LANDSAT IMAGERY OF PHYTOPLANCTON DEVELOPMENT IN THE BALTIC SEA

by

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Abstract

LANDSAT imagery of March 3rd, 1976, shows distinct patterns of phytoplancton at the beginning of its spring bloom in the southwestern Baltic. The traces demonstrate, that phytoplancton development, light limited at this time of the year, takes place in shallow nearshore and inshore waters, from where it drifts towards deeper areas. Distinct eddy-like patterns give information on the complicated hydrography and mixing processes in these waters. Similar patterns, even more distinct, can be observed in mid summer in the Baltic proper on images of August 7th, 9th, and 11th, 1975, when blue green algae, predominantly *Nodularia spumigena*, have developed and accumulated at the sea surface.
The paper shows applicability of remote sensing for phytoplancton ecological investigations, especially for the variability of horizontal distribution of near surface plancton.

LANDSAT imagery of March 3rd, 1976, displays white to grey patterns in the surface waters of the southwestern Baltic in its MSS 4 (Fig. 1) and MSS 5 channels. The recording was taken at a time, when this part of the Baltic has been free of ice. Water analysis in the Kiel Bay and the Danish archipelago indicates,

that the satellite image coincides with the beginning of the phytoplancton spring bloom in this area, consisting predominantly of Diatoms.
In temperate waters during the winter months phytoplancton productivity is light limited, while after the spring bloom phytoplancton productivity is restricted by mineral nutrients until the latter part of the year, October and November.
The spring bloom is the result of increased radiation of light onto the surface water layer, after sufficient mineral nutrients for phytoplancton growth have accumulated during the winter months. The start of the phytoplancton development in spring, however, is not only dependant on the intensity of the radiation onto the water, but also on the length of the presence of the phytoplancton community in the near surface euphotic layer. Phytoplancton development in early spring therefore starts in areas, where stratification forbids vertical mixing processes, or in shallow waters, where in addition light reflection on sandy bottoms improves the light climate in the water.
This fact explains the distribution patterns of suspended material including phytoplancton in the southwestern Baltic on March 2nd and 3rd, when on three consecutive days images with 60% overlapping were taken.
Wind and current have drifted the newly developed phytoplancton from shallow waters and nearshore regions with little turbulence in the surface layer towards the deeper waters, where mixing processes allow the algae to stay in the light penetrated zone for only a limited period of time. The image therefore gives evidence for waterbodies of high phytoplancton content, originating from shallow water areas, as they drift into the current-system of the southern Belt Sea.
Hydrographical data and information from water gauges show (Hardtke, personal communication) three different current situations on the three consecutive images:

1. an inflow-situation from the Baltic sea into the Baltic sea,
2. a transition period, and
3. an outflow-situation on March 4th, showing the watermasses drifting out of the Baltic sea.

The images can be considered as a useful tool for phytoplancton ecological studies, demonstrating the seeding of phytoplancton from shallow water areas into deep water. Additionally the images on three consecutive days display new aspects of the complicated current system in the area.
LANDSAT imagery of August 1975 displays even stronger patterns, this time visible in all four multispectral LANDSAT channels (Fig. 2). Digital image processing and false colour presentation show the appearance of mass accumulation of the blue-green algae *Aphanizomenon flos aquae* and *Nodularia spumigena* (Fig. 3) in the Baltic (Ulbricht et al. 1977, 1978). Nearshore blooms are considered to be stimulated by phosphorus discharge into the Baltic and favoured by the fact, that these blue-green algae can fix nitrogen from the air (Horstmann et al. 1978).
After a growth period, when the algae are suspended in the euphotic layer, the trichoms of blue-green algae, due to their gasvacuoles, emerge to the sea surface, where the intense light radiation damages their pigments and turns them yellow.
The filaments often occur in large conglomerations, giving the impression of yellow snowflakes. These flocks are difficult to recognize in rough or even moderate sea because of surface wave induced turbulences. As soon as the weather is calm, the algae accumulate at the surface again and become clearly visible. With no wind at all and almost no wave action, the accumulation of blue-green algae can be so dense, especially in areas of convection of waterbodies, that they form a yellowish pulp at the sea surface. Near shore, the algae rarely appear in yellowish flocks, but tend to stain the water olive-green, indicating healthy populations of algae during their growth period, as has been observed along the Swedish East Coast and the area east and north of the Island of Rügen. Sometimes, when the wind drifts the surface water towards the shore, the floating algae accumulate and form a greenish or yellowish pulp, which can cover the beach.
A microscopical examination of the algae accumulations reveals, that the mass occurrence of blue-green algae in the Baltic consists mainly of the two species: *Aphanizomenon flos aquae* and *Nodularia spumigena* (Horstmann et al. 1978).
To explain blue-green algae blooms in summer, when usually the

