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Pine pollen grains in coastal waters of the Baltic Sea

by

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Abstract

Measurements relating to a yellow deposit covering large areas of the Baltic Sea in spring are reported. Analysis of water samples showed it to be of terrestrial origin and to consist mainly of pine pollen grains. The equivalent spherical diameter (ESD) of these grains ranged from 29.1 to 78.4 μm, with a maximum between 47.7 and 56.3 μm. Surface water concentrations of pollen in the coastal zone near Ustka showed that its proportion in the total suspended particulate matter (SPM) might be as high as 30-40%. Such high surface water concentrations of hitherto neglected substances critical to water color formation can give rise to serious errors in remote measurements of water composition and properties.

Key words: pine pollen grains, coastal zone, LISST, Baltic Sea, volume concentration

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Introduction

To a large extent, the properties of the waters of the Baltic Sea, basically an inland water body, are determined by allogenic material, supplied mainly by terrestrial runoff and offshore winds. Waters containing both autogenic constituents, i.e. products of the local ecosystem, and allogenic components, are classified as Case 2 (Morel, Prieur 1977; Antoine et al. 2014). Baltic waters belong to this class and usually contain large amounts of suspended particulate matter (SPM) and dissolved terrigenous matter (e.g. Kaczmarek, Woźniak 1995; Kowalczuk 1999; Woźniak 2011). SPM in natural waters is usually divided according to its optical properties, that is, into phytoplankton particles (algal particles – AP) and other, non-phytoplankton particles (non-algal particles – NAP); the latter, are further subdivided into organic (detritus) and inorganic (minerals). Organic NAP are mainly the metabolic and decay products of aquatic organisms (e.g. dead plankton and its decomposition products, the secretions of zooplankton). In the case of the Baltic, huge amounts of detritus and mineral particles derived from terrestrial runoff are carried to the sea by rivers and other watercourses. These constituents absorb and scatter light, thereby modifying the color of the water, which is a fundamental source of information provided by the remote sensing of the Baltic. Our observations and analyses of measurements have shown that in the Baltic in spring, there is another very important, hitherto ignored, constituent of the water, which could significantly alter the remote reflectance spectrum. This is pine pollen, large amounts of which float on the water. Keller & Matrai (1998) demonstrated that pine pollen grains, the absorption spectra of which they measured in water samples from the Gulf of Maine, significantly increase the absorption in the short-wave region of the visible spectrum (wavelengths <500 nm). The reflectance of pollen grains is high for wavelengths >450 nm, which corresponds to their high level of absorption in this spectral region. Since light wavelengths from the 450-550 nm region are often used in remote sensing algorithms to detect chlorophyll *a* concentrations, the presence of pollen grains may lead to erroneous determinations of this crucial constituent of the water.

Materials and Methods

Measurements were made during a total of 20 research cruises in the southern Baltic from 2012 to 2014. During all the cruises, which took place in the second half of May, large concentrations of yellow suspended matter were observed floating on the water. Microscopic analysis showed this matter to consist of pine pollen grains. Fig. 1 maps the stations where large concentrations of this pollen were observed. During the cruises, the SPM volume concentration was measured continuously in 32 size classes, ranging from 1.25 to 250 μm, using a LISST-100x type B particle size analyzer (Sequoia Inc.). In 2012 and 2013, the water for continuous measurements (along transects) was sampled from a depth of 2 m and then pumped through a hose to the LISST instrument installed on deck. In 2014, the measurement station was modified so that the pump was placed just beneath the surface and hence the water could be sampled from a depth of ca. 30 cm. At the same time, surface water was sampled at selected stations, immediately preserved in Lugol's solution, and sent for microscopic analysis. Sample preservation and microscopic analysis of phytoplankton were carried out in line with the HELCOM recommendations for the Baltic Sea monitoring (HELCOM 2001). The microscopic analysis and size determination of pollen grains and phytoplankton were performed using a CKX41 (Olympus) inverted microscope (Fig. 2c, d). The equivalent spherical diameter (ESD) was determined by comparing the measured pollen grain diameters with a stereometric figure (Karp-Boss et al. 2007) and then used for the interpretation of the empirical data obtained with the LISST-100x instrument.

