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Impact of fertilizers on aquatic ecosystems and protection of water bodies from mineral nutrients

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Abstract

Pollution by nutrients from agricultural activities causes many problems in the environment. Fertilization is considered as one of the main sources of pollution of water bodies caused by agriculture. When high fertilizer rates are applied which are not in line with the codes of good agricultural practice, nutrient losses, e.g. by surface runoff, take place which pollute land-based and aquatic ecosystems.

Fertilizer use, its impact on water bodies and their protection are comprehensively discussed in this contribution. An oversupply with inorganic nitrogen and phosphorus compounds causes an increased nitrification, oxygen demand, intensification of the primary production of plankton including „red tides“, excessive growths of macro-algae and other water plants as well as formation of the toxic un-ionized ammonia.

The negative impact of nutrient losses from agriculture on ecosystems in ponds, lakes, rivers as well as to seas and oceans varies. Oxygen deficiencies in the bottom waters of shallow areas may result in the production of hydrosulfide which is highly toxic. Low oxygen concentration in deep water layers where fish spawn may prevent the development of eggs. Increased density of macro-algae in shallow waters of seas might affect the composition of species too.

Defense strategies were developed in order to minimize the environmental burden caused by agricultural pollution. The so-called end of the pipe solution which means to clean up the water body after pollution occurred is rather inefficient in natural waters. A preferable alternative is the reduction or even prevention of pollution, e.g. by making fertilization more efficient and more environmentally friendly.

Programs for protecting the water bodies against input of nutrients from agriculture are developed and are being implemented. Such programs could be supported by concepts like balanced fertilization, ecological agriculture etc.. The more updated programs are serving a holistic view and try to combat, minimize or prevent pollution by nutrients.

Key words: Agriculture, environment pollution, marine environment protection, nutrients

Zusammenfassung

Einfluss von Pflanzennährstoffen auf aquatische Ökosysteme und Schutz von Gewässern vor Eutrophierung

Die Verschmutzung von Gewässern mit Nährstoffen aus der Landwirtschaft ist ein schwerwiegendes Problem des Umweltschutzes. Von besonderer Bedeutung sind hier Stickstoff und Phosphat, da diese Minimumfaktoren für das Wachstum von Organismen im Wasser sind. Bekannte Folgen der Belastung von Gewässern mit diesen Nährstoffen sind "rote Fluten", ausuferndes Wachstum von Riesenalgen und die Freisetzung von Ammoniak. Die negativen Wirkungen der Eutrophierung sind je nach Art der betroffenen Gewässer verschieden. Sauerstoffmangel in den tieferen Schichten flacher Gewässer ist häufig der Grund für die Produktion toxischen Schwefelwasserstoffs.

Sauerstoffmangel in tiefgründigen Gewässern, die Fische für die Eiablage bevorzugen, behindert die Entwicklung der Fischbrut. Im Bewusstsein dieser schwerwiegenden Probleme sind eine Reihe von Strategien zur Vermeidung der Gewässerverschmutzung mit Pflanzennährstoffen entwickelt worden. Darunter ist die bloße Beseitigung von Umweltschäden die am wenigsten effiziente. Moderne Umweltschutzprogramme zielen auf eine gesamtheitliche Betrachtung des Problems ab und haben die Vermeidung des Eintrages von Nährstoffen als Teil der landwirtschaftlichen Produktionstechnik zum Ziel.

Schlüsselworte: Landwirtschaft, Meeresumweltschutz, Nährstoffe, Umweltverschmutzung

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1 Introduction

Pollution by nutrients from agriculture causes many problems in the environment. One of the main sources of these problems are fertilizers. Industrial production and the usage of fertilizers have led to a sharp increase in food production that has been accompanied by the population growth in almost all countries around the world. While fertilizers restored into soil have had the requested affect, considerable amounts of fertilizers are carried to land-based and aquatic ecosystems by leaching, surface run-off and other processes. These ecosystems have been adversely affected by nutrients.

Assumption that a stabile food supply in the future is essential, means that nutrients have to be added to agroecosystems and fertilization has to be continued. Nevertheless, one should try to minimize the adverse impact of fertilization to the environment.

