TRENDS IN NUTRIENT LOADS FROM THE DANUBE RIVER AND TROPHIC STATUS OF THE BLACK SEA*

September 2006

***Extended version of a briefing note originally provided to GEF Council on 6 June 2006**

Joint Report of the GEF-UNDP Black Sea Ecosystem Recovery Project and the GEF-UNDP Danube Regional Project

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Summary - the story to date

This briefing note brings together available data on trends in Danube River flows, concentrations and loads to the Black Sea, in addition to an assessment of the Sea itself, concentrating on the NW shelf where the Danube discharges. The available data are complex, open to a range of interpretations and sometimes even contradictory[1], but the overall picture that emerges is one of a situation that is beginning to improve:

- While the emphasis of the DRP and BSERP projects has been (and remains) on nutrient source reduction, some of the best indicators of the trophic status of the receiving waterbody (the Black Sea and, more specifically, the North West Shelf) are at least as closely allied to organic enrichment as they are to nutrient enrichment (Sections 7 and 8). Further emphasis on reducing organic loading to the Danube and the Black Sea could, therefore, contribute to improvements in the ecological status of the Black Sea. However, no studies are known to have been undertaken comparing the importance of riverine and coastal anthropogenic organic carbon discharges with organic loads produced by primary production in shallow, coastal waters.

- River loads of nitrogen and phosphorus increase with the river discharge (Figs. 3.3 and 3.5). The large variability in annual flow rates makes it difficult to undertake statistics on short time-series of loads. The increasing trend of the annual water volume during the past 15 years may (partly) obscure any river load trends as a result of anthropogenic emissions (e.g. Figs. 3.2 and 3.3). Also, even after excluding statistical “fliers” the error margin in measured nutrient concentrations is in the region of 10-20%, a fact which may obscure (weak) trends.

- Short-term nutrient concentration data (2000-2003) show an improving trend (i.e. concentrations are decreasing) in the upper and middle reaches of the Danube (Fig. 2.1). More recent (2003-2005) data suggests that this improvement is now being reflected in reducing nitrate loads to the Black Sea (Section 3, Fig. 3.4).

- In absolute terms, there appears to have been a trend of decreasing total phosphorus and increasing inorganic nitrogen loads between 1988 and 2005 (Fig. 3.2). However, when the trend of increasing river flow is accounted for, there is actually a marginal decrease in inorganic nitrogen loads and a much more substantial decrease in total phosphorus loads (Fig. 3.8). While annual flow-corrected data over the period 1996-2001 suggest no real improvement in inorganic N (Fig 3.4) or total P (Fig. 3.6) loads, instantaneous flow/concentration

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[1] For example, inorganic nitrogen loads measured at Reni as part of the Trans National Monitoring Network (TNMN) are not consistent with data collected at Sulina (one of the three main branches of the Danube discharging into the Sea) by the Romanian National Institute for Marine Research and Development (NIMRD). A seven-fold decrease in the inorganic nitrogen load over a ten year period (NIMRD data, not shown) is considered to have been extremely unlikely, and therefore the TNMN data have been used as the basis for assessing load inputs via the Danube in this note.

plots (Figs. 3.3 and 3.5) indicate that progress is still being made. The large increase in annual total phosphorus load during 2005 can be explained by the high flows during that year (Figs 3.7 and 3.8).

- To date, the emphasis on nutrient control has focused primarily on point source reduction. The benefits of capital investment in nutrient-stripping technology to date have been rather small, and there is an apparent need to re-focus attention on diffuse sources. However, the benefits of major reductions in livestock numbers and inorganic fertilizer usage since 1988 (e.g. Fig. 2.2) almost certainly have not yet been fully realized. When they are (and agriculture-derived nutrient loads fall substantially), capital investment in waste water treatment plants will become progressively more important.

- The longer-term trends in inorganic nitrogen loads, while initially appearing to be disappointing, should be taken in context, since recent (2003-2005) data suggest that real improvements are beginning to occur upstream (Fig. 2.1). There is a widely acknowledged lag phase for nutrient source reduction being reflected in reduced river concentrations and loads. There are two main reasons for this: (i) for diffuse sources-derived nutrients, the time taken to flush historically accumulated nutrients from soils and groundwaters to surface waters (ii) internal loading in waterbodies (in this case referring to both the Danube and the Black Sea) from historically-enriched sediments until new sediment-water equilibria can be established.

- The reducing nutrient concentrations (2000-2003; Fig. 2.1) in upper and middle reaches of the Danube suggest that this lag period may be nearing an end, a hypothesis supported by 2003-2005 nitrate data from Reni (Fig. 3.4). The pattern of improvements being shown first in upstream sections of the river is fully consistent with what would be expected as the lag phase begins to end.

