ANNEX 11 Causes and Effects of Eutrophication in the Black Sea

DANUBE POLLUTION REDUCTION PROGRAMME

CAUSES AND EFFECTS OF EUTROPHICATION IN THE BLACK SEA

SUMMARY REPORT

JUNE 1999

Programme Coordination Unit
UNDP/GEF Assistance
prepared by
Joint Ad-hoc Technical Working Group ICPDR - ICPBS

Preface

The Black Sea is regarded as a regional sea that has been most severely damaged as the result of human activity. Based upon comprehensive studies by scientists, in 1996, Ministers of the Environment from Black Sea countries recognised, amongst other things, that "*The Black Sea ecosystems continues to be threatened by inputs of certain pollutants, notably nutrients. Nutrients enter the Black Sea from land based sources, and in particular through rivers The Danube River accounts for well over half of the nutrient input of the Black Sea. Eutrophication is a phenomenon which occurs over wide areas of the Black Sea and should be a concern to the countries of the Black Sea Basin.*" Further more, the Ministers agreed that "*A Black Sea Basin Wide Strategy, negotiated wit all states located in the Black Sea Basin should be developed to address the eutrophication problem in the Black Sea. The objective of the Strategy should be to negotiate a progressive series of stepwise reductions of nutrient loads, until agreed Black Sea water quality objectives are met.*"

In order to facilitate the development of such a strategy, it is necessary to have a clear common understanding of the nature of the problem, its causes and the options available for solving it. The purpose of this report is to present, in a concise but accessible manner, evidence linking the development of eutrophication in the Black Sea to the human influenced changes in discharges of dissolved compounds of nitrogen, phosphorus and silicon entering the sea from land based sources.

The present report was prepared taking into account the results of the Joint ad-hoc Technical Working Group established between the International Commission for the Protection of the Black Sea and the international Commission for the Protection of the Danube River. It is a product of the excellent cooperation, which exists between specialists from Black Seas coastal countries and those who represented the Danube Basin in this Group.

A first draft Summary Report has been prepared by Laurence D. Mee, on behalf of UNDP/GEF. This Report was discussed in the 3rd meeting of the Joint as-hoc Technical Working Group on December 10/11, 1998. It has been finalised on the basis of these initial discussions and on additional amendments agreed upon.

The present report is based on the five national reports on additional scientific literature, on reports of the Black Sea Environmental Programme (BSEP) and the Environmental Programme for the Danube River Basin (EPDRB), and on the professional experience of the representatives to the 'Joint as-hoc Group' and additional participant in its Meetings. The above mentioned five natinal reports were commissioned by the UNDP/GEF Danube River Pollution Reduction Programme, each with a title"Report on the Ecological Indicators of Pollution in the Black Sea". The responsibilities for the coordination of the national reports is as follows:

(a) Bulgaria: Prof. B. Bojanovsky, Gaculty fo Biology, Sofia University;
(b) Romania: Dr. A Cociasu, Romanian Marine Research Institute, Constanta;
(c) Russian Federation: Ms. Liubov Stapanova, State Committee for Environmental Protection;
(d) Turkey: Dr. Ösden Başturk, Institute for Marine Sciences at the Middle East Technical University (METU);
(e) Ukraine: Dr. Oxana Tarasova, Ministry for Environmental protection and Nuclear Safety.

Overall coordination of the activity of the Joint ad-hoc Technical Working Group was assessed by Joachim Bendow, Project Manager of the Danube Pollution Reduction Programme and Laurence D. Mee from the Black Sea PIU. Chairman of the working sessions were Walter Rust from UNEP, Nairobi and Andrew Hudson from UNDP/GEF, New York. The report was edited by Michael Sokolnikov.

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Executive Summary

The Black Sea Strategic Action Plan, adopted at the Ministerial level in 1998, recognises the phenomenon of eutrophication as one of the principle causes of transboundary degradation of the Black Sea environment. Furthermore, it affirms the need for a coordination of actions across the entire Black Sea drainage basin in order to reduce eutrophication and restore key Black Sea ecosystems. The 'Danube River Protection Convention (DRPC)' is having a 'river basin approach'; it also stresses its responsibility for actions stemming from the River Danube Basin impacting on the Black Sea. Within the Environmental Programme for the Danube River Basin (EPDRB), the relevant Strategic Action Plan was adopted at Ministerial level in December 1994. This SAP makes also reference to the impacts from the River Danube Basin to the Black Sea. With the entry into force of the DRPC on October 22nd, 1998, the tasks and responsibilities of the EPDRB, including the Danube SAP, have been transferred from the former Task Force of the EPDRB to the decision making body charged to implement the DRPC, the ICPDR.

In response to the need to link all states impacting on the Black Sea and the states holding the Black Sea as 'a shoreline resource', a Joint ad-hoc Technical Working Group was established between the 'International Commission for the Protection of the Black Sea – ICPBS – i.e. the Istanbul Commission of the Bucharest Convention)' and the 'International Commission for the Protection of the Danube River – ICPDR – i.e. the Vienna Commission of the Sofia Convention)'. The 'Group' received its specific TOR, which did not only include eutrophication phenomena, but asked also for the clarifying of issues of hazardous wastes. This 'Group' examined the best available evidence for the problems and their causes and proposes remedial actions. Its findings are summarised in the present report.

Eutrophication is a phenomenon caused by the over-fertilisation of the sea by plant nutrients, usually compounds of nitrogen and phosphorus. The quality of water bodies affected by eutrophication gradually deteriorates and may result in the development of species with low nutritious value to larger animals including fish. It may also lead to severe oxygen depletion and the so-called "dead zones", where no animals can survive, and biological diversity is lost. It has a severe impact on the economy of human populations, amongst other things through fisheries and tourism loss. The Black Sea (i.e. the Black Sea proper plus the Sea of Azov) environment has been severely damaged by eutrophication since the 1970s. Evidence summarised in the present report shows how the structure of the ecosystem was damaged at every level, from plants to fish and mammals. Ukrainian colleagues estimate the losses of bottom animals between 1973 and 1990 as 60 million tons, among them 5 million tons of fish (i.e. 'on average 180.000 t per year'). To which extent this is due to the increased input of nutrients, and to which due to overfishing, is impossible to allocate now. The increased input of nutrients, with the subsequent changes along phototrophic growth, has had negative consequences throughout the Black Sea. It may also have contributed to the success of the comb-jelly *Mnemiopsis*, brought by accident to the Black Sea in the mid 1980s; it attained a biomass of some one billion tons in 1989, causing catastrophic damage to the ecosystem.

Results of extensive studies coordinated by the Black Sea Environmental Programme (BSEP) suggest that over 70% of nutrients entering the Black Sea are transported by major rivers, principally the Danube; however, the atmospheric input was not a part of the balance. A large share of the nutrients entering these rivers comes from Black Sea countries, which are having a shoreline. Because of the BSEP pollution source inventory, it has been possible to gather data on the inputs of dissolved nitrogen and phosphorus compounds to the Black Sea in 1995. However, the following data by Topping, Sarikaya and Mee do not reflect the inputs via the atmosphere. Some 14% of total nitrogen are from Bulgaria, 27% from Romania, 12% from Ukraine, 10% from the Russia Federation, less than 1% from Georgia, 6% from Turkey and about 30% from the non-coastal countries (Austria, Belarus, Bosnia and Herzegovina, Croatia, Czech Republic, Former Yugoslavia, Germany, Hungary, Moldova, Slovakia, Slovenia). In the case of phosphorus, the figures are

Bulgaria, 5%; Romania, 23%; Ukraine, 20%; Russia, 13%; Georgia 1%; Turkey 12% and 26%, for the remaining countries, a similar story to that of nitrogen. The importance of showing these numbers is to illustrate that nobody is "innocent", not even the Georgians whose low percentage input reflects the current collapse in the coastal economy, probably a temporary feature.

Studies undertaken in the framework of the Environmental Programme for the Danube River Basin suggest the following: (a) About half of the nutrients discharged 'internally in the Basin to the fine web of the river network' are from agriculture; (b) somewhat more than one quarter from domestic sources; (c) an additional larger share is from industry; (c) the remainder is from 'background sources'. The loads of nutrients entering the Black Sea from the Danube have fallen in recent years due to the collapse of the economies of many of the Danubian and former Soviet countries, the measures taken to reduce nutrient discharge in the upper Danube countries, and the implementation of a ban in polyphosphate detergents in some countries.

There is evidence of some recovery in Black Sea ecosystems, but the ecological status of the 1960s is for sure not yet reached. It is widely considered that nutrient discharges are – in line with the expected economic growth - likely to rise again, with consequent damage to the Black Sea, unless action is taken to implement nutrient discharge control measures as part of the economic development strategies.

Based on the reported positive signs (reduced input loads and improved ecological status in the Black Sea shelf), and also aware of the missing knowledge of the comparability of input loads (resolution both in time since the 1960s, and in space all over the Black Sea and the Sea of Azov), and aware that the load reductions are very likely linked with the decline of economic activity in the countries in transition, but that towards the future economic development is expected to take place in the overall Black Sea Basin, the 'Working Group' defined in its 2nd Meeting the possible strategies as follows:

- *The long-term goal for all States in the Black Sea Basin is to take measures to reduce the loads of nutrients and hazardous substances to such levels necessary to permit Black Sea ecosystems to recover to conditions similar to those observed in the 1960s.*
- *As an intermediate goal, urgent control measures should be taken by all States in the Black Sea Basin in order to avoid that the discharges of nutrients and hazardous substances into the Seas exceed those, which existed in 1997* [1]*. The 'Group' recognised that these 1997 discharges are only incompletely known and that further work has to be undertaken to substantiate the size of the loads received by the Seas (Black Sea proper; Sea of Azov).*
- *The 'Group' concluded that the inputs of nutrients and hazardous substances into both receiving Seas have to be assessed in a comparable way, and that to this very end a common AQC system and a thorough discussion about the necessary monitoring, including the sampling procedures, has to be set up.*
- *The 'Group' also concluded that the ecological status of the Black Sea and the Sea of Azov has to be further assessed, and that the comparability of the data basis has to be further increased.*
- *Both the reported input loads as well as the assessed ecological status will have to be reported annually to both the ICPBS and the ICPDR.*

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[1] Loads reported for 1997 to have been transported in River Danube were: orthophosphate, 16,000 tons (as P); total inorganic nitrogen, i.e. the sum of ammonia-N, nitrite-N and nitrate-N, 300,400 tons (as N) [A.Cociasu, 1998]. River scientists indicate that in order to 'level the impact of river hydrology on the transport of pollutants out', an averaging over e.g. a span of five years should be undertaken. This would yield for River Danube an 'averaged load for 1995' of 12,700 tons per year of orthophosphate-P and 456,000 tons of inorganic nitrogen per year. The corresponding value for 1997 can only be known as soon as the value for 1999 is known.