The topic of this paper is the impact of fertilizers on different aquatic ecosystems as well as how to protect water bodies. A brief historical review shows that there is a strong correlation between soil fertility, industrial production of mineral fertilizer, food production and population growth. This contribution will also prove the rising awareness on environmental issues worldwide in the second half of the century. Aquatic ecosystems are described with respect to nutrients and trace element contents under so called natural conditions. Comparison with the actual nutrient and trace elements conditions should take place and the adverse impact of fertilizers on the ecosystem should be explained. A clear distinction between direct and indirect effect seems to be helpful. The focus here are marine ecosystems, and in particular those of coastal zones and regional seas. Finally, concepts and programs on how to protect water bodies from nutrient discharges from agriculture are presented.

2 Brief historical review

2.1 *Soil fertility and population growth*

For millions of years people have made their living by hunting, fishing and picking. With transition in the relationship between man and his means of sustenance from nomadic to permanent settlement, from the existence mainly based on hunting and picking to one mainly based on agriculture and animal breeding, an important change took place. This process became prerequisite for the division of labor, development in trade and science, urban settlements and higher organizational and administrative structures within tribes. The emergency of agriculture was a lengthy process which started in the Neolithicum in the Near East and spread to other regions.

A relatively high and stabile food production from agriculture accelerated population growth, which conversely increased food demand. Some regions benefited from natural fertilization like Egypt where the floods of the river Nil renewed the fertility of the soil almost each year. Climatic variations, i.e. unfavorable weather conditions led to famines, and together with wars reduced the population number. Since fertility was low in large areas of the earth and people at that time did not know how to improve that, agricultural fields had to be extended mainly by deforesting. In safeguarding food supply agricultural measures strongly affected the nature. In parallel, remaining forests were used for agriculture and animal breeding, but at the same time forests were partly damaged in Europe in the Middle Ages because of lack of maintenance.

Maintaining or improving the fertility became more important along with further population growth. Discovery in 1847 by the German agricultural chemist Justus von Liebig, that all the nutrients plants removed from the soil could be restored in mineral form, was the basis for far-reaching changes. It took some hundred years more until a comprehensive usage of fertilizers took place. Already in the second half of the 19th century population growth in cities around the Baltic Sea took place with a sharp and strong increase after 1880 (Oden, 1980).

The global use of fertilizers increased from 14 mill. tons/y to 146 mill. tons/y between 1950 and 1989, and during the same period of time the grain production nearly tripled (Brown, 1997). World population grew from 2.5 billion in 1950 to about 5.5 billion in about 45 years (Flavin, 1997). In the mean for the whole world, and in most regions of the world the increase of food production overcame the population growth during the last half century. Only in the Sub-Saharan Region the basic argument by Thomas Malthus (1766 - 1834) that natural resources could not assure such an expansion in food supply that would match the population growth was proven correct.

Despite this optimistic view concerning the security of the global food supply there are also other views and developments which might slow down the optimism for the future (Pinstrup-Anderson et.al., 1997). These are among others:

- ongoing population grow
- growing water scarcity
- possible climatic changes
- declining soil fertility

2.2 *Rising awareness regarding agricultural impact to nature and ecosystems*

The impact of agriculture to nature did not happen overnight. Over the centuries agricultural activities have been considered as cultivating and civilizing measures only.

It is perhaps surprising that the relation between agriculture and environment has not been very widely taken into account since a huge fraction of arable land has been used for planting and animal husbandry. Deforesting has led, at least under humid climate conditions to changes, e.g. land to be used for agriculture, and reduction in biodiversity are considered positive or neutral (Kevles, 1997). Some adverse impact to the water bodies was recognized in the early stage. Trivial changes were first defined to the immediate vicinity of urban areas. In the Baltic region, industrialization and especially that one based on forestry, like pulp and paper mills, but also the increasing use of

Table 1
Regional Seas Conventions

Adopted	Convention
1972	Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (Oslo Convention; North Sea and N-E Atlantic)
1972	Convention for the Prevention of Marine Pollution by Land-based Sources (Paris Convention; N-E Atlantic)
1992	Convention for the Protection of the Marine Environment of the North-East Atlantic
1974 and 1992	Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention; Baltic Sea)
1976	Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention)
1978	Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution
1981	Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region
1981	Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific
1982	Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment
1985	Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region
1986	Convention for the Protection of the Natural Resources and Environment of the South Pacific Region
1992	Convention on the Protection of the Black Sea against Pollution

fertilizers were the main reasons for a strong increase of nutrient input since the turn of this century (Dybern et al., 1981). For centuries the way of re-circulating organic substances within agriculture in China and may be other Asian countries too, has been used as good example. By different reasons these way of thinking seems to go to be forgotten now, in the 21st century.

