Short-term changes in the hydrochemical constituents in the water column of the Gdańsk Deep (Baltic Sea) in spring. Part 2. Modelling of diel changes in nutrient concentrations in the euphotic layer*

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Abstract

The paper deals with the diel fluctuations of nutrient concentrations and oxygen in the euphotic layer of the Gdańsk Deep in spring in the years 1989–1996. Using non-linear regression, these diel variations were modelled under a variety of typically spring density stratifications: in the absence of thermal layering, in the presence of a distinct thermocline and during thermocline formation.
The diel cycle of nutrients in the euphotic layer showed two maxima and two minima, probably due to variability in photosynthetic intensity.

1. Introduction

Besides the seasonal cycle of variations in nutrient concentrations, which decrease in spring during the burgeoning phytoplankton bloom, distinct diel fluctuations in nutrient concentrations also occur in surface waters. Their variability is proportional to the rates of assimilation and destruction

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of organic matter. These are controlled by physical factors such as water temperature and insolation, chemical factors like the abundance of nutrients, and biological parameters, *e.g.* the numbers and species composition of phytoplankton, zooplankton and bacteria.

Not very many papers are available in the bibliography on organic matter transformation or on the short-term variability of chemical parameters in the marine environment (Strickland, 1968; Renk *et al.*, 1983, 1985; Ochocki *et al.*, 1984; Brockmann *et al.*, 1990; Tamminen, 1990). This paucity of papers is probably due to the fact that such undertakings are extremely time- and labour-consuming.

The objectives of this work were to demonstrate the nature of the diel variability of nitrogen (nitrites, nitrates and ammonia) and phosphorus (phosphates and total phosphorus) compounds in the water column of the Gdańsk Deep, and to determine the relationship between these compounds on the one hand, and the oxygen content and the variable density stratification in this region on the other.

2. Material and methods

The procedure involved in collecting materials for this work, and the methods of sampling and chemical analysis are described in detail in Part 1.

3. Results

This paper is based on the results of investigations of the euphotic layer of the Gdańsk Deep during various periods in the spring. These results are set out in tabular form and are described in Part 1 of this article.

4. Discussion

Nutrient concentrations in the isothermal layer above the thermocline are of great importance as their scarcity may limit primary production. Nutrient depletion has been recorded sporadically in the Gulf of Gdańsk during the last six years but is more often recorded in open Baltic waters during intensive algal blooms.

The productive euphotic layer is no thicker than 18–19 m (Renk, 1990), so in May and June it may overlap the thermocline. The lack of a thermocline, a natural temporary barrier to vertical transport, leads to greater nutrient concentrations in the uppermost layer, this enrichment proceeding by way of diffusion, upwelling and advection.

In order to put forward a mathematical model of the fluctuations in the nutrient concentrations and the relative density in the isothermal layer above the thermocline, the following real situations were selected:

- the thermocline is in the process of formation, and temperature drops are very evident from 5 m downwards (2–6 June 1992 – Fig. 2, profile E, Part 1),
- above the thermocline there is a well-developed isothermal layer spreading down to 20 m (19–23 June 1993 – Fig. 2, profile G, Part 1),
- there is no thermocline limiting turbulent mixing in the surface layer (8–13 May 1995 – Fig. 2, profile A, Part 1).

Diel variability in chemical parameters at particular depths of the euphotic layer were mathematically described by applying non-linear regression and Marquard's algorithm:

$$A(t) = a_0 + a_1 \sin(\omega t + \varphi_1) + a_2 \sin(2\omega t + \varphi_2), \tag{1}$$

where

$A(t)$ – substance concentration at time t,
a_0 – mean concentration of the substance throughout the investigation,
a_1 – 24 h concentration amplitude of the substance,
a_2 – 12 h concentration amplitude of the substance,
ω – $2\pi T^{-1}$; T – 24 hours,
φ_1 – phase shift of a 24 h component [radians],
φ_2 – phase shift of a 12 h component [radians].