- *The States within the overall Black Sea Basin shall have to adopt strategies that will permit economic development, whilst ensuring appropriate practices and measures to limit the discharge of nutrients and hazardous substances, and to rehabilitate ecosystems which assimilate nutrients.*
- *Based on the annual reports and on the adopted strategies for the limitation of the discharge of nutrients and hazardous substances, a review shall be undertaken in 2007. It will focus on the further measures that may be required for meeting the long-term objective (reaching an ecological status similar to the conditions observed in the 1960s).*

The actions required to attain these goals need not be costly at this stage and may be achieved through a mechanism of basin-wide joint implementation including country commitments and external grants and loans. They should build on existing initiative where possible. Such actions fall within the following areas:

- Reform of agricultural policies.
- Improved wastewater treatment, where applicable also by alternative technologies.
- Rehabilitation of essential aquatic ecosystems.
- Changes in consumer practices (including use of phosphate-free detergents).
- Establishing of a legal frame.

Suggestions for implementing these actions are made in the report. It is recommended that follow-up activities should be at the policy development and practical project levels:

1. At the policy level. The TOR of the 'Joint *ad-hoc* Group' requires that the Group's Report will be made available to both the International Commission for the Protection of the Black Sea and the International Commission for the Protection of the Danube River, as well as GEF as donor. This Report will be an input to a Meeting between the Black Sea and the River Danube side, at the level of Heads of Delegations. The Heads of Delegations of both Commissions should in such a joint meeting, based on cooperation, consider endorsing the proposal to maintain nutrient levels at or below the loads recorded in 1997, subject to review in 2007. They should also approve a series of practical measures to achieve this goal including a total ban on polyphosphate detergents, clear targets for wetland restoration, an agreement on monitoring, and a mechanism for "joint implementation".
2. At the project level. Donors should establish mechanism(s) to support the agreed policy objectives by funding a series of demonstration projects to share the costs of measures to reduce nutrient discharge following the approach outlined in 10 (above). The approach could use GEF funding to cover the incremental costs of specific projects. The support of donors other than the GEF will be necessary in order to meet the agreed policy objectives. For their part, the Contracting Parties to the Bucharest and Sofia Conventions should ensure that a 'Memorandum of Understanding' is in place for implementing and monitoring the agreed policies. Furthermore, funds should be made available for the important task of raising the awareness of the general public and supporting local initiatives for reducing nutrient discharge or protecting key (aquatic) ecosystems.

1. Introduction to the Problem of Eutrophication

Simply defined[1], the term ***eutrophication*** describes an enrichment in the sea of plant nutrients because of human activity. This enrichment most commonly results in the excessive stimulation of phytoplankton[2] growth but may also trigger the growth of larger plants (macrophytes) on the sea floor in shallow areas. "Plant nutrients" mainly refers to inorganic compounds of nitrogen and phosphorus, essential for the growth of photosynthetic organisms. They also include dissolved silica, essential for the growth of diatoms, a class mostly consisting of free floating phytoplankton with silica skeletons (almost like tiny glass boxes), as well as micronutrients such as iron and manganese. Though the definition is simple, the phenomenon however, is a complex one because natural variations in the nutrient supply to the aquatic environment are very large.

Nutrient limitation occurs when the presence of one of these substances is insufficient for the continued growth of a particular community or species. Marine systems are generally considered to be nitrogen limited whereas freshwater plankton systems are generally phosphorus limited. This is because several species of freshwater phytoplankton are capable of "fixing" atmospheric nitrogen but, with minor exceptions, this is impeded in marine water. The nutrient requirements of individual species varies however, and a disturbance in the ratio of nitrogen, phosphorus, silica and perhaps iron, will result in changes in the composition of a particular plankton community. In many respects, all four nutrients may be considered as limiting. Lack of silica limits diatoms, for example, a phenomenon first observed in natural blooms off Cape Mendocino in the USA and since observed in the NW Black Sea as a consequence of the construction of inland dams including the Iron Gates dam. Where there are very large supplies of nutrients, light for photosynthesis may be the only mechanism limiting the scale of phytoplankton blooms.

For a better understanding of eutrophication, it is worthwhile to consider the typical ***succession*** of events during the eutrophication process. Firstly, it is important to understand that phytoplankton is not evenly distributed in the sea, neither in space nor time. In the similar manner to plants in temperate woods or meadows, species bloom and fade with changing seasons and are sometimes grazed by animals - only that in the sea, if they are not attached to the sea floor, plants are also at the mercy of tides and currents. The distribution of phytoplankton is patchy and individual species have developed their own particular physiology in order to have a comparative advantage over their competitors. This favours their development under certain optimal conditions. Some have particularly extraordinary adaptations including flagella, which permit them to seek better conditions of light or nutrients, or poisons against those animals that feed on them. It is important to recognise that this "patchiness" makes it difficult to establish baseline (typical) conditions. A large set of observations is necessary in space and time. Furthermore, the examination of spatial and temporal variability of phytoplankton requires laborious work of microscopic identification and counting by dedicated highly trained specialists.

When nutrients are added to the marine environment because of human activities, there is a general increase in the density of phytoplankton communities. At the same time, more subtle changes occur as the species composition adjusts to the new ratio of nitrogen, phosphorus and silica. High nutrients and low light (the plants tend to shade one another) favour smaller species with large amounts of surface chlorophyll. Phytoplankton is relatively short-lived and dies or is grazed by zooplankton and quickly falls to below the depth at which sufficient light can penetrate to promote photosynthesis (the euphotic zone). These cells, together with faecal material from zooplankton are

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[1] GESAMP (1990) Review of potentially harmful substances. Nutrients. IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution. Rep. Stud. GESAMP, 34, 40 pp. (participant authors: J. Portmann, R. Elmgren, I. Koike, L.D. Mee, M.A. Saad, J. Stirn and A. McIntyre). An alternative wider definition has been proposed by Nixon (Ophelia 41:199-219, 1995): An increase in the rate of supply of organic matter to an ecosystem.

[2] Phytoplankton are microscopic free-floating aquatic plants.

subjected to bacterial decay, a process that consumes oxygen. In extreme cases, processes of diffusion and mixing are insufficient to replace the oxygen and this becomes depleted to the degree that no animals can survive in the water. This becomes a so-called "dead zone".

Eutrophication is widely considered a regional problem of global significance. ***Hypoxic*** or "***dead zones***" have been recognised in many estuaries and coastal waters. A case attracting much recent press attention has been the sea area adjacent to the Mississippi delta in the Gulf of Mexico. By 1997, 16,000 km^2 of the Gulf of Mexico's benthic northern shelf had become hypoxic because of nutrient discharges from the Mississippi River, a phenomenon that severely damages the $3 billion gulf fishing industry[3]. Much of the nutrient load is derived from the $98 billion Mississippi basin farm economy - the relative monetary value of these industries giving a clue as to the difficulty for implementing costly nutrient reduction policies. It is equivocal however, to consider that the profits of one sector cannot be achieved without losses in another. High agricultural yields may be obtained without discharging huge amounts of nitrogen and phosphorus to rivers if suitable practices are adopted in response to appropriate incentives.

The problem of eutrophication is not simply limited to extreme events characterised by the formation of "dead zones". The change in the composition of phytoplankton communities in the sea often affects the entire marine food chain. It may alter the composition of zooplankton, minute animals, which rely upon phytoplankton as food. Zooplankton include some fish larvae and these may be unable to feed on the tiny phytoplankton cells which are characteristic of eutrophication. A typical symptom of eutrophication is an increase in the abundance of jellyfish, which adapt more easily to the altered environmental conditions than other predators such as fish. It has also been associated with an increase in the frequency of blooms of toxic species, sometimes affecting human health. Eutrophication also has direct economic impacts: the aesthetic qualities of seawater are diminished and bathers see the green or brown eutrophic waters as "dirty" and unattractive. In some areas, phytoplankton species may bloom which produce foams in a similar manner to detergents. Beaches close to areas affected by "dead zones" may be strewn with dead animals.

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[3] Malakoff, D. (1998) Death by suffocation in the Gulf of Mexico. Science 281: 190-192.

2. Scientific Information on the Black Sea: Sources, Quality and Techniques of Comparative Study

Scientists have been gathering useful information on the state of the Black Sea ecosystem since the beginning of the present century. This information has, unfortunately, often been very fragmentary and somewhat anecdotal. This is not surprising as marine science was in its "exploratory" phase where a small number of academic specialists dedicated their lives to discovering and classifying the plants and animals in the marine biosphere. There were few co-operative or systematic quantitative studies of how the discovered communities functioned and varied in their composition with time and space. Some specialists however, did conduct "time series" of measurements, in which they studied particular communities or individual species over a relatively long time-span, sometimes representing their entire working lives. These data sets are invaluable jig-saw puzzle pieces, which help to contribute to the overall picture. The sampling methods used do not generally correspond with those employed by modern quantitative biologists but are consistent within each data set and, as trends, are fully comparable. Care must be taken not to over-interpret some of the observations by comparing individual data sets taken using very different methodologies, a particularly important matter when, for example comparing the diversity of zooplankton using different types of net or bottom fauna using different dredging techniques.

Some of the chemical data must be treated with great caution. Prior to the 1960's, methods for measuring phosphate and nitrate suffered from many systematic errors and the methods were rather unreliable, particularly in seawater where chemical interferences from other sea-salts had not been fully recognised. The introduction of simple methods by the groups of Riley (UK) and Grasshoff (Germany) led to a rapid improvement in data quality and comparability. Even so, recent intercomparison exercises conducted in the framework of the CoMSBlack, Danube, and similar programme revealed unacceptable errors of as much as 30% (after the removal of "outliers" - data which is obviously wrong) between analysts. Since the beginning of these exercises however, the quality of the data sets has considerably improved.

So how do we employ older data sets for chemical analyses? The work of validation relies on two principles. The first is internal consistency of the measurements - we have acquired considerable knowledge of the way nutrients vary with space and time and, unless explained by an obvious external source or physical phenomenon, a very "noisy" data set may be treated with suspicion. Secondly, we look for consistency in measurements at deep "reference stations" since the concentration of most nutrients varies very little in the deep sea and the values are rather predictable.

Having said this, great care must be taken not to compare data from cruises with very different densities of measurement points or between years where the studies did not pay regard to seasonal trends. Even the time of day in which observations were made is important in eutrophication studies as vast masses of photosynthetic algae "breathe in and out" as they photosynthesise and respire during the course of a day and oxygen may be "supersaturated[1]" during the day and depleted at night. For this reason, comparative records of surface oxygen content are of dubious use unless all the observations were taken at the same time of day (rather unlikely during most oceanographic cruises). Measures of oxygen below the illuminated "euphotic zone" however, are somewhat more reliable as the daily changes due to plant activity are less strongly expressed.

