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# Relations Between Water Transparency and Maximum Depth of Macrophyte Colonization in Lakes[1]

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**ABSTRACT**

Using data from lakes located in Finland, Florida, and Wisconsin, we demonstrate that there is a significant positive relationship ($r = 0.70$; $P < 0.01$) between water transparency as measured by use of a Secchi disc (SD) and the maximum depth of colonization (MDC) by aquatic macrophytes. This relationship was used to develop and test an empirical model to predict MDC values from SD values. The best fit logarithmic model was $\log(MDC) = 0.61 \log(SD) + 0.26$ where MDC and SD values are expressed in meters. The model, however, has a 95% confidence interval of 46-236 percent of the calculated MDC value. Separate regression equations were subsequently developed for each geographic region. It is hypothesized that differences in the light compensation points of different species of aquatic

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macrophytes may account for a large portion of the variability in the MDC-Secchi relationships. Influence of light availability and lake morphometry on potential aquatic weed problems in lakes is discussed.

*Key words:* Secchi, water transparency, macrophytes, aquatic weeds, hydrilla, models.

## INTRODUCTION

Excessive growths of aquatic macrophytes have caused serious weed problems in many lakes throughout the world. Thus, when native aquatic macrophytes, or introduced species such as hydrilla (*Hydrilla verticillata* Lf. Royle) begin to colonize a lake or expand their existing areal coverage, there are questions concerning how much of the lake is suitable for colonization and to what extent the weed problem may become. Although many physical, chemical, and biological factors influence the extent of macrophyte colonization, the maximum depth to which aquatic macrophytes can colonize (excluding depths where pressure becomes important) is determined to a large degree by water transparency. For example, Pearsall and Hewitt (1933) noted that when Secchi disc depths changed from 5.5 m to 4.5 m in Lake Windermere, the maximum depth at which macrophytic vegetation grew changed from 6.5 m to 4.3 m. Maristo (1941) also demonstrated a relationship between Secchi disc depth and the depth of colonization by macrophytes in 27 Finnish lakes. The relationship between water transparency and the maximum depth of macrophyte colonization, however, has not been quantified for a large number of lakes.

In this paper, we use data from Finland, Florida, and Wisconsin to develop and test an empirical model that quantifies the relationship between the maximum depth of colonization by aquatic macrophytes (MDC) and water transparency as measured by a Secchi disc (SD). We discuss the limitations of this model and present examples of how lake morphometry interacts with light availability to determine the potential extent of aquatic weed problems.

## METHODS

Data on water transparency as measured by a Secchi disc and the maximum depth of macrophyte colonization in lakes located in Finland, Florida, and Wisconsin were gathered from the published literature (Maristo 1941; Belonger 1969; Modlin 1970) and our unpublished studies in Florida. Published literature (methods for data collection are described in the individual papers) provided data for 27 Finnish lakes and 55 Wisconsin lakes. We provided data for 26 Florida lakes. For the Florida lakes, determinations of SD and MDC in meters were made once during the period of peak macrophyte abundance (June to October) in either 1981 or 1982. SD values were determined by use of a 20 cm black and white Secchi disc. MDC values were determined by use of a Raytheon DE-719 fathometer. For ten Florida lakes, the quantity of light at the maximum depth of macrophyte colonization was determined by use of a Li-Cor Model 185A quantum meter fitted with a LI-1925B quantum sensor. Light meter readings were correlated to the concurrently measured SD values ($r=0.96$). A regression equation was developed and this equation was used to predict the amount of light reaching the maximum depth of macrophyte colonization in other Florida lakes where only Secchi disc depths were recorded.

