

CHAPTER 4

QUALITATIVE AND QUANTITATIVE ASSESSMENT OF THE PROBLEM

4.1 INTRODUCTION

The aim of this chapter is to review the major classification of lakes and how chemical, hydrological and biological studies of lakes can be applied and modified for assessment of lake typology and classification. While a biological classification is approved and accepted for running waters (Kolkwitz & Marsson, 1909; Liebmann, 1951, 1960), we are confronted with a high diversity of methods for running waters:

1. **Classification** based on the abiotic and biotic conditions in the lakes,
2. **Models of eutrophication** (or pollution) based on the loading from the catchment area.

The knowledge of structure and function of the limnetic ecosystem (see Chapter 2) is one of the suppositions for the study of lake classification. Because of the importance of the biogeochemical cycles, especially nutrient cycling, we will again briefly refer to it. Then the basic techniques ("How to do it") in field studies on lake classification will be described.

4.2 NUTRIENT CYCLES: THE PHOSPHORUS CYCLE

For a detailed discussion of the phosphorus cycle, can be referred to textbooks in limnology (e.g. Wetzel, 1983). Only some features which are typical and important for lake classification and typology can be described here.

1. In the epilimnetic open water zone we find the following fractions (Fig 4.1): **particulate phosphorus** contains the bulk of phosphorus. The fraction of **soluble orthophosphate** is very small with an extremely short turnover time (often minutes). From the low molecular weight **organic phosphorus** fraction orthophosphate continuously is released, predominantly by the activity of free phosphatases, and then become

available to phytoplankton. The primary production of epilimnetic phytoplankton is based on this fast running cycling pool. Due to their metabolic activity (high degradation rate of particulate phosphorus, exoenzyme activity) bacteria are of major importance for the dynamics of phosphorus cycling in waters.

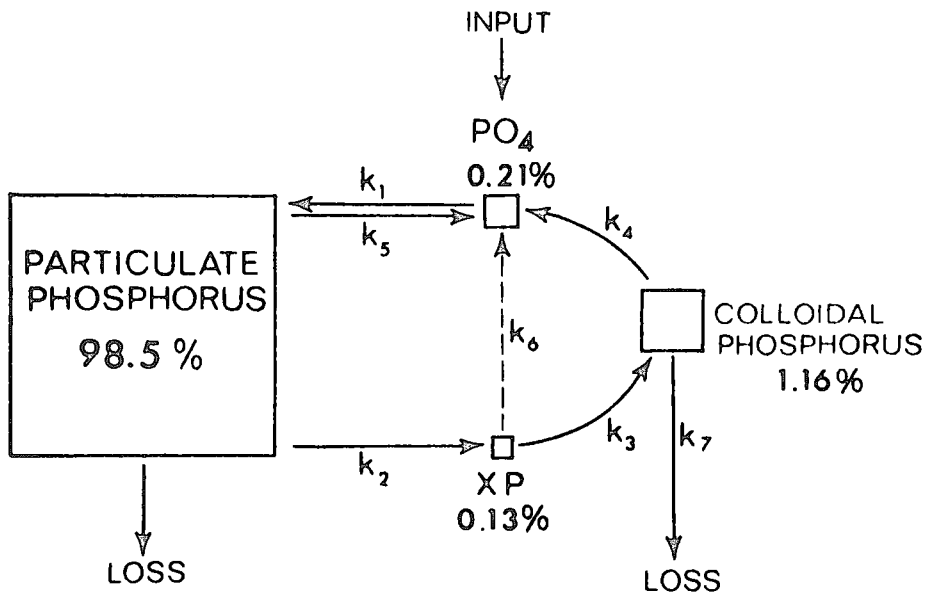


Figure 4.1 Phosphorus movement within the epilimnetic open water zone of lakes, showing the relation between particulate and dissolved phosphorus fractions (from Wetzel, 1983).