- Nutrient data for a coastal water site near to Constanta showed a decrease in nitrate levels during the late 1970s, which has been maintained since (albeit with 2005 being a year of unexpectedly high concentrations, corresponding to relatively high flows in the Danube River). Phosphate levels at the same site showed a substantial fall during the early-mid 1990s, with a lower level being maintained since the late 1990s (Fig. 5.1).

- The situation and trends (since 1990) in nutrient levels throughout the NW Shelf as a whole remains unclear because of the paucity of available data, perhaps the fairest interpretation of which is either an increase or no change in nutrient concentrations (full data not shown). Amalgamated marine average annual nutrient concentrations show wide variability, so timescale is critical when assessing trends. The inclusion or exclusion of a couple of years of annual average values could dramatically change this assessment. However, for the Romanian part of the NW Shelf, while nitrate concentrations show an increasing trend (1990-2004), phosphate levels have shown a decreasing trend (Fig. 5.2).

- Despite data suggesting that the nutrient status of the NW Shelf has not yet improved substantially, and may even have worsened at some sites during the last 15 years, there is clear and compelling evidence of improving biological status (Sections.6 and 7). Causes underlying this biological recovery are not fully understood, but the most likely influencing factors are: (i) climate change; (ii) over-fishing; and (iii) the invasive combjelly *Mnemiopsis leydyi,* a planktonic organism that first appeared in the Black Sea in the early 1980s. *Mnemiopsis* feeds "actively" on zooplankton and fish larvae, but only "passively" on phytoplankton.

- Climate change could be a contributory factor in increasing nutrient concentrations in the Black Sea, with internal loading of nutrients in the NW Shelf appearing to be linked to wind speed, direction and duration. This may be a direct effect of physical mixing at the sediment-water interface and/or a indirect effect caused through changes to the dissolved oxygen status of shallow benthic areas: at higher dissolved oxygen levels less phosphate is released from sediments, nitrification is promoted and dentrification is inhibited. Further work on sediment-water nutrient exchange is planned as part of the final BSERP cruise.

- Over-fishing may have resulted in decreased grazing pressure on zooplankton and, therefore, increased grazing pressure on phytoplankton. However, available historical commercial fishing data for the Black Sea Region are (in general terms) sparse and incomparable. BSERP has funded a number of workshops and studies on fish stock assessment methodologies to promote regional harmonization in the future, but these will not help re-build historical datasets.

- Phytoplankton results strongly suggest an improving situation throughout the 1990s, and continuing improvements since then (Figs. 6.1-6.3). This conclusion is supported by remote sensing data of chlorophyll-like substances, available since the late 1990s (Fig. 6.4).

- The Danube continues to have an impact on zoobenthos populations just offshore of the delta, but further north the Dniester River is almost certainly an additional cause of disturbance to zoobenthos communities (Figs. 8.1 and 8.3). However, zoobenthos biodiversity nears to Constanta has increased greatly since the late 1980s, suggesting that the impact of the Danube has reduced greatly (Fig. 8.2).

- Dissolved oxygen concentrations in the 1970s showed a huge deterioration in environmental conditions/trophic status of the NW shelf in the 1970s and early 1980s. However, by the mid 1990s substantial improvements had been recorded (Fig. 8.1). The overall situation appears to have improved further since then, albeit with a temporary return to eutrophic conditions in 2001. A further return of hypoxic conditions was also reported off the coast of Constanta (Romainia) and in the Ukrainian part of the NW Shelf during 2005, but the extent and severity of this event remains unclear (Section 8).

1. Introduction

During the 1970s and 1980s, the trophic status of the Black Sea, and particularly the NW Shelf increased dramatically, resulting in extended and extensive periods of hypoxia, with severely damaged pelagic (water column) and benthic (sediment) ecosystems. The following short- and long-term nutrient-related targets have been agreed upon for the recovery of the Sea:

Short-term: to avoid exceeding loads of nutrients discharged into the Sea beyond those that existed in 1997.

Long-term: to reduce the loads of nutrients discharged to levels allowing Black Sea ecosystems to recover to conditions similar to those of the 1960s.

Trophic status is determined by nutrient and organic loads/concentrations. Organic matter in the Sea can be derived from external sources (River flows and discharges from land) or can be generated within the sea itself via photosynthesis, predominantly by phytoplankton, the growth of which are stimulated by elevated nutrient concentrations. Thus, both nutrient and organic loads/concentrations need to be considered in assessing the recovery of Black Sea ecosystems.

This briefing note provides information on indicators of Black Sea recovery, focusing on the NW Shelf, and nutrient/organic discharges via the River Danube.