General doubts about the validity of the one-sided assessment of the role of agriculture in preserving environmentally sustainable development arose rather late in Europe in the second half of the 20th century. Strong increase in the food production and population growth in conjunction with the increasing fertilizers and pesticides use strengthened the impact to the environment, in particular to water bodies. Industrial pollution, culminating in catastrophes like Minamata illness in Japan, 1956, and the impact of pesticides to birds (reflected e.g. in „Silent spring“ by Rachel Carson, 1962) led to a rising awareness and paved the way for investigations in different seas and regions with an aim to clarify the actual state of pollution. Working group under ICES (International Council for the Exploration of the Sea) to investigate the state of pollution in the Baltic Sea was established in 1968, and the working group found the Baltic Sea heavily polluted (ICES, 1970). Similar conclusions were drawn concerning other sea areas, too. These results have been discussed at different national and international meetings, and measures which should include curative and preventive means to fight pollution were demanded. Under the pressure of the public awareness international agreements and conventions were concluded few years later (Table 1), beginning in Europe and shifting to other areas. This development culminated in 1992 when the Rio-Conference took place.

3 Soil fertility and natural composition of nutrients in soil and water

3.1 Natural concentrations of nutrients in soil and water

Planture, among others, macro and micro nutrients for growth. If a plant is harvested and picked up from the ground the soil becomes impoverished in substances. To keep the soil fertile, nutrients have to be restored to soils by fertilization.

Concentrations of nutrients in the soil and water vary significantly pending on the basic material (rocks and weather beaten rocks) modified during millions of years by climatic and other conditions. River waters are naturally rich in those elements and substances available and soluble in the hydrological basin and, to a certain extent, in the atmosphere. So, we can not speak about nutrients' concentration in a „mean soil“ or a „mean river“ but to define the concentration of nutrients in the soil and water optimal for the agricultural purposes or the sustainability of ecosystems.

Table 2

Concentrations of major constituents (eleven) and of some trace elements in the ocean with 35 ‰ salinity (after Nehring, 1969 and Grasshoff et. al., 1981)

Major constituents	g/kg	Trace elements	mg/l
Chloride (Cl)	19.345	Iron	0.01
Sodium (Na)	10.752	Zinc	0.01
Sulphate (SO ₄)	2.701	Molybdenum	0.01
Magnesium (Mg)	1.295	Manganese	0.002
Calcium (Ca)	0.416	Copper	0.003
Potassium (K)	0.39	Arsenic	0.003
Hydrogen carbonate	0.145	Cadmium	0.0001
Bromide (Br)	0.066	Nickel	0.0005
Boron (H₃BO₃)	0.027	Chromium	0.00005
Strontium (Sr)	0.013		
Fluoride (F)	0.0013		

Elements to be found in fertilizers are in bold

The annual run-off from land to ocean is about 50 000 km³. Depending on the special conditions in the hydrological basin rivers carry substance, including nutrients, into oceans. Due to big water amount in the oceans the contribution by rivers (and other sources at the ocean floor) is in the magnitude of 10⁻⁵ per year only and the composition of sea water remains very stable over long periods. All known chemical elements are solved in the ocean, but in different concentrations. Only eleven of them, Na, K, Mg, Ca, Sr, Cl, S, inorganic C, Br, B and F (major constituents) round up to about 99 % of the whole salinity. This group includes the main fertilizer components except nitrogen and phosphorus and boron, a trace element. There is a stable relation between chlorine content and salinity in sea water, which makes it possible to indicate the amounts of the other major constituents after measuring the chlorine content.

Nitrogen and phosphorus are not defined as major constituents of sea water and their relation to chlorine is not fixed. Their concentration and distribution differ in the Indic, Pacific and Atlantic Oceans. In the surface layer of the oceans the nitrate concentration is about 1-2 mikrogrammatom/l and increases to 20-40 with depth. When such nutrient rich water reaches the surface (up-welling), high biological productivity can be observed.

4 Impact of fertilizers on aquatic ecosystems

4.1 General remarks

Large amounts of nitrogen and phosphorus are carried via rivers into the seas and oceans. Atmospheric transport of phosphorus is almost negligible. The percentage of airborne nitrogen depends on many factors like industrialization, traffic, climatic conditions etc. About one third of all nitrogen input into the Baltic Sea is estimated to be airborne and the percentage is similar for the North Sea and

the Mediterranean. Nitrogen deposition in Europe roughly originates both from nitrogen oxides and ammonia. While nitrogen oxides mainly originates from power plants and traffic, it has been estimated that the agricultural sector is responsible for more than 90 % of ammonia emissions (HELCOM, 1997b; Swedish Board of Agriculture, 1995). Animal husbandry in conjunction with the production and usage of manure contributes between 80 and 90 % to these emissions but, commercial fertilizers are estimated to be responsible for about 10-15 %.