Results and Discussion

This is the first time that concentrations of pine pollen grains have been measured in the Baltic waters. It appears that the presence of pollen can seriously affect the quality of remote sensing measurements. Using the remote sensing from aircraft or satellites, one can measure the concentrations of optically active constituents (OAC) in water, as long as the signal reaching the sensors from the water is correctly interpreted. As previously mentioned, Baltic waters are classified as Case 2. This means that the water-leaving radiation is modified by a complex mixture of autogenic

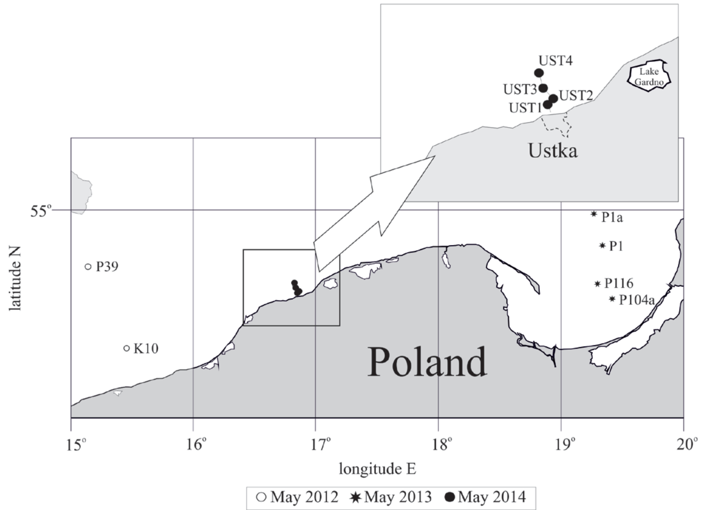

Figure 1

Locations of the stations where large concentrations of pollen grains were observed in the southern Baltic Sea in 2012-2014