2. Fig. 4.2 shows the generalized vertical distribution of soluble (P_s) and total (P_T) phosphorus in stratified lakes of very low (oligotrophic) and high (eutrophic) productivity. During periods of stratification in the eutrophic lake with oxygen depletion in the hypolimnion, a strong increase of dissolved, mostly inorganic phosphorus is found in deeper anoxic parts. Because of the low exchange rate between epilimnetic and hypolimnetic waters this accumulation of phosphorus is not immediately available for the epilimnetic primary production.

High exchange rates across the sediment interface are under anoxic conditions responsible for internal loading of the hypolimnion. The phosphorus cycle is thus strongly connected with the **redox conditions** of the lake: in the epilimnion and after intrusion of oxygen during the autumnal circulation into the deeper anoxic parts of the lake ferrous iron will be oxidized and produces a drastic reduction of dissolved inorganic phosphate

partly by adsorption on ferric hydroxide and CaCO_3 , partly by precipitation of ferric phosphate. An oxidized microzone on the sediment surface acts as phosphorus trap preventing a significant release of dissolved phosphate from the interstitial waters of the sediments to the overlying bottom waters of the lakes. Besides this the phosphorus content of metalimnion and hypolimnion depends on rates of sedimentation of plankton, rates of decomposition and development of microbial populations in the depth of the lakes.

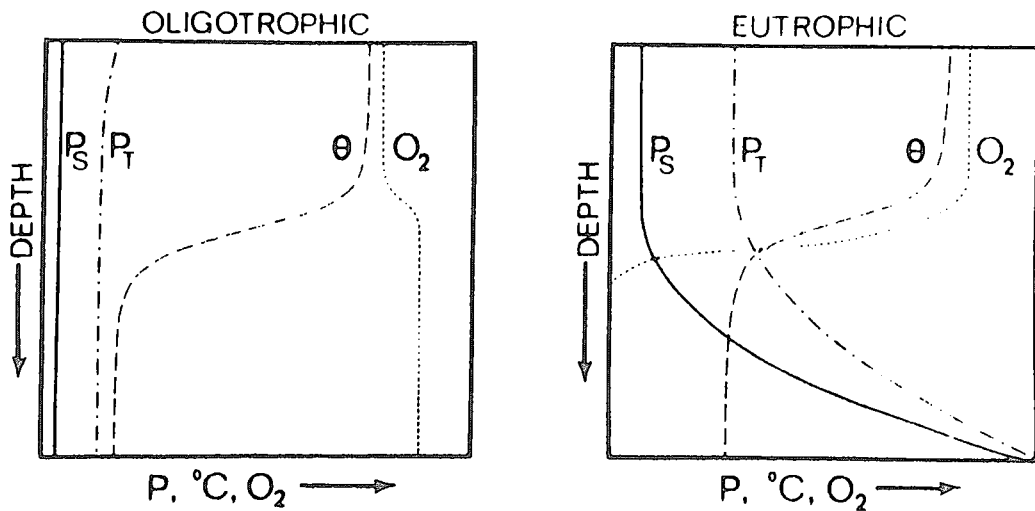


Figure 4.2 Generalized vertical distribution of soluble (P_S) and total (P_T) phosphorus in lakes of very low and high productivity (after Wetzel, 1983).

4.3 THE NITROGEN CYCLE

Dissolved nitrogen compounds include ammonia nitrogen, nitrite, nitrate, dissolved molecular nitrogen and a high diversity of organic compounds (e.g. amino acids, proteins, nucleotides, refractory humic compounds with low nitrogen content). In contrast to the phosphorus cycle, with a very important physico-chemical component, the nitrogen cycle is controlled by microbiological processes: nitrification, denitrification, fixation of molecular nitrogen, nitrate ammonification. Oxygen has a decisive influence on the whole cycle, determining rates of nitrification or denitrification