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[1] Supersaturation occurs when oxygen is introduced molecule by molecule by plants into water already physically saturated with air through mechanical mixing. Supersaturation of130% is quite typical in productive coastal waters.

In conducting the present review, data that has not been validated or does not form part of a longer time series has been omitted. Under some circumstances, the information may be useful but for the purposes of the current review, it was decided to adhere to the criteria outlined above.

Some compromises have been made in analysing data. The data on river inputs of nutrients, for example, has often been gathered using an inadequate sampling intensity. The problem is that nutrient loads in rivers vary considerably with time and a "spate" of high discharge may last for just a few days. Such spates may transport large amounts of phosphorus, since this is often associated with sediment particles that are re-suspended more easily when flow rates are high. There is a higher statistical probability of underestimating loads than overestimating them when the sampling frequency is low. It has been suggested that at frequencies of sampling below 52 per year, the sampling error is generally more significant than that of random analytical measurements themselves. This is why river monitoring should be a continuous process at a small number of "key" points.

In the Black Sea, the current economic situation has resulted in the suspension of most programmes for systematic monitoring. The coasts of Russia, Georgia and Bulgaria, for example, have not been systematically monitored since the late 1980's. The monitoring programme in Romania has been maintained however, since the early 1960's and provides a record of the direct causes and effects of eutrophication at the discharge of the River Danube. In the case of Ukraine, there have been a series of research cruises, which though irregular, have occurred annually for several decades. Changes in the network of stations make some of this data difficult to interpret. In Turkish waters, there has never been a regular monitoring network but, since the early 1990s, Turkey has conducted excellent oceanographic research studies, often in co-operation with Ukrainian and US research institutions (with occasional participation of institutions from Bulgaria, Romania and Russia). These have paid considerable attention to data quality control and the application of modern technology, including remote sensing by satellite. Many of the co-operative oceanographic research studies were co-financed by NATO. From 1995-1997, a European Union Project, EROS-2000 (European River-Oceans Systems), worked together with research institutions from Bulgaria, Romania and Ukraine to examine the impact of the Danube River on the NW shelf of the Black Sea and published valuable information. Unfortunately, the study was discontinued owing to lack of EU funding.

Thanks to the earlier systematic studies in the former Soviet Union and Bulgaria, the continuous studies in Romania and the recent work co-ordinated from Turkey, it is possible to piece together evidence for cause and effects of eutrophication in the Black Sea. Regarding studies of the inputs to the Black Sea, the Danube Basin Environmental Programme has sponsored a number of research projects to bring together existing information and to improve the quality of monitoring programmes in the Danube. In the case of the Dnieper, Ukraine has regularly monitored the quality of its waters though the data has not been corroborated by independent quality checks. Direct (point source) inputs to the Black Sea have been studied using the WHO Rapid Assessment Method applied in each Black Sea country by the Black Sea Environmental Programme. There have been estimates of atmospheric inputs of nitrogen compounds by the World Meteorological Organisation (atmospheric phosphate inputs are usually negligible). If countries are to count on information necessary to make adequate management decisions, it will be necessary to maintain and hopefully improve the available monitoring systems.

3. Evidence of Long-term Changes in the Black Sea

We are fortunate that there is one set of measurements of indisputable quality, which allows us to examine the overall pattern of change in the Black Sea over the past seventy years. This is the measurement of water transparency using a device known as the Secchi disk. The Secchi disk is a weighted white disk of standard dimensions that is gradually lowered from the side of a ship by a piece of rope with depth markers. When observed from directly above, it disappears from sight at a depth proportional to the transparency of the water. Most of the changes in transparency in the open sea are due to fluctuations in the amount of phytoplankton present in the water. Almost all scientific expeditions to the Black Sea have routinely conducted these measurements and thousands of such data have been collected by scientists from the Marine Hydrophysical Institute in Sevastopol, Ukraine, covering a period from the 1920s to present[1]. The results are illustrated in Figure 1. Though there were inter-annual variations in the mean Secchi Depth (SD) of up to 5 m, depths of over 20 metres (very transparent water) were recorded on several occasions prior to 1972, from when transparency gradually decreased to a minimum of only 6 m in 1991. This was the result of huge blooms of phytoplankton following a major ecological disturbance of the entire Black Sea ecosystem. The transparency has since gradually recovered to values similar to those recorded in the early 1980s.

The reason for some of these changes to occur will be discussed in subsequent sections, the important point to recognise is that changes have been recorded in the entire Black Sea though it will be shown that the most heavily impacted areas are clearly adjacent to the river inputs.

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[1] Vladimirov, V.L., V.I. Mankovsky, M.V. Solov'ev and A.V. Mishonov (1997) Seasonal and long-term variability of the Black Sea optical parameters. In: Sensitivity to Change: Black Sea, Baltic Sea and North Sea, E. Özsoy and A. Mikaelyan (eds.), Kluwer Academic Publishers, Netherlands

4. The Black Sea Eutrophication Problem in Perspective

The Black Sea is also one of Europe's newest seas. It was formed a mere seven or eight thousand years ago when sea level rise caused Mediterranean water to break through the Bosphorus valley refilling a vast freshwater lake tens of metres below the prevailing sea level. The salty water sank to the bottom of the lake, filling it from below and forming a strong density gradient (known as a pycnocline) between the Mediterranean water on the bottom and the freshwater mixed with some seawater near the surface. The depth of this natural density barrier depended (and still depends) upon the supply of fresh water from rivers and rain, and the energy available from the wind and the sun for mixing it with the underlying seawater. The oxygen in the incoming water was quickly exhausted by the demands of bacteria associated with decaying biota and terrestrial organic material falling through the density gradient into the bottom water. Within a few hundred years, the Sea, below some 100 - 200 metres depth, became depleted of oxygen. The bacterial population switched to organisms capable of obtaining their oxygen by reducing dissolved sulphate to toxic hydrogen sulphide and the resulting water body became the largest volume of anoxic water on our planet.

For several thousand years therefore, only the surface waters, down to the "liquid bottom" pycnocline, have been capable of supporting higher life forms. Though not very biologically diverse compared with open seas at similar latitudes, the Black Sea developed remarkable and unique ecosystems, particularly in its expansive north-western shelf where the sea is relatively shallow. The seabed in this part of the Black Sea was well oxygenated since it is well above the pycnocline. This area, and the adjacent shallow Sea of Azov, also receives the inflow of Europe's second, third and fourth largest river basins, the Danube, the Dnieper and the Don. These rivers transport nutrients and sediments from an area at least five times that of the sea itself. The areas adjacent to the river discharges (including the entire Sea of Azov) were comparatively productive. On the North-western shelf, a particularly unique ecosystem developed, based on the “keystone” benthic (bottom living) red algae, *Phyllophora* sp., which formed a vast bed with a total area equivalent to that of Belgium and The Netherlands. The term “keystone” is not used lightly: like the keystone in the middle of a stone bridge, its removal causes the entire structure to collapse in a precipitous manner. This particular keystone was also a place of great beauty, vast underwater fields of red algae, home to a myriad of dependent animals, linked together in a complex web of life.

Despite its uniquely fragile natural physical and chemical characteristics, the Black Sea ecosystem appears to have been relatively stable. During the first half of the twentieth century, perhaps until three decades ago, there was little evidence of human impact on the Sea or on its flora and fauna. Some changes had occurred however, and these were precursors of much worse events to come. Sensitive monk seal populations, for example, began to decline from the late nineteenth century, driven from their breeding grounds by human activities. Nowadays the rarely sighted minuscule population of these seals seems certainly doomed. Indeed, there is no certainty that any of these animals remain in the Black Sea. Another early change was through the introduction of a number of exotic animal species, introduced by accident from the hulls, bilge or ballast tanks of ships, and which flourished to the detriment of the Black Sea's characteristic fauna. The voracious predatory sea snail *Rapana thomasiana*, for example, arrived from waters around Japan in the mid-1940s and devastated beds of the Black Sea genotype of the common oyster, *Ostrea edulis*. It is one of a list of some twenty-six species introduced through human activity (accidentally or intentionally) since the beginning of the century and which have profoundly altered the Black Sea ecosystem[1].

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[1] Zaitsev, Yu., 1992. Recent changes in the trophic structure of the Black Sea. Fish. Oceanogr., 1(2): 180-189

Another gradual change was taking place on the coastlands of the Black Sea. Urban construction occurred in an unplanned and haphazard manner. The Black Sea was an increasingly popular tourist venue, particularly for the peoples of the former Soviet Union and the other Eastern and Central European COMECON countries. This, together with competing demands for space from shipping, industry and coastal settlements (mostly with inadequate waste disposal), placed increasing demands on coastal landscapes. The damming of many rivers brought hydrological changes, particularly through the decrease in sediment flux to the coast, a phenomenon that led to major problems of coastal erosion[2]. This, in turn, was often ineffectively combated by the construction of a very large number of structures to protect beaches (groynes). These further degraded the landscape and exacerbated pollution problems. In the competition for coastal space, the natural environment was the seemingly inevitable loser. The human population has continuously encroached on the ecosystem that it is part of and upon which it depends.

From the late 1960s to the early 1990s, events occurred in the Black Sea that can objectively be considered as an environmental catastrophe[3]. The strongest single symptom of the catastrophe was the virtual elimination of the *Phyllophora* ecosystem of the Black Sea's north-western shelf in a matter of some ten years. The chain of events leading to the decline of this ecosystem started with an increase in nutrient flux down the major rivers, particularly in the late 1960's when fertiliser use increased markedly as a result of the “Green Revolution”. However, there were several issues which coincided. Enabled by the "Green Revolution", primary agricultural produce was converted with an increasing bigger share into meat. This 'meat production' was also undertaken in large-scale industrialised production units, where it became more and more difficult to re-utilise animal manure on fields. At about the same time, urban settlements were increasingly sewered, but nutrients were not removed from sewage concurrently with the expansion of the sewer systems. Furthermore, polyphosphates were introduced into detergent formulations, thus increasing the loads of phosphorus in the loads transported. This increase in the long-distance transport of nutrients brought about a decrease in light penetration in the sea due to the increased intensity of phytoplankton blooms (eutrophication). Deprived of light, the red algae and other photosynthetic bottom dwelling (benthic) species quickly died. Their function was lost as a source of oxygen to the bottom waters of the shelf seas and as a habitat for a wide variety of organisms. The bottom waters of the north-western shelf became seasonally hypoxic (very low oxygen) and even anoxic (no measurable oxygen). Thousands of tons of benthic plants and animals were washed up on the shores of Romania and Ukraine and the seabed became a barren area with a very low biological diversity.

