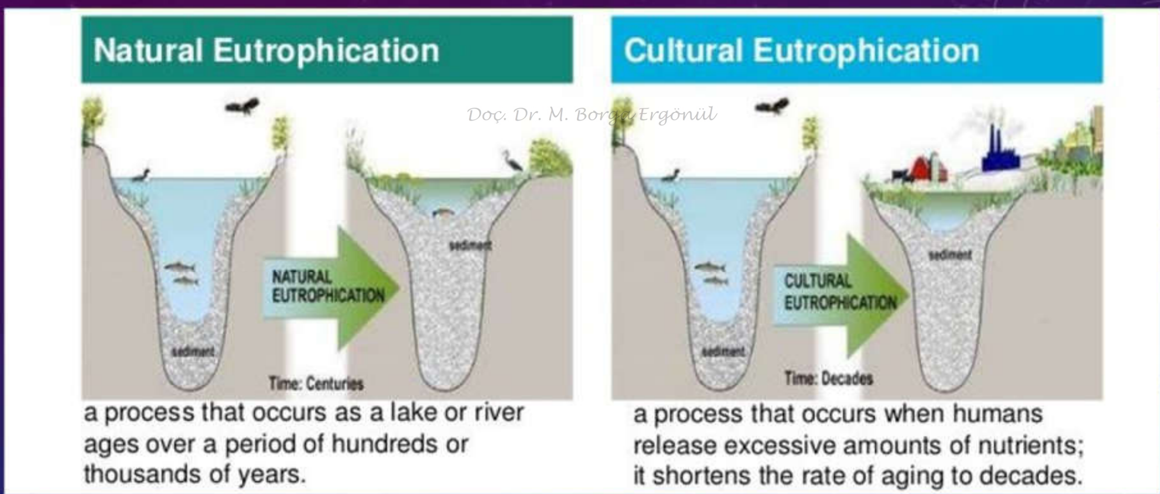
Eutrophication

Eutrophication is a leading cause of impairment of many freshwater and coastal marine ecosystems in the World. Eutrophication is characterized by excessive plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis, such as sunlight, carbon dioxide, and **nutrient fertilizers (mainly N and P)**. Eutrophication occurs naturally over centuries as lakes age and are filled in with sediments.



Eutrophication

Before

After

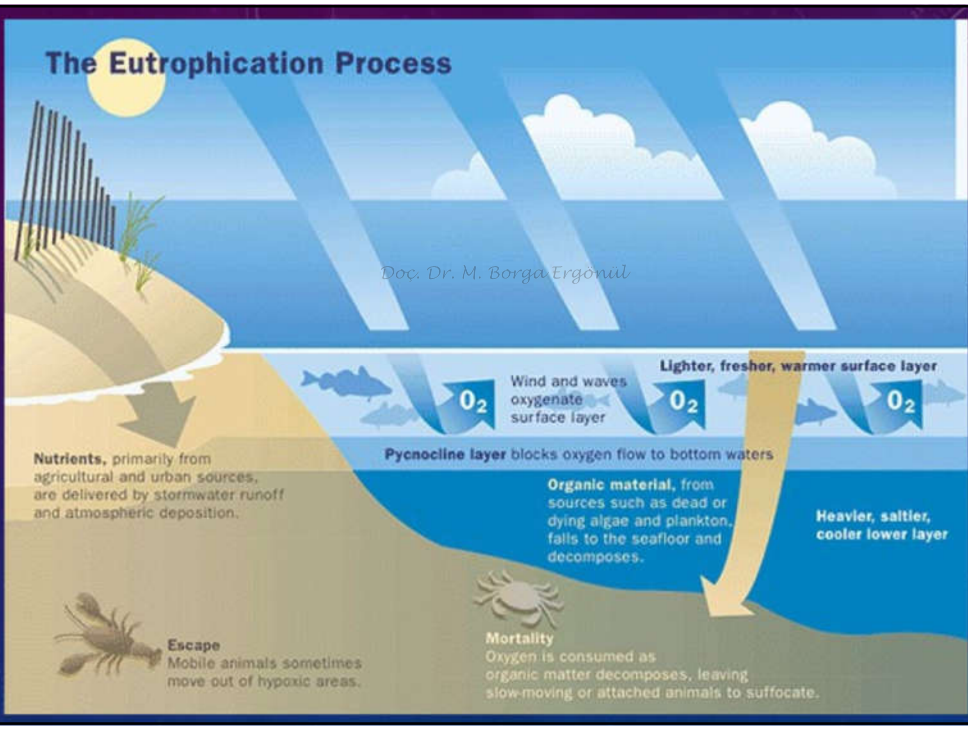
Human activities such as point-source discharges and non-point loadings of limiting nutrients, such as nitrogen and phosphorus, into aquatic ecosystems accelerates the rate and extent of eutrophication (i.e., cultural eutrophication). This lead to dramatic consequences for drinking water sources, fisheries, and recreational water bodies.

