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# Factors affecting light penetration in shallow lakes

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*Key words:* Danube Delta, water transparency, light extinction, plankton, detritus, water turbulence

## Abstract

Light conditions were studied in six lakes of the Danube Delta for a period of 2 years and were described as a function of 12 independent variables forming a data matrix with more than 1000 sample units. Light extinction was explained in percentage of 64% by phytoplankton, of 11% by detritus, of 7% by zooplankton, of 1.4% by dissolved organic matter and of 0.15 by bacterioplankton. The influence of mineral particles was insignificant. Equations are produced here for the relationship to water turbulence, wind intensity and lake depth. The threshold for full water turbulence was between 7 and 8% for a fluctuation domain of critical winds of 3.2–5.4 m $s^{-1}$ and for a depth domain of 1–3 m.

## Introduction

Eutrophication of lakes commonly enhance development of planktonic organisms which subsequently contribute to reduce light penetration through the water column. Therefore, Secchi transparency has been used as an easy measure of the trophic state reflecting the collective optical effects of the primary and secondary planktonic productivity (Karabin, 1985).

In shallow lakes, several morphometric and climatic conditions interfere with the relationship between trophic state and light climate. So, the frequent winds can cause a decrease of water transparency by resuspending of sediments and by internal regeneration of nutrient pool. Surface area, depth, but especially specific ratio between these and between length of shore line and surface area (shore development) influence these relations.

The objective of this paper is to distinguish and quantify the main causal relationships involved in the determination of the light conditions in shallow lakes. This study has been performed in the framework of the Romanian research on the mechanisms and effects of accelerated eutrophication in the Danube Delta lakes.

## Study sites

The Danube Delta is a heterogenous and dynamic complex of ecosystems of various types and in different successional stages. Aquatic systems (lakes, channels, canals, river arms) and wetlands (marches, flooded areas) represent between 67–81% of the 442 300 ha of the Romanian delta. Reeds cover over 64% of the delta, forming so called 'Plaur', an unique plant community represented by floating mats constituting 'borders' of the most lakes.

The high surface to depth ratio and the absence of a firm border makes these lakes very sensitive to changes in light, temperature and wind conditions. The different position and morphometric features of each lake generate a variable influence of hydrological and hydrochemical parameters of the Danube River (Table 1).

During recent years, large areas (>74 000 ha) have been dammed and drained for agriculture and fishery purposes. Also, the ecology of the Danube Delta is imperiled by a system crisis which has resulted in accelerated eutrophication of the water-dominated systems.

## Materials and methods

Regulations of light conditions of shallow lakes are described in the conceptual model in Fig. 1. The main variables defining the light conditions are the light extinction coefficient of water ($\varepsilon$) and the light extinction coefficient due to the interception by the submerged macrophytes ($\varepsilon_p$). The independent variables that influence directly these coefficients (compartment 0) are organic suspended particles (POC, box 1, 2 and 4), mineral suspended particles (MINS, box 6) and water colour depending directly on the dissolved organic substances (DOC, box 5). An important part of POC, the detritus (DETR, box 4) is under direct influence of the biota (box 1, 2 and 3) and the water turbulence (TURB, box 7). Water turbulence, due to its influence on content of particles (by resuspension) and on submerged macrophyte development, is affected by wind (box 8) and lake morphometry (box 9 and 10).

The complex and reversible relations between water turbulence and submerged macrophytes (unnumbered arrows) are not the focus of this paper. The variables and the interrelations studied quantitatively here are represented graphically by numbered boxes and thick arrows.

Sampling of water and measurements of particles were carried out monthly on 28 stations in six representative lakes in the Danube Delta (Baclanesti, 3 sites, Babina, Matita, Bogdaproste, Isac and Rosu, all 5 sites), between November 1984 and October 1986 (Cristofor, 1987). The dynamics of all variables were described based on arithmetic means of sampling units from each lake.