The loss of the north-western shelf ecosystem had an impact on the entire Black Sea. It also coincided with a period of expansion in the fisheries industry and the application of high technology fish-finding hydro-acoustics and more efficient, though unregulated and destructive, purse seining and bottom trawling gear. The consequence was a decrease in the diversity of commercially exploitable fish species from some 26 to 6, in less than two decades. As eutrophication advanced in the Black Sea, the smaller fish species such as anchovies and sprat were favoured since they depend upon the phytoplankton-driven pelagic ecosystem, rather than the benthic one. Furthermore, their predators had often been removed by overfishing or habitat loss. As a consequence, fishing effort switched to these lower value species. Annual catches of anchovy for example, rose from 225,000 tons in 1975 to some 450,000 tons a decade later[4].

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[2] Kos’yan, R.D., & O.T. Magoon (eds) (1993). Coastlines of the Black Sea. Procedings of the 8th Symposium on Coastal and Ocean Management, Coastal Zone ’93. Coastlines of the World, American Society of Civil Engineers, 573pp.

[3] Mee, L.D. (1992) The Black Sea in crisis: The need for concerted international action. Ambio 21(4): 278-286.

[4] MacLennan, D.N., T. Yasuda and L.D.Mee, 1997. Analysis of the Black Sea Fishery Fleet and landings. Black Sea Environmental Programme, Istanbul, 25pp

In the mid-1980s, another exotic species arrived in ship's ballast waters, the ctenophore *Mnemiopsis leidyi*, sometimes known as the comb jelly[5]. This species was brought from the eastern seaboard of America and, without predators, flourished in the eutrophic Black Sea environment where it consumes zooplankton including fish larvae. Perhaps the word "flourished" is an understatement. At its peak in 1989-90, it is claimed to have reached a total biomass of about one billion tons (1,000,000,000 tons wet weight) in the Black Sea, more than the world annual fish harvest! This massive population explosion had an enormous impact on the Black Sea's ecosystems and commercial fish stocks. The loss of zooplankton allowed huge populations of phytoplankton to develop in a series of blooms that reduced the mean Secchi depth (the maximum depth to which a white disk lowered into the sea from a ship remains visible) from the normal average of twenty metres, to only five metres. Anchovy catches plummeted in 1990 to only 60,000 tons.

The situation in the Black Sea was mirrored by another environmental stress on its coasts. The economic decline of the Black Sea coastal countries and the political upheaval of transition to a market economy led to a lack of maintenance of waste treatment facilities for domestic sewage and industrial waste. Of course, many cities had never had effective sewage treatment but the general decline was evidenced by an increased frequency of outbreaks of waterborne diseases such as cholera and frequent beach closures due to unsanitary conditions. In Ukraine, for example, 44% of bathing water samples taken in 1995, did not meet the national microbiological standards[6]. This environmental problem, coupled with the decline in standards of tourism infrastructure and limited spending power of people in the region, also led to a sharp decline in tourist numbers and in the local economies[7].

The state of the environment in the Black Sea in the early 1990's gave little reason for optimism. The economic crisis did however give some respite for pollution. Farmers were often unable to apply the quantity of fertilisers used in the former centrally planned economies. Many large energy-inefficient and polluting industries were forced to close. By 1996 there was already some evidence of recovery of benthic ecosystems on the north-western shelf of the Black Sea, albeit small. Furthermore, *Mnemiopsis* populations started to decline and the anchovy fisheries recovered, almost to their mid-1980s level. Most local economists and ecologists agree however, the pressure on the environment will return as the economies recover, unless urgent measures are taken to limit the environmental impact of renewed growth. Furthermore, new environmental pressures are emerging as a result of the rapid increase in the use of the Black Sea as a maritime transport route, particularly for the shipment of oil en-route from the newly opened Caspian oil fields.

Recent data[8] has shown that the current nutrient loading to the Black Sea is much lower than in the period of the seventies and eighties but appears to remain higher than in the 1960s. Data for N and P, observed by the Romanian Marine Research Institute[9] on Black Sea shelf waters indicate that the phytoplankton growth in the Romanian shelf area seems to be limited by P; this 'observation area' is some 60 km east from Constanta. A cruise of the Turkish Research Vessel Bilim in March and April 1995 [10] showed along a transsect in this area, and also along two additional transsects vertical

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[5] GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), 1997. Opportunistic settlers and the problem of the ctenophore *Mnemiopsis leiydi* invasion in the Black Sea. Rep.Stud.GESAMP, (58):84p.

[6] BSEP (1997) Black Sea Transboundary Diagnostic Analysis, (Ed. L.D. Mee) United Nations Publications, New York. ISBN 92-1-126075-2, August 1997, 142pp.

[7] BSEP (1996) Black Sea Sustainable Tourism Initiative (Background report), Istanbul, Turkey, 322pp.

[8] see Annex I to the current report.

[9] For Orthophosphate-P, data are available since 1963, for the sum of inorganic N (ammonium-N, nitrite-N and nitrate-N) since 1980,i.e. the N to P ratio can be observed since 1980.

[10] See the Turkish National Report, coordinated by Dr. Ö. Bastürk.

to the Bulgarian coast, the same results. However, Turkish data [11] show that the Black Sea is in its 'open deep waters' nitrogen limited. These observations are here reported, albeit - as indicated before - marine ecosystems are generally felt to be nitrogen limited. For the decision making process, however, the situation in the Black Sea (Black Sea shelf area; deep waters of the Black Sea) is important.

There is strong evidence of partial recovery of coastal ecosystems, though the recovery does only partially extend to benthic systems or to predatory fish. The remarkable recent decrease in some loads is a result of economic failure of agriculture and industry in coastal countries and to the success of nutrient reduction programmes, particularly phosphate removal, in the upper Danube countries. It has to be assumed that the economic failure in coastal countries is a temporary situation and that it represents a "window of opportunity" for recovery of marine ecosystems and for taking management actions to avoid a return to the previous situation of chronic eutrophication.

There is in general agreement that eutrophication is the most serious medium/long term problem to be overcome in the Black Sea. This problem is certainly not exclusive to the Black Sea. Nitrate reduction policies have had limited success in the countries of the European Union despite new legislation. It is difficult to implement these policies where there are strong divisions between sectors involved in competitive agricultural production and environmental protection and where the public itself is generally unaware of the long-term dangers of a "business as usual" approach.

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[11] See again the Turkish National Report, coordinated by Dr. Ö. Bastürk.

5. Evidence for the Decline of Black Sea Ecosystems

Annex I to this report is a set of tables which summarise many of the conclusions of the national reports commissioned by the Danube and Black Sea programmes. Care has been taken to review each statement and to qualify it where necessary. The information is presented in sequence of trophic levels, starting with nutrient fluxes and nutrient concentrations in the Sea, and ending with fish. Only very limited information has been presented on fish populations as this was not the main focus of the national reports. Information has been limited to the phenomenon of eutrophication and its biological consequences. No attempt has been made at this stage to examine the causes or to assess the socio-economic impacts.

The information in the tables constitutes a remarkable quantitative account of the collapse of a major ecosystem, largely as a result of eutrophication. The reader will note that the system became destabilised in the early 1970s. The collapse of benthic ecosystems was catastrophic, occurring in the space of less than three years (Romania). The entire ecosystem appears to have switched from one relatively stable state to one of great instability but with a shortening of trophic chains (food chains), particularly favouring the so-called "dead end" species of gelatinous organism. "Dead end" refers to the fact that these organisms have few predators. The consequence is that the system produces more biomass but this has a low food value for fish which are consequently impoverished.

A summary of the switch in the species composition of the ecosystem is given by Zaitsev (1992) and included as Figure 16 for ease of reference. Prior to the onset of eutrophication, the Black Sea included two major interacting ecosystems; a benthic (bottom living) system with "keystone" species of macro-algae (such as *Phyllophera* and *Cystoseira*) and including benthic animals and fish, and a pelagic (upper water column) system supporting a food chain extending to predatory fish and mammals. Eutrophication has virtually excluded the benthic system and severely altered the pelagic one.

The reader will appreciate that the study of eutrophication in the Black Sea is an extremely complex one and that there are a number of gaps to be filled in our current understanding. The current decline in monitoring programmes is a particular cause for concern since the continuity of measurements is essential for determining the effectiveness of future nutrient limitation strategies.

6. Implications of the Study

- The impacts of eutrophication are not limited to the coastal margins. The entire Black Sea ecosystem has been altered by the combination of eutrophication and the intruding of opportunistic alien species.
- There has been some recovery of the Black Sea ecosystem in the past five years but this does not imply that the degradation taken place is now fully reversed. The system has not yet returned to a state similar to the 1960s. It is currently unlikely to do so as some species have disappeared and others have arrived from outside.
- The presence of large biomasses of gelatinous organisms in the Black Sea is a cause for the decline in the health of higher trophic levels, including fish. This presence is made possible by eutrophication.
- Shelf waters south of the outfall of River Danube, and down to the Bulgarian coast, appear to be phosphorus limited from the extremely low concentrations of phosphate in surface waters, see the former quotations. This is not the case for the Central SW Black Sea[1] where surface N/P is below the Redfield ratio[2].
- Any nutrient reduction possible should be undertaken. The question 'where to put the money first' seems legitimate. However, the full recovery of the Black Sea ecosystems is not merely a matter of reducing phosphate loads (though such reductions may be achieved at a relatively low cost and with a comparatively bigger speed). The ratio of phosphate and nitrate (and in some cases silicate) in the sea should be maintained as close as possible to the natural level (the Redfield ratio) and strategies are necessary for decreasing both nitrate and phosphate inputs to the Sea. There seems currently to be a large excess of total dissolved nitrogen in river inputs.
- Protection of the remaining beds of benthic algae (*Phyllophera; Cystoseira barbata*) is important to aid eventual recovery of the benthic ecosystem.
- Increased effort is needed for comprehensive monitoring of the Black Sea and its tributaries if improved Environmental Quality Objectives are to be developed in the future.

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[1] For the SW Black Sea, mean phosphate concentrations are 0.12 µM P and mean nitrate is 0.28 µM N (Turkish report).

[2] The molar algal requirement for N:P is 7:1, which corresponds to a mass ratio (= 'weight ratio') of 15.5:1. It seems that marine scientists use molar ratios, whereas limnologists are used to mass ratios. It is important to be aware of the differences between 'molar ratio' and 'mass ratio'.

7. Sources of Nutrients to the Black Sea and Nutrient Control Programmes

The problem of eutrophication cannot be resolved without integrating the nutrient management strategies of all the States within the Black Sea basin. From a load allocation perspective, this is not an easy matter as the assimilation and conversion processes along the paths of flow are only incompletely known. Th Group also recognises that in the case of the Danube Basin, the ICPDR is in charge of the load allocation.