Because different methods were used to collect the data in Finland, Florida, and Wisconsin, a certain amount of variability due to sampling error is expected. Prior to statistical analysis, all data were transformed to their common logarithm unless stated otherwise. To avoid problems associated with developing and testing a model with the same data, we randomly sorted data into two groups. One group was used for model development. The other group (model verification) was used to test the predictive ability of the empirical model. To evaluate our model, we calculated the five measures of precision used by Canfield and Bachmann (1981) to evaluate various nutrient loading models. Correlation coefficients and best fit linear regression equations were calculated for the relationship between measured and calculated MDC values. An empirical 95 percent confidence limit for the model was determined by calculating the standard deviation of the mean difference between the measured and the calculated MDC values. The average model error was calculated as the mean of the absolute values of the differences between the untransformed calculated and measured MDC values. The percentage error was the mean of the same differences divided by the measured values and multiplied by 100. The 1979 Statistical Analysis System package (Helwig and Council 1979) was used for all statistical analyses.

## RESULTS AND DISCUSSION

For the sampled Finnish, Florida, and Wisconsin lakes, there is a significant positive relationship between the maximum depth of colonization by aquatic macrophytes (MDC) and Secchi disc (SD) depth (Figure 1; $r=0.70$; $P<0.01$). Although correlation analyses can not prove a cause and effect relationship, our analysis provides further support

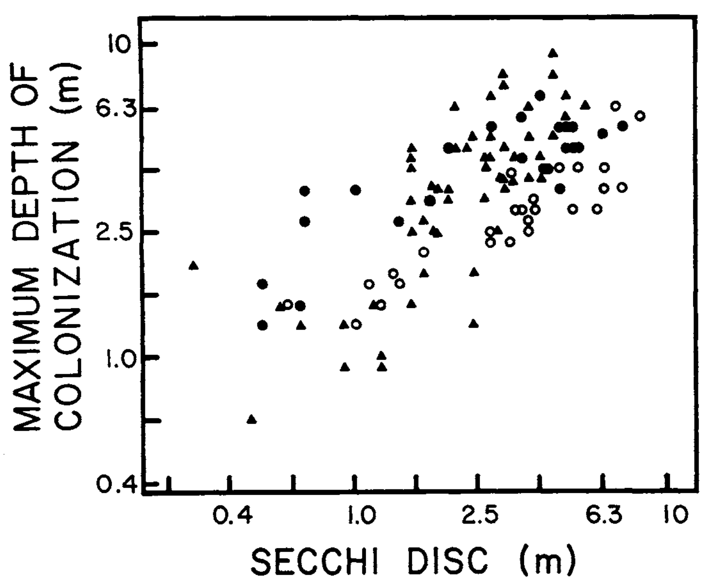


Figure 1. Relationship between maximum depth of macrophyte colonization and Secchi disc depth for Finnish (○) Florida (●) and Wisconsin (▲) lakes.

for the hypothesis that the maximum depth at which aquatic macrophytes can grow depends largely on the transparency of the water, irrespective of plant type or geographic location of the lake. We, therefore, used our model development data set to develop an empirical model that can be used to predict MDC values from SD data. The best fit logarithmic regression equation for our data set is:

$$\log \text{MDC} = 0.61 \log \text{SD} + 0.26$$

where MDC and SD values are expressed in meters. The coefficient of determination for this model is 0.56, which indicates the model explains a little more than half of the observed variance.

We tested the ability of this model to predict MDC values for those lakes contained in our model verification data set. The correlation between measured and predicted MDC values is significant ($r=0.66$; $P<0.01$), but weak. The model tends to underestimate maximum depths of colonization in very clear waters and over estimate colonization depths when Secchi disc depths are low (the slope coefficient for the regression of measured MDC values on calculated MDC values is 0.81). The 95% confidence limit for the model is also large, ranging from 46% to 236% of the calculated MDC value.

Although the model is not as precise as one might like, the predictive ability of our model is similar to that of other commonly used empirical nutrient loading, chlorophyll-nutrient, and Secchi-chlorophyll models (see Canfield and Bachmann 1981; Canfield and Hodgson 1983; Canfield 1983). Furthermore, we suggest that the calculated MDC values are reasonable as a first approximation given the variability observed in lakes. For example, examination of Figure 1 clearly shows that there is a wide range of maximum depths of colonization by aquatic macrophytes for a given Secchi disc value. Obviously, improvements in the predictive ability of the model will occur only after we understand which factors contribute to the variability in MDC values.