This function takes two variability components into account, *i.e.* the 24 h and 12 h ones, which well describe the average diel changes in nutrient concentrations (Fig. 1). The summation of these components (eq. (1)) enabled the diel changes in the nitrogen and phosphorus concentrations, the oxygen content and the relative density in the euphotic layer of the Gdańsk Deep to be described (Figs. 2–4). The functions obtained displayed two maxima and two minima, manifested in most cases by inorganic nitrogen and phosphorus compounds and by the oxygen content. Minimal concentrations of nutrients were recorded either at midday or in the afternoon, depending on the study period, and had probably resulted from their uptake during photosynthesis. This conclusion is based on the fact that these minima were accompanied by organic phosphorus maxima. The temporal changes in organic phosphorus in the euphotic layer in May and June demonstrated high maxima at midday and less pronounced ones before noon (Figs. 2 and 3); May 1995 was an exception, when only one maximum was found, and that in the afternoon (Fig. 4). The maxima and minima do not necessarily appear at the same time of the day, and the shifts between them, due to the differing light requirements of the predominant algae in the various study periods, may be as long as a few hours.

The question thus arises whether the observed variability in the substances under examination is a reflection of diel changes in photosynthetic

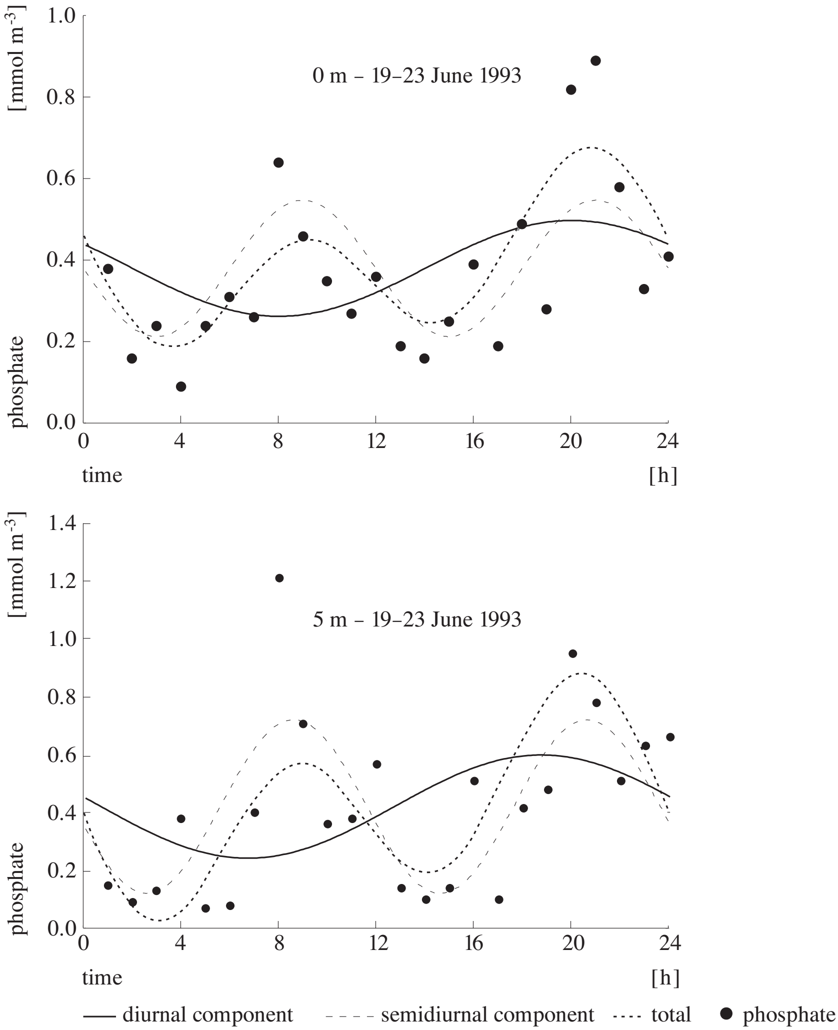

Fig. 1. Examples of function components (eq. (1)) describing diel changes in the substances analysed in relation to the measured value

intensity, or whether it is due to dynamic processes affecting the diel changes in density σ_T.

In the first situation selected (2–6 June 1992), only the diel nitrate variability was in a good agreement with diel changes in density σ_T, and this was valid only for the first maximum observed. The variability in the other substances was of a different character (Fig. 2), their maxima and minima displaying a different pattern at all the depths analysed, and usually the surface pattern (*e.g.* ammonia, nitrites, phosphates) strayed.