The common consequences of cultural eutrophication include blooms of blue-green algae (i.e., cyanobacteria tainted drinking water supplies, degradation of recreational opportunities, and hypoxia in water which leads to animal deaths.

Harmful algal blooms in Milford Lake, Kansas

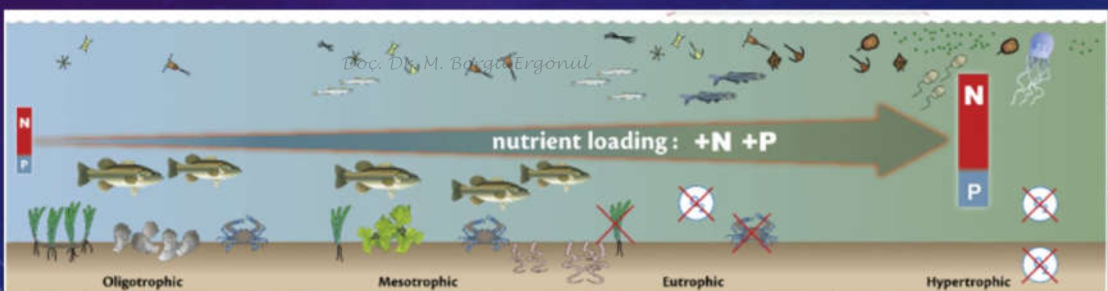
Algal bloom in 2010 along the coast of Qingdao, eastern China

The most conspicuous effect of cultural eutrophication is the creation of dense blooms of noxious, foul-smelling phytoplankton that reduce water clarity and harm water quality. When these dense algal blooms eventually die, microbial decomposition severely depletes dissolved oxygen, creating a hypoxic or anoxic 'dead zone' lacking enough oxygen to support most organisms. Furthermore algal blooms limit light penetration, reducing growth and causing die-offs of plants in littoral zones.



Some algal blooms pose an additional threat because they produce toxins (cyanotoxins). Harmful algal blooms (**HABs**) lead to degradation of water quality, destruction of economically important fisheries and public health risks and also risk for animal husbandry. Within freshwater ecosystems, cyanobacteria are the most important phytoplankton associated with HABs. Toxigenic cyanobacteria tend to dominate nutrient-rich, freshwater systems due to their superior competitive abilities under high nutrient concentrations, low nitrogen-to-phosphorus ratios, low light levels, reduced mixing, and high temperatures. Poisonings of domestic animals, wildlife, and even humans by blooms of toxic cyanobacteria have been documented throughout the World. Furthermore, cyanobacteria are responsible for several off-flavor compounds found in drinking water.

Eutrophication is also associated with major changes in aquatic community structure. During cyanobacterial blooms, the biomass of planktivorous fish is often positively related to nutrient levels and ecosystem productivity; leading to a decrease in fish like trout. The whole species composition changes resulting in a decrease in intolerant species, and a decrease in total number of species and an increase in number of individuals.

