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Nutrient pollution of waters: eutrophication trends in European marine and coastal environments

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Resum

En els darrers cinquanta anys, l'eutrofització (l'enriquiment natural o artificial de nutrients d'un ecosistema aquàtic) ha esdevingut un problema de contaminació ambiental àmpliament estès, a causa de l'augment de la població i de les àrees urbanes, així com de l'augment de producció en els sectors agrícoles i ramaders. Tot i que aquest problema és d'especial importància en els països desenvolupats i en zones d'elevada població, la implantació de sistemes d'agricultura intensiva en zones en desenvolupament (com els països de l'Est d'Europa), pot dur a la propagació de l'eutrofització en poques dècades. L'any 2004, per tal d'establir un nombre reduït d'indicadors estables, però que puguin mostrar tendències temporals i espacials, i que responguin a qüestions prioritàries de política ambiental, l'Agència Europea del Medi Ambient (EEA) va identificar un conjunt de 37 indicadors que cobreixen sis àrees ambientals i quatre sectors prioritaris respecte als quals es dirigeixen les estratègies de l'EEA. En aquest treball, l'avaluació de la informació facilitada per quatre indicadors seleccionats permet valorar la situació actual respecte a l'eutrofització als mars europeus. Es conclou que, tot i la creixent implantació de les directives europees dirigides a la millora de la qualitat del sistemes aquàtics, no s'ha observat en termes generals una reducció de l'eutrofització. Aquest fet emfatitza la lenta recuperació dels ecosistemes perjudicats per l'acció humana.

Paraules clau: eutrofització marina, qualitat de l'aigua, contaminació per nutrients, conjunt d'indicadors essencials

Abstract

In the last 50 years, eutrophication (the natural or artificial nutrient enrichment of an aquatic ecosystem) has become a widespread environmental pollution problem due to the growing population, rapid urbanization of previously rural areas, and increased agricultural and livestock production. Even though this problem has particular relevance in developed countries and in areas with large populations, the implementation of intensive agriculture systems in developing zones (such as in Eastern Europe) may lead to the further propagation of the eutrophication in the coming decades. In 2004, the European Environment Agency (EEA) set out to answer to certain priority policy questions. For this purpose, it selected a small number of relevant indicators that are stable but sensitive to temporal and spatial trends. The core set of 37 indicators (referred to as CSI) covers six environmental subjects and four sectors that reflect the priorities of the EEA. In this work, the information rendered by four of the 37 selected CSI was used to assess the current state of eutrophication in European seas. The analysis showed that, despite implementation of those EU Directives aimed at improving the quality of aquatic environments, no general reduction in eutrophication has occurred. This fact emphasizes the slow recovery rate of ecosystems damaged by human actions.

Keywords: Marine eutrophication, water quality, nutrient pollution, core set of indicators

Eutrophication was defined by the Urban Wastewater Treatment Directive (91/271/ECC) as "the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned". In coastal waters, eutrophication leads to increased growth of algal blooms and foaming during periods when the algae die and degrade. Eutrophication also leads to oxygen depletion, which causes an increase in the mortality of marine organisms [1]. Thus, eutrophication is a specific kind of pollution that negatively impacts several aspects of the environment, such as the structure and function of marine ecosystems, biodiversity, and the natural resources of demersal fish and shellfish. These changes lead to negative socioeconomic

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consequences, including a decrease in the income from maricultures of fish and shellfish, reduced recreational value and income from tourism, and increased risk of poisoning of animals, including humans, by algal toxins due to their bioaccumulation [2].

Some authors use the term eutrophication in a strictly ecological sense. According to their definition, eutrophication occurs if even a slight increase in the concentration of a particular nutrient induces a change in equilibrium between a species and the trophic structure of the system [17].