(occurs only under anoxic or low oxygen condition), etc. Fig. 4.3 summarizes the numerous oxidation and reduction stages of nitrogen compounds. Ammonia is nitrified largely by *Nitrosomonas* to nitrite. Oxidation of nitrite proceeds further to nitrate by *Nitrobacter*. Both bacteria are chemolithotrophic bacteria. Much of the energy released by the oxidation is used for CO₂-fixation via the Ribulosediphosphate-Carboxylase (Rubisco):

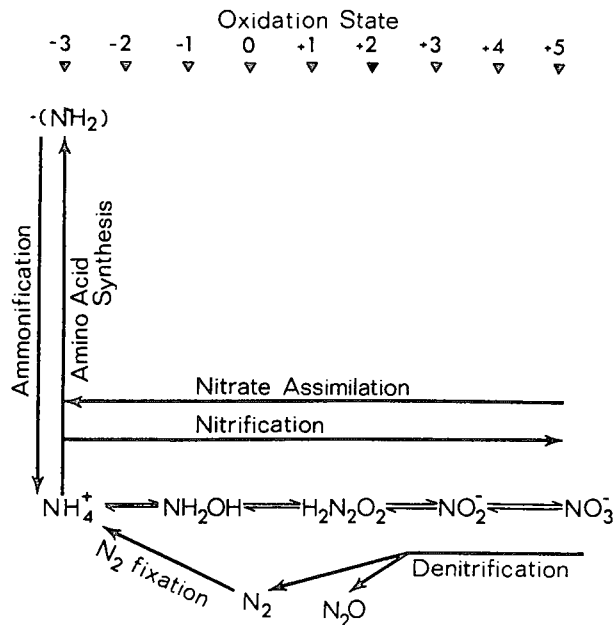
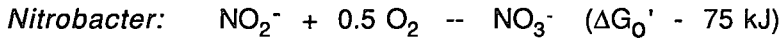
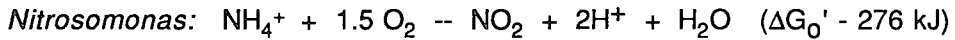


Fig. 4.3: Biochemical reactions influencing the distribution of nitrogen compounds in water (from Wetzel, 1983).

Nitrification means the biological conversion of organic and inorganic nitrogenous compounds from a reduced state to a more oxidized state. In the pelagic zone of the lake the number and activity of nitrifying bacteria is unexpected low. Nitrifying bacteria are originally soil bacteria, their specific field of activity is therefore the sediment.

In contrast again to the phosphorus cycle the loading of a lake with nitrogen compounds from direct terrestrial run-off can be very high: nitrogen compounds have a high mobility and are not absorbed to soil, clay, ferric hydroxide etc., as it is the case with phosphorus. Depending on local

meteorological conditions loading of a lake by precipitations can also be very important.

Fig 4.4 summarizes the general vertical distribution of nitrate and ammonia in stratified lakes of high and low productivity. In anoxic hypolimnetic waters ammonia is accumulated due to denitrification of nitrate, release of reduced nitrogen compounds from the sediment, and decomposition (desamination of organic nitrogen compounds). In well-oxygenated waters the concentrations of ammonia are generally low, but depend on the actual state of metabolism. Thus, after a breakdown of phytoplankton populations also in the aerated epilimnion higher amounts of ammonia may be present before nitrification of the reduced nitrogen compounds. Very common is the development of a "nitric plate" in the metalimnion due to nitrification or denitrification of the metabolically extreme active bacterial populations in this part of the lake.