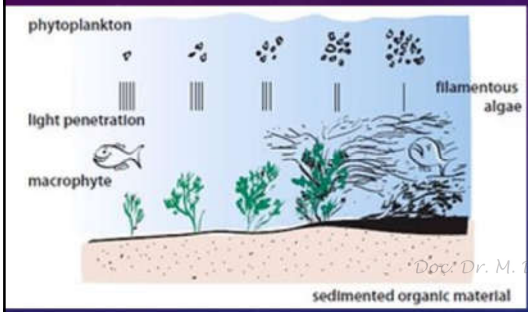


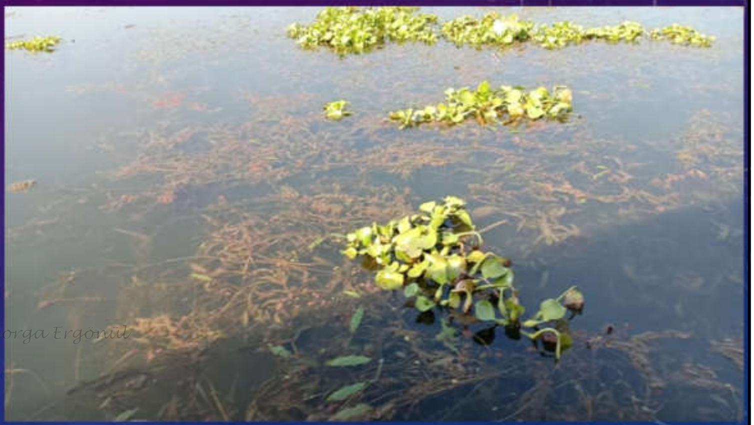
Effects of Eutrophication

- species diversity decreases and the dominant biota changes (tolerant species become dominant, biodiversity decreases; disappearance or significant reduction of economically important fish with and an increase in undesirable ones such as carp)
- plant and animal biomass increase; (excessive growth of aquatic macrophytes*)
- abundance of particulate substances (phytoplankton, zooplankton, bacteria, fungi and debris) that effect the turbidity and colouration of the water; lowering the success of predators that need light to pursue and hunt
- rate of sedimentation increases, shortening the lifespan of the lake
- poor water quality (odour, color, taste; undesired chemicals such as ammonia, nitrites, hydrogen sulphide)
- possible poisoning due to HAB;
- loss of recreational uses
- decrease in oxygen concentrations which may lead to anoxia.

**Excessive growth of aquatic macrophytes*

Increased nutrient levels can stimulate other forms of primary production, in addition to algae and cyanobacteria. The littoral zones of many nutrient-enriched water bodies are often chocked with excessive growths of aguatic macrophytes, which can influence recreational activity and alter the structure of the food web. Excessive growth of phytoplankton and macroscopic plants in the water create aesthetic problem and reduce the value of the body water as a recreational resource. From a purely aesthetic point of view, crystal clear water characteristic of oligotrophic systems is most attractive for swimming and boating. High phytoplankton concentrations cause the water to appear turbid and aesthetically unappealing. Macroscopic plants can completely cover the entire surface of eutrophic lakes making the water almost totally unfit for swimming and boating.





Oligotrophic Lakes

Oligotrophic lakes are those that are unproductive: net primary production is only between 50 and 100 milligrams of carbon per square metre per day, nutrients are in poor supply, and secondary production is depressed. Water is usually clear, non-turbid or of very low turbidity. This allows light to penetrate to lower levels of the water and oxygen levels are also good because there are not a lot of algae covering the surface of the water, which would compromise light and oxygenation levels. Concentrations of elements such as nitrogen and phosphorous would be on the low side in such a lake. Oligotrophic lakes typically have fewer photosynthetic organisms present.

The productivity of autotrophs, such as plants, is called primary productivity, while the productivity of heterotrophs, such as animals, is called secondary productivity.