amount of mineral nutrients in the euphotic zone limits the phytoplancton growth, we must realize, that many blue-green algae species, especially those with heterocysts, can fix nitrogen from the air. Qualitative and quantitative investigations resulted in the conclusion, that nitrogen fixation by *Nodularia* and *Aphanizomenon* plays a considerable role in the nitrogen budget of the Baltic sea.

From the number of heterocysts found during a Nodularia bloom in Hanö bight, Öström calculated the amount of N-fixation. From a satellite photographic image he calculated the bloom to be present in the whole Baltic and assumed it to last for fourteen days. He calculated the annual amount of N-fixation in the Baltic to be 2000 tons, allowing a variation of one order of magnitude up and down.

We do consider this conclusion not to be too realistic. Calculations recently given by a Finnish group (Rinne et al. 1977) seem to reinforce our view. The group obtained a considerable amount of N-fixation data from several stations in the central and northern Baltic in the Gulf of Finland during cruises in 1974 up to 1975. They took into consideration both vertical distribution and differences in daily fixation rate, and obtained a yearly average value of 100 000 tons of air nitrogen fixed by blue-green algae added to the nitrogen cycle of the Baltic sea.

Together with adequate ground truth measurements, LANDSAT data should make it possible to give more information on the amount and distribution patterns of phytoplancton in the Baltic and within of nitrogen fixed by blue-green algae. Better approximations could be obtained by calculating the area covered by blue-greens via satellite measurements. Through consideration of traces in the different multispectral channels, conclusions as to the depth distribution within the surface layer can be obtained, and consequently information on the order of magnitude of the existing algae in the upper water layer. Correlation with a "nitrogen fixing factor", necessarily obtained from in situ experiments, will result in more information on the nitrogen input into the Baltic. Supervised maximum likelihood classification (Fig. 4, Fig. 5), using target areas with heavy to light algae appearance in different spectral channels, seems to be a possible way for the estimation of the biomass of blue-green algae in the upper water layers.