The input of nitrogen means permanent and additional fertilization, which might not be harmful as long as this does not exceed the critical load. The critical load for eutrophication nitrogen is defined as „a quantitative estimate of an exposure to deposition of nitrogen as ammonia and/or nitrate below which harmful effects in ecosystem structure and function do not occur according to present knowledge“ (EMEP, 1997) and, has to be seen in line with sulfur and nitrogen deposition of acidifying compounds.

4.2 Aquatic ecosystems

Rivers:

Rivers collect water from the hydrological basin and, on its way through soil, rocks etc. resolve substances containing nutrients and trace elements. Water is used for human activity and the input of untreated and treated waste water from municipalities and industries as well as from agricultural activities has made rivers strongly polluted. The increase in nutrient input from agriculture into rivers has become often three-fold or more over the last three or four decades and is well recognized in many countries (Loigu, 1989, Enell et.al, 1989). Rivers are not fertilized but there is a strong indirect impact of fertilization to the ecosystem, i.e. not the fertilizer itself but the effects caused by it are the reason for the impairment. For inorganic nitrogen and phosphorus compounds the indirect impacts are:

- nitrification oxygen demand because of the microbial oxidation of ammonia
- intensification of the primary production of plankton, macrophyta and other water plants by increased availability and use of nutrients

and finally

- formation of the toxic ammonia (NH₃), which is indirectly supported by fertilization assuming that the above mentioned intensification of primary production produces big amounts of organic material containing nitrogen which is mineralized to the ammonium ion. The percentage of not ionized ammonia in the total ammonia (NH₄ + NH₃) essentially depends on the pH-value and the temperature of the water (Hamm, 1991). In eutrophic waters daily variations often raised with the pH-value to more than 9 which shifts the balance of the total ammonia towards unionized ammonia. Unionized ammo-

nia is toxic to fish, vertebrates and plants. Another effect of the eutrophication is, among others, a possible rise in water level by an excessive growth of macrophyta in conjunction with increasing friction. The ecosystems in the water course as well as at the banks will be affected, too.

Lakes:

Lakes have their own hydrological basin or, they are in the course of a river, i.e. they are similar to rivers as far as the fertilizer impact is concerned. Again, as there is no direct impacts and the indirect ones are those valid in rivers as well (e.g. the indirect effects by ammonia in conjunction with high pH-value and temperature). The important difference is, of course, that the residence time indicating the mean period a water molecule and other substances remain in the water body. Therefore, rivers damaged by the pollution can be cured much faster than lakes which keep the substance longer. In the most unfavorable case, i.e. if a lake (or pond) has no outflow then the substances in the water are trapped and even small amounts given constantly over long periods will lead to high concentrations if there are no or only small sinks for that substance. The result is that lakes become vulnerable to nutrients and the effect of the eutrophication is observed as green belts in the shallow waters by reed and macrophyta. Additionally, phytoplankton covers the lakes' surface. A high primary production generated by the availability of nutrients causes high oxygen demand in the course of mineralization of the organic material. Anoxic conditions make life impossible both for the animals and plants, i.e. the ecosystem will be destroyed.

Seas and oceans:

Oceans receive lots of substances via rivers resolved in the water or transported as unsolved material by friction. Additionally, different substances are deposited from the atmosphere. Due to the relatively small annual amount by rivers and by the atmosphere in comparison to the amount already resolved in the oceans, the concentration of chemical elements in the oceanic waters is rather stable over long periods. That does not apply to the coastal areas which are influenced by river waters and, in particular by nutrients. Coastal areas often are affected by eutrophication. There is also concern about the increasing input of nitrogen into the oceans in particular into parts where nitrogen is the limiting factor of biological growth (for example the Antarctic waters). Eutrophication can also cause explosive blooming of algae - „red tides“ - which cover the surface of the sea and are responsible for huge losses in commercial fisheries. There are indications that the blooms, toxic or otherwise, are increasing (GESAMP, 2001a). On the other hand there are proposals even to fertilize sea in order to activate the growth of phytoplankton

and to increase fish catches (see under 4.4 : Baltic Sea in conjunction with the effects of eutrophication on fishery).