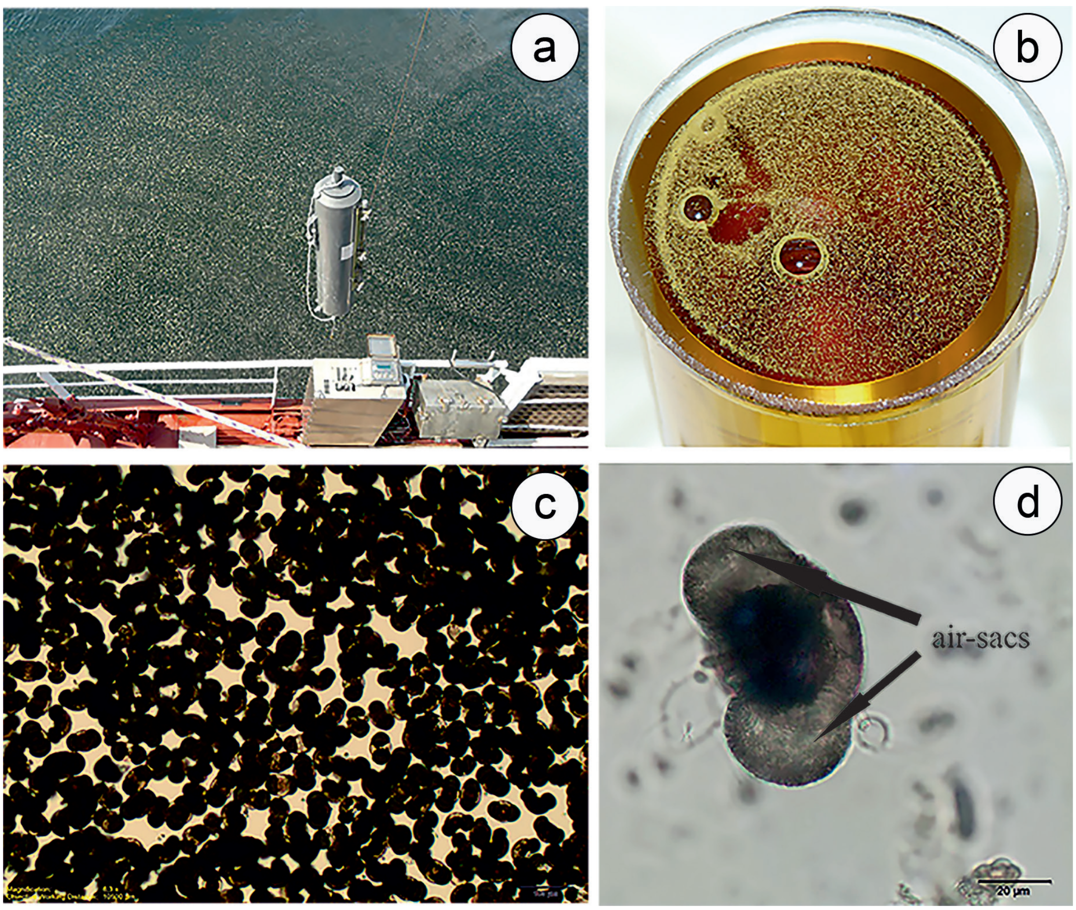

Figure 2

Pine pollen grains in coastal waters of the Baltic Sea (a), pine pollen grains floating on the water surface in a sedimentation chamber (b) and pine pollen grains obtained from the watersurface (c, d). Photos: a, b – D. Ficek, c, d – M. Pawlik and allogenic constituents: phytoplankton pigments (mainly chlorophylls *a*, *b*, c, carotenoids, phycobilins), SPM (i.e. AP + NAP) and colored dissolved organic matter (CDOM). Accurate qualitative and quantitative remote sensing of these constituents requires robust algorithms to isolate from the total signal the parts best correlated with the target constituent. Obviously, in view of the great spatial and seasonal variability of the properties and concentrations of these constituents, the algorithms used for their detection have to include properly selected coefficients allowing for the specifics of the region being monitored.

One constituent not taken into consideration so far, which could be the source of serious errors in remote measurements, is pine pollen, very large amounts of which reach Baltic waters in spring. The photographs on Fig. 2 show pollen floating on the water as seen from on board ship (Fig. 2a), a surface water sample in the Utermöhl sedimentation chamber (Fig. 2b), the suspended matter at 100× magnification (Fig. 2c) and a single grain of pine pollen magnified 400 times (Fig. 2d). The pine pollen forms a distinctive yellow film on the water surface, which evidently changes the water's color. Pine trees flourish in the climatic and habitat conditions of this part of Europe; in Poland they make up 59.1% of the forest cover (Zajączkowski et al. 2013). When pines are releasing their pollen, for a period of 2-3 weeks starting in mid-May (Latałowa, Góra 1996), a characteristic yellow deposit covers large areas of land and Baltic waters. According to a study carried out in Finland, pine forests produce between 10 and 80 kg of pollen per hectare during the growing season, which corresponds to a deposition rate of 30-280 thousand grains of pollen per cm^2 per year (Koski 1970). They are carried to the Baltic by wind and terrestrial runoff. Wind transport of pollen grains, even over long distances, is facilitated by their waxy outer coating and air-sacs (see Fig. 2d). The distance they are carried on the wind depends, among other things, on its strength, duration, direction and turbulence: it is nothing unusual for pollen grains to be carried 50 km and farther (Dyakowska 1959). We were able to confirm this during the cruises in May 2012 and 2013, when we observed yellow patches of pollen at considerable distances from the shore (stations P39, P1, P1a on Fig. 1).

Pine pollen grains are relatively large. According to Faegri & Iversen (1978), their diameters range from 60 to 75 µm; Wodehouse (1935), on the other hand, states that their diameters are from 32 to 65 µm. This differentiation depends on the species of pine in question. For the purposes of the present work, diameters of pine pollen grains were measured microscopically in samples of the Baltic coastal water taken near Ustka in 2014. Fig. 3 lists the diameters of 130 such pollen grains, categorized into the same size classes as used by the LISST-100x instrument for assessing the size distributions of SPM. The pine pollen grain range in diameter from 29.1 to 78.4 µm, the most numerous group being grains of diameter about 56 µm.

