pacific upwellings showed that the waters upwelled from deeper sea layers differed from the surface waters in almost all physico-chemical and biological properties *e.g.* temperature, salinity, the concentrations of oxygen, chlorophyll *a* and nutrients as well as phyto- and zooplankton taxonomic composition.

In the Baltic Sea, some mechanisms of coastal upwelling evolution have been recognized. According to the Eckman's theory, one of them could be affected by the Coriolis force that is a result of earth's rotation (Svansson 1975, Pedlosky 1975, Bowden 1983). In shallow water (*ca.* 10 m depth), upwelling could arise as a direct dynamic response of water body to the offshore wind influence (Svansson 1975). The combination of high horizontal current speed and topographic effects as well as the propagation of internal Kelvin wave along the coast could also be the reasons for the upwelling water motions (Walin 1972, Svansson 1975, Lund-Hansen and Vang 2003).

Geographical position, wind conditions or bottom topography of the Baltic Sea favour the local upwelling occurrence along almost the whole coast. In the Baltic Sea, nearly 30 sites have been identified where upwelling could be expected at particular wind direction (Bychkova and Viktorov 1987, Bychkova *et al.* 1988, Urbański 1995, Kowalewski 1998, Myrberg and Andrejev 2003). During last decades the extensive use of thermal satellite sea-surface images and simulations based on mathematical models has markedly facilitated the localization and observations of upwellings. Nevertheless, Baltic upwellings are

still poorly recognized. Although the number of papers based on satellite techniques (Horstmann 1986, Bychkova and Viktorov 1987, Gidhagen 1987, Lass *et al.* 1994, Kahru *et al.* 1995, Lass *et al.* 1996, Krężel 1997, Siegel *et al.* 1997, Semovsky *et al.* 1997, Lehmann *et al.* 2002, Krężel *et al.* 2005,) and mathematical modeling (Fennel and Strum 1992, Kowalewski 1998, Jankowski 2000, 2002, Myrberg and Andrejev 2003, Siegel *et al.* 2004) has been gradually increasing, the data on direct physico-chemical and biological observations are still rare. The results obtained hitherto from *in situ* observations provide only preliminary and fragmentary data on nutrient concentrations (Yurkovsky *et al.* 1976, Haapala 1994, Heiskanen *et al.* 1998), phytoplankton (Kahru *et al.* 1984, Nõmmann *et al.* 1991, Uitto *et al.* 1997, Danielsen *et al.* 1998, Vahtera *et al.* 2005) and zooplankton (Kostrichkina and Yurkovskis 1986).

The Atlantic and Pacific upwellings are regular, long lasting and extensive. Their biological effects, manifested by a distinct increase in fishing productivity, are commonly known. Since those regions are attractive in respect of fishing, comprehensive scientific investigations have also been undertaken there. However, such studies have not been carried out in the Baltic Sea. Therefore, it is still uncertain whether there is any relationship between Baltic upwellings and fishing productivity. The importance of upwellings in not confined only to fishing productivity. The waters that emerge periodically from deeper sea layers and occur at the surface and close to the coast could have great weight to primary production and the way, turnover rate and transport of organic carbon in the ecosystem. Therefore, a series of important questions should be elucidated. Does a seasonal increase in primary production in upwelling regions contribute to the nutrient enrichment of highly fertile Baltic Sea? Is the enrichment of local character and does it affect the adjacent regions? Does the upwelling-induced, accelerated cycle of nutrients purify the environment or increase its degradation? A separate but equally important question is the evaluation of upwelling influence on more and more frequent blooms of toxic cyanobacteria.

Baltic upwellings appear irregularly, and their intensity and duration (from several hours to 20-30 days), depend, first of all, on wind force and direction (Bychkova and Viktorov 1987, Bychkova *et al.* 1988, Urbański 1995, Kowalewski 1998, Kowalewski and Ostrowski 2005). Generally, in the Baltic Sea region baffling winds, which seldom keep up longer than several days, are noted (Kwiecień 1987). A small number of direct observations of Baltic coastal upwellings result from very short period in which wind conditions favourable for upwelling evolution could be expected, and from logistic difficulties resulting from the maintenance of permanent readiness for measurements. Therefore, the main obstructions in direct measurements of upwelling effects at

the Baltic coast are difficulties in determining occurrence time, intensity and duration of upwelling.

In the region of Polish Baltic coast, four sites of intensive and relatively extensive upwellings have been identified: in Kołobrzeg, Łeba, the Hel Peninsula and the Vistula Lagoon regions (Urbański 1995, Krężel 1997, Kowalewski 1998). Shallow, coastal regions of the open Polish coast are poorly recognized in respect of their productivity, stability and importance for the surrounding waters. Therefore, an attempt to register the consequences of upwelling was fully reasonable. The investigations were carried out within the scientific project *Upwelling events influence on the marine biological productivity along the Polish coast of the Baltic Sea* (KBN Project No 6 P04G 061 17). The subject matter and methods applied were of interdisciplinary character. They included:

- direct measurements of physical, chemical and biological parameters during Hel upwelling;
- analysis of Hel, Łeba and Kołobrzeg upwellings by satellite teledetection method;
- application of mathematical model for the description of conditions and occurrence frequency of upwellings at the southern coast of the Baltic Sea.