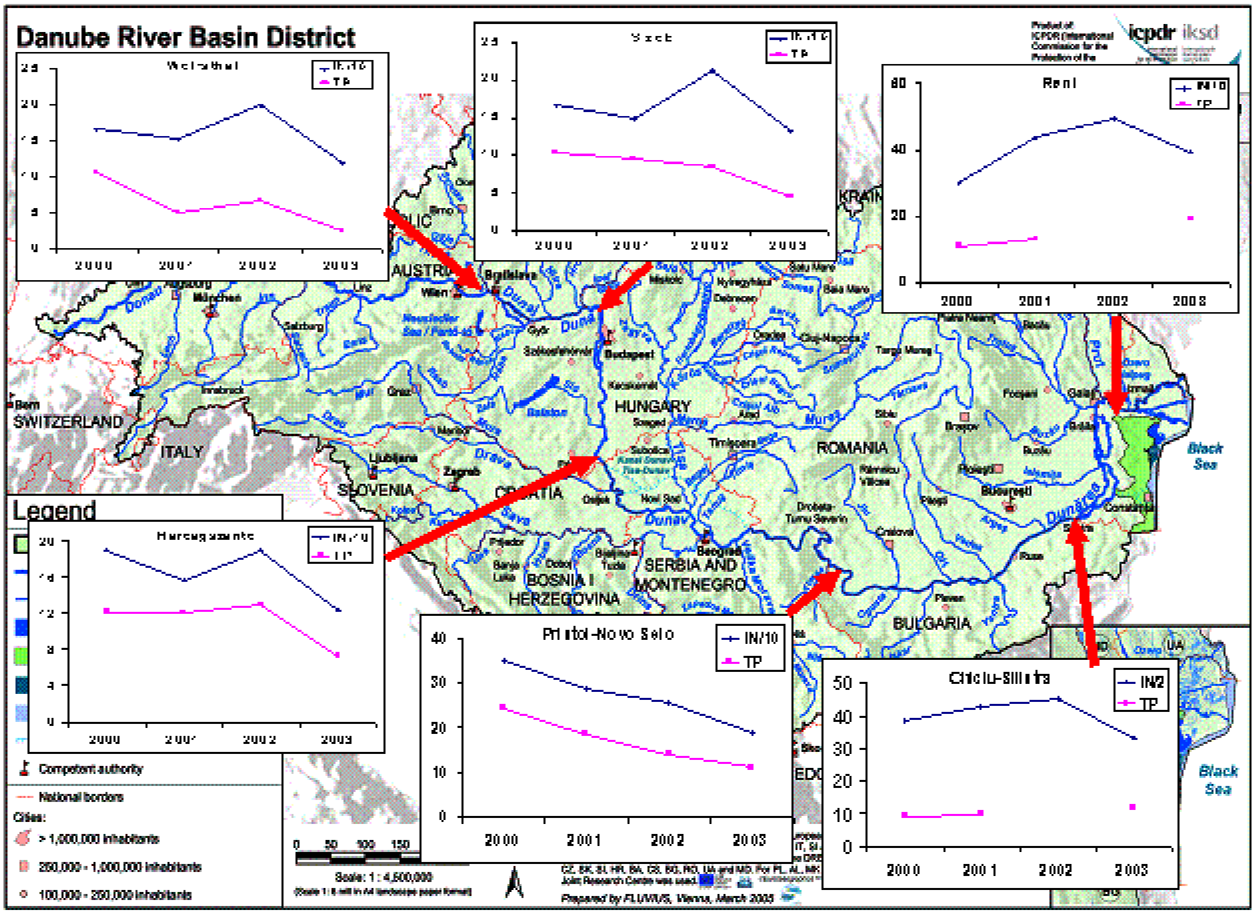
2. Nutrient concentrations in the Danube River

Between 2000 and 2003, nutrient concentrations in the middle and upper reaches of the River Danube showed a decreasing trend (Fig, 2.1). However at the two most downstream sites, nutrient concentrations either showed no discernable trend or an increase. Reasons for the difference in trends between the four most upstream sites and two downstream sites remain unclear but must be linked to nutrient inputs from Bulgaria/Romania, the effect of the Iron Gates Reservoirs (formed by dams across the Danube River) and/or the release of nutrients from sediment in the lower Danube River itself.

In the upstream reaches (above the Serbia and Montenegro/Hungary border), using Dablas data on nutrient reduction loads generated from capital investment in Sewage Treatment Works and comparing these with instream loads, the resultant maximum reduction is only of the order of 7% for phosphorus and 2% for nitrogen. This suggests that even with the huge capital investments to date, and further potential capital investments in point source nutrient reduction in the future, little progress is likely to be made unless inputs from diffuse sources can be effectively tackled.