Difference between Oligotrophic and Eutrophic Lakes/Ponds

Sl. No.	Oligotrophic Lakes	Eutrophic Lakes
1	Oligotrophic lakes are usually deep in depth	Eutrophic lakes are shallow in depth
2	Poor nutrient content in the water especially nitrates and phosphates	High nutrient content in the water especially nitrates and phosphates
3	Low primary productivity	High primary productivity
4	Oxygen rich water in the hypolimnion	Oxygen deficient water in hypolimnion
5	High species diversity of green algae and low species diversity of blue green algae	Low species diversity of green algae and high species diversity of blue green algae
6	Green algae dominate in the ecosystem	Blue green algae dominate in the ecosystem
7	# Carlson's Trophic State Index: <30 – 40	Carlson's Trophic State Index: 50 – 70
8	Chlorophyll content in the ecosystem: 0 – 2.6	Chlorophyll content: 20 – 56
9	Level of phosphate in the water: 0 – 12	Level of phosphate: 24 – 96
10	Low density of species	High density of species

11	Plant nutrient flux will be low	Plant nutrient flux will be high
12	Algal blooms occur very rarely	Algal blooms occur very frequently
13	Clear water	Water usually dark due to the growth of algae
14	Drinking water quality	Water may not good for drinking purpose due the high growth of algae
15	Commonly occur in cold regions	Usually occurs in warmer regions
16	Chance of eutrophication is less	Chance of eutrophication is high

The Trophic State Index (TSI) or Carlson Trophic State Index is a classification system designed to "rate" individual lakes, ponds and reservoirs based on the amount of biological productivity occurring in the water. Using this index, one can gain a quick idea about how productive a lake is. Classifications range from 1 to 100 and are generally described as follows:

TSI values	TrophicStatus	Attributes
< 30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30-40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer
40- 50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
50-60	Eutrophic	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60-70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70-80	Eutrophic	Heavy algal blooms possible throughout the summer, often hypereutrophic
>80	Eutrophic	Algal scum, summer fish kills, few macrophytes

The method calculates a separate component TSI for nitrogen, phosphorus and chlorophyll a. These components are then combined, as indicated in equations A-C below, to determine the overall TSI. This procedure is the basis for all Water Atlas TSI calculations. As previously stated, the procedure first calculates separate TSI values (via empirical equations that use the natural logarithm [ln], an exponential function in which the base is 2.71828+) for chlorophyll (a) [chl(a)], total nitrogen [TN] and total phosphorus [TP] sample concentrations, and then combines the values through addition. The calculations are shown in the empirical equations one through five below. These equations calculate the TSI for various nutrient relationships. The result of equation one is used for all calculations. The result of equations two and three are used for nutrient balanced lakes (those where the TN to TP ratio is greater or equal to 10 and less or equal to 30). The result of equation four is used for phosphorus limited lakes (those where the TN to TP ratio is greater 30) and the result of equation five is used for nitrogen limited lakes (those with a TN to TP ratio of less than 10).

1. $TSI_{(chl\ a)} = 16.8 + [14.4 \times \ln(chl\ a)]$
2. $TSI_{(TP)} = 18.6 \times [\ln(TP \times 1000)] - 18.4$
3. $TSI_{(TN)} = 56 + 19.8 \times \ln(TN)$
4. $TSI_{2\,(TP)} = 10 \times [2.36 \times \ln(TP \times 1000) - 2.38]$
5. $TSI_{2\,(TN)} = 10 \times [5.96 + 2.15 \times \ln(TN + 0.001)]$

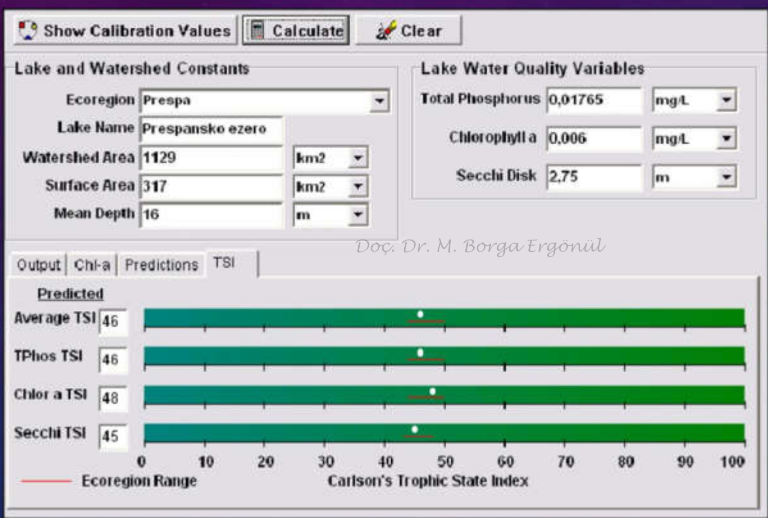
The final TSI is then determined by averaging the above values based on the limiting nutrient determined for the lake using final equations A-C below.