Organic particles were measured by fractionating of POC based on carbon, chlorophyll *a* and ATP contents determined on GF and MF filters of different pore size, according to Vadineanu *et al.* (1987). Mineral particles were determined as the ash content on filters. The DOC concentration was indirectly evaluated as chemical oxygen demand of filtered water by open reflux method.

The wind intensity was measured with cup anemometer placed at 2.5 m above the water. Water turbulence was estimated as the ratio between mean height of the waves and water depth.

The light extinction in water ($\varepsilon$) was calculated from the equation

$$\varepsilon = (\ln I_0 - \ln I_z)/Z_1 \,, \qquad (1)$$

where $I_0$ = the subsurface illumination and $I_z$ = the illumination at $z$ depth (Ikusima, 1970). $I_0$ and $I_z$ were determined with a luxmeter type PV 150 with a selenium photocell.

To quantify the influence of the water turbu-

*Table 1.* Main morphometric parameters of the Danube Delta Lakes.

| Lake | Mean depth (m) | Surface (ha) | Surface: Depth ratio ($10^4$ m) | Shore development | Transparency (%) | Chlorophyll *a* ($\mu g\, l^{-1}$) |
|---|---|---|---|---|---|---|
| Baclanesti | 1.40 | 241 | 172 | 1.82 | 88 | 9 |
| Babina | 1.90 | 432 | 227 | 1.41 | 53 | 36 |
| Matita | 2.39 | 652 | 272 | 1.06 | 30 | 75 |
| Bogdaproste | 1.50 | 435 | 290 | 1.22 | 86 | 19 |
| Isac | 2.20 | 1101 | 500 | 1.10 | 30 | 79 |
| Rosu | 2.61 | 1445 | 553 | 1.23 | 32 | 50 |