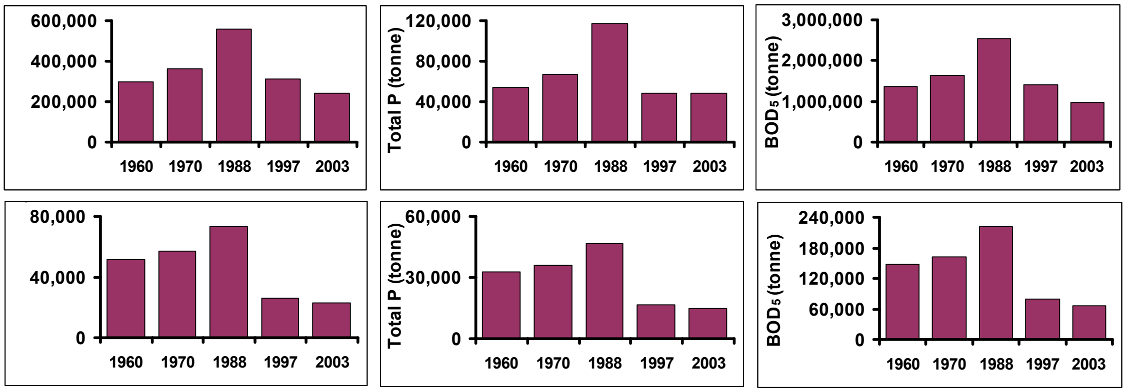
However, having said this, nutrient (and organic carbon) loads from livestock (cattle, pigs, poultry, sheep and goats) have decreased massively in many Danube/Black Sea countries since the economic collapse of the late 1980s/early 1990s (e.g. Fig. 2.2). Likewise, huge reductions in the use of inorganic fertilisers have also occurred (data not shown).

Figure 2.1. Trends in nutrient concentrations (inorganic N and total P) in the Danube River (2000-2003)



Data source: Trans-National Monitoring Network database

Figure 2.2. Nutrient and BOD_5 content of livestock manure in the Black Sea sub-basins[2] of Romania (top) and Bulgaria (below), 1960-2003



Data source: Dumitru, M. (2005) Romanian livestock assessment; Petkova, E. (2005) Livestock numbers and potential nutrient/organic loads to the Black Sea from riparian countries. National report – Bulgaria. Both reports prepared under BSERP, Phase 2.

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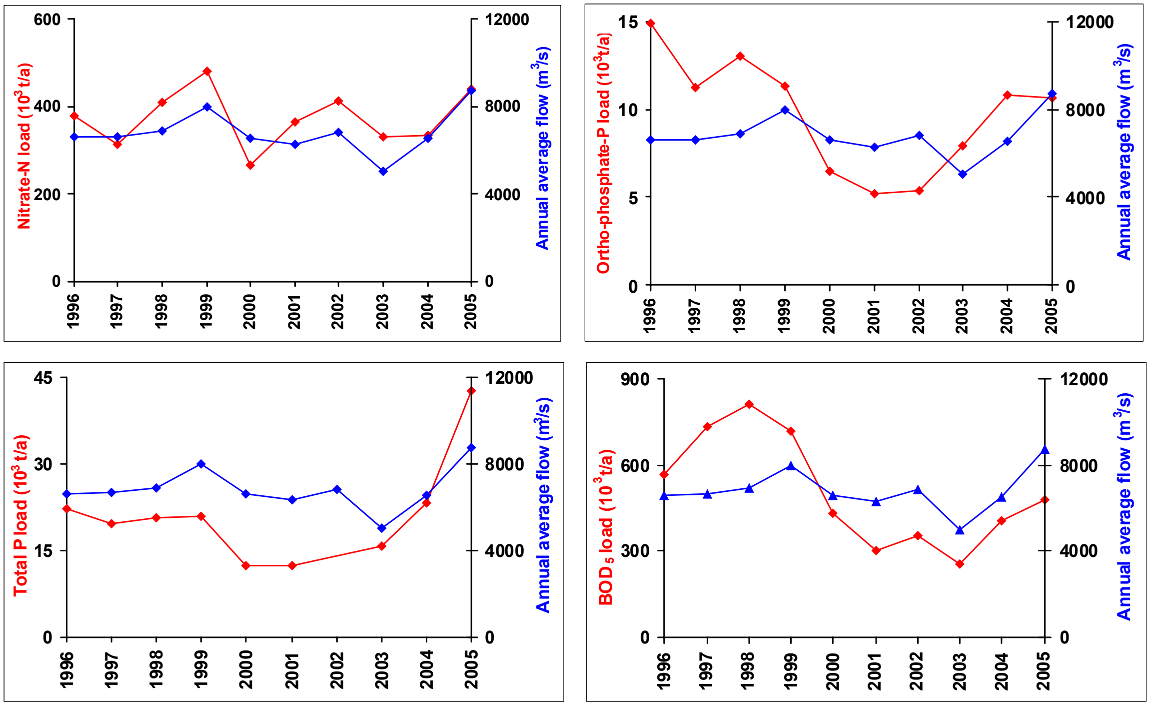
[2] Land draining either directly into the Black Sea or into the Black Sea via the Danube

3. Danube loads to the Black Sea

Danube loads to the Black Sea are calculated from flow and concentration data measured at Reni, approx 30-40 km upstream of the Danube Delta (Fig. 3.1). Data from 200-2003 are officially endorsed by the ICPDR, while pre-2000 and post 2003 date are unofficial, albeit monitored at the same site.