A. Nutrient Balanced Lakes ($10 \le TN/P \le 30$):
$TSI = (TSI_{(chl\ a)} + [TSI_{(TN)} + TSI_{(TP)}] / 2) / 2$

B. Phosphorus-Limited Lakes ($TN/TP > 30$):
$TSI = [TSI_{(chl\ a)} + TSI_{2\,(TP)}] / 2$

C. Nitrogen-Limited Lakes ($TN/TP < 10$):
$TSI = [TSI_{(chl\ a)} + TSI_{2\,(TN)}] / 2$

Lake Eutrophication Analysis Procedure (LEAP) is a part of software package, Wisconsin Lake Modelling Suite (WiLMS) can also be used to calculate TSI



Control of Eutrophication

Rehabilitation of eutrophic waters encompasses three components: control of pollutant sources, restoration of the damaged ecosystem, and catchment basin management. The eutrophication process is affected not only by physical and chemical variables, but also by biological variables. Although the influence factors have been known for several decades, the control methods have only been slightly successful. Natural factors, including light and temperature, are almost impossible to change and so to improve the nutritional status of lakes it is better to start from controlling human factors. Many conventional and novel methods that use physical, chemical, and biological processes have been applied to improve and eliminate contaminants in eutrophic lakes

Chemical methods are more suitable for lakes with a serious nutritional status resulting in blue-green algae outbreaks. Earlier attempts for chemical eutrophication management mainly involved copper sulfate ($CuSO_4$), herbicides, and algicide to kill algae. However, besides toxic effects of those chemicals on biota, dead algal material should be considered, too.

Adding dissolved aluminum (Al) into the anoxic sediments of eutrophic lakes may inhibite P recovery and further eutrophication. Likely, in-lake dosage of Fe^{2+} is an appropriate method of reducing the P loading of hypereutrophic systems. However, all of those chemical methods may result in undesired situations. They should be used with precautions.

Physical methods are also called engineering measures. The most important corrective action for eutrophication in lakes is the reduction of endogenous nutrient loading.

Dilution as a potential management technique, which replenishes the lake with water from an extraneous source or another lake that is lower in nutrient levels and preferably higher in Ca^{2+} and HCO_3^-, directly reduces the concentration of nutrients. Dilution is a simple and rapid technique that is more effective for the treatment of small-scale water bodies. However, its success depends greatly on the sustained availability of good-quality water.

Deep aeration

The nutrient concentration of the lake bottom is higher than that of the surface. The release of P from the sediment can be efficiently prevented through the use of mechanical stirring, air injection, oxygen injection, or other measures. Deep aeration mainly has two purposes: (1) to improve the concentration of dissolved oxygen (DO) without changing the water layer, thereby stimulating transformation of the anaerobic environment into an aerobic environment; and (2) to enhance the growth environment of benthic organisms and increase the food supply. The economic and technological restrictions of large lakes make it hard to alleviate eutrophication using deep aeration; therefore, this approach is often applied to small-scale water bodies.

Sediment dredging

Eutrophic lakes are seriously affected by internal P loading from the sediments. When the external load reduced, the presence of an internal load causes continued eutrophication and the re-release of contaminants from sediments (such as P) is a major factor in endogenous contamination. Sediment dredging, a tool for rapidly improving water quality, is one of the most direct and effective lake remediation techniques. It can be used to remove the contaminant-rich sediment surface layers and control contaminant release, as well as reduce the impact of internal loading in the lake Resuspension of contaminated sediment and destruction of the surface sediment structure of the water body follows sediment dredging, leaving the lake with secondary pollution.