Determining the in situ concentration of pine pollen grains in water is quite complicated. Their structure, described previously, causes them to clump together on the water surface, forming aggregations of the kind illustrated in Fig. 2a, b. The vertical distributions of these aggregations vary, depending on the conditions prevailing at sea (wind, wave action etc.). When there is no wind and only minimal wave action, the pollen deposits float on the water, but the increasing wind strength and wave action break up these surface layers to a greater or lesser extent, and an inhomogeneous structure occurs, both on the surface (see Fig. 2a) and in the vertical profile. SPM concentrations measured under such conditions depend on the method of water sampling, i.e. from which layer and place the water is taken. The considerable spatial and temporal variability of these pollen grain aggregations as well as the dynamic changes in their concentrations mean that routine microscopic analyses for the determination of their sizes, numbers and composition in water sampled at particular stations do not guarantee results that reflect the real distributions of pollen grains in the water. In addition, the considerable financial outlay and amount of time required by this method mean that in most cases just a small number of samples are taken for analysis. One possible solution to this problem is to use instruments that measure in situ SPM levels with high frequency. Such an instrument, the LISST-100x, was used in the present work to measure the concentration and size distribution of pine pollen grains. But even with such a device the problem of measuring pollen grain concentrations is not easy to solve. Placing the instrument in the surface water layer and taking direct measurements is hampered by wave action and the presence of bubbles. Measurements in deeper water layers do not show such large concentrations of SPM as at the surface, because they decrease with increasing depth. Continuous

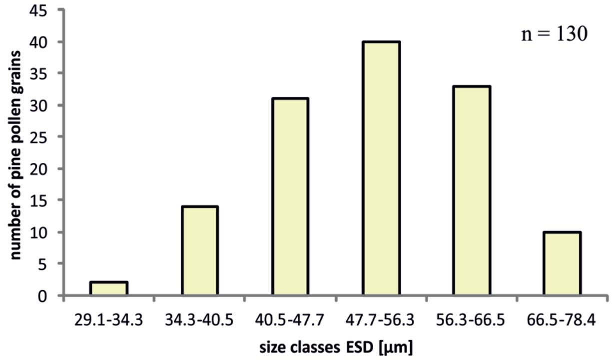

Figure 3

Equivalent spherical diameter (ESD) of pine pollen grains sampled from coastal waters of the Baltic Sea in specific LISST-100x size classes

measurements performed in 2012 and 2013 using the LISST-100x analyzer did not reveal the presence of pollen grains in the water, even though large aggregations of pollen were visible on the water surface. The reason was that the water had been sampled at too great depth (ca. 2 m). In May 2014, an experiment was carried out in the Baltic coastal zone using a modified measurement setup: the pump bringing water to the LISST-100x analyzer was installed just below the water surface. Fig. 1 shows the locations of the measurement stations, at which the measurements in Fig. 4 and 5 were made. The SPM size distributions shown in Fig. 4 were measured at station UST1 (where the River Słupia flows into the Baltic). The dominant pollen grain diameters in the surface water ranged from 29.1 to 109.0 µm with a distinct peak between 47.7 and 56.3 µm. Microscopic analysis (see Fig. 3) of those water samples showed that the majority of pollen grains within this size class were from pine trees. It was not possible to estimate pollen concentrations using the standard microscopic method for determination of the phytoplankton concentrations in a sedimentation chamber. Fig. 2b shows clearly that the pollen grains did not pass through the water, but floated on its surface.