From these data it appears that there have not been substantial reductions in Danube-derived nutrient or BOD_5 loads to the Black Sea during the last decade. Indeed, the total phosphorus load during 2005 (a high flow year) compared to previous years. The increase was proportionally much greater than for ortho-phosphate, suggesting that it could largely be explained by an increase in particulate phosphorus, concomitant with elevated suspended solids levels/discharges (data not shown). It is interesting to note that the ortho-phosphate and BOD_5 load plots follow similar patterns, suggesting that both of these loads are derived primarily from the same "animal" source.

Figure 3.1. Danube River annual nutrient/BOD_5 loads and flows to the Black Sea (1996-2005)

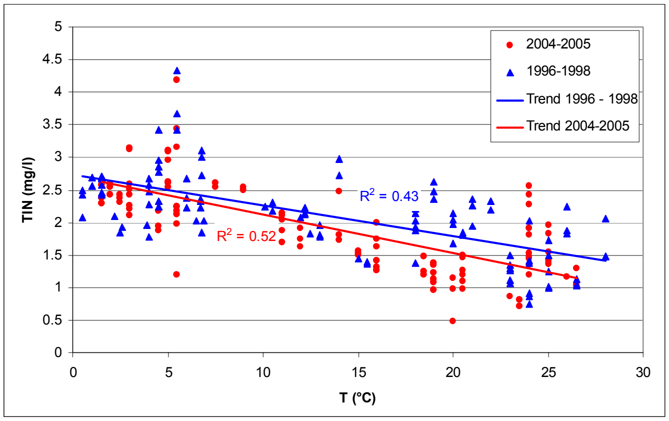


Data source: Trans-National Monitoring Network database; Romanian Waters National Administration. Plot provided by Dr M. Zessner, Institute for Water Quality, Technical University of Vienna.

Temperature, reflecting seasonality, is also an influencing factor on nitrogen loads to the Black Sea (Fig. 3.2), with an overall decrease in medium-high flow-related loads during 2003-2005 compared to 1996-1998 (Figure 3.3). When both temperature and flow are accounted for, the beginnings of a decrease in inorganic nitrogen loads during 2003-2005 is apparent (Fig. 3.4), suggesting that the upstream trend of decreasing inorganic nitrogen concentrations during 2000-2003 (Fig. 2.1) is beginning to follow-through to a reduction in recent loads to the Black Sea (2003-2005).

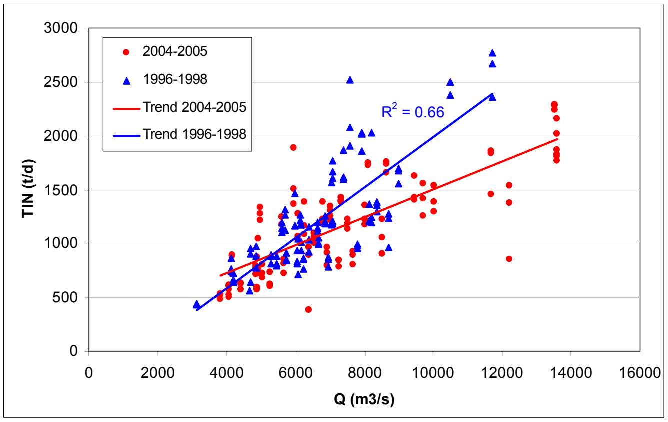
For total phosphorus, as with nitrate, during 2003-5 there was a tendency towards lower instream loads during high flow events, but at moderate flows, loads appear to have increased when compared to the 1996-1998 situation. However, then the influence of river flow is removed from loads, the large increase in the 2005 load at Reni (see Fig. 3.1) is effectively removed (Figure 3.6), revealing no apparent trend over the 1996-2005 period.

Figure 3.2. **Inorganic nitrogen load/temperature relationships at Reni during 1996-1998 and 2003-2005**



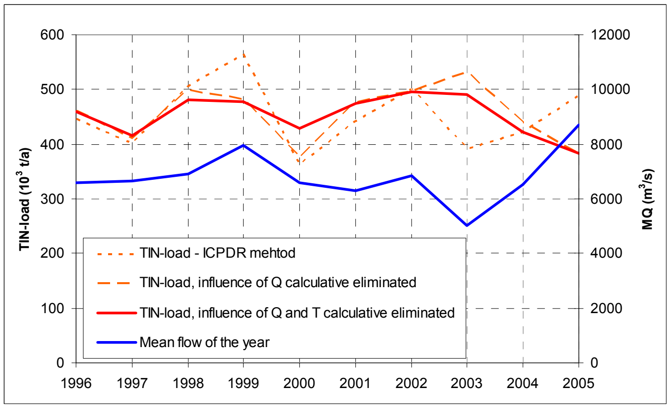
Data source: 1996-998 Trans-National Monitoring Network database; 2004-2005 Romanian Waters National Administration. Plot provided by Dr M Zessner, Institute for Water Quality, Technical University of Vienna.