At the present time, we cannot definitively determine which factors might be the most important causative agents of variability in the MDC-Secchi relationship. Sampling error is probably an important factor as the ability to detect the maximum depth at which macrophytes grow depends on the technique used to find the plants (e.g., grab samples, fathometer, SCUBA). Part of the observed variability could result because MDC may have been determined by water transparency conditions that existed prior to the time of sampling. There may also be regional differences in the response of plants to changes in light availability. For example, we developed separate regression equations for the lakes from Finland, Florida, and Wisconsin (Table 1). There are differences in the slope coefficients and intercept values. Coefficients of determination range from 0.57 to 0.82.

We suggest, however, that the major factor contributing to the variability in the MDC-Secchi relationship is the type of plants colonizing the lake bottom. Different species of aquatic macrophytes have different light requirements. For example, Van et al. (1976) determined hydrilla has a light compensation point (LCP) of 15 microE/m$^2$/s whereas coontail (*Ceratophyllum demersum* L.) has a LCP of 35 microE/m$^2$/s and Cabomba (*Cabomba caroliniana* Gray) has a LCP of 55 microE/m$^2$/s. If we assume 2000 microE/m$^2$/s represents full sunlight, the LCP for hydrilla is about 0.75% of full sunlight. The amount of light at the maximum depth of colonization by hydrilla in the sampled Florida lakes is close to this value in 7 of the 11 lakes where hydrilla was found (Table 2). In Lakes Sampson and Rowell, hydrilla had only recently become established and had not yet colonized the deeper areas at the time of sampling, but did become established in deeper waters during 1983 (Canfield, unpublished data). In Lake Stella, Secchi disc depths reach to the bottom of the lake so hydrilla was not light limited. Hydrilla could potentially colonize deeper waters in Lake Kerr, but hydrilla growth in this lake seems to be limited more by nutrient availability than light (Langeland 1982).

Although additional research will be needed to improve the predictive capabilities of the empirical MDC-Secchi models developed in this paper, we believe the models can be used, to provide a first approximation of how changes in SD values caused by either natural factors or anthropogenic activities may affect the extent of macrophyte colonization in lakes. In using these models, however, basin morphom-

TABLE 1. REGRESSIONS OF THE MAXIMUM DEPTH OF MACROPHYTE COLONIZATION (MDC) ON SECCHI DISC DEPTHS (SD) FOR LAKES LOCATED IN FINLAND, FLORIDA, AND WISCONSIN. ALL MEASUREMENTS ARE IN METERS AND N REPRESENTS THE NUMBER OF LAKES SAMPLED.

| Region | N | Equation | Coefficient of Determination |
|---|---|---|---|
| Finland | 27 | log(MDC) = 0.51 log (SD) + 0.18 | 0.82 |
| Florida | 26 | log(MDC) = 0.42 log (SD) + 0.41 | 0.71 |
| Wisconsin | 55 | log(MDC) = 0.79 log (SD) + 0.25 | 0.57 |

TABLE 2. PERCENT TRANSMITTANCE OF FULL SUNLIGHT AND SPECIES PRESENT AT THE MAXIMUM DEPTH OF AQUATIC MACROPHYTE COLONIZATION IN SOME FLORIDA LAKES.

| Lake | Species | Percent transmittance |
|---|---|---|
| Lochloosa | *Hydrilla verticillata* | 0.46 |
| Orange | *Hydrilla verticillata* | 0.68 |
| Tyler | *Hydrilla verticillata* | 0.75 |
| Pineloch | *Hydrilla verticillata* | 0.82 |
| Fairview | *Hydrilla verticillata* | 0.86 |
| Catherine | *Hydrilla verticillata* | 1.1 |
| Milldam | *Hydrilla verticillata* | 1.2 |
| Wauberg | *Nuphar luteum* | 1.9 |
| Watertown | filamentous algae | 2.3 |
| Sampson | *H. verticillata* | 2.7 |
| Gap | *Eleocharis baldwinii* | 3.2 |
| Apopka | filamentous algae | 3.2 |
| Townsend | *Ceratophylum demersum* | 3.4 |
| Turkey Pen | *E. baldwinii* | 3.8 |
| Dunford | *Utricularia vulgaris* | 4.1 |
| Rowell | *H. verticillata* | 4.3 |
| Merial | *E. baldwinii* | 4.8 |
| Stella | *H. verticillata* | 5.4 |
| Compass | *E. baldwinii* | 6.1 |
| Round | *E. baldwinii* | 6.3 |
| Ocean Pond | *E. baldwinii* | 8.3 |
| McKenzie | *U. vulgaris* | 8.3 |
| Down | *Mayaca aubletti* | 8.7 |
| Newnan | *C. demersum* | 1.1 |
| Kerr | *H. verticillata* | 1.1 |
| Mirrow | *E. baldwinii* | 1.1 |