4.3 The example of the Baltic Sea

The Baltic Sea receives annually about 480 km³ fresh water via rivers and about 260 km³ by the precipitation (Fennel, 1996). Rivers contain chemicals and other material from the hydrological basin of the Baltic Sea which is about 1.72 Mill. km² and populated by more than 80 million people with strong agricultural and industrial activities.

The annual total nitrogen (N) input into the Baltic Sea is estimated to be around one million tons and phosphorus (P) input around 50 000 tonnes. The main sources of N within the Baltic Sea catchment are agriculture, municipalities, industry, power plants and traffic and, of P agriculture, municipalities and industry (HELCOM, 1995; Kremser, 1997). The importance of these sources varies from one country to another according to the economic structure and standards.

Nutrients are mainly carried into the Baltic Sea via rivers, about one third the N load is estimated to be airborne. Also, the contribution via groundwater and direct discharges cannot be neglected. The atmospheric load of P to the Baltic Sea is almost negligible. To balance the nutrients load in the Baltic Sea is more complicated, e.g. immobilization, remobilisation and other interaction as well as the water exchange between the Baltic Sea and the North Sea have to be taken into account. Other sources and sinks estimated by Nehring et al. (1996) and, mainly based on investigations under HELCOM indicate that ships and fisheries as nutrient sources for such a balance are negligible. Denitrification counts for losses of about 470 000 tons and the profit by N₂-fixation is estimated to be 130 000 tons per year. The net balance for N by the water exchange with the North Sea is 150 000 tons leaving the Baltic Sea annually, and, for P zero.

These estimations are based on measurements, calculations and extrapolations using plausible assumptions. As the natural processes show strong variations in time and space the figures have to be interpreted on the basis of the statistics. For instance, the nitrogen input into the Baltic Sea via rivers correlates strongly with the river discharges and, a single value or a mean considered over a year only might be misleading. This suggests that the nitrogen losses from arable land are partly generated by surface run-off in conjunction with a heavy rain or melting waters (Nehring et al., 1996).

Among all nutrient sources agricultural activities are very important. The drastic increase in the fertilizer use since the 50's in the Baltic Sea Catchment area correlates highly with the mean phosphate and nitrate concentration during winter in the Bornholm Basin and, certainly in other basins as well.

As mentioned earlier the particular conditions of the Baltic Sea including the fresh water discharge by rivers result in somewhat different concentrations of trace metals in the Baltic Sea in comparison with the oceans. Additionally, there is an anthropogenic input by municipal and industrial waste water, by atmosphere as well as by agricultural activities. In most cases the concentrations of trace metals in the Baltic Sea are smaller than in the North Sea and in all cases much smaller than required by the drinking water standards. Consequently, there are no toxic effects to the animals and plants (Kremling, 1996).

An excess of nutrients mainly causes eutrophication, increased plankton biomass and oxygen deficiencies in the bottom water of shallow areas and of basins. In the Baltic Sea about 30 phytoplankton species have been proved to be harmful, e.g. cyanobacteria which can affect fish and birds. Even cattle and dogs have died after being intoxicated. In 1988 the bloom of *Chrysochromulina polylepis* caused trouble to fish farms and, killed marine organisms (HELCOM, 1997a; Lenz, 1996). It can be argued that the increasing frequency of harmful blooms in the Baltic Sea generated by the nitrogen input from agricultural activities might correlate with the changes in the Redfield N:P ratio. Such events as, for instance, toxic algal blooms are normally very well reported in the media and they also disturb tourism.

Another field affected by the eutrophication is fishery. Heavy algae blooms and mass development of plants and marine organisms can affect fishing process even mechanically. At the beginning of the century the annual fish catches were about 100 000 tons. Up to the World War II the amount rose slightly and has increased steeply since the 50's. A maximum yield was reached in 1984 amounting roughly to one million tons. This development certainly took place parallel to the eutrophication due to the nutrient input to the Baltic Sea and the rise in primary production (Thiel et al., 1996). Later on the catches decreased to some 600 000 tonnes (Thurow, 1980; Rechlin, 1996) caused by over-fishing of cod and economic/commercial reasons.

This development is mostly considered to be positive by the fishery sector itself. However, there has been observations on changes in the structure and composition of fish stocks, which relates to the eutrophication. One example is the opposite development of pike and pike-perch stocks, e.g. the population of pike is dropping while that of pike-perch's is increasing because of the improvement in the conditions for pike-perch that prefers muddy coastal waters when pike does not. Drastic drop in the catches and even disappearance altogether have happened with some other fish in the Baltic Sea as well.