Figure 3.3. **Inorganic nitrogen load/instantaneous flow relationships at Reni during 1996-1998 and 2003-2005**



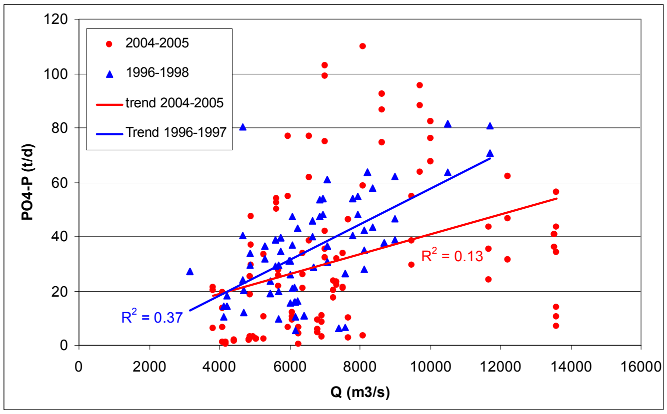
Data sources: 1996-1998 Trans-National Monitoring Network database; 2004-2005 Romanian Waters National Administration. Plot provided by Dr M. Zessner, Institute for Water Quality, Technical University of Vienna.

Figure 3.4. **Inorganic nitrogen loads at Reni (1996-2005), accounting for flow and temperature**



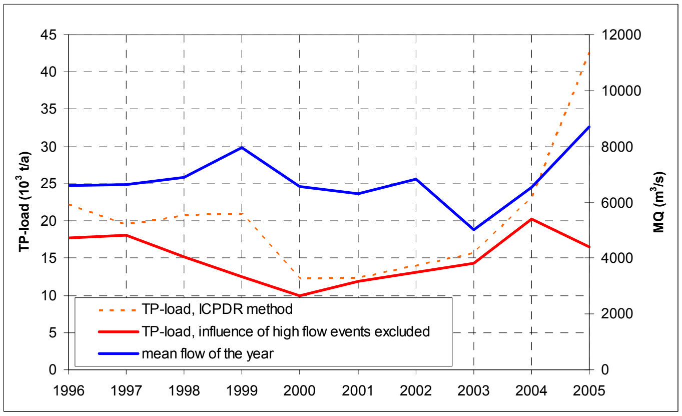
Data source: Trans-National Monitoring Network database; Romanian Waters National Administration. Plot provided by Dr M. Zessner, Institute for Water Quality, Technical University of Vienna.

Figure 3.5. **Total phosphorus load/instantaneous flow relationships at Reni during 1996-1998 and 2003-2005**



Data source: 1996-1998 Trans-National Monitoring Network database; 2003-2005 Romanian Waters National Administration. Plot provided by Dr. M. Zessner, Institute for Water Quality, Technical University of Vienna.

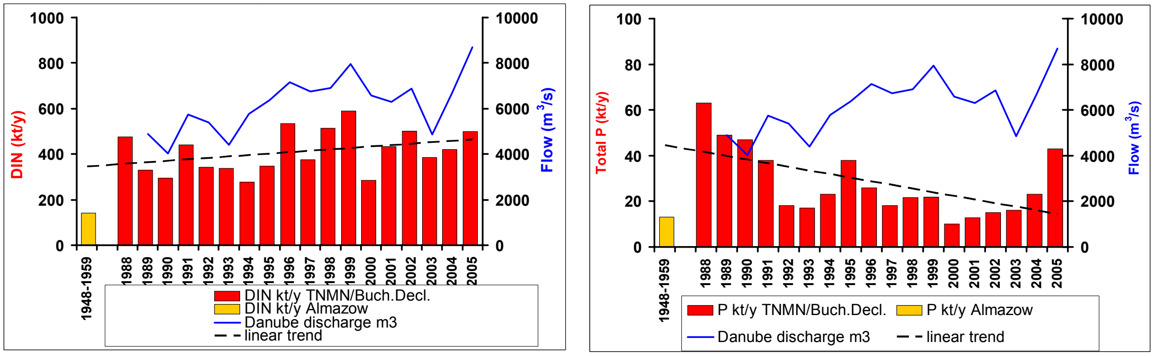
Figure 3.6. **Total phosphorus loads at Reni (1996-2005), accounting for flow**



Data source: Trans-National Monitoring Network database; Romanian Waters National Administration. Plot provided by Dr M. Zessner. Institute for Water Quality, Technical University of Vienna.