In the EU Commission's "Workshop on Eutrophication Criteria", held on May 26–28, 2002, in Brussels, the challenge of establishing European guidelines for defining eutrophication that facilitate implementation, monitoring, and reporting, but which also allow catchment managers to respond to local ecological conditions was broadly discussed [14]. The Workshop recognized the need for "an operational approach [...] giving the attribute 'eutrophicated' to ecosystems that exhibit deleterious effects of excessive primary production, but not to ecosystems where there is only nutrient enrichment, but no present or potential noxious effects on the ecosystems and/or on water use". As a result, the following operational definition of eutrophication was accepted: "a new state of enrichment of the ecosystem, compared with pristine conditions, creating clear degradation or nuisances both for human uses of water and for general water quality (shift of species with loss of biodiversity, flora and fauna morbidity)".

Eutrophication in marine waters

Nitrogen (in the form of nitrate, nitrite, or ammonium) and phosphorus (in the form of orthophosphate) are the main nutrients that cause eutrophication. Although it is generally considered that nitrogen is the limiting factor in seawater eutrophication [7], in a work published in 1999 [15], Tyrrell concluded that available nitrogen is often the limiting nutrient in coastal waters, mainly in steady-state situations, whereas longer-term marine productivity is controlled by phosphorus.

Several human activities contribute to the emission of nutrients to the environment. for example, the manufacture of fertilizers and detergents and the agricultural use of manure. In addition, effluents from sewage-treatment plants and waste waters from urban areas have a high content of nutrients. Another source of nitrogen compounds is from the combustion of fuel and its emission into the atmosphere.

There are several routes in which nutrients are incorporated into marine and coastal waters [4]:

- Direct input into water: direct discharges from industries, municipalities, or pleasure boats in marine and coastal waters
- Riverine input: entry of a nutrient load from coastal waters with river inflow.
- Atmospheric input: wet and dry precipitation in marine and coastal waters (only relevant for nitrogen compounds)

The sensitivity of an area to the nutrient load is mainly determined by the hydrography and increases with the residence time and the strength of the stratification of the water column.

Seawater eutrophication in Europe

Historical evolution

In the occidental world, the end of the World War II marked the beginning of a period of material prosperity unknown till then, one that was characterized by extensive industrialization and increasing production. The most relevant contribution of nutrients to coastal and marine waters took place during those prosperous years.

An analysis of the data available for the Lower Rhine area [16] led Gerlach [8] to the conclusion that a sevenfold increase of phosphate concentrations had occurred between 1950 and 1975. There was a fourfold increase in the amount of dissolved inorganic nitrogen during the same period of time. Gerlach estimated that, for German coastal waters, there had been a threefold increase in the amount of airborne nitrogen between 1950 and 1980.

In general terms, the nitrogen loads to the North-East Atlantic (excluding the Arctic area) and the Baltic Sea were estimated to have doubled between 1950 and 1980 [9]. For phosphorus, a fourfold increase from 1940 to 1970 was determined. According to the European Environment Agency (EEA), the historic progression in the nutrient load to the Mediterranean Sea was probably of the same order of magnitude, although there are no data that confirming this supposition [2].

During the 1980s, eutrophication was raised as a relevant environmental problem. The accumulated data together with a general concern for the state of the environment led to the development of monitoring and restoration programs. However, a decrease of nutrient input into water (by means of waste water treatment plants and a reduction in the use of fertilizers and detergents) did not cause the expected improvement in water quality. Some authors concluded that 5–10 years are needed for an ecological system to respond to restoration measures [12].

Marine organisms and water-quality legislation

At the European level, several international and regional marine commissions have been directed to evaluate European seas, compile data, and develop and initiate monitoring programmes:

- AMAP: Artic Monitoring and Assessment Programme
- Helcom: Baltic Marine Environment Protection Commission
- OSPAR: Commission of the Convention for the Protection of the Marine Environment of the North-East Atlantic
- UNEP/MAP/Medpol: Mediterranean Action Plan/Mediterranean Pollution Monitoring and Research Program

The areas covered by each of these groups is depicted in Fig. 1. The Black Sea, which is covered by the Black Sea Envi-