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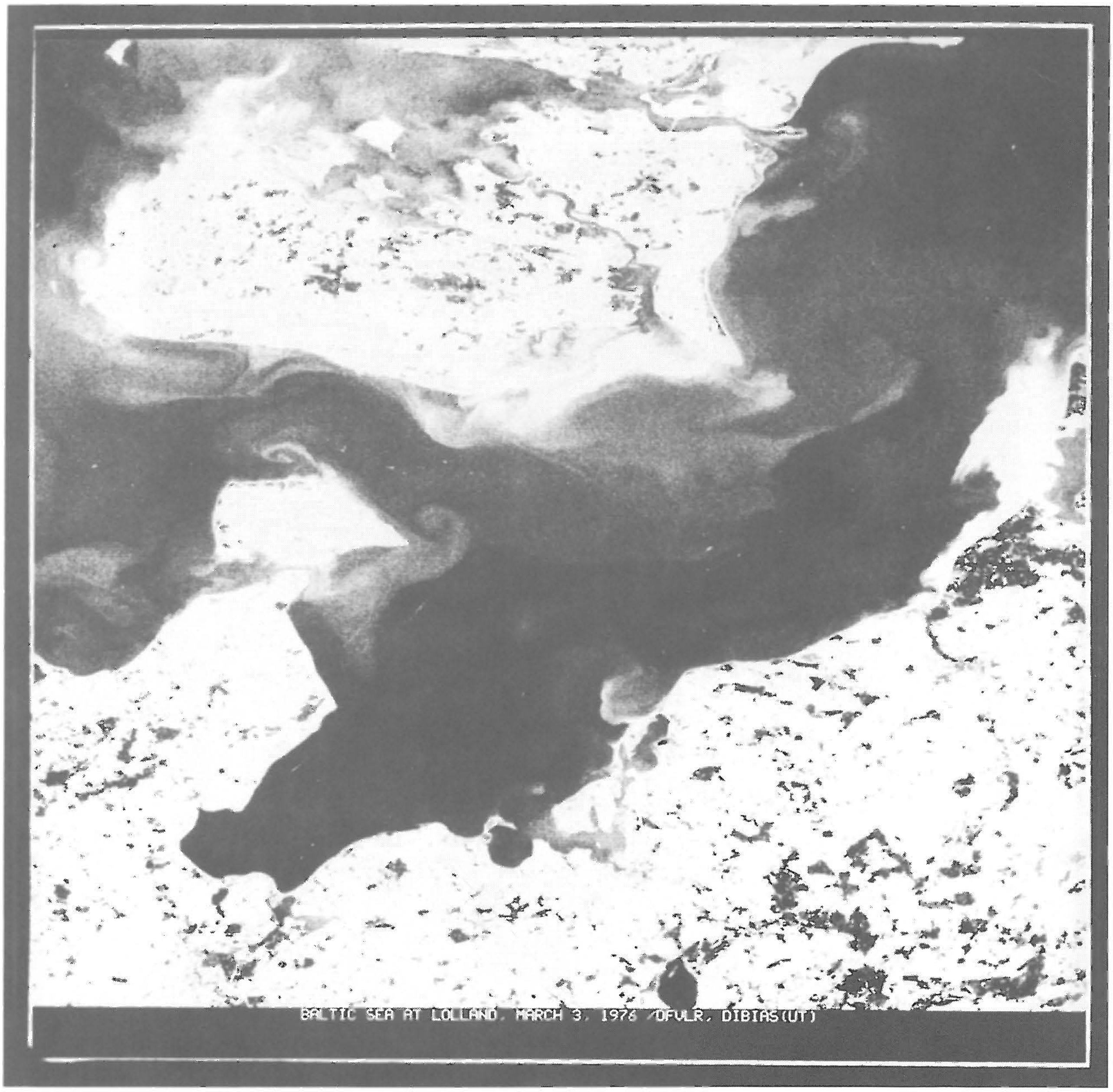

Fig. 1: MSS 4 version of LANDSAT scene of March 3rd, 1976, of southwestern Baltic sea, showing the beginning of a phytoplancton spring bloom.