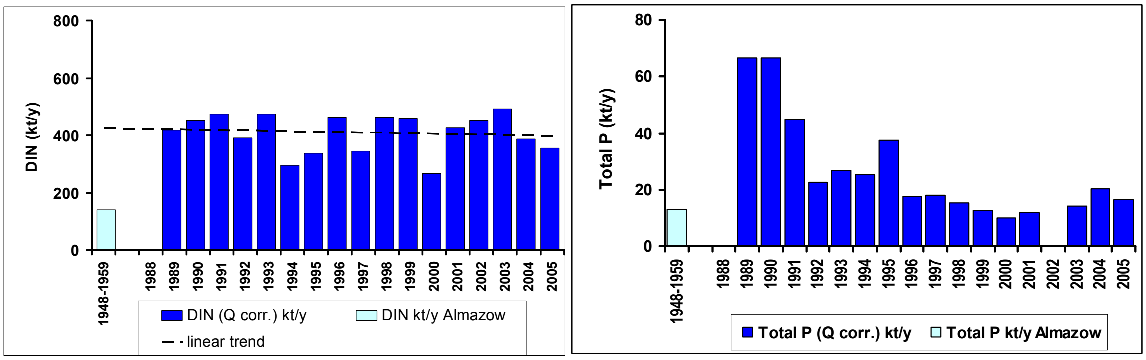
Over a longer period (1988-2005) the picture that emerges is of increasing inorganic nitrogen loads and decreasing total P loads (Fig. 3.7). However if account is taken of flows, there is actually a slight decrease in organic nitrogen loads and a much larger decrease in phosphorus loads (Fig. 3.8). It is clear from Figs. 3.7 and 3.8 that annual nutrient loads need to be reduced by a factor of 1.5-3 to reach the levels measured prior to 1960.

Figure 3.7. Danube River annual nutrient loads and flows to the Black Sea (1988-2005)



Data source: Trans-National Monitoring Network database; Romanian Waters National Administration;. Plots provided by Dr J. van Gils, WL delft hydraulics, Delft, The Netherlands.

Figure 3.8. River Danube annual inorganic nitrogen and total phosphorus loads (corrected for annual discharge) to the Black Sea (1989-2005)



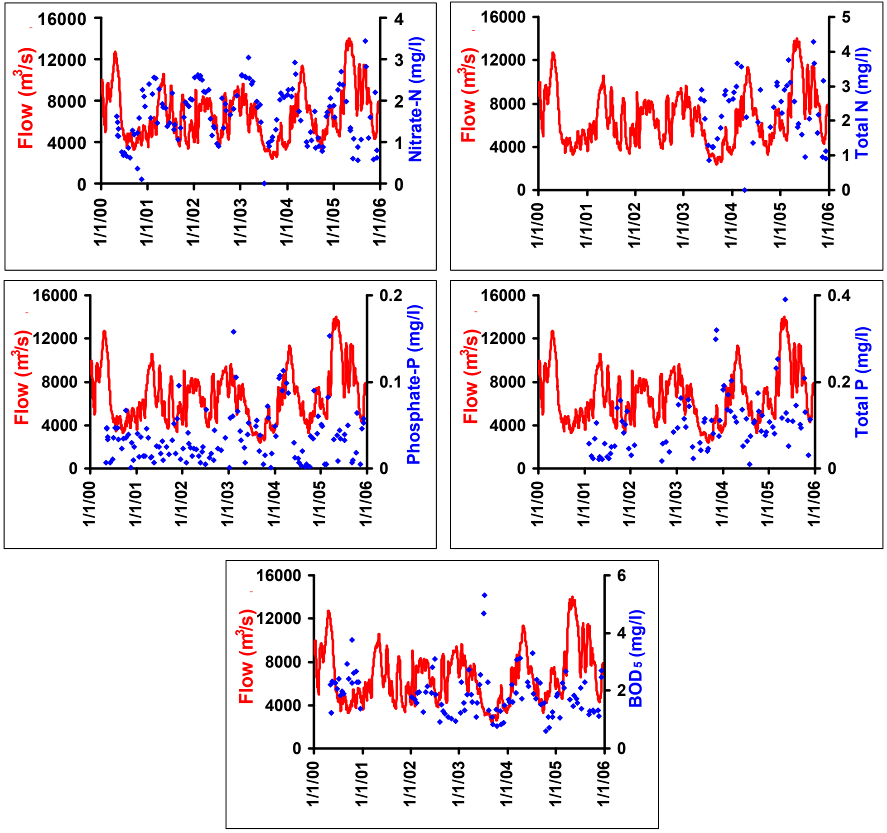
Data source: Trans-National Monitoring Network database; Romanian Waters National Administration. Plot provided by Dr J.van Gils, WL delft hydraulics, Delft, The Netherlands and Dr. M. Zessner, Institute for Water Quality, Technical University of Vienna.

4. Danube flow/concentration relationships

Annual flows in the Danube show clear seasonality, with highest flows in spring. Concentration data for 2000-2005 are plotted against flow (Fig. 4.1). Nutrients and BOD_5 showed only very weak correlations with instantaneous flow, albeit that the overall relationships were slightly positive for nutrients. Nevertheless, this is not surprising, considering the lack of seasonality shown by all of the parameters, except for nitrate (Fig. 4.2).