As a result of the pollution source inventory conducted during the preparatory work for the Black Sea Strategic Action Plan, it has been possible to gather data on the inputs of dissolved nitrogen and phosphorus compounds to the Black Sea in 1995. However, the atmospheric input of nitrogen was not taken into account in this inventory. Based on this pollution source inventory and some additional data, [Topping, Sarikaya and Mee][1] conclude the following:

For total nitrogen, 14% are from Bulgaria, 27% from Romania, 12% from Ukraine, 10% from the Russian Federation, less than 1% from Georgia, 6% from Turkey and about 30% from the non-coastal countries[2] (Austria, Belarus, Bosnia and Herzegovina, Croatia, Czech Republic, former Yugoslavia, Germany, Hungary, Moldova, Slovakia, Slovenia).

For phosphorus, the figures are Bulgaria, 5%; Romania, 23%; Ukraine, 20%; Russia, 13%; Georgia 1%; Turkey 12% and 26%, for the remaining countries, a similar story to that of nitrogen.

The importance of showing these numbers here is simply to illustrate that nobody is "innocent", not even the Georgians whose low percentage input reflects the current collapse in the coastal economy, probably a temporary feature.

Romania plays a particularly important role in the discharge of nutrients to the Black Sea. Its entire territory drains into the Black Sea, mostly through the Danube. The industrial and agricultural practices adopted during the former political regime paid little regard to environmental protection, especially in the "green revolution". Now that the economy of Romania is market-based, many subsidies on fertilisers have been removed and large animal production complexes are closing. The decrease in fertiliser use is beneficial to the environment but unless alternative and cost-effective agricultural practices are adopted, there will be enormous social problems of unemployed farm workers unable to compete with cheap food exports from places where cheaper production techniques are applied and/or fertilizer subsidies still exist. A similar situation prevails in neighbouring Moldova where large animal complexes have also closed but where smallholders now have excessive numbers of animals literally in their back gardens, in very unsanitary conditions. Human health is already declining in these places and shallow wells, the main local water supplies, are polluted. A complete solution to these problems would require a change in consumption patterns themselves - and how can countries with rampant over-consumption in the west demand changes of their poorer neighbours in the east?

Though the biggest single contributor of nutrients to the Black Sea seems to be Romania it contributes less than one third of the total waterborne load. All the States in the Black Sea basin share the responsibility to reduce nutrient loads to the Sea. The Danube river basin has its own management regime, which includes the Danube River Protection Convention (which has entered into force on October 22nd, 1998) and the 'International Commission for the Protection of the Danube River

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[1] Topping, G., H. Sarikaya and L.D. Mee (1998) Sources of pollution to the Black Sea. In: Mee, L.D. and G. Topping (Eds) (*in press*) Black Sea Pollution Assessment. UN Publications, New York, 280pp

[2] The loads of nutrients discharged into the 'fine drainage web' of the river network in a regional drainage area and the ones reaching the receiving Seas will always differ. For the Danube Basin, it will be one of the tasks of the ICPDR to come up with good estimates for the reasons of these differences.

(ICPDR)' charged to implement it, plus a Strategic Action Plan[3] developed under the EPDRB, the implementation of which with the DRPC's entry into force is now under the responsibility of the ICPDR. The current 'GEF River Danube Pollution Reduction Programme (GEF-RDPRP)' will help to define new strategies for reducing pollution, including nutrients, in the entire Danube Basin. Similarly, in the Dnieper River (shared by Ukraine, Belarus and Russia), a GEF-supported programme is developing a new Action Plan. Parallel projects have been developed for the Prut river (Tacis funding), the lower Don river (World Bank funding), the Sea of Azov (primarily Dutch government funding) and the Dniester river (various donors).

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[3] EPDRB (1994) Strategic Action Plan for the Danube River Basin, 1995-2005, Environmental Programme for the Danube River Basin, Vienna, 109pp.

8. Policy Perspectives for Controlling Eutrophication

It is not possible at this stage, and with the limited historical data available on nutrient inputs, to set clear ultimate targets for nutrient reduction. The data set tells us about the historical state of the environment but eutrophication does not follow a linear cause-effect relationship. The collapse of ecosystems seems to have occurred rather abruptly as the system "flipped" from one state to another. However, the partial recovery of parts of the Black Sea ecosystem is encouraging.

The Black Sea Strategic Action Plans takes a pragmatic approach to the issue of pollution control which follows the "paradigm of iterative management[1]". The basic approach is rather simple. Firstly, there has to be a recognition that the integrity of marine and coastal ecosystems and/or human health is threatened by pollution. The complete removal of the threat would be desirable but is often impracticable in the short/medium term for social and economic reasons and an interim strategy is necessary for pollution control. It also requires that there are measurable indicators of ecosystem health. The coastal states (or those of the entire basin in the case of nutrients) as the cooperating partners involved then agree on a short term target for reduction. In the first iteration, the reduction is agreed on the basis of what can reasonably be achieved within a given time frame. The agreement is made on the basis of common but differentiated responsibilities, in this case each partner finds the most economically convenient approach for reaching the agreed target. It is understood from the outset that the first reduction is modest and somewhat empirical. The partners involved also agree on a programme of research and monitoring to refine the estimates of optimal reductions so that - at the end of the first period - new targets may be set with lower uncertainty regarding the outcome. The iterations should continue until all partners agree that the environment is adequately protected. At the same time, public understanding of the issues will also gradually improve, as will the public's demands for tighter criteria for protection and, hopefully, their willingness to pay. This is an open-ended process with a moving target, driven by continuity of observation and reasoning and the full involvement of all stakeholders. Such an approach avoids creating a stark division between "the public" and "the polluters" and seeks a consensus that addresses pollution at its root causes.

This general approach was applied by the "Group" in the following manner:

- by recognising and thus proposing to both Commissions concerned that the ecological status to be aimed at should be similar to the one of the 1960s but that it is not practicable to achieve this in a short time frame;
- by considering that in order to start with, an agreement is needed on the limits of the inputs of nutrients (and in fact also hazardous substances) into the Black Sea (and the Sea of Azov) and on the ecological status related with these inputs;
- to propose to both Commissions to limit the discharges to the Black Sea to the (only partially known) 1997 level, in order to learn to know how the Black Sea ecosystem(s) respond in regard to the already observed improvements.

The purpose of this approach is that there has to be agreement on improving the 'knowledge base' for optimal reductions such that at the end of this period, new targets can be set with a better certainty regarding the social and economic implications of the decisions to be taken.

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[1] See, for example, Costanza, R., F. Andrade, P. Antunes, M. van den Belt, D. Boersma, D. F. Boesch, F. Catarino, S. Hanna, K. Limburg, B. Low, M. Molitor, J.G.Pereira, S.Rayner, R.Santos, J.Wilson and M. Young (1998). Principles for Sustainable Governance of the Oceans. Science 281:198-199

In order to arrive at the goal to further maintain and hopefully improve the ecological status of the Black Sea, the following principles for nutrient management measures and strategies will be necessary:

- Nutrients have to be 'kept on land' where they are needed for phototrophic productivity, and
- they have to be kept away from any waterborne transport.

The latter aim is to limit the phototrophic productivity in the receiving waters to adequate conditions, including the receiving area of the overall Black Sea.

The public understanding of the basic issues involved will hopefully increase in the overall Black Sea Basin over time, as hopefully will the willingness of this public to pay for actions required. In order to arrive there, all 'inlanders' will have to be made aware of what has happened with the ecological status of the overall Black Sea over time, and what – after the signs of improvement since 1992 – has to be avoided towards the future. The public should also know that 'exact values for the permitted discharges to the Black Sea' for the needed good ecological status are not yet known, and that in order to arrive there, solid observations, good scientific reasoning and a full co-operation are needed.

Based on the reported positive signs (reduced input loads and improved ecological status in the Black Sea shelf), and also aware of the missing knowledge of the comparability of input loads (resolution both in time since the 1960s, and in space all over the Black Sea and the Sea of Azov), and aware that the load reductions are very likely linked with the decline of economic activity in the countries in transition, but that towards the future economic development is expected to take place in the overall Black Sea Basin, the 'Working Group' defined in its 2nd Meeting the possible strategies as follows:

- *The long-term goal for all States in the Black Sea Basin is to take measures to reduce the loads of anthropogenically applied nutrients and hazardous substances to such levels necessary to permit Black Sea ecosystems to recover to conditions similar to those observed in the 1960s.*
- *As an intermediate goal, urgent control measures should be taken by all States in the Black Sea Basin in order to avoid that the discharges of nutrients and hazardous substances into the Seas exceed those that existed in 1997*[2]*. The 'Group' recognised that these 1997 discharges are only incompletely known and that further work has to be undertaken to substantiate the size of the loads received by the Seas (Black Sea proper; Sea of Azov).*
- *The 'Group' concluded that the inputs of nutrients and hazardous substances into both receiving Seas have to be assessed in a comparable way, and that to this very end a common AQC (Analytical Quality Control) system and a thorough discussion about the necessary monitoring, including the sampling procedures, has to be set up.*
- *The 'Group' also concluded that the ecological status of the Black Sea and the Sea of Azov has to be further assessed, and that the comparability of the data basis has to be further increased.*

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[2] Loads reported for 1997 to have been transported in River Danube were: orthophosphate, 16,000 tons (as P); total inorganic nitrogen, i.e. the sum of ammonia-N, nitrite-N and nitrate-N, 300,400 tons (as N) [A.Cociasu, 1998]. River scientists indicate that in order to 'level the impact of river hydrology on the transport of pollutants out', an averaging over e.g. a span of five years should be undertaken. This would yield for River Danube an 'averaged load for 1995' of 12,700 tons per year of orthophosphate-P and 456,000 tons of inorganic nitrogen per year. The corresponding value for 1997 can only be known as soon as the value for 1999 is known.

- *Both the reported input loads as well as the assessed ecological status will have to be reported annually to both the ICPBS and the ICPDR.*
- *The States within the overall Black Sea Basin shall have to adopt strategies that will permit economic development, whilst ensuring appropriate practices and measures to limit the discharge of nutrients and hazardous substances, and to rehabilitate ecosystems which assimilate nutrients.*
- *Based on the annual reports and on the adopted strategies for the limitation of the discharge of nutrients and hazardous substances, a review shall be undertaken in 2007. It will focus on the further measures that may be required for meeting the long-term objective (reaching an ecological status similar to the conditions observed in the 1960s).*

It is clear that placing such a "cap" on nutrient discharges would be a bold step towards restoration of the Black Sea ecosystem. It would give the Black Sea ecosystem a chance to recover and would offer economic benefits for the coastal countries in terms of improved fisheries and tourism. It would also offer global and regional benefits, measured in terms of biological diversity. By contributing to this process, the non-coastal areas within the overall Black Sea's hydrographic catchment – including those within the River Danube Basin – would also contribute to these non-tangible global benefits.