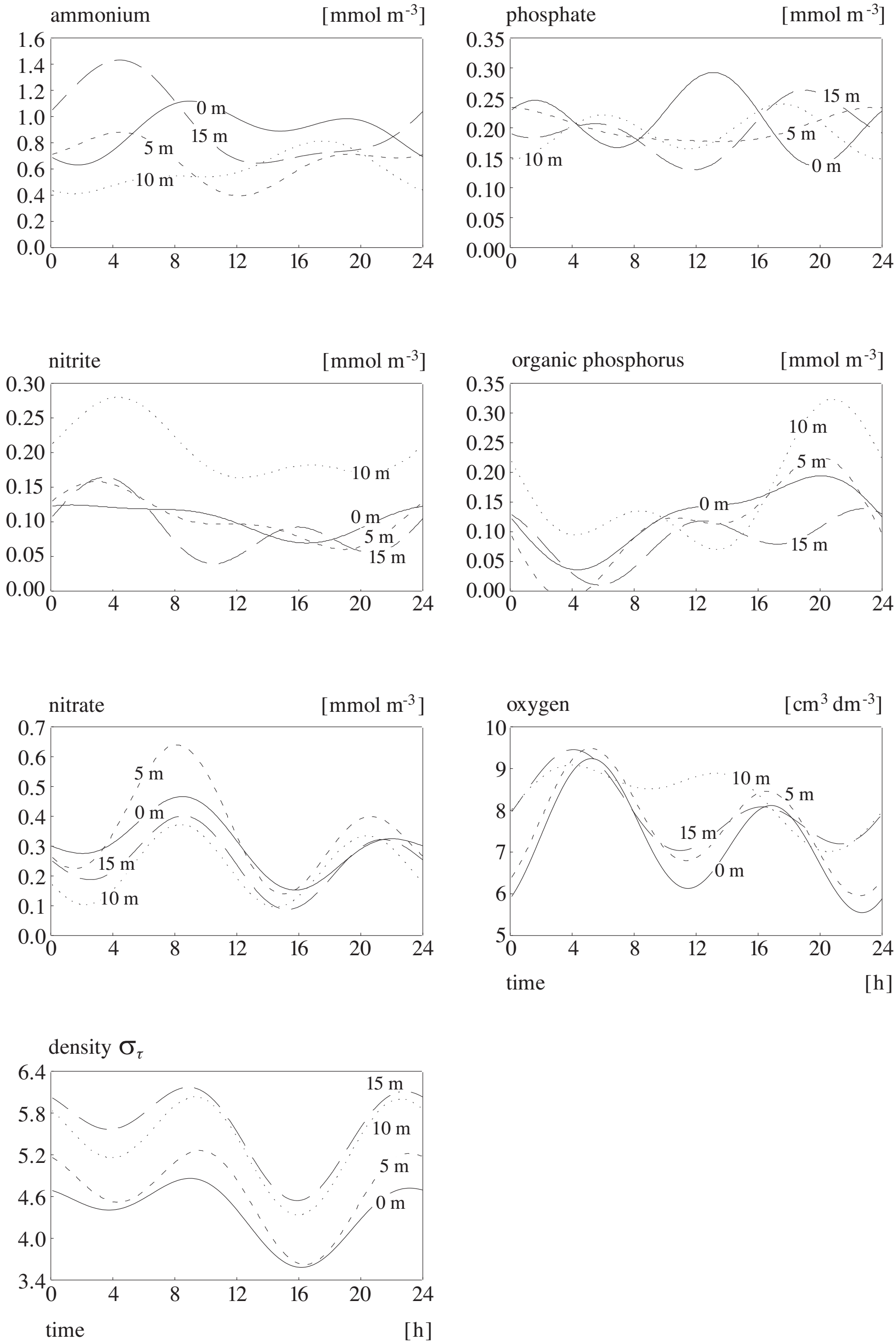

Fig. 2. Diel cycle of changes in nitrogen and phosphorus compounds, oxygen, and density in the euphotic layer of the Gdańsk Deep (2–6 June 1992)