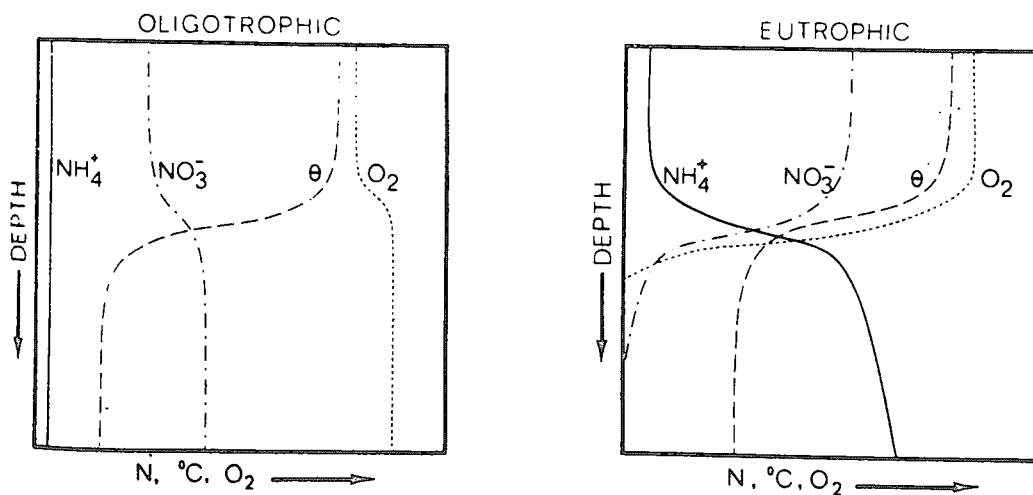


Figure 4.4: Generalized vertical distribution of ammonia and nitrate, nitrogen in stratified lakes of very low and high productivity (from Wetzel, 1983).

4.4 METHODS FOR TROPHIC STATE QUALIFICATION

The evaluation of the trophic status of a lake, is based upon many data, such as lake basin morphology, physico-chemical parameters, biological parameters and various rates of lake metabolism. In addition, hydrological parameters are also indispensable.

In the following we will give a comprehensive list of methods and how they can be used to assess the problem. The methods are not given in the text but references on where to find details. It seems reasonable to consider also older methods which are still useful and applicable; although they often are of regional value only.

1. Composition of the phytoplankton community (Nygaard)

Nygaard (1949) determined a quotient of the relation of numbers of species of *Cyanophyta*, *Chlorococcales*, *Centric Diatoms* and *Euglenophyta* on the one side and *Desmidiiales* on the other side. The quotints can be related to different lake-types in the following way:

oligotrophic	fresh waters:	< 1
eutrophic	fresh waters:	1 - 5
polytrophic	fresh waters:	> 20

2. Protein content of water (Ohle)

Ohle (1955) applied protein as measure of biomass and combined it with Nygaard's phytoplankton quotient:

Trophic state	Time	µg protein / l
oligotrophic	year	< 300
low eutrophic	< 1 month	> 300
medium eutrophic	several months	> 500
strongly eutrophic	year	> 500

3. Correlation between total phosphorus and chlorophyll A (Dillon an Rigler)

Regarding the fact that eutrophication of lakes is connected with an increased biomass Dillon and Rigler (1974a and b) evaluated a correlation between total phosphorus and chlorophyll A. Precondition for a good correlation and probability of prediction is a N:P ratio > 12, i.e. phosphorus must be the potential limiting factor. The regression with a correlation-quotient of $r = 0.95$ is as follows:

$$1g(\text{chl A}) = 1.499 \lg P - 1.136$$

Sakamoto (1966) published a similar relation for Japanese lakes.

The chlorophyll A content, i.e. the development of phytoplankton during summer months can thus be predicted from the phosphorus content in the lake during spring overturn, that is in temperate lakes immediately after icebreak before development of the spring bloom.

From the predicted biomass (chlorophyll A) the tolerable phosphorus content of the lake can be estimated.

The correlation can be combined with the nutrient loading model (Vollenweider, 1979) predicting the phosphorus content during spring overturn from the phosphorus loading (see also Chapter 6).

For similar approaches see also Shapiro (1979), Forsberg and Ryding (1980).

4. Multivariate Trophic State Index (Carlson)

Carlson's (1977) Trophic State Index is based on the following studies:

Prediction of phosphorus concentration in lakes from loading data (Vollenweider 1969, 1976, 1979; Kirchner and Dillon 1975),

Correlation of total phosphorus/chlorophyll A (Sakamoto 1966, Dillon & Rigler 1974),

Prediction of the hypolimnetic oxygen deficit from Secchi disk measurements (Lasenby 1975).