The decrease of macrophyte in coastal areas has reduced the reproduction of fish that needs these plants for the eggs to grow up. Moving to other areas - often to more shallow ones with acceptable plants - can lead to high density of

eggs and the reproduction can be threaten by oxygen deficiency. The probability for the oxygen deficiency in shallow and deep waters of the Baltic Sea is increased by the eutrophication. A high primary production produces big amounts of dead organic material which sinks down to be mineralized in the bottom. The mineralization needs oxygen from the water, e.g. the oxygen content in the water is diminishing if there is no other source to compensate the loss. The vertical transport of oxygen in the Baltic Sea is impeded due to the increased water density with depth. Therefore, the only source to bring fresh salinity and oxygen to the deep waters in the Baltic Sea basins is major inflows of saline water, which occurs at irregular intervals (HELCOM, 1997a).

Certain fishes, like cod have the reproduction area in the deep basins and, they are adjusted to certain salinity, water temperature and oxygen content. Reproduction gets complicated if the oxygen content is less than 2 mg per liter (Schnack, 1996). Needless to say that all life except bacteria will be destroyed if the conditions become anoxic.

Due to the increased fish catches in conjunction with the eutrophication it has been proposed to promote the primary production by fertilization in seas and parts of the oceans (Hoell, 1996). The state owned Norsk Hydro has launched a five year research program called Maricult, designed to consider the cultivation of marine ecosystems for a more comprehensive use of the oceans and the sustainable harvest of marine resources in the future. This includes the addition of nutrients. As learnt from the example of the Baltic Sea an addition of nutrients means an increase in the primary production. But that would be only one side of the coin the other one being, inter alia, an unpredictable change of marine flora and fauna. Additionally, it is in contradiction to the letter and spirit of international agreements to tackle nutrient inputs to the marine environment (Lutter, 1996).

4.4 Other regional seas

From the example of the Baltic Sea the following can be generalized: Nutrient load into waters may lead to:

- intensification of primary production
- intensified oxygen demand
- deterioration of the ecosystem.

Despite the basic processes in different waters are the same the results vary because of differences in e.g.

- basic characteristics of the sea, in particular related to exchange conditions with the open sea and interaction with the sediment (immobilization, remobilization)
- climatic conditions
- human activities (e.g. fishery and other sinks regarding the nutrient balance).

Therefore the "visible" impact of nutrient load to regional seas varies and this fact also affects the ranking of

pollution from agricultural sources in the regional seas programs. In these programs nutrients are regarded as priority issue only for the Black Sea (and the Baltic Sea) whereas other regional seas programs classify nutrients as less important.

5 The protection of water bodies

Despite agricultural activities always have been a burden to nature it took centuries to acknowledge this truth. Agriculture and fertilization became a problem in the second half of the 20th Century at least in Europe and certainly in America too in line with strong increase of food production, fertilization and population growth. Now it has been officially recognized as a problem in Europe and world wide and it can be considered as first step for dealing with the problem properly.

5.1 Mineral fertilization and protection of water bodies

Since stable food supply in future is essential, mineral fertilization has to be continued. But one should try to minimize the adverse impact to the environment - otherwise the basis of our life will be destroyed. With other words:

There is no alternative to fertilization and no alternative to protecting the environment and the water bodies.

The impact of fertilization to water bodies could start from

- improving the efficiency of fertilization and
- taking measures for protecting the water bodies.

Improving the efficiency could be achieved by coating, granulation of the fertilizers, precision agriculture, tailor made compositions of the fertilizers etc., which should not be discussed further here. Measures for protecting the water bodies are dealt with in the following chapter.

5.2 The protection of the marine environment of the Baltic Sea (as an Example)

Measures for protecting the water bodies as such means to decrease the nutrients run-off into the water bodies by other means, what should be described at the example of the Baltic Sea.

The Baltic Sea has a long history in dealing with pollution problems which started in 1968 (see chapter 2.2). The outcome of the first pollution checking of the Baltic waters were considered on national and international level and lead in the consequence to the UN Conference on the Human Environment held in 1972 in Stockholm, Sweden. First time in history environmental protection has been considered a problem of global dimension.