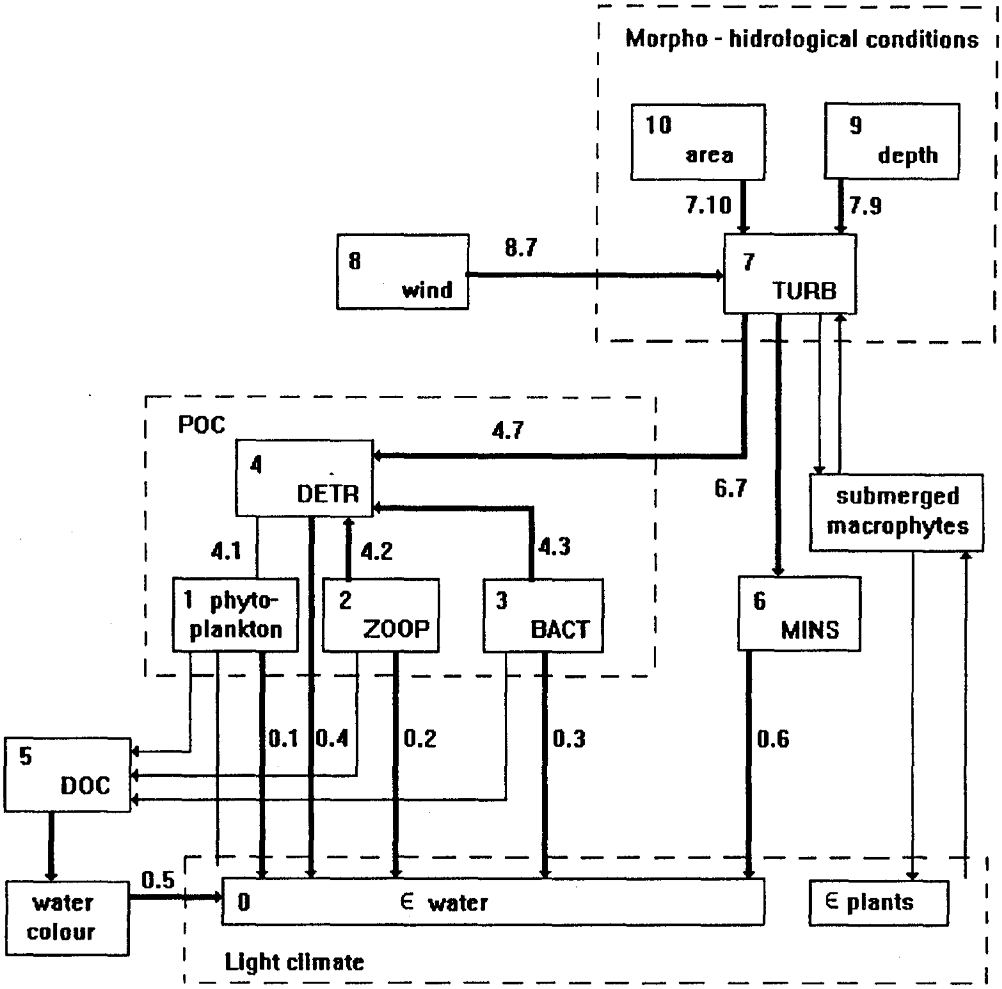


*Fig. 1.* Conceptual model including the variables that influence light conditions in water of the Danube Delta.

lence, a multiple regression equation of exponential form was calculated based on the literature (Bondar, 1965):

$$h_{max} = 0.176 \cdot H^{0.362} \cdot V^{1.285}, \quad (2)$$

in which $h_{max}$ = maximum mean height of waves (m), $H$ = water depth (m), $V$ = wind intensity (m $s^{-1}$).

On this base the threshold of water turbulence above which the sediments are resuspended was firstly calculated theoretically:

$$\mathrm{TURB}_r = 7.92 \cdot H^{-0.02023}, \quad (3)$$

where resuspension turbulence threshold ($\mathrm{TURB}_r$) belongs to a limited domain of values (7.7–8%), for a large fluctuation domain of depth ($H$) (0.5–5 m).

## Results and discussion

The amplitude of variation in light penetration was sufficiently wide (0.2–2.1 m for Secchi depth $T$, and 0.6–12.05 $m^{-1}$ for the light extinction coefficient ($\varepsilon$) to allow a good statistic modelling. The majority of previous authors have shown linear correlations between Secchi transparency and light extinction (Best, 1981) or light transmission in water (Matusiak & Wojciechowski, 1975; Pelletier, 1984; Szczepanski, 1968). However, the present data show a curve fitting well (*** very highly significant) described by the equation:

$$\varepsilon = 1.694 \cdot T^{-0.799} \quad (4)$$
$$(n = 227;\ r = -0.92^{***})$$

where transparency $T$ is in meters (Fig. 2). Predicting from this model is also in agreement with earlier general findings such as a ratio of 2.5 between the depth of the euphotic zone and the Secchi depth (Pelletier, *op. cit.*), a percentage of 13–15% of surface light at the Secchi depth (Matusiak & Wojciechowski, *op. cit.*) and a maximum possible transparency of 64 m (Karabin, 1985 and Riber, 1984).

The relative importance of the factors that influence light extinction in water was determined by usual methods of multiple analysis of variance. Starting with the initial relative wide scatter of points, corresponding to the simple regression

$$\varepsilon = 0.542 \cdot \mathrm{CHLA}^{0.404} \quad (5)$$
$$(n = 112;\ r = 0.77^{***});$$

the analytical steps of the multiple regression showed the gradual grouping of points around the regression line till the relation (Fig. 3):

$$\varepsilon = 0.254 \cdot \mathrm{CHLA}^{0.34} \cdot \mathrm{PIGR}^{-0.34} \cdot \mathrm{DETR}^{-0.17} \cdot \mathrm{ZOOP}^{0.1} \cdot \mathrm{DOC}^{0.35} \cdot \mathrm{BACT}^{-0.02} \quad (6)$$
$$(n = 112,\ r = 0.91^{***})$$

that was able to account for 83% of the variation in ε. All variables, excepting phytoplankton, are expressed in mg C $l^{-1}$. The concentration of chlorophyll *a* CHLA ($\mu g\ l^{-1}$) and the pigment ratio *PIGR* ($E_{665} \div E_{480}$) represent the phytoplankton compartment. The influence of the independent variables on ε was very highly significant (***): phytoplankton 64% (CHLA 59% and PIGR 5%), suspended detritus *DETR* 11%, zooplankton *ZOOP* 7%, dissolved organic carbon *DOC* 1.4% and bacterioplankton *BACT* 0.15%. The relation was not significantly influenced by mineral suspension *MINS*.