From correlations between Secchi disk readings, chlorophyll A and total phosphorus, equations are derived for the determination of Trophic State Index (TSI). Secchi disk readings are the key parameters of TSI.

The application of such index is rather problematic. For example the biomass of phytoplankton (chlorophyll A) can be controlled by the grazing pressure of the zooplankton, resulting in a smaller biomass than predicted from the equations. On the other hand an increase of the phytoplankton biomass beyond the predicted values may be due to a short circuit phosphorus metabolism.

Modifications of the TSI of Carlson from Porcella, Peterson and Larsen (1979) (LEI - Lake Evaluation Index) and Osgood (1982).

5. Quantitative assessment (Schröder and Schröder)

The Schröder's (1978) model is based on two different groups of parameters, which are indicative for production and decomposition:

Production (P)

Annual average concentration of total phosphorus in the euphotic zone (0-10 m)

Annual average temperature of this zone quotient from radiation of one year divided by a longterm medium value of radiation.

Mean depth (z).

Decomposition (R)

Annual average concentration of ammonia as % of total inorganic nitrogen in the whole water column.

Annual average temperature above sediment in °C.

Area of the lake in km².

The P:R ratio included in the Schröder-model is an excellent functional index of the relative maturity of a system. If the P:R ratio approaches 1, production and decomposition are balanced as it is the case in the mature or "climax" ecosystem (Odum, 1971). If the P:R ratio is less than 1, decomposition exceeds production. In the opposite case (P:R > 1) production exceeds decomposition. In both cases appropriate remedial techniques are needed to balance the system.

6. Lake metabolism as index of trophic state of a lake

By measurement of the primary production with ¹⁴C-bicarbonate (Steemann-Nielsen, 1952) and the heterotrophic microbial activity by means of the heterotrophic potential using ¹⁴C labelled organic substrates (Wright and Hobbie, 1966) production and decomposition can directly be measured. There is a good correlation between pelagic autotrophic production and decomposition rate of bacterial populations. The bacteria are extremely adapted to the trophic state of the lake. Therefore, a Trophic State Index can be measured rather simple and fast (20 min) from uptake rates of bacteria (Overbeck, 1973). As an average in eutrophic lakes with a production of 500-1000 mg C m⁻² d⁻¹, the heterotrophic potential amounts 1 µg C l⁻¹ h⁻¹; in oligotrophic lakes 0.1 µg C.

The ¹⁴C-labeled organic substrates which are commonly used for measurement of a heterotrophic potential are glucose, acetate or aminoacids. By application of different concentrations the determination of uptake kinetics in situ is possible: from the max. uptake rate and the K_m-value we get informations on the physiological state of bacteria and phytoplankton.

Application of one dissolved organic substrate for measurement of heterotrophic activity does not comprise the total microbial production.

Fuhrmann and Azam (1982) introduced the incorporation of thymidine as a measure of total heterotrophic bacterioplankton production. This method is now widely used and gives adequate correct values for comparing the bacterial production with the autotrophic site of the ecosystem.

A comprehensive introduction into field and laboratory methods offer Limnological Analysis by Wetzel and Likens (1979). The book is highly recommended.

J. Schwoerbel (1980) "Methoden der Hydrobiologie - Süßwasserbiologie".

L. Hakanson (1981) "Lake Morphometry".

Proceedings of the Second Workshop on Measurement of Microbial Activity in the Carbon Cycle, ed. by J. Overbeck et al., *Ergebn. Limnol.* 19: 1-316 (1984). The book includes all major contemporary methods for studying aquatic bacteria.

The measurement of photosynthetic pigments in freshwaters and standardization of methods. Proceedings of the Second Workshop, ed. by H. Rai and A.F.H. Marker, *Ergenb. Limnol.* 16: 1-130 (1982). One of the best publications in this field.

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