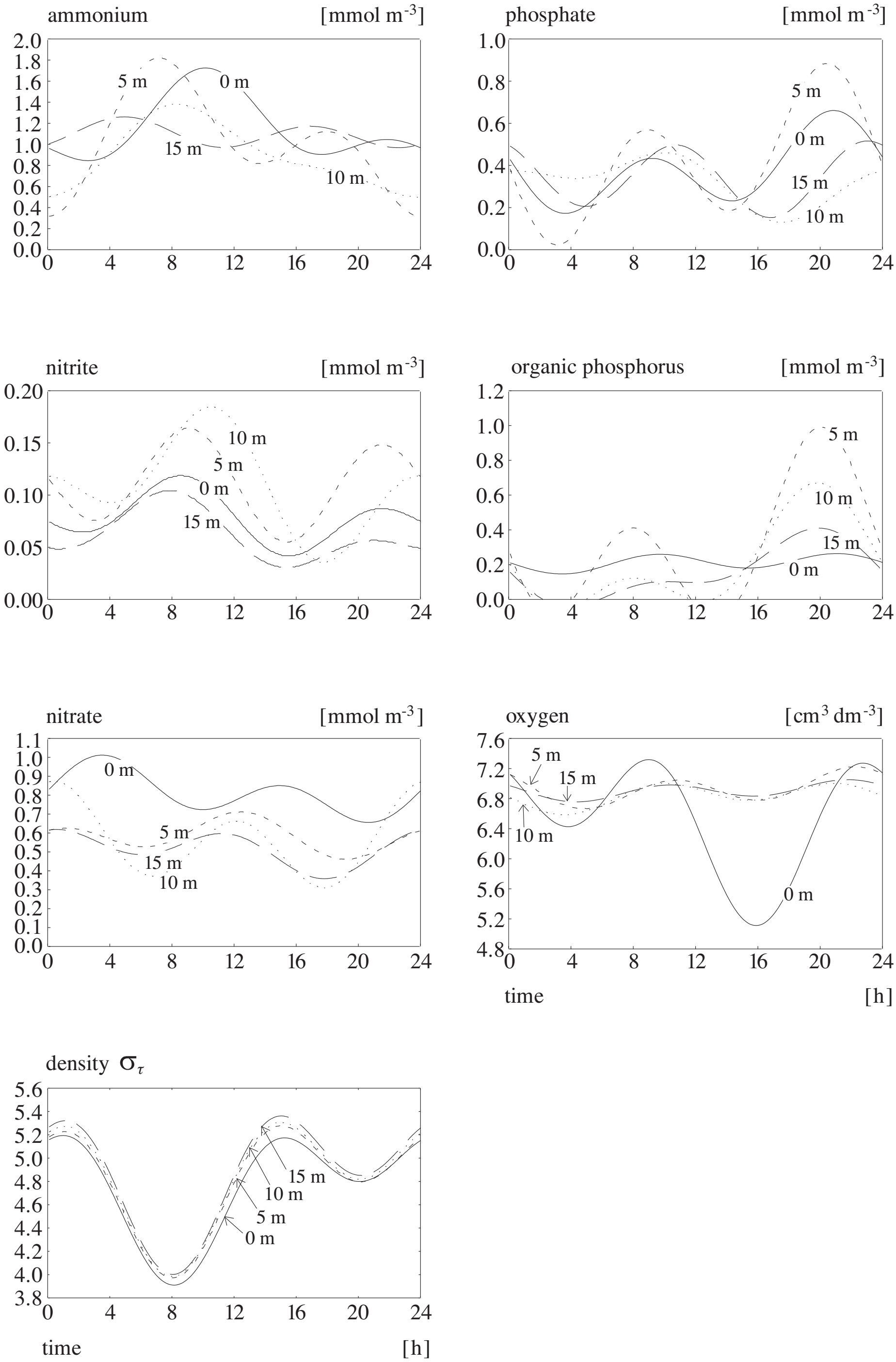

Fig. 3. Diel cycle of changes in nitrogen and phosphorus compounds, oxygen, and density in the euphotic layer of the Gdańsk Deep (19–23 June 1993)