Simulations made by Kowalewski and Ostrowski (2005) showed that strong vertical currents ($> 10^{-4}$ m s^{-1}) could be observed from the side of the open sea of the Hel Peninsula. In that region, despite a significant contribution of strong upwellings (27.1%), downwellings constituted still great part (37.1%). Therefore, the registration of physical, chemical and biological parameters in highly dynamic environment is more valuable. The observations were performed between 2000 and 2002. They covered so-called warm period of the year, *i.e.* from the mid of April till the mid of October. At that time, it was possible to localize upwellings by satellite methods based on the differences in surface water temperatures between various sea regions.

Seawater thermal-salinity conditions during seven coastal upwellings occurring along the seaside of the Hel Peninsula (the Baltic Sea) were described by Matciak *et al.* (2005a). Standard seawater optical properties (Secchi depth, PAR irradiance profiles, light-beam attenuation coefficient and fluorescence of chloprophyll *a*) were presented by Matciak *et al.* (2005b). Mass concentrations (total SPM, POC, PN) and particle abundance during upwelling events were estimated by Bradtke *et al.* (2005). The distribution of basic nutrient concentrations (inorganic nitrogen, phosphorus and silicon, total organic nitrogen and phosphorus) and oxygen conditions in upwelling area were quantified by Burska and Szymelfenig (2005). Biochemical parameters, such as chlorophyll *a* concentrations and primary production, were estimated by

Zalewski *et al.* (2005). Finally, qualitative and quantitative plankton composition during upwelling events in the region of the Hel Peninsula (the Baltic Sea) was analyzed: phytoplankton by Gromisz and Szymelfenig (2005) and mesozooplankton by Bielecka *et al.* (2005).

Generally, the water masses distinguished during upwellings were characterized by different values of physical and chemical parameters. The waters influenced biological properties of the marine environment in that region.

The upwelling along the northern seaside of the Hel Peninsula could be very clearly distinguished by temperature field. Maximum decrease in sea surface temperature reached almost 14 °C. Water transparency, measured by the range of Secchi disc visibility, also showed great changes, from 3 to near 16 m. The above parameters appeared to be most effective in the localization of the upwelling centre. It was surprising, however, that a significant increase in salinity was not noted in the upwelling waters. This finding was in contradiction with the standard mechanism of the emergence of more saline waters from deeper sea layers. Cold and transparent waters were characterized by a decrease in mass concentration (total SPM, POC, PON), particle abundance and particle size distribution as compared to the reference area. The above changes were reflected in the structure of phyto- and mesozooplankton assemblages, *i.e.* lower abundance and biomass, and differences in plankton taxonomic composition in the upwelling centre compared to the surrounding waters. They were accompanied by low chlorophyll *a* concentration and low values of primary production. At the same time, high values of assimilation number and intensive emergence of biogenic salts, chiefly phosphates, were noted. It could create, together with other factors (*e.g.* an increase in water temperature), potentially favourable conditions for phytoplankton and zooplankton development.

The results obtained from *in situ* observations served to present the first description of Baltic upwellings in which so many parameters have been taken into account. The value of the data lays, first of all, in qualitative and quantitative characteristic of the registered changes that provide the understanding of real and possible contrasts in marine environment. The knowledge should warrant the evaluation of the organisms sensitivity and their response to a sudden change in the physico-chemical parameters.

Based on satellite images it was shown (Urbański 1995, Krężel 2005) that the area of upwellings along the Polish coast could reach even 10000 km^2 what was about 30% of Polish economic zone. According to the simulations by a numerical model (Kowalewski 1997), it was found that the sites of upwellings and downwellings occurrence appeared to be almost the same. Simultaneously, because of the predominance of western winds the frequency of downwellings

was significantly higher than that of upwellings (Kowalewski and Ostrowski 2005). Therefore, an inflow of the surface, nutrients-free waters from the open Baltic could be expected as a result of downwelling inshore transport. Consequently, coastal upwellings prevent a persistent decrease in nutrient concentration along the Polish coast. It was evidenced by simulations (Kowalewski 2005), which showed that during one-month spring and autumn upwellings the nutrient load brought by the Hel upwelling was almost equal to the load brought in the same periods by the Vistula, one of the biggest rivers in the catchment area of the Baltic Sea. The importance of nutrient vertical transport from deeper water layers and their input into the matter cycle to general nutrient balance in highly eutrophicated Baltic Sea is a separate question which needs further studies. It should also be determined whether and to what degree strong upwellings improve oxygen conditions in bottom sea areas.

ACKNOWLEDGEMENTS

This research was supported by the State Committee for Scientific Research, Poland (Project No 6 P04G 061 17). Editing assistance of the article was provided by BALTDER (EVK3-CT-2002-80005), founded by the European Commission under the 5th Framework Programme.

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