9. The Danger of Doing Nothing

Holding nutrient inputs at their 1997 levels does not imply "doing nothing". There is an urgent need to develop agriculture and industry in Black Sea and Danube Basin countries as the present economic and food supply situation is unsustainable. These sectors should be developed in a manner which will afford greater protection to the environment and decreased economic loss from wastage. However, such development will require the commitment and engagement of all concerned and the support of international donors. As will be discussed in a later section, many of the necessary national policies and regulations are already in place but require activation.

Clearly, if nothing is done and the economies wil start again to be active by a strong 'principle of materials flow-through', nutrient loads reaching the Black Sea and the Sea of Azov will soon begin to rise again. The weakened ecosystems would degrade again and phenomena such as "dead zones" would return. This could eventually lead again to a loss of biological diversity. It would also inflict economic damage on the renascent tourist industry and affect fisheries in an unpredictable manner.

10. Practical Short-term Measures

How can low-cost practical measures be developed for implementing the agreed goals? In a developing or transition economy, there are many opportunities for implementing nutrient reduction policies without huge capital costs. This is because many of the contaminating industries and practices are already highly inefficient and in need of modernisation as part of a suite of measures for economic reform. The removal of subsidies for fertilisers for example, provides an incentive to reduce wastage and exploit animal manure currently discharged into rivers. In some cases however, new technologies fall short of nutrient removal because they address problems of short-term national interest. Many new municipal wastewater treatment plants (WWTPs) are being planned for example by oxydizing the biodegradable carbon in sewage, but these generally lack provisions for nutrient removal and, despite solving important domestic problems of human health, further exacerbate nutrient discharges. Such WWTPs are a good example of domestic baselines; the cost of adding a nutrient reduction stage would be the incremental cost to address regional and global environmental problems[1]. Similarly, a wetlands rehabilitation project, of immense value for biodiversity conservation, may have true additional incremental benefits in the maintenance or enhancement of a capacity for nutrient removal. This "ecosystem service" is rarely taken into account when planning biodiversity projects: the cost of wetlands protection and restoration is an incremental one and maybe a meaningful investment.

The "Group" has discussed some of the low-cost measures that could be taken to prevent increases in nutrient discharge to the Black Sea. Some of these measures will have to be set in the context of a new or revised legal frame, but the "Group" did not discuss this issue in any detail. The recommendations for measures fall into four general categories:

1. ***Reform of agricultural policies.*** The use of market fertiliser has strongly declined in many Danube Basin and NIS[2] countries due to the current economic crisis. Agricultural production has slumped to unprecedented levels. The sector is currently being restructured in many countries in order to improve its productivity in several cases via assistance from the World Bank. If a return to large increases in nutrient run-off is to be avoided, it is important to include relatively simple policy provisions in the restructuring process. These include such things as leaving strips of unploughed land ('buffer strips') near streams, rivers and lakes; provision of storage clamps for overwinter storage of manure; erosion control through practical demonstration projects, and incentives for "biofarming[3]". Regulations concerning buffer zones for streams and rivers are already in place in some countries (eg. Ukraine), but enforcement is still rather poor. Another area requiring attention is freshwater fish farming: extensive (low feeding) aquaculture should be encouraged rather than intensive rearing which has very large nutrient discharges. Intensive farms should be subjected to discharge permits and levies as an incentive for proper treatment of waste. Effective levies should also be imposed on intensive animal rearing facilities that do not treat or recycle their waste.
2. ***Improved waste-water treatment, where applicable through the use of alternative technologies.*** As mentioned earlier, conventional primary and secondary domestic wastewater treatment does not prevent large nutrient discharges. Tertiary treatment

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[1] In practice, the matter is more complex. Even if funding can be raised to cover the capital cost of technological removal of phosphorus and nitrogen, the operation and maintenance cost may be virtually unaffordable for many countries in transition or in development. Funds from the GEF might theoretically cover the capital costs but not the operations and maintenance. These issues of sustainability must be carefully considered when prioritizing GEF interventions.

[2] The term NIS, Newly Independent States, refers to the countries of the former USSR.

[3] The term "organic farming" is commonly employed in some countries. In the UK, for example, standards for this practice are set by the Soil Association.

(including nutrient removal) implies high operation and maintenance charges which may be unaffordable under current economic conditions. For small communities, an example of low-cost alternative technology is the use of reed-bed techniques for sewage treatment following screening. This is now also employed for small towns in western countries. This technique has not been successfully applied for larger towns or cities, and it cannot be recommended without adequate feasibility studies. One option that should be properly evaluated for towns in Russia, Georgia and Turkey, is the use of deep discharge diffusers. They can carry wastewater to depths well below the pycnocline (the density gradient at about 100m depth in the Black Sea). With careful design, diffusers can be effective in keeping the nutrients away from the phototrophic zone. With industrial wastewater, nutrient removal should also be a statutory requirement.

3. ***Rehabilitation of key basin (aquatic) ecosystems.*** The creation of protected areas, particularly in the case of wetlands, encourages the natural assimilation of plant nutrients. The reflooding of wetlands results in nutrient removal in two stages - a fast initial removal as aquatic plants grow and then a slower continuous removal as phosphorus is bound into sediments and nitrogen returned to the atmosphere by denitrification. What is presently only partially known is the long-term effectiveness of wetlands for nutrient removal (respectively the 'backholding' of nutrients). The protected or reflooded wetlands serve as biodiversity reserves and productive areas for fisheries. It was also felt that the areas needed for such ecosystem rehabilitation should not only be along the main rivers, but in the overall drainage web. The creation of terrestrial protected areas is also very important as it allows buffer zones to enhance carbon and nitrogen removal. An urgent priority is to afford protection to the remaining areas of marine macro-algae such as the *Cystoseira* beds in Russia or the *Phyllophera* beds in Ukraine in order to seed recovery of the Black Sea's ecosystems. These beds are currently under threat as a result of development of the oil industry (Russia), tourism development (all areas) and trawling (all areas).
4. ***Changes in consumer practices (including use of phosphate-free detergents).*** The prohibition of polyphosphate-based detergents leads to a major reduction in phosphate discharge to aquatic systems. These detergents seem to be already banned in most Danubian countries and the ban should be extended to all Black Sea countries as soon as possible (such a ban should be part of an agreement for cooperation). Public awareness of the eutrophication issue should be raised and clear information provided on modifying the consumer practices that lead to higher nutrient discharges. Awareness should also be raised of the need for protected areas and the consequence of their loss to developers.

11. Follow-up

The work of consolidating the information on eutrophication in the Black Sea, including the Sea of Azov, is still incomplete. There are many gaps to be filled in, and research to be continued. This report integrates a consistent record of change from which the impact of the phenomenon of eutrophication of the Black Sea and the Sea of Azov can be clearly highlighted and practical measures developed for controlling it. There is a broad consensus between specialists from Black Sea and Danubian countries regarding the validity of the observations and deductions.

There are two follow-up actions necessary at this point:

1. At the policy level. The TOR of the 'Joint *ad-hoc* Group' requires that the Group's Report will be made available to both the International Commission for the Protection of the Black Sea and the International Commission for the Protection of the Danube River, as well as GEF as donor. This Report will be an input to a Meeting between the Black Sea and the River Danube side, at the level of Heads of Delegations. The Heads of Delegations of both Commissions should in such a joint meeting, based on cooperation, consider endorsing the proposal to maintain nutrient levels at or below the loads recorded in 1997, subject to review in 2007. They should also approve a series of practical measures to achieve this goal including a total ban on polyphosphate detergents, clear targets for wetland restoration, an agreement on monitoring, and a mechanism for "joint implementation".
2. At the project level. Donors should establish mechanism(s) to support the agreed policy objectives by funding a series of demonstration projects to share the costs of measures to reduce nutrient discharge following the approach outlined in 10 (above). The approach could use GEF funding to cover the incremental costs of specific projects. The support of donors other than the GEF will be necessary in order to meet the agreed policy objectives. For their part, the Contracting Parties to the Bucharest and Sofia Conventions should ensure that a 'Memorandum of Understanding' is in place for implementing and monitoring the agreed policies. Furthermore, funds should be made available for the important task of raising the awareness of the general public and supporting local initiatives for reducing nutrient discharge or protecting key (aquatic) ecosystems.

Annexes

Annex I

Summary of Data Sets Showing Evidence for Eutrophication and Its Effects

Location	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Nutrients			
Estimated values of outflow	1988/92	Estimated values calculated on the basis of the Bucharest Declaration monitoring data. Loads into surface water re-calculated from Danube country reports, with modelled retention. See note regarding assumptions: Annual emissions into surface water in 10 out of 13 Danubian States: (1988/89) 990kt N; 130kt P (1992) 820kt N; 105kt P Flow into Black Sea: (1988/89) 447kt N; 46kt P (1992) 345kt N; 25kt P		EPDRB (1997), Nutrient Balances for Danube Countries - Project EU/AR/102A/91, Final Report	These are estimated values which make assumptions regarding total/inorganic ratios. Quoted errors are typically +/-20%. Data demonstrates effectiveness of river system in decreasing loads to the sea.
Danube outflow, measured in the Sulina channel	1959-1960 and 1980-97	The values presented are yearly ones and thus do not reflect the existing hydrological variations. **Inorganic Phosphate** load **increased**[1] from 12 kt P/yr (1959/60) to a maximum of 30.7 kt P/yr in 1991. **Inorganic nitrogen increased** from 140 kt N/yr (1959/60) to a maximum of 813 kt N/yr in 1989. **Silicate decreased** from 790 kt Si/yr (1959/60) to 154 kt Si/yr (1990).		[Rom., Table 1]	These data are calculated from concentration in one branch of the delta times total river flow. This is an estimate of load for the whole river. See footnote on accuracy and source of data.
Danube outflow, as above	1980-97	All mass fluxes presented here are gliding averages over 5 years, with the 'middle year' being representative for the point in time. This 'gliding averaging' is levelling out yearly fluctuations. **Increase in inorganic phosphate** between 1980-89 from 12.1 kt/yr to 27.8 kt/yr, **then decrease** to 12.7 kt/yr for 1995. Gradual **decrease in total nitrogen** discharge from 730 kt N/yr in 1990 to 456 kt N/yr in 1995. **Decrease of silicate** from 417 kt Si/yr for 1982 down to a range of 234 - 265 kt Si/yr for the years between 1991 to 1995. **Mass N/P ratios** varied from 50-70 in 1988-92, rising to over 100 in 1993-94 and gradually falling to current values of about 40 **Mass Si/P** about 40 from 1988-94, then steadily rising to over 110 in 1997	Fig.2	[Rom]	These data are computed from values using very consistent sampling and measurement methodologies. They represent the most up-to-date set of data on the discharge of the Danube (though they are taken from a single site).
Danube (Vilkovo)	1994 - 96	Doubling of nitrate to 1.9 mg/L 65% decrease in inorganic phosphate to 0.27 mg/L	Table 1	[Ukr.]	This is a small data set, changes do not represent a statistically valid trend
Kerch Straits (from Azov Sea)	1952-81	Increase of total nitrogen from 31.5kt/yr in 1952-56, to 62.5kt/yr in 1977-81 Irregular trend in phosphorus showing no net increase.		[Rus]	Systematic data sets were kept until 1981 and for rivers until 1986. The input from the Kerch straits was usually about 10% that of the Danube
NW. Shelf (Romanian Sector)	1959-1997 for P and Si; 1980-97 for N	**Onshore:** Pre 1970 surface PO_4 values below 0.5 µM then spectacular increase in period from 1971 to 1991 with values from 4-9 µM. Current levels have since **declined** to about 1µM. Almost no decline in total inorganic nitrogen over period from 1980. Silicates have declined to about 30% of 1960s levels.	Fig. 3 (based on Figs 4 and 5b of	[Rom]	Information from one of the best data sets in the Black Sea region. Full accounts of seasonal variations are found in the Romanian report. Note that onshore P levels were heavily

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[1] This change (phosphates) is not statistically significant with this limited data set. Note that the 1959-60 data of Almazov has been questioned by the 'Group' in regard to its 'statistical meaning', as the method of arriving at the loads and as the sampling and analytical procedures involved are not adequately known.