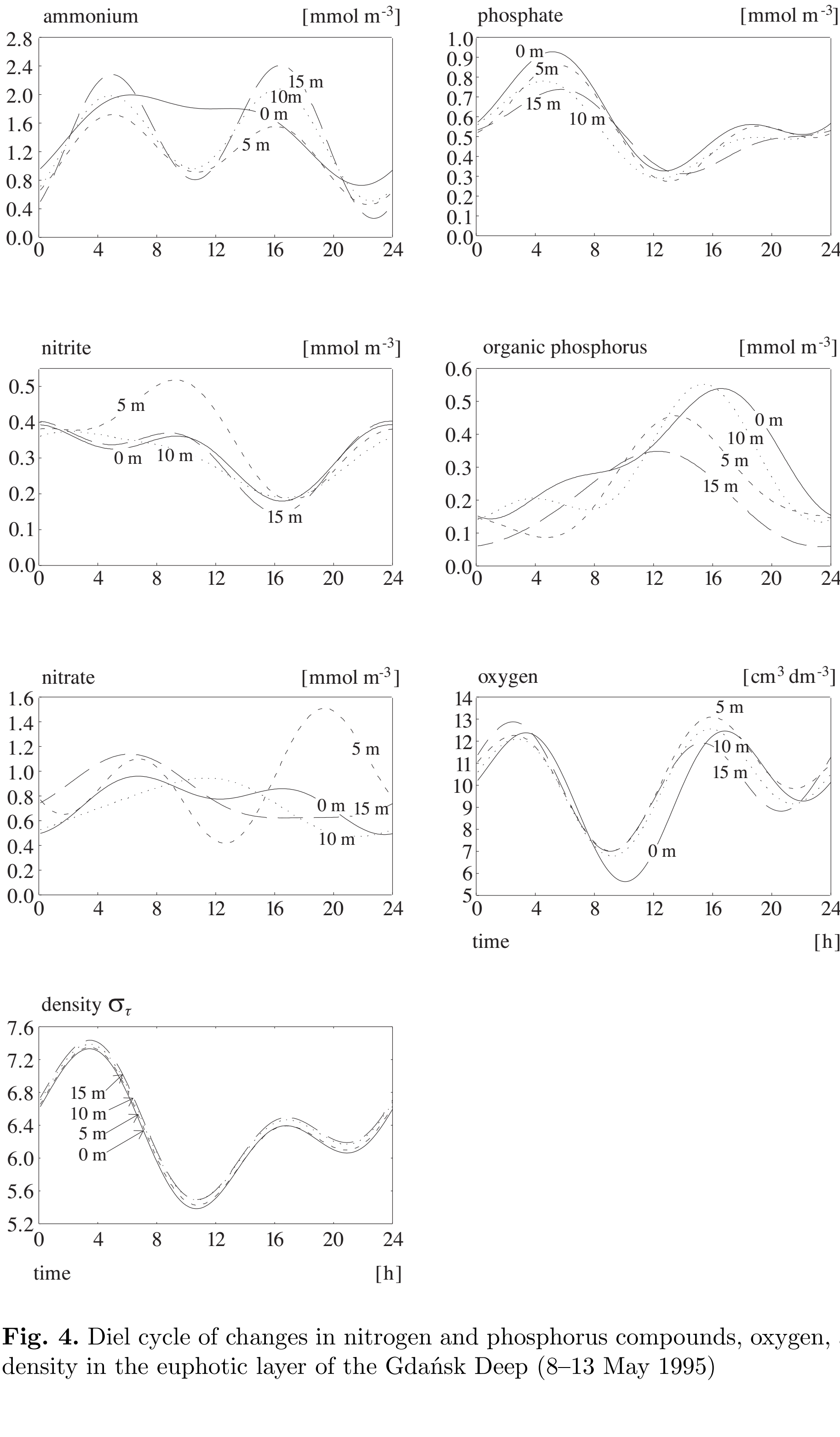

Fig. 4. Diel cycle of changes in nitrogen and phosphorus compounds, oxygen, and density in the euphotic layer of the Gdańsk Deep (8–13 May 1995)

A more regular depth-to-depth variability was observed in June 1993 (the second case) when there was a pronounced isothermal layer (Fig. 3). All the parameters measured manifested two maxima during a 24 h period, which, however, did not coincide with the function describing variability in diel density σ_T.

In May 1995 (the third selected period; Fig. 4), in the absence of a thermal gradient, some nutrients, *e.g.* nitrites, nitrates, phosphates, displayed only one element of the changes at 10 and 15 m, and did not show the second maximum in the diel cycle. Though displaying a similar pattern, the maximum concentration of organic phosphorus shifted from the surface in the afternoon towards deeper layers at midday, a fact suggesting a 24 h cycle for this parameter.