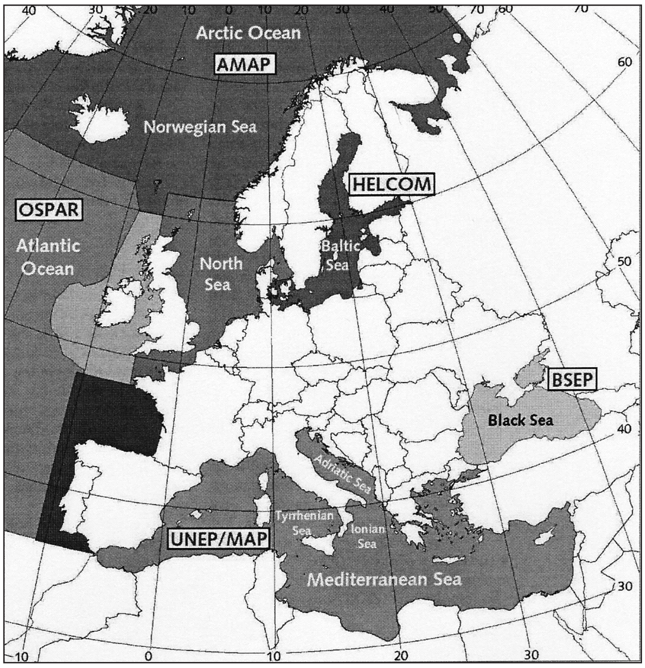

Figure 1. European marine conventions [4]

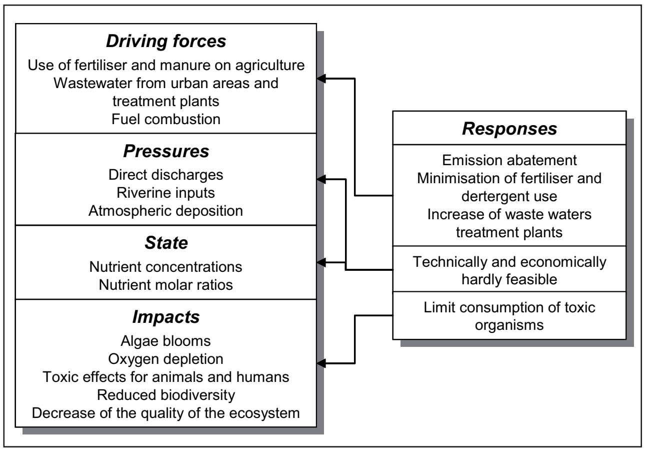

Figure 2. The DPSIR approach for eutrophication (adapted from [2])

ronmental Programme (BSEP), is included due to the incorporation of eastern countries into the European Union.

Since there is no specific legislation that governs monitoring eutrophication, several EU Directives, tackling different aspects of the problem, have been implemented. Eutrophication polices are included in those addressing nature conservation, agriculture and, mainly, water quality [17]. The most relevant legislation concerning eutrophication comes from the water management field:

- Nitrate Directive (91/676/EEC)
- Urban Waste Water Directive (91/271/EEC)
- Water Framework Directive (2000/60/EC)

From these Directives and other EU documents, environmental policy for aquatic ecosystems has been established. The main objectives include: (i) to prevent further deterioration of aquatic ecosystems and to ensure a progressive reduction of groundwater pollution; (ii) to achieve levels of water quality that pose no risk to human health; and (iii) to progressively reduce anthropogenic inputs of organic matter and nutrients into the water environment, as these inputs are likely to cause eutrophication and problems arising from oxygen depletion [3]. With this purpose, full implementation of the Urban Waste Water Treatment Directive (92/271/ EEC) and of the Nitrates Directive (91/676/ EEC) is a relevant factor in reducing eutrophication.

The DPSIR assessment framework

The DPSIR assessment framework is the approach used by the EEA to analyze environmental issues. Thus, *driving forces* (or human activities) lead to *pressures* (emissions) on the environment. As a result, changes in the *state* of the environment lead to *impacts*, such that *responses* must be defined to reduce the adverse effects. Figure 2 shows the DPSIR approach to responding to eutrophication. As seen in the figure, response policies aim at avoiding pollution rather than cleaning up and mitigating its effects. As a consequence, according to present European policies, measures must preferably be taken at the level of the driving forces. This is in agreement with the idea that, when possible, sustainable development should minimize the input of raw materials, energy, and emissions into the environment [11].