This development resulted in signing regional seas conventions, among them the Convention on the protection of the marine environment of the Baltic Sea (1974 and 1992,

Helsinki Commission, HELCOM). It was an encouraging step forward in times the cold war divided the Baltic Sea and most countries located around the Sea into NATO- and Warsaw-Treaty members.

5.2.1 The Helsinki Convention

The Baltic Marine Environment Protection Commission (see homepage of HELCOM: www.helcom.fi) works through the Commission, the Secretariat, Working Groups and projects. In 1992 the Program Implementation Task Force (PITF) for coordinating the implementation of the Baltic Sea Joint Comprehensive Environmental Action Program (JCP) which is working within the framework of the HELCOM has been established.

One of the strongest tools of HELCOM is to elaborate and adopt Recommendations.

There are different means by the Helsinki Commission for reducing the nutrient load into the Baltic Sea. It is done mainly by

- Recommendations related to agriculture, marine and land-based transport and industry as well as by
- implementing the JCP.

The Recommendations become legally binding after having transferred into national law for implementation in the countries. Monitoring and assessment of the load (sources and paths), concentrations in water bodies etc. are organized under HELCOM working groups. The implementation of the JCP is done by the countries with support by the International Financial Institutions and other governmental and non-governmental organizations and institutions.

During the first years of existence HELCOM focused on issues like

- safety on sea
- prevention and combating of oil pollution
- reduction of pollution by harmful substances.

It took until 1986 until the first Recommendation (7/2) on agriculture was adopted, titled „Measures aimed at the reduction of discharges from agriculture“ (Full text of Recommendations: See home page of HELCOM).

In this Recommendation is taken note of the fact that increasing concentrations of nutrients in the marine environment cause negative effects on ecosystems including eutrophication and oxygen depletion. Furthermore, the importance of discharges from agriculture as source of pollution of the marine environment by nutrients is recognized. Fertilization plans and water protecting zones are demanded.

Regarding reduction of nutrient input into the Baltic Sea a mile stone was set in 1988 by the Ministerial Declaration which demanded a reduction of loads of harmful substances nutrients by about 50 % until 1995 based on the 1988 figures.

Inspired by that Declaration new agricultural Recommendations recognized diffuse sources as substantially contributing to the eutrophication problem. Artificial fertilizers should be applied according to crop need promoted by economic incentives. Fertilizer and crop-rotation planning and prognosis tools for nitrogen and phosphorus application should be taken into account (HELCOM Recommendations 13/9 and 13/10). Sufficiently broad vegetation zones (filter strips) along water courses should be considered as an additional measure.

The Contracting Parties are obliged to report on the implementation to the Commission.

In 1996 the Baltic Sea Summit addressed, inter alia, the pollution from agricultural sources and called for urgent elaboration of an annex on agriculture to the Helsinki Convention. This work was done by a HELCOM Project on Agriculture and adopted as HELCOM Recommendation 19/6.

The annex stated that agricultural activities within the catchment area of the Baltic Sea are responsible, inter alia, for pollution of water and air by nitrogen, phosphorus and plant protection products, causing negative effects on the Baltic Sea ecosystem including eutrophication, oxygen depletion and reduced biological diversity. The Recommendation lists up different requirements, e.g. on application rates for nutrients and refers to water protection measures and nutrient reduction areas.

The situation regarding pollution from agricultural sources could not be solved immediately and it was stated that this problems needs permanent attention.

5.2.2 Recent and at present activities of HELCOM related to agriculture

In 1999 HELCOM reacted on the need to focus on reduction of nutrient input to the Baltic Sea and established a Working Group on Agriculture. The main issues of the Working Group are aimed at combating eutrophication of the waters by implementing the Annex III to the Convention and by elaborating and implementing national Codes on Good Agricultural Practice in the countries concerned. The working program includes also issues like balanced fertilization and ecological farming.

Following the agreements by the Rio-Conference and based on the knowledge that environmental and social problems are connected, the overall development is now aimed at sustainable development. In the Baltic Sea Region additional activities are taken towards sustainability by the Baltic Agenda 21 which comprises eight sectors among them agriculture. A huge GEF Baltic Sea Regional Project also contains a strong agricultural component and is linked to HELCOM and to Baltic 21. The HELCOM Working Group on Agriculture has the coordinating function regarding agriculture in the Baltic Sea Region.