Microscopic measurements showed that, apart

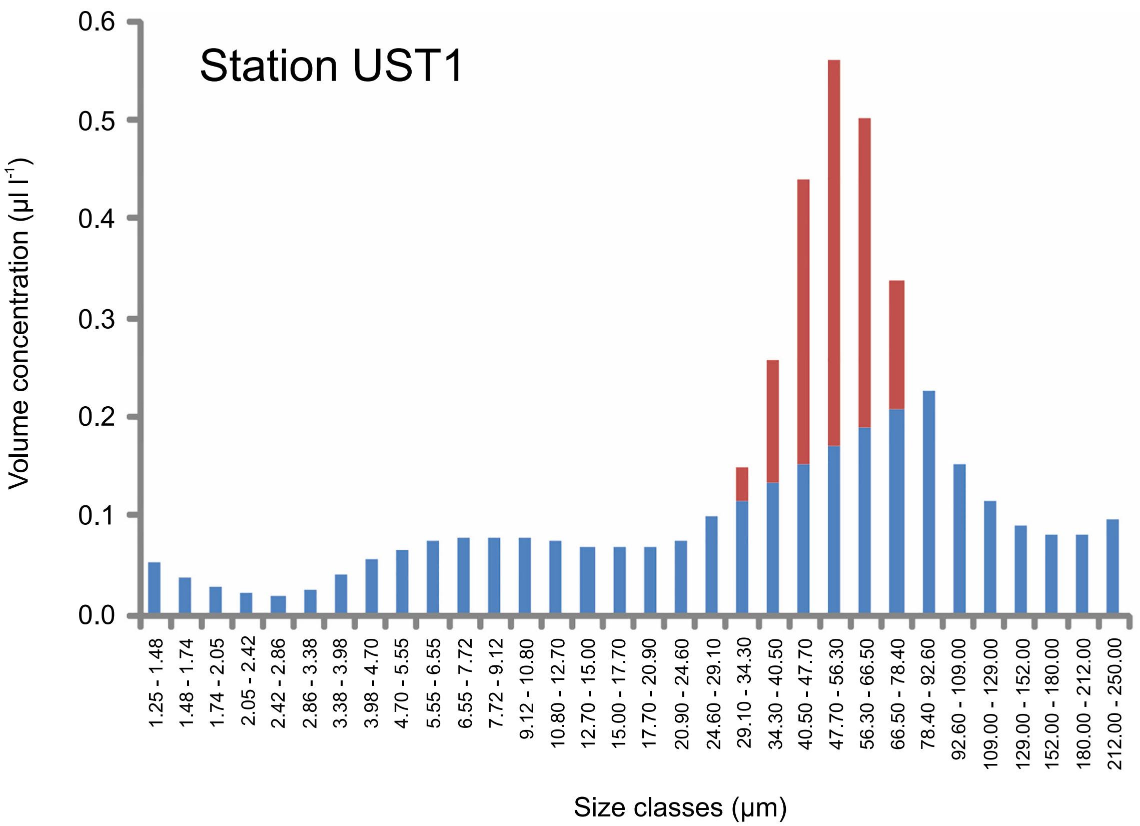

Figure 4

Concentrations of suspended particular matter measured in surface water at station UST 1. Concentrations of pollen grains in water measured using the method described in this paper are shown in red.