The use of the chlorophyll *a* and of the pigmentary ratio green: yellow to represent phytoplankton quantity allowed a better description of

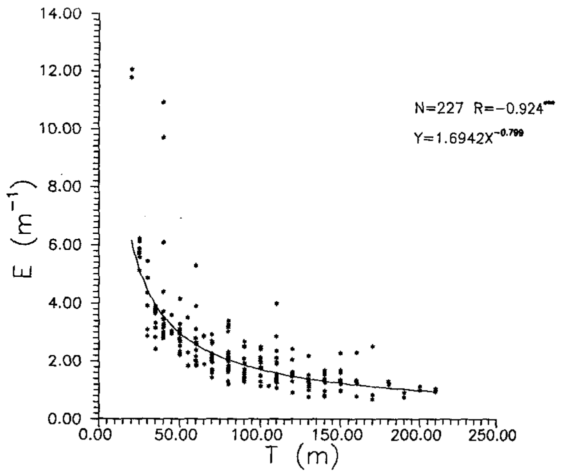


*Fig. 2.* The relationship between light extinction in the water (ε) and Secchi transparency ($T$) in six lakes of the Danube Delta.

the optical properties relative to the use of phytoplankton biomass.

The exponential functions of multiple regression were adequate also to describe the dynamics of detrital particles as a function of, mainly phytoplankton density (69%) and water turbulence (24%).

To establish the threshold for complete resuspension water turbulence a regression model for the residual detritus $\mathrm{DETR}_r$ (after having eliminated the variations caused by plankton) was developed.

The parabolic function of second degree proved to be most adequate for that purpose:

$$\mathrm{DETR}_r = 2.62 - 0.134\,\mathrm{TURB} + 0.039\,\mathrm{TURB}^2, \quad (7)$$
$$(n = 112;\ r = 0.41^{***})$$

This relation approximate an independence of the $\mathrm{DETR}_r$ values for the definition field of TURB ≤7.99 indicating the value of about 8% as threshold limit of resuspension turbulence, in agreement with the values calculated by equation [3].

For a depth domain of 1 to 3 m the critical winds corresponding to this value fluctuated in the field between 3.2 and 5.4 m $s^{-1}$. These values are in agreement with the wind intensity 3 on the Beaufort scale, mentioned by Weisser (1978) for