5.2.3 Results of HELCOM activities towards reduction of nutrient loads into the Baltic Sea

The Ministerial Declaration 1988 demanded, inter alia, the reduction of input of nutrients into the Baltic Sea by about 50 % until 1995. The target was not achieved as a statistical mean taken over the entire catchment area of the Baltic Sea. However, several countries reached the goal, supported by adverse economic conditions (which made the use of fertilizer to expensive for the farmers). Due to additional measures implemented, the target of 50 % reduction is planned to be achieved in 2005.

The implementation of the JCP contributes to the overall goal of reducing the nutrient load to the sea. When launching the program, areas and sites of high emission or discharges from one or more point- and/or diffuse sources were classified as Hot Spots (Kremser, 2001). Originally 132 Hot Spots located in the catchment area of the Baltic Sea were listed, among them 17 agricultural ones. Between 1991 and 1998 the emissions and discharges from Hot Spots have been reduced by 39 % (Phosphorus) and by 28 % (Nitrogen). One agricultural Hot Spot was deleted from the list in the year 2001 and others are expected to be deleted soon.

The reductions as indicated above are also reflected in the improvement of the water quality in the coastal waters (HELCOM, 2001, Fourth Periodic Assessment). The interpretation mainly points to achievements in the wastewater sector in connection to municipalities and industry and less to agricultural activities including fertilization. Despite the dramatic decrease of use of mineral fertilizers over several years in some countries in the hydrological basin of the Baltic Sea (countries in economic transition), the nutrient runoff remained almost the same.

5.3 The protection of the marine environment of other lakes and seas

There is the question what message could be taken from the experience of the Baltic Sea region and transferred to other regional seas in order to be used there. The answer seems to be easy:

There is the need to have programs based on international agreement and – if possible – to make it legally binding (like a Convention). Implementing the program needs international cooperation and a solid financial basis. The latter one is not always the case as reflected in the rating of financial status of regional sea and action plans by UNEP (Table XX: Third global meeting of regional seas and action plans, Monaco, 2000).

The example of the Baltic Sea, i.e. the implementation of both the Helsinki Convention and the JCP, has been very successful. That is why the programs are

- targeted to a convincing goal: The protection of the Baltic Sea and the restoration of the ecosystem,

- adjusted to the specific environmental problems, structured in order to safeguard a long-lasting progress,
- have been up-dated from time to time in order to adjust to the changed political, social, economic, environmental, etc. conditions,
- the partnership does include the governments, national authorities on local, regional and national level, the International Financial Institutions (IFI's), donors, private sector and NGO's and
- the implementation of the programs is directly related to a sustained political commitment and broad-based public support in the region.

6 Conclusions

The purpose of agriculture is to guarantee a secure food supply and this requires fertilization. Preserving the environment including marine ecosystems is of the same priority as agriculture.

Fertilization causes few direct but many indirect effects which impair ecosystems. The eutrophication of rivers, lakes and seas is considered as one of the important environmental problems, generating or/and supporting oxygen deficiency, production of toxic NH_3 , algal blooms, change in spatial distribution of marine organisms, increase and depletion of fish stocks, change in reproduction conditions for fish and marine fauna etc.

Fertilization is one factor among the agricultural activities being responsible for the decisive percentage of the whole nutrient input to the marine ecosystems via atmosphere, rivers etc. The example of the Baltic Sea shows that adopting and implementing tailored programs for reducing the nutrient input is eventually a successful way.

Many other Regional Seas have much better mixing conditions as the Baltic Sea and the exchange with the open waters gives the impression that the nutrient input is not really a threat to the ecosystems. This impression, however, is illusive! Human beings think linear but the nature interacts non-linear, i.e. we even do not know where we are at the moment with respect to the change of mode.

Consequently there is the demand to preserve the marine ecosystems. It needs action now which is supported, inter alia, by the IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). This working group concluded that land-based activities are the major sources of problems and threats facing the oceans, especially coastal areas, except for the effect of fishing and the threats posed by global climate change (GESAMP Reports and Studies No 71, 2001):

„In the past decade, there have been some notable successes in curbing the negative impacts on land-based activities on the marine and coastal environment. Unfortunately, from a global perspective, the degradations of the

oceans and coastal areas has continued, and in many places even intensified. Degradation is much more severe in the coastal areas than in the open ocean.

The most serious problems associated with land-based activities are:

- alteration and destruction of habitats and ecosystems
- effects of sewage on human health
- widespread and increased eutrophication
- changes in sediment flow due to hydrological changes“.

The available knowledge demands to reduce pollution of seas and oceans by nutrients. This knowledge has to be converted into action now. The decisive question is however, whether political intension and financial power world wide do support such a goal.

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