		N/P ratios have increased from 2-3 (1982-88) to over 15 (1997) **Offshore:** Pre 1970 surface PO_4 values below 0.5 μM then spectacular increase in period from 1971 to 1991 with values of up to 2.6 μM. Current levels have since **declined** to below 0.4μM. Gradual decline in total inorganic nitrogen over period from 1980, currently reaching about 5μM. N/P ratios have decreased from values over 100 (1982-88) to below 50 (1997)	[Rom]		influenced by a fertilizer factory now closed. Offshore changes mirror those of the Danube.
NW Shelf (Ukrainian Sector)	1950-1997	Very similar pattern observed to that of the study in the Romanian sector	Table 2	[Ukr.]	No sampling locations provided - clarification requested from authors of report.
W Shelf (Bulgarian sector, Sozopol station), neritic zone	1987-1996	Sharp **decline** in phosphate since 1990 (except for single high value in 1996) No clear trend for Nitrate or ammonia		[Bulg]	The frequency of sampling for obtaining this data set is unclear as are the relative errors and the units employed. The similarity with patterns observed in other countries is striking however.
Sea of Azov, Taganrog Bay	1985-89, 1990-95	Inorganic nitrogen halved between the two periods due to reduction in economic production. Total phosphorus and silicates remain approximately the same (nitrates + ammonium averaged 335 μg/L in 1985-89; total phosphorus, 57 μg/L).		[Rus]	No information is given on the sampling network and measurement frequency. The data is included as a contrast to the NW Shelf.

Hypoxia

Open Black Sea	1970-1998	Suboxic zone enlarging towards the surface by about 0.3-0.4 density units (some 10 metres)		[Tur] [Bastürk]	Data from various cruises by US and Black Sea scientists
NW Shelf	1950s - 1995	Hypoxic bottom waters often present on NW Shelf in summer after 1960 and covered up to 15,000 km2 from 7-8 to 35-40m depth in 1980s. They have recently receded to 1960s levels.		Zaitsev, 1992; EROS-2000 cruise data, 1996]	More research needed on historical data sets to document this phenomenon accurately.

Phytoplankton and chlorophyll

NW Shelf near Constanta	1983-1997	**Chlorophyll** - the **range of variation** for offshore and inshore stations has generally exceeded 50 μg Chl_a/L (some very large values), lower since 1994 with a high in 1997.	Table 3	[Rom]	Unfortunately there are no pre-1983 reference figures. Also median values need to be computed.
Western Black Sea (rim current and central gyre)	1986-1997	**Chlorophyll** - Large fluctuations but increasing concentrations to 1992, particularly in the rim current. Decrease in both areas after 1994 (slightly higher concentrations in 1996). This is evidence of eutrophication as a basin-wide phenomenon	Figs 4 & 5	[Tur] Yilmaz	Important study based upon the results of ocean-ographic cruises and satellite observations

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NW Shelf near Constanta	1962-1994	As eutrophication has progressed, blooms of microplankton and nannoplankton have become increasingly important. Species of Cyanobacteria (blue-green algae) and coccolithophorads which were rare before 1970 have become frequent or even dominant.	Table 4	[Rom]	The table illustrates the change in species dominance, the Romanian data set is extremely extensive.
Bulgarian Black Sea region (Cape Galata)	1961-97	Huge increase (about 40x) in phytoplankton biomass between period 1961-63 and 1983-90 then 30% decrease to present.	Fig. 6	[Bulg]	This data is based on over 30 years of systematic research. The sampling frequency may mean that some blooms were unsampled.
Bulgarian Black Sea region (Varna Bay)	1954-95	Until 1971, by far the dominant species belonged to the bacillariophyta (diatoms). From 1972 to 1989 dinophyta often dominated as eutrophication advanced. Some recovery of diatoms was noted from 1990 - 93 (the flora is more diverse than previously however) The transition from a stable diatom dominated system to an unstable one was a remarkably sharp one.	Fig. 7	[Bulg] Petrova-Karadjova	An extraordinary time series of seasonal measurements has been made which illustrates the apparent association between eutrophication and changed species composition.
Bulgarian Black Sea region (Varna Bay)	1981-96	Incidence of unusually intense blooms seems to have diminished since 1992. The diversity has also increased (some of the blooms in the mid-1980s were virtually monospecific)	Fig 8	[Bulg]	Author of the report (Moncheva) considers it too early to assert that the system has significantly recovered.
Ukrainian Black Sea region (NW Shelf)	1950-95	Overall decrease in species diversity as a result of eutrophication. Diatoms have decreased in diversity, dinoflagellates have increased (similar observation to Bulgarian colleagues)	Table 5	[Ukr]	Work based upon extensive data set covering over 40 years
Novorossiisk Bay (Russia)	1930s-40s, 1980s-90s	Change from diatom dominated blooms to increasing incidence of dinoflagellate blooms		[Rus]	Report does not include sufficient information to assess the representativity of the data set

Marine macrophytes

NW Shelf	1960s-80s	Zernov's phyllophora field occupied 11,800 . sq. km in 60s with total biomass of these alga 9 million t. By the end of 70s, the phyllophora biomass was 1.4 million t, but by the end of 80s it did not exceed 0.3 million t and occupied only 500 sq. km. No trace of the field was found in 1998 cruises by Ukrainian scientists.		[Ukr]	Data based upon extensive field observations but requires further updating and revision.
NW Shelf (Romanian and Ukrainian sectors)	1971-79	Disappearance of the "keystone species" *Cytoseira barbata* (150m wide belt). 5,400 t (fresh weight), 1971; 755t, 1973; 123t, 1979. Similar reports in Ukrainian sector. Cytoseira was replaced with opportunistic species of short life cycle.		[Rom] [Ukr]	Supports notion of sudden collapse of the ecosystem in the early 1970s.

Zooplankton

NW Shelf (Romanian sector)	1970 -86	Increase in copepods between decade of the 70s and the 80s. The summer biomass increased by six times. These are food species for *inter-alia*, sprats, the production of which also increased.	Table 6	[Rom]	This illustrates how the NW shelf ecosystem started to shift from a system dominated by benthic production to a pelagic one as eutrophication advanced.
NW Shelf (Romanian sector)	1980-91	Development of huge blooms, especially in the summer of *Noctiluca scintillans*, a gelatinous zooplankton which is not considered to contribute to the trophic chain (ie. act as food for larger species). The species has contributed up to 99.8% of the summer biomass.	Tables 7 & 8	[Rom]	As eutrophication advanced further the "dead end" gelatinous organisms were increasingly favoured.
NW Shelf (Romanian sector)	1983-94	Change in seasonality and the decline of zooplankton communities. The arrival of the gelatinous ctenophore, *Mnemiopsis* seems to have led to the collapse of summer blooms of "fodder zooplankton" (those species which, unlike *Noctiluca*, can contribute to the marine food chain). This has severe implications for fish populations. Some recovery was noted in 1996-97.	Fig 9	[Rom]	This illustrates how eutrophication can eventually impoverish the food chain.
Bulgarian Black Sea coast	1967-95	Summer biomass of non-gelatinous "fodder"species declined to about 20% of late 1960s values. Noctiluca densities doubled in the same period.	Fig. 10	[Bulg]	Observations in the Bulgarian sector are very similar to those in Romania.
Ukrainian NW Shelf	1950-95	Similar situation to that described for Romanian sector. The "fodder species" in 1992-95 were the lowest since observations first began, the zooplankton communities had become dominated by Noctiluca.	Table 9	[Ukr]	The longest continuous record available highlights the clear pattern shown in other study areas.
Novorossiisk Bay (Russia)	1950-90	Copepods declined from constituting 44% of the biomass in the 50s-60s, to 8.8% at the beginning of the 90s. A sharp four fold increase in the amount of Noctiluca was reported between the 70s and 80s.		[Rus]	The report is sketchy on details but it is clear that profound changes occurred in the eastern Black Sea at the same time as those in the west.
Overall offshore Black Sea	1955-96	Analysis of time series by Turkish scientists together with their own data from recent cruises, illustrates decline of fodder species in the NW Shelf region of the Black Sea, particularly since the late 1980s when Mnemiopsis emerged. This region was the richest in fodder zooplankton in the 1960s but from the 1970s the NE region was equally important. The Turkish data gives evidence of some recovery during the 1990s in the W and SE region. In 1976, 11 of 13 common species of Black Sea copepod were present in Sevastopol Bay; by the 1990 only 6 species remained and only one was present in the summer months.	Fig. 11	[Tur]	This is a useful compilation of offshore data which illustrates the disturbance of the entire Black Sea ecosystem and the reduced availability of fodder for higher trophic levels.