It thus emerges from these three cases that there is no significant relationship between the function describing diel variability in density and the chemical parameter analysed, described with the same mathematical model. Hence, the diel changes in nutrients and oxygen in the productive layer of the sea are governed by other processes, *e.g.* photosynthesis. It is also very likely that the light dose reaching particular depths may be responsible for the single or double maximum in the diel cycle.

The diel cycle of phytoplankton biomass determined from the variability in chlorophyll *a* concentration and the phytoplankton cell number in different growing seasons in the Gulf of Gdańsk has been described by Renk *et al.* (1983, 1985) by the following formula:

$$\mathrm{Chl} = \mathrm{Chl}_0 + \mathrm{Chl}_1 \cos \omega (t - t_0), \tag{2}$$

where

Chl_0 – mean 24 h chlorophyll concentration,

Chl_1 – amplitude of chlorophyll concentration changes,

t – time [h],

t_0 – time at which chlorophyll concentration reached a maximum,

ω – $2\pi T^{-1}$; T – 24 h.

Validation of the model by these authors showed it to be in good agreement with the relative fluctuations in chlorophyll concentrations and with the plankton cell number measured down to a depth of 30 m every half metre at two- and four-hour time intervals and under moderate insolation. On the basis of this model they found one principal maximum in the diurnal cycle of phytoplankton and chlorophyll *a* in the Gdańsk Deep, which occurred in the afternoon. The model assumptions (eq. (2)) applied by these researchers take only the 24 h component into account, which considerably simplifies the variability; this therefore precludes the possibility of finding more than one maximum in the 24 h cycle. Analysis of the time distribution of the discrete values obtained by Renk *et al.* (1983, 1985) reveals a conspicuous initial increase in chlorophyll concentration before noon followed by its gradual decline with depth.

These remarks suggest that solar radiation exerts a significant influence on the diurnal intensity of nutrient assimilation by phytoplankton. However, the penetration depth of the photosynthetically active band of light can be severely restricted by large quantities of suspended matter or humus, or by DOC (Bricaud *et al.*, 1981; Dera, 1992). Moreover, some authors (Behrenfeld *et al.*, 1993a,b) point out the lethal impact of solar radiation during periods of intensive insolation, with the consequent inhibition of photosynthesis in the surface layers at such times. The increased dose of UV–B (280–320) radiation reported in recent years could also be a factor inhibiting photosynthesis. Even a relatively small increase in the radiation of this wavelength not only inhibits photosynthesis but also affects the growth or reproduction of various marine organisms (Hardy and Gucinski, 1989). Behrenfeld *et al.* (1993 a,b) has suggested that, at least in summer, primary production of phytoplankton in temperate to tropical oceans is inhibited by UV–B radiation. The sea surface 'soup' of phytoplankton, fish eggs and larvae of benthic organisms is exposed to the negative impact of this radiation. Renk *et al.* (1985) reported a 'fading of chlorophyll', by which they meant that its concentration decreased in the surface layer of the Gdańsk Deep during intensive insolation at midday. Revealing decreased assimilation, these findings could explain the increase in nutrients around midday, and therefore the appearance of the 12 h cycle in nutrient variability in spring. A very similar type of nutrient concentration variability was observed in the same study periods in the surface microlayer of the Gdańsk Deep. At midday there was a marked increase in nitrogen and phosphorus concentrations, accompanied by a simultaneous decrease in chlorophyll *a* and neuston organisms of similar proportions (Falkowska, 1996).

5. Conclusions

- The diel fluctuations in nutrient concentrations and oxygen in surface waters were periodic in nature. They were only slightly affected by the diel variations in water density.
- The diel variability in nutrients and oxygen content in the productive layer of the sea is determined by the intensity of uptake and destruction. The radiation dose reaching particular depths may be responsible for the occurrence of one or two maxima in the diel cycle. Two maxima and two minima were found to be present mainly

where inorganic compounds of nitrogen and phosphorus, and oxygen was concerned. Minimal nutrient concentrations, usually followed by maximum organic phosphorus concentrations, appeared either at midday or in the afternoon, depending on the study period.

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