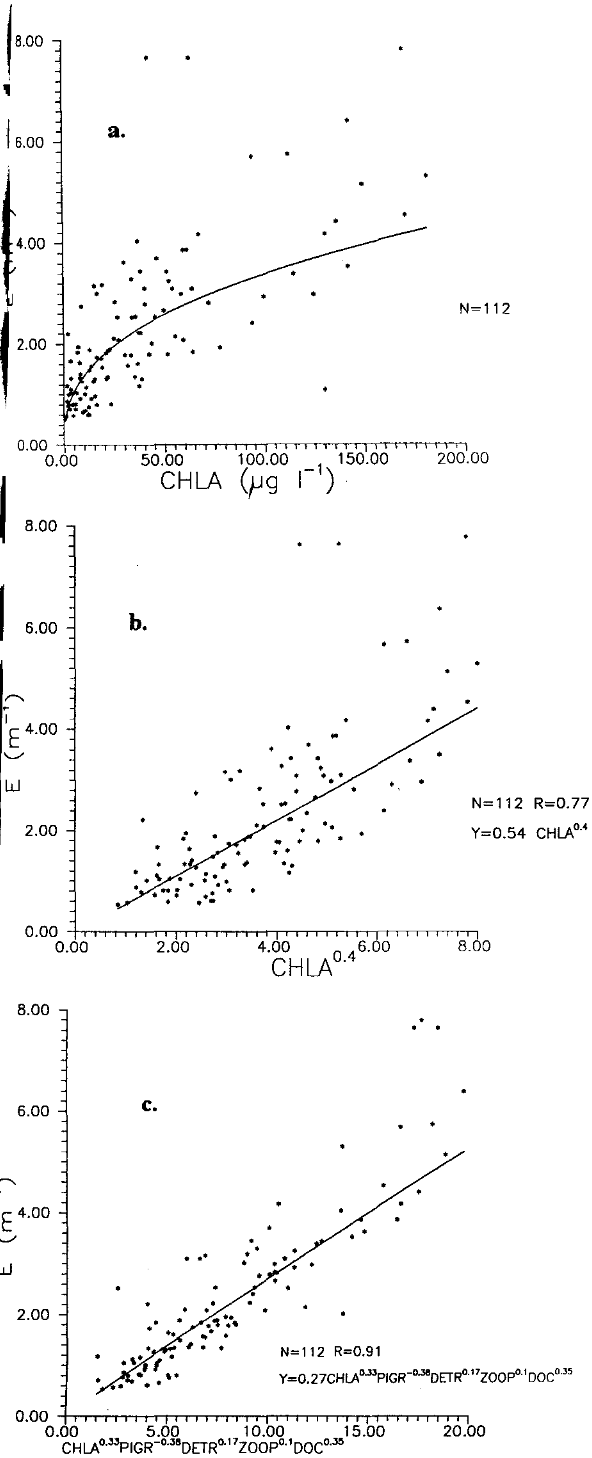


*Fig. 3.* The relationship between light extinction in the water ($\varepsilon$) and phytoplankton density in terms of chlorophyll *a* (Chla) (a, b), contents of suspended and dissolved materials (c).

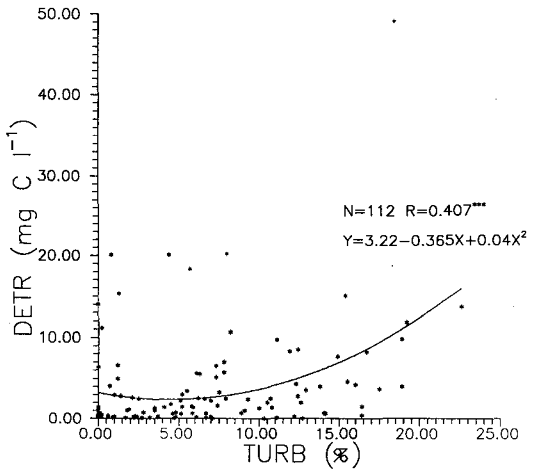


*Fig. 4.* The relationship between density of suspended detritus $DETR_r$ (after having eliminated the variations induced by plankton) and water turbulence TURB.

Neusiedlersee. These values were calculated using the relations [2] and [3].

## Conclusion

Based on the data sampled in six lakes in different trophic state, the equation [2] allow to calculate for a very high level of significance the light extinction coefficient in function of Secchi transparency.

The direct influence of the different factors on light extinction was: phytoplankton 64%, detritus 11%, zooplankton 7%, dissolved organic matter 1.4% and bacterioplankton 0.15%.

The indirect interference of wind, water turbulence and morphometrical parameters of the lake was demonstrated in the form of exponential and parabolic functions.

The dynamics of detrital suspended particles in the water was mainly accounted for by variation in the phytoplankton biomass (69%) and water turbulence (24%).

The threshold for full turbulence of the water registered a value of about 8%. The critical intensities of the wind generating this turbulence fluctuated in the field 3.2–5.4 m $s^{-1}$ for a depth between 1 and 3 m.

Keeping in mind that in the Danube Delta winds over this threshold limit blow the most days of a year (68–80%) the effect of the wind on the light regimen in this lake is obviously important.

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