Other physical methods

For many years, artificial mixing has been used to prevent lake eutrophication and cyanobacterial growth. For deeper lakes, mixing is more effective than reducing external nutrient loading because it results in an increased oxygen content

Aquatic plants and algae can absorb a large amount of nutrients. They can be directly harvested by machines to improve the ecological environment of the lake surface. This is a simple and safe method that has been used in different lakes in various areas; however, it consumes much energy and increases the cost of algal disposal (Sim *et al.* 1988).

Sediment capping can be achieved by several methods to decrease sediment P-release (e.g. gravel, plastic films, pulverized fly ash, calcareous mud), but these measures probably have negative effects on the development of submerged macrophytes.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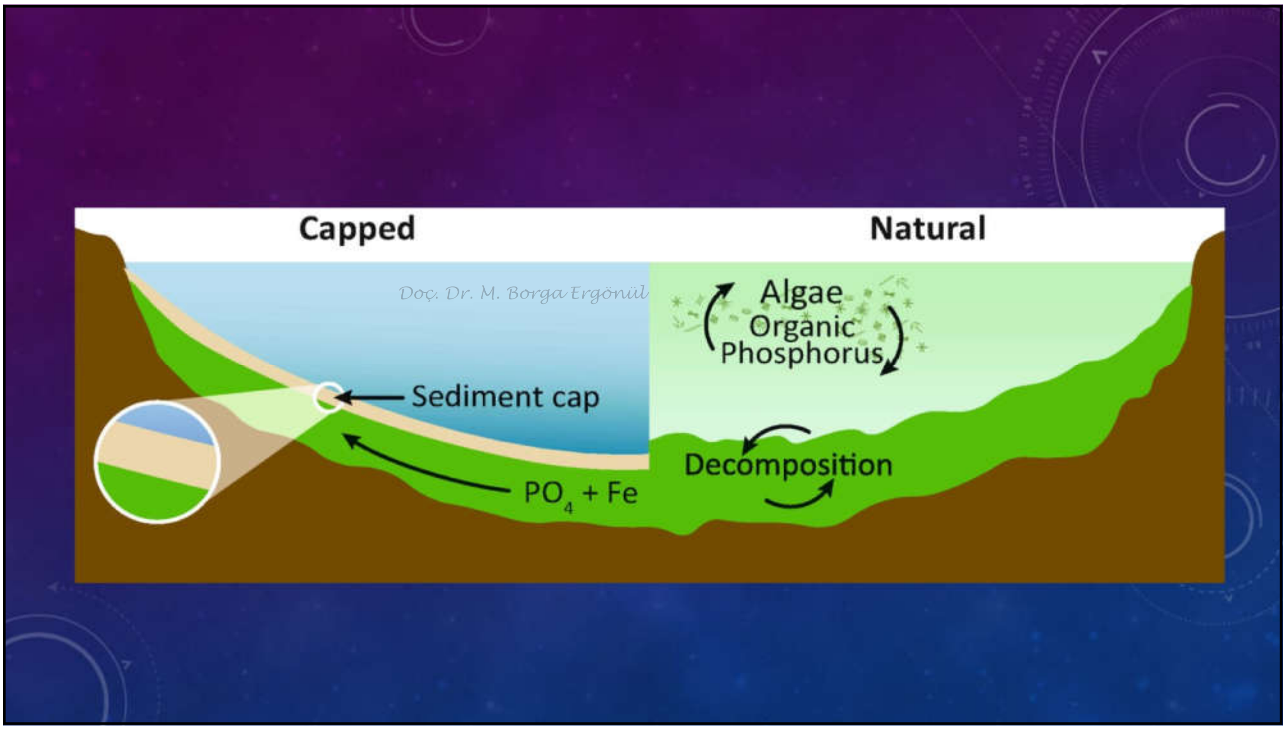
Capped
Natural
Doç. Dr. M. Borga Ergönül
Algae
Organic
Phosphorus
Sediment cap
Decomposition
PO4 + Fe