Core set of indicators for eutrophication

In 2004, the European Environment Agency (EEA) set out to answer to certain priority policy questions. For this purpose, it selected a small number of relevant indicators that are stable but sensitive to temporal and spatial trends. The core set of 37 indicators (referred to as CSI) covers six environmental subjects (air pollution and ozone depletion, climate change, waste, water, biodiversity, and terrestrial environment) and four sectors (agriculture, energy, transport, and fisheries) that reflect the priorities of the EEA.

According to the EEA definition's, "an indicator is a measure, generally quantitative, that can be used to illustrate and communicate complex phenomena simply, including trends and progress over time …[providing] a clue to a matter of larger significance or [making] perceptible a trend or phenomenon that is not immediately detectable […]. An indicator reveals, gives evidence, and its significance extends beyond what is actually measured to a larger phenomenon of interest" [6].

In order to provide useful information to environmental experts, policy makers, and other interested parties in an simple and understandable way, each indicator answers a key policy question related to its environmental target. Moreover, specific policy questions are the focus of some indicators. Table 1 summarizes four EEA indicators that are relevant to the assessment of eutrophication in marine and coastal environments. An integrated evaluation of the information rendered by these CSI allows assessment of the current situation concerning eutrophication in European seas.

Assessment of CSI and trends

CSI 024 and CSI 025 refer to the effectiveness of European policies, mainly the Nitrate Directive (91/676/EEC) and the Ur-

Table 1. Core Set of Indicators relevant for eutrophication assessment.

CSI	*Indicator title*	*Definition*	*Key policy question*
021	Nutrient in transitional, coastal and marine waters	Winter nitrate and phosphate concentration (μg/l) N/P ratio (molar concentrations)	Are nutrient concentrations in our surface waters decreasing?
023	Chlorophyl in transitional, coastal and marine waters	Mean summer surface concentration of chlorophyll-a (μg/l)	Is eutrophication in European surface waters decreasing?
024	Urban wastewater treatment	Percentage of population connected to primary, secondary and tertiary wastewater treatment plants	How effective are existing policies in reducing loading discharges of nutrients and organic matter?
025	Gross nutrient balance	Potential surplus of nitrogen on agricultural land (balance between all nitrogen added to an agricultural system and all nitrogen removed from the system per hectare of agricultural land)	Is the environmental impact of agriculture improving?

ban Waste Water Directive (91/271/EEC), to control and diminish nitrogen and phosphorus inputs into the environment.

Several studies have confirmed the relevant role of agricultural run-off as the principal source of nitrogen pollution [10, 13]. Agriculture contributes between 50 and 80% of the total nitrogen load. The total area-specific load (kg N/ha per year) increases with increasing human activities, in particular with more intensive agricultural production in proximity to catchments.

Accordingly to the last EEA report on the European environment [5], the gross nutrient balance (CSI 025) is high (> 100 kg N per ha and year) in the Netherlands, Belgium, Luxembourg, and Germany. It is low in most Mediterranean countries due to less livestock production in that part of Europe. Nevertheless, it should be noted that the gross nitrogen balance decreased 16% at the EU level between 1990 and 2000 (from 66 to 55 kg/ha). In that period of time, all national gross nitrogen balances showed a decrease, except for that of Ireland (22 % increase) and Spain (47 % increase).

For phosphorus, point sources such as households and industry still tend to be the most significant [10, 13]. Consequently, the level of waste water treatment before discharge determines the magnitude of the impact on aquatic ecosystems. The Urban Waste Water Treatment Directive (91/271/EEC) regulates the level of treatment required before discharge. This has led to a reduction in nutrient and organic matter discharges from point sources.

There are three levels for waste water treatment. Primary (mechanical) treatment removes part of the suspended solids; secondary (biological) treatment uses aerobic or anaerobic micro-organisms to decompose most of the organic matter and retain some of the nutrients (around 20–30%); and tertiary (advanced) treatment generally includes phosphorus retention and, in some cases, nitrogen removal. Analysis of the data collected by CSI 024 (urban waste water treatment) shows that waste water treatment in all parts of Europe has improved significantly since the 1980s. However, the percentage of the population connected to waste water treatment in southern and eastern Europe, as well in EU accession and candidate countries, is relatively low. In the northern and central European countries, more than 80% of the population is currently connected to waste water treatment plants with tertiary treatment. By contrast, only about half of the populations of southern countries and of the accession countries are connected to such plants. Some 30–40% of the population is connected to secondary or tertiary treatment [3, 5].