etry must be considered. For example, we present in Figure 2 the hypsographic curves for two Florida lakes. For a SD value of 1.1 m, we would calculate using the MDC-Secchi model for Florida lakes (Table 1) a MDC value of 2.7 m for both lakes. If only light was limiting and macrophytes grew in all suitable areas, approximately 68% of the shallower lake and 20% of the deeper lake would be colonized by macrophytic vegetation. If the plants colonizing these lakes were major weed species such as hydrilla, the weed problem would be perceived to be much worse in the shallower lake. If Secchi disc depth was reduced to 0.5 m in each lake, we would expect an MDC value of about 1.9 m. Because of the shape of the basins, colonization by macrophytes to a depth of 1.9 m would cover less than 15% of each lake. The weed problem in each lake would then be judged by the public to be similar. The potential for severe weed problems (based upon areal coverage) during years of increased water transparency, however, would be greater in the shallow lake. With this type of information, management agencies could plan appropriately and justify preventative management programs.

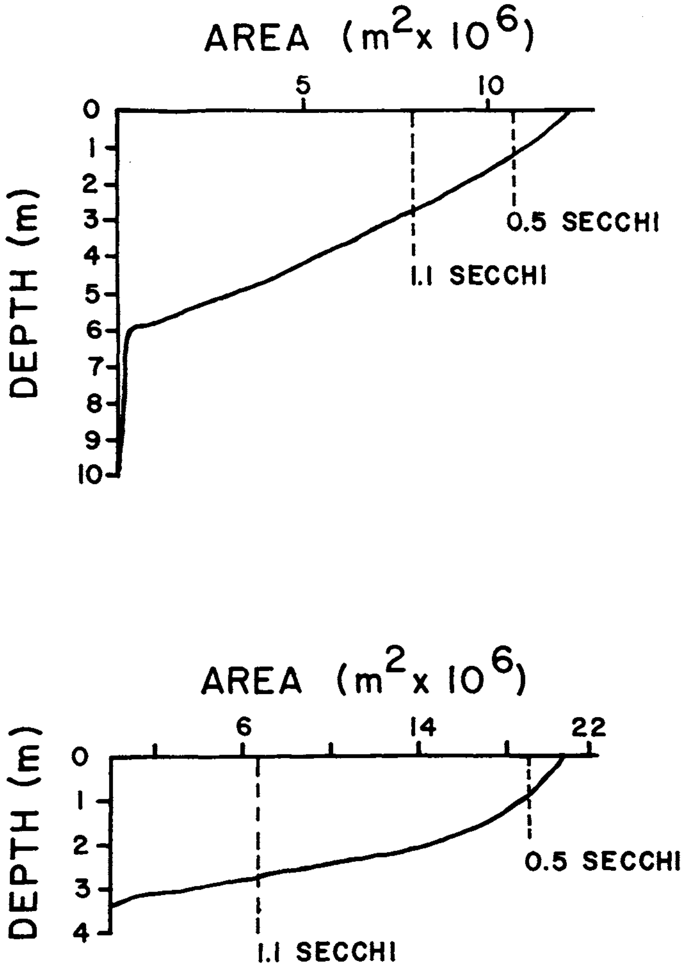

Figure 2. Hypsographic curves for a deep (upper) and shallow (lower) Florida lake.


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