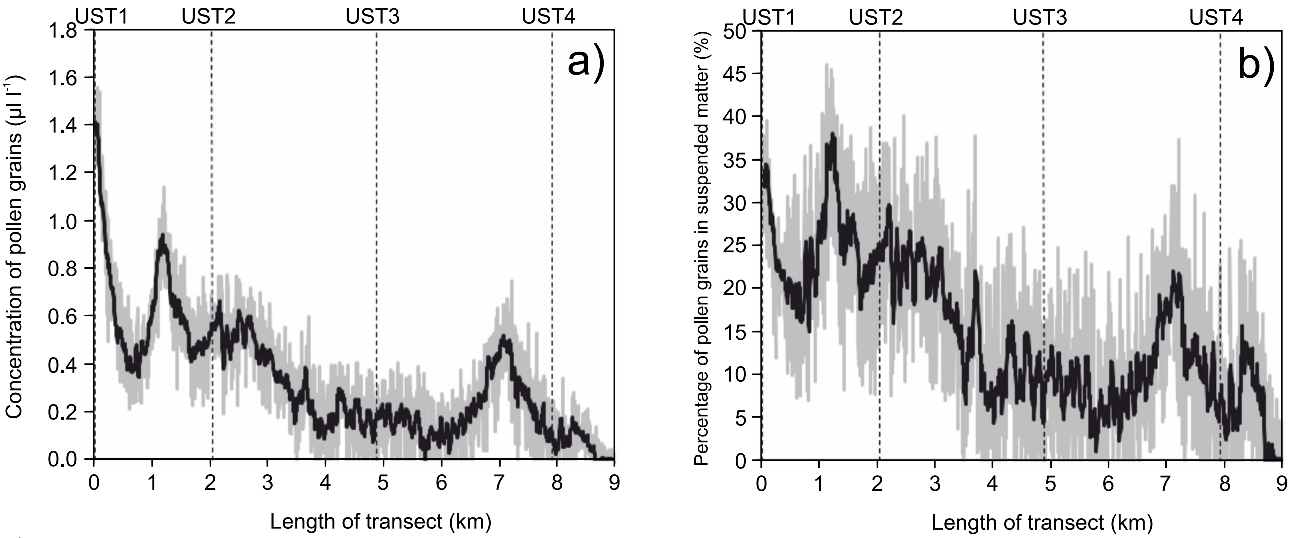

Figure 5

Concentration of pollen grains in surface water measured along the transect shown in Fig. 1 on 20.05.2014: a) absolute concentration, b) relative concentration, i.e. the ratio of the number of pollen grains to the total number of suspended particles. The average value is shown in black.

from the pollen, the samples analyzed did not contain any large concentrations of phyto- or zooplankton of dimensions within the range of the dominant maximum shown in Fig. 3. The concentrations of *Dinophysis acuminata* and *Pseudopediastrum boryanum* with ESD from 34.3 to 40.5 µm and *Actinocyclus* sp. with ESD from 66.5 to 92.6 µm do not explain the distinct maximum seen on Fig. 3. One can therefore assume that the maximum from the 29.1-78.4 µm range is due to the pine pollen and that the magnitude of this maximum gives a rough indication of its concentration in the water. Since there are other kinds of SPM in the water apart from pollen grains, certain simplifications were made when estimating pollen levels. It was assumed that the concentration of SPM with ESD both lower and higher than those measured for pine pollen grains, i.e. <29.1 µm and >78.4 µm, constituted a background, and only values above this background could be taken into consideration when estimating pollen grain concentrations. The level of the background signal between these limiting values was assumed to change linearly (see Fig. 3). The signal from the pollen grains included values higher than the line drawn between the concentrations from outside the pollen grain ESD interval (the red area in Fig. 4).

In accordance with the above scheme, the concentration of pollen grains along the entire transect on 20 May 2014 was estimated (upper right-hand corner in Fig. 1). The results (see Fig. 5a) point to considerable spatial variability. The highest concentrations (ca. 1.6 µl l^{-1}) were found at the outer entrance to the port of Ustka (the mouth of the river Słupia). As the distance from the shore increases, there is a gradual decrease in the pollen grain concentration to almost zero values at the most distant measuring station (about 9 km from the shore). There is also a series of larger and smaller local maxima along the transect, resulting from the uneven distribution of pollen grains on the water surface. Moreover, usually the total SPM concentration in the water decreases with increasing distance from the shore. Fig. 5b shows the concentration of pollen grains relative to the total SPM concentration. Despite the drop in absolute pollen grain concentrations with increasing distance from the shore, their relative concentration in the SPM remains at a fairly high level. Up to 3 km from the mouth of the Słupia, more than 20% of the total SPM consisted of pollen grains. The drop in SPM concentration between stations UST1 and UST2 meant that the relative concentration of pollen grains measured there was higher even than that recorded at the mouth of the Słupia, locally exceeding 35%.

Conclusions

The measurements presented in this paper indicate that the optical properties of the Baltic surface waters in late spring may be largely determined by the presence of pine pollen grains. These tend to form clumps on the water surface, which in large concentrations can strongly modify the color of water. Measurements made in the surface water layer revealed considerable spatial variability in pollen concentrations; locally, relative concentrations on the surface exceeded 40% of the total SPM concentration. Hitherto, algorithms for the remote sensing of water properties and for estimating the concentrations of optically important constituents have not allowed for the presence of pollen. This can lead to erroneous interpretations of remote sensing data. This problem is particularly important in the Baltic, an inland sea surrounded by forests with a high proportion of pine trees. This issue needs to be addressed further.

Acknowledgements

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