Gelatinous predators (other than Noctiluca)					
Overall Black Sea	1949 - 1990	In the Black Sea the average biomass of the jellyfish *Aurelia aurita* increased from 670 th.t in 1949-1962 [28] up to 222 ml.t in 1976-1981 [11] and up to 300 - 500 ml.t by the end of 80s. The opportunistic invader *Mnemiopsis*, arrived in the mid-1980s and developed quickly, by 1989 attaining a total biomass of some one billion tons (wet weight), or 2 kg/m^2! The eutrophic conditions of the Black Sea favoured the development of this species.	Fig 12	[Ukr} [Tur]	Jellyfish and other gelatinous species are often characteristic of eutrophic ecosystems. The invasion of Mnemiopsis is probably the most devastating case of accidental introduction this century.
Offshore Black Sea	1991-97	*Mnemiopsis* is still present in large quantities in both E and W parts of the Black Sea. 1997 cruise data reports biomasses of some 600 g/m^2 in the E and 300g/m^2 in the W. Similar biomasses of the jellyfish Aurelia were also recorded	Fig. 13	[Tur]	These data are for individual cruises and should not be interpreted as annual or seasonal averages. Nevertheless they provide extremely important evidence of the continuation of the Mnemiopsis infestation.
Bulgarian Black Sea region	1997	The ctenophore[2] *Beroe ovata*, which can predate on Mnemiopsis, was first identified in the Black Sea in October 1997. Bulgarian scientists are concerned that this will herald a new invasion.		[Bulg]	The arrival of *Beroe* has unpredicatable consequences. It may act as a control to Mnemiopsis but it may also pose an even greater threat to the existing ecosystem.
Zoobenthos					
NW Shelf (Romanian sector)	1965-1982	Changes in **sandy sublittoral**: 14 species of polychaete in 1965, 2 in 1982 17 species of amphipod in 1965, 2 in 1982 density of species in 1965 = 100,000 individuals/m^2 , 4,000 -60,000 in 1982		[Rom]	These figures are consequences of the changes from benthic dominant ecosystems to pelagic ones as a consequence of eutrophication
NW Shelf (Romanian sector)	pre 1980s-1993	Changes in **rocky bottoms**: 28 crustacean species before 1980 at 3m depth, 14 in 1993		[Rom]	Report not very strong on benthic studies. Most significant changes noted here.
NW Shelf (Romanian sector)	1977-1980	Catastrophic collapse of communities in **muddy bottom** habitat: 15 species of crustacean in 1977, 2 in 1980 20 species of mollusc in 1977, 4 in 1980 Biomass reduced proportionally: 30 (1977), 10 (1978), 1 (1980)		[Rom]	Massive loss of species in a three year period
NW Shelf (Romanian sector)	1994-1997	Apparent **recovery** of species diversity in prodeltaic sector: 1994, 14 species; 1995, 23 species, 1996, 25 species; 1997, 30 species		[Rom]	Gradual recovery confirms the value of nutrient reduction.

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[2] A ctenophore is a tube-like gelatinous organism, sometimes known as a comb-jelly. This organism is a predator of zooplankton including copepods, fish-larvae etc. Both Mnemiopsis and Beroe are ctenophores, neither of which are native species of the Black Sea. Mnemiopsis is believed to have been transported to the Black Sea in the ballast water of a ship, presumably from the eastern seaboard of America.

NW Shelf (Ukrainian sector)	1973-1990	Mortalities due to hypoxia were estimated as 100-200 t/km^2, including 10% young and adunt fishes. Between 1973 and 1990 losses were estimated as 60 million t bottom animals including 5 million.t of fish.	Table 10	[Ukr]	These estimates, coupled with the areas given in the table give a sense of the magnitude of loss of the benthic ecosystem
Coastal area near Novorissijsk, Russia	1960s-1980s	In living *Cystoseira* beds[3], there is a relative stability in zoobenthos, especially as compared with the NW shelf.		[Rus]	The importance of keystone species is highlighted with this example.
		Fish[4]			
Anchovy populations in the Black Sea	1968-1997	Anchovy stocks and fisheries increased rapidly from the late 1960s to 1988, attaining over 500,000 tons annual catch. With the arrival of *Mnemiopsis*, the catch plunged to less than 100,000 tons in one year. Since then it has gradually recovered and is currently over 400,000 tons. The recovery is entirely on the S side of the Black Sea (mostly the coast of Turkey) and there is evidence that spawning grounds have switched from the N to the S. Most fish stocks in the NW Black Sea are still depleted.	Figs. 14 & 15	[Tur]	Figures show catch statistics and larval distribution. The larval distribution studies conducted from Turkey have been very extensive, enabling a clear picture of the recent developments.
Western Black Sea	1965-97	Following the mid-1970s, benthic fish populations (eg. turbot) collapsed and pelagic fish populations (small pelagic fish such as anchovy and sprat) started to increase. This may have resulted from habitat loss as the benthic algal beds were lost. The commercial fisheries diversity declined from some 25 fished species to about five in twenty years (60s to 80s).			There are two reasons for the collapse of benthic species: eutrohication and overexploitation. Scientific evidence points to eutrophication as the most significant factor.

Information contained in the Annexes I to III is - not for all quotations, but for a large share - based on the reports undertaken for the National Studies furnished by the teams of the shoreline Riparian States (Bulgaria; Romania; Russian Federation; Turkey; Ukraine), see also Annex V.

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[3] The coast of Russia has intact beds of *Cystoseira*. These have been reduced in size, possibly through oil pollution, but are living remnants of the earlier Black Sea coastal benthic ecosystem.

[4] The analysis of fish populations has not been attempted in most of the country reports. The reader is referred to the studies of Prodanov et al. (1996) and McLennan et al (1997) for further information.

Annex II

The Supporting Tables 1 to 10

Table 1 **Content of Nutrients in the Danube Water, in micrograms of N or P/l, as indicated, for the station Vylkovo, at Kilia arm, 1994-1996 (from the Ukrainian National Report)**

[illegible]	[illegible]	[illegible]	[illegible]
N inorganic			
Average	890	1960	1920
Max	1500	2400	2800
Min	260	130	120
P inorganic			
Average	430	190	270
Max	1000	580	90
Min	180	70	100

Table2 **The changes of content of major nutrients(% of measured in the 50-60s.) in the north-western shelf of the Black Sea (from the Ukrainian National Report, original data by Garkavaia G.P., 1998)**

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NH_4	25,0	100	1780	262	133
NO_2	2,5	100	216	196	126
NO_3	10,0	100	424	454	587
$N_{organic}$	230,0	100	192	237	517
PO_4	13,5	100	214	248	118
$P_{organic}$	16,0	100	159	166	77
SiO_3	1262,0	100	106	73	48

Table 3 **Chlorophyll-a concentrations along the Romanian marine area, in µg/l, and where the highest concentrations are reported for the part just in front of the (now abolished) fertiliser plant discharging phosphates to Sea. (From the Romanian National Report). The control area on the shelf (10 to 30 miles off the coast reported values between 0.04 - 1 µg/l).**

[illegible]	[illegible]	[illegible]
1983	0.031	85.32
1984	0.1	49.68
1985	0-1.09	62.50
1986	0.12	59.34
1987	0.09	86.91
1990	0.06	35
1991	0.01	96.80
1992	0.13	25.62-292.44
1993	0.06	36.48- 44.64--406.90-427
1994	0.14	3.66
1995	0.18	46.86
1996	0.08	31.58
1997	0.16	58.12

Table 4 **Maximum density (in millions of cells/l) produced by dominant species during 1980-1994 (from the Romanian National Report).**

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Skeletonema costatum	0.01 - 82.6	0.01 - 97	40		87.6	3.68	1074016	41.2	50.4	16.5	21.9	0.45	15.0	52.1	53
Cerataulina bergonii				0.80		0.95		0.10	0.56	7.09	11.1	2.73	9.38	9.46	2.13
Detonula confervacea										33.7					
Chaetoceros socialis										53.6				4.13	
Chaetoceros similis					1.38					0.25				0.57	
Cyclotella Caspia	0.032 -12	0.009 - 9			1.63		0.25	1.29	2.40	0.53	0.65				
Prorocentrum cordatum	1- 4	10 - 100		421	47.8	6.89	13.5		30.9	164	3.27	115	204		
Heterocapsa triquetra		1.85- 40.5	65.2		3.12		5.35	0.30	7.73					29.5	3.49
Apedinella spinifera		0.014	1.7			21.5						0.40		21.3	2.52
Mantoniella squamata													5.97	1.36	12.5

Table 5 **Changes of Phytoplankton Diversity (total number of species) in the north-western shelf of the Black Sea before and after large scale eutrophication (from the Ukrainian National Report; data by Zaitsev, Yu.p. and B.G. Alexandrov, 1998)**

[redacted]	[redacted]	[redacted]
Bacillariophyta	180	116
Pyrrophyta	76	104
Chlorophyta	62	52
Cyanophyta	24	30
Chrysophyta	17	20
Euglenophyta	12	2
Xanthophyta	1	2
Total	372	326

Table 6 **Mean values of the densities (D=individuals per m^3) and biomass (B=mg per m^3) of the pelagic copepods in the Romanian waters of the Black Sea during 1970-1979 and 1980-1986 (from the Romanian National Report, data by PORUMB, 1989).**

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
1970-1979	2502	10.37	1340	7.10	6075	19.90	4742	5.38	4337	14.37
1980-1986	463	14.58	2131	21.67	8267	127.47	9840	81.41	7184	61.59

Table 7 **Seasonal mean densities (D = individuals per m^3) and biomasses (B = mg per m^3) of *Noctiluca scintillans* in Romanian continental shelf waters (from the Romanian National Report)**

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1980-1986	16296	1300.86	17086	1367.33	62439	5022.43	40232	3258.77

Table 8 **The dominance (share in %) of *Noctiluca scintillans* in the total quantities of summer zooplankton in the Constantza area (from the Romanian National Report)**

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total density	91.5	94.7	95.6	41.0	91.5	92.3	91.5	97.9	97.5	99.2
Total biomass	95.8	96.7	99.1	34.3	98.3	98.5	98.5	99.9	99.3	99.8

Table 9 **Abundance (D = individuals per m^3) and biomass of zooplankton (B = g per m^3) in the period 1950 - 1995 in the north-western part of the Black Sea (from the Ukrainian National Report; data by Zaitsev Yu.P., and B.G. Alexandrov, 1998)**

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1950-60	2806	0.16	9897	0.08	1511	0.03	16606	0.37
1961-70	2930	0.17	7177	0.02	727	0.02	19662	0.25
1971-80	43772	2.53	11955	0.06	2657	0.03	63254	2.71
1981-90	60996	4.33	8999	1.09	2670	0.41	111104	6.59
1992-95	14276	0.37	741	0.06	898	0.56	23636	0.93

Table 10 **The change over time of the area where hypoxic conditions and bottom animal deaths were observed during the years 1973-1990 (from the Ukrainian National Report; data by Yu.P. Zaitsev, 1992)**

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973	3.5	1979	15.0	1985	5.0
1974	12.0	1980	30.0	1986	8.0
1975	10.0	1981	17.0	1987	9.0
1976	3.0	1982	12.0	1988	12.0
1977	11.0	1983	35.0	1989	20.0
1978	30.0	1984	10.0	1990	40.0

(It should be noted that the improvements with the eutrophication process in the Black Sea started after 1990!)

Annex III

The Supporting Figures 1 to 16