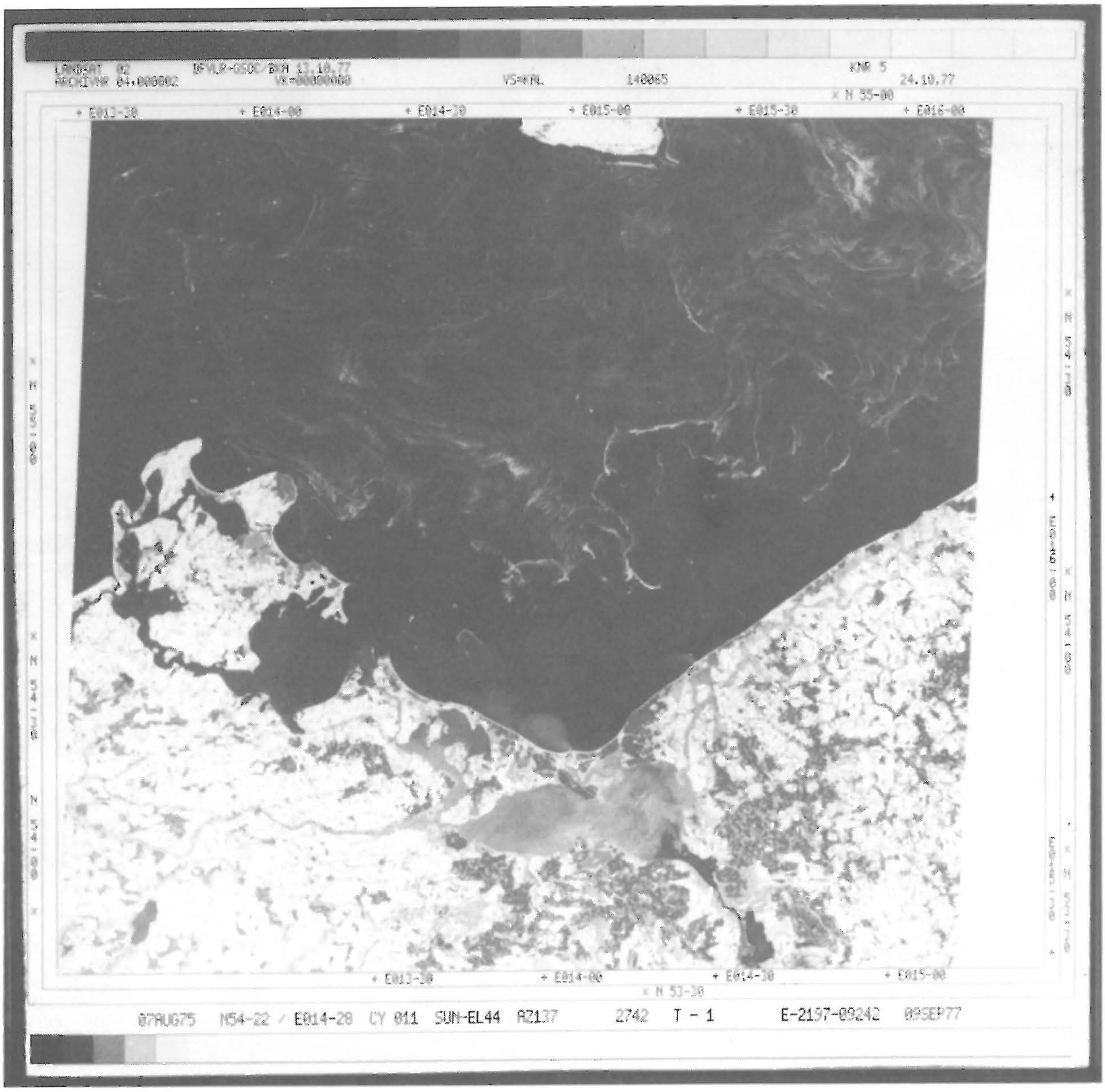

Fig. 2: LANDSAT spectral channel MSS 4 of August 7, 1975, showing mass appearance of blue-green algae in the southwestern Baltic sea. Algae point out eddies, characteristic for this part of the Baltic.

