NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

# Relationship between Secchi depth and the diffuse light attenuation coefficient in Danish estuaries

**Ciarán Murray** (cim@dmu.dk) **Stiig Markager** (markager@dmu.dk)

## Aim

Our aim was to quantify the relationship between the light attenuation coefficient ($K_d$) and Secchi depth (SD) and analyse the variability in time and space.

## Background

Light attenuation is a key parameter in coastal ecosystems. It responds to changes in nutrient loadings and governs the growth and distribution of underwater vegetation. Moreover it is essential for modelling of primary production. Thus, a correct representation of light attenuation is essential in coastal ecosystem models. Current monitoring programs often use direct light measurements, allowing a calculation of the light attenuation coefficient ($K_d$) but older data is often found as Secchi depth (SD) observations. A correct validation of models back in time therefore requires quantification of the factor $K_d$*SD, which also represents the percentage of surface light remaining at the Secchi depth.

## Results

KdSD varies from 1.87 to 2.15, corresponding to a variation in the percentage light at Secchi depth from 11.7% to 15.4%. The lowest values were observed in the summer and the highest from September to December (Fig. 1)

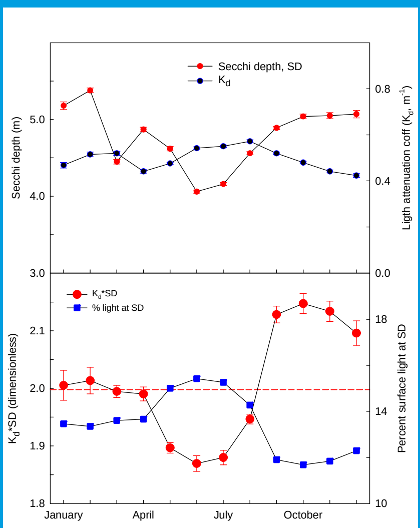



***Figure 1***
*Annual variation in $K_d$ and SD (upper panel) and $K_d$*SD (lower panel) for 174 stations (37049 observations) in Danish estuaries. (mean ± std. error). For $K_d$*SD the Mean value of 2.00 is indicated, together with the corresponding percent of surface light at the Secchi depth.*

The most important factor in explaining the variation is $K_d$*SD is the total concentration of suspended solids (TSS). This accounts for 23% of the variation seen in annual mean $K_d$*SD in a subset of 20 stations (Figure 2). Because measurements of TSS were only available for a limited subset of data (20 stations), station depth was considered as a proxy for this parameter, enabling us to make an analysis for all stations (Figure 3). The shallower stations are subject to a greater resuspension of settled particulate matter and therefore TSS decreases with increasing depth.

The negative relationship with TSS corresponds with a study of Alaskan lakes (Koenings and Edmundson 1991) that showed a significant inverse relationship between Kd*SD and the ratio between turbidity and colour. The low $K_d$*SD-values during summer are most likely due to higher concentrations of phytoplankton and detritus in the productive season.

## Conclusions

- The mean value for $K_d$*SD at 174 stations (37049 observations) is 2.00.
- There is a significant annual variability with the lowest values during summer and the highest values in late autumn and early winter.
- The direct negative effect of phytoplankton is statistically significant but too small to be quantitatively important.
- The most important effect is a decrease in $K_d$*SD with increasing particle concentrations, causing a maximum in $K_d$*SD in late summer due to accumulation of detritus during the growth season.
- An empirical model is given for $K_d$*SD as a function of depth, salinity and month.

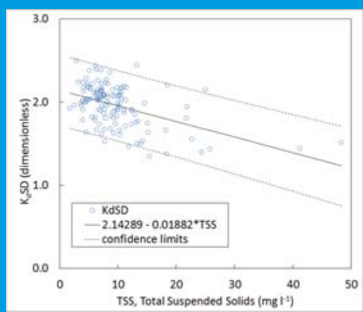



***Figure 2***
*Variation of mean $K_d$SD with total suspended solids, showing linear regression ($p < 0.0001$, adjusted $R^2 = 0.2291$)*

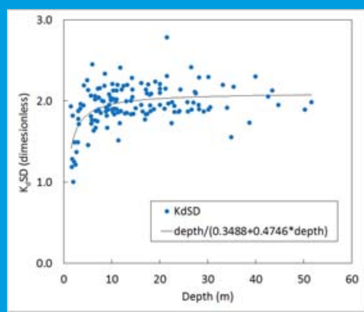



***Figure 3***
*Nonlinear regression of mean $K_d$SD on station depth (m)*

## Empirical model

$$K_d * SD = \frac{Depth}{a + b * Depth} + c * Salinity + d(Month)$$

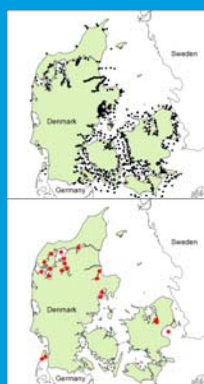
a = 0.2544 m
b = 0.4498
c=-0.006626 PSU$^{-1}$

| Month | d |
|---|---|
| January | -0.1311 |
| February | -0.1427 |
| March | -0.0491 |
| April | -0.0933 |
| May | -0.1784 |
| June | -0.2306 |
| July | -0.1928 |
| August | -0.1187 |
| September | 0.0105 |
| October | 0.0129 |
| November | 0.0205 |
| December | 0.0000 |

## Methods

- Observations used from the Danish national monitoring program. Data was recorded in the period 1985-2011 at 174 stations.
- $K_d$ was obtained by regression of light intensity profiles. $K_d$*SD was calculated for matching observations of SD and light intensity profile.
- Annual variation in $K_d$, SD and $K_d$*SD was analysed. Variation in $K_d$*SD was analysed by regression on parameters, including salinity and concentrations of chlorophyll-a and total suspended solids (TSS)†.
- Average of $K_d$*SD at each station was compared with depth for all stations.

†*A subset of 20 stations had TSS observations available.*




**References:** Koenings, J. P., and J. A. Edmundson 1991. Secchi disk and photometer estimates of light regimes in Alaskan lakes: Effect of yellow color and turbidity.

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