Unfortunately, the promising and progressive implementation of Nitrates and Waste Water Treatment Directives has not been reflected in the eutrophication status of the seas of Europe. This is indicated by the results for CSI 021 (nutrients in transitional, coastal and marine waters) and CSI 023 (chlorophyll in transitional, coastal and marine waters), as reported by the EEA [5]. Phosphate concentrations in some coastal sea areas of the Baltic and North Seas have decreased during recent years, but they remained stable in the Celtic Sea and increased in some Italian coastal areas. Nitrate concentrations have generally remained stable over recent years in the Baltic, North and Celtic Seas but have increased in some Italian coastal areas.

The assessment of CSI 023 shows no overall trend in summer surface chlorophyll-a concentrations, either in the open-sea areas of the Baltic Sea and the Greater North Sea, or the coastal waters of Italy and Greece in the Mediterranean Sea. Furthermore, at some sites the trend is either increasing or decreasing. This lack of a clear general trend indicates that measures to reduce nutrient loads have not yet succeeded in significantly reducing eutrophication. Table 2 summarizes the mean summer surface chlorophyll-a concentrations found in the different European marine areas [5]. It must be remarked that the table shows the chlorophyll concentrations only for those areas in which spatial and temporal data were available to European data bases.

From the analysis of CSI 023, the latest EEA report on the European environment [5] concluded that there has been no general reduction in eutrophication (as measured by chlorophyll concentrations) in the Baltic Sea, the Greater North Sea, or the coastal waters of Italy and Greece.

Conclusions

- Eutrophication, the natural or artificial nutrient enrichment of an aquatic ecosystem, is an issue of major concern in Europe, due to the undesirable effects that it has on the

Table 2. Mean summer surface chlorophyll-*a* concentrations (in μg/l) found in different European marine areas (data obtained from [5]).

CSI	*Baltic Sea*	*North Sea*	*Mediterranean Sea*	*Black Sea*
<1 μg/l			Sardinia, Greek coastal waters, Spanish Costa del Sol, Italian east and west	
1-2,5 μg/l		Open North Sea	Northern Adriatic	Ukranian waters
2,5-4 μg/l	Baltic Proper Gulf of Finland		Bay of Gibraltar	
>4 μg/l	Some Swedish, Estonian, Lithuanian, Polish and German coastal waters	Elbe estuary Belgian, Dutch and Danish coastal waters Liverpool Bay		

quality of water and the trophic structure of ecosystems. Several European marine and coastal areas are affected by eutrophication.

- For the implementation and success of programs for both eutrophication monitoring and restoration, the development of suitable indicators is mandatory. These must encompass major causal factors, be meaningful, and be useful on a routine basis. They must also allow the detection of temporal trends and permit comparisons of the different areas. The CSI, established in 2004 by the EEA, is a very practical tool that allows environmental managers to assess and monitor systems affected by eutrophication.
- Data compilation procedures regarding areas under the control of different marine conventions in Europe must be brought into alignment with each other.
- Despite the efforts made, a reduction in the phosphorus load has been only partly successful, whereas the nitrogen load is decreasing very slowly. The general decrease in direct inputs of nutrients is mainly due to the use of phosphate-free detergents, changes in the use of fertilizers, and the proliferation of waste water treatment plants.
- Despite the promising and progressive implementation of EU Directives focused on improving the quality of aquatic environments, there has been no general reduction in eutrophication (as measured by chlorophyll-*a* concentrations) in the Baltic Sea, the Greater North Sea, or the coastal waters of Italy and Greece. This fact emphasizes the slow recovery rate of ecosystems damaged by human actions and misguided development policies.
- As the historical evolution of eutrophication shows, all human activities have consequences in the environment. It is therefore our responsibility to consider both the short– and long-term effects of any activities on sustainable development, such that the future of the planet and of coming generations is not endangered.

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