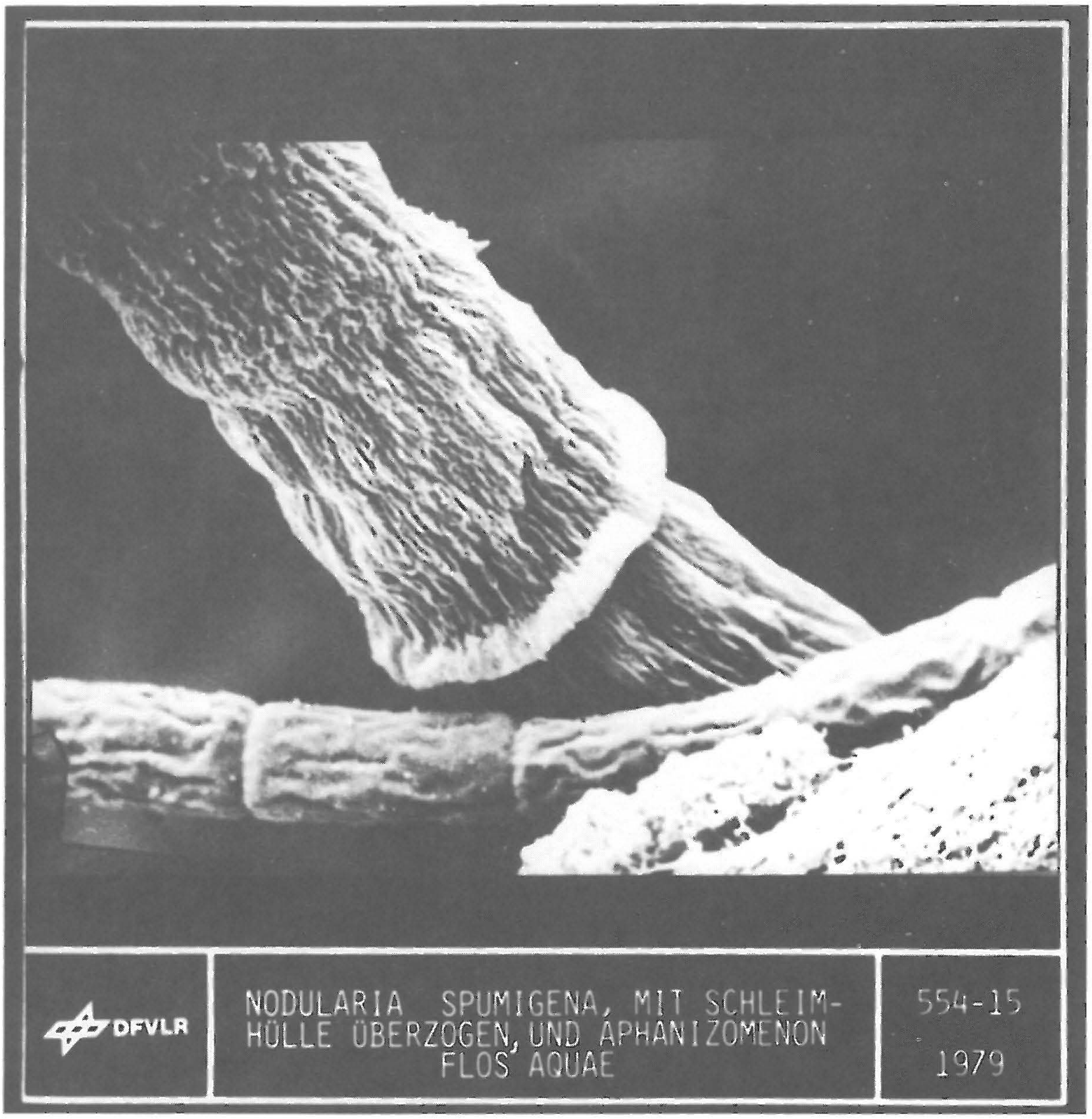

Fig. 3: ESM Photography of the blue-green algae *Nodularia spumigena* covered with mucus layer (diagonal, above), and *Aphanizomenon flos-aquae* (below). (Length of black line on lower left corner is 4 /u).

Fig. 4: Black and white rendition of colour coded MSS 4,5 and 6, version of test area in the Baltic sea, depicting eddies traced through blue-green algae in the upper layer of the water.

Fig. 5: Area of Fig. 4 after application of maximum likelihood classification, (using four different training areas) for determination of coverage of the algae (black and white rendition of colour coded original).