Thus, while higher annual flows tend to results in higher loads of nutrients (nitrate and total P; Fig. 3.1), it is only concentrations of nitrate that may substantially increase at higher instantaneous flows (Fig.4.2). This is a surprising conclusion for total P, especially considering the high annual total P load for 2005, corresponding to high annual flows

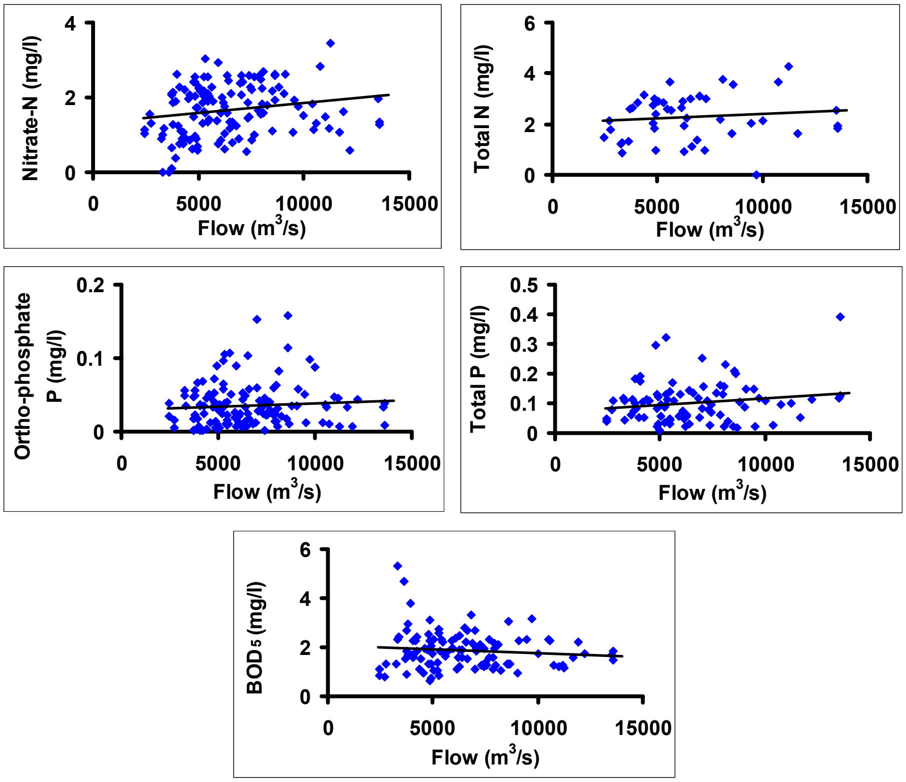
Figure 4.1. **Time series of nutrient and BOD_5 concentrations at Reni (2000-2005)**



Data source: Dr M. David, Romanian Waters National Administration

(Figs. 3.1 and 3.2), but could be a reflection of the relative contributions of point and diffuse source-derived phosphorus to instream loads at high and low flows. However, for nitrate the situation is more complex than such simple statements suggest, since peak concentrations often do not occur at the same time as annual peak flows (Fig. 4.1) thereby weakening the instantaneous flow/concentration relationship (Fig. 4.2).

Figure 4.2. Danube flow-concentration relationships for nutrients and BOD_5 at Reni (2000-2005)



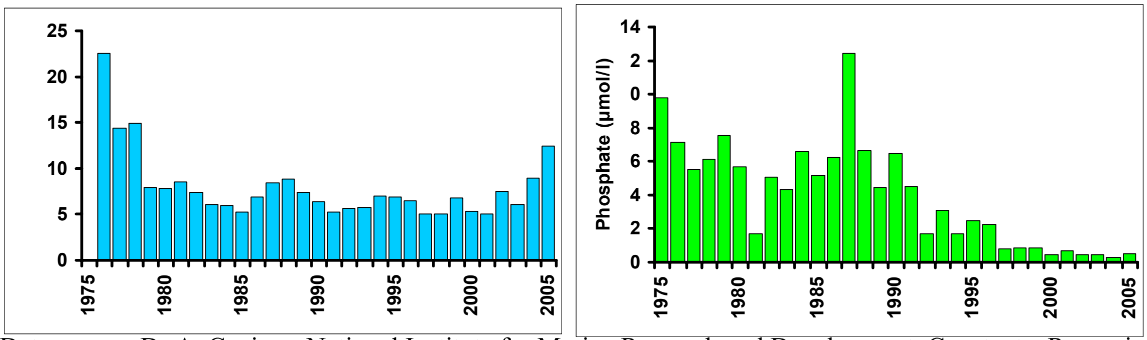
Data source: Dr M. David, Romanian Waters National Administration

5. Nutrient concentrations in NW Shelf waters

Annual average nutrient concentrations at Constanta are shown in Fig .5.1. This show a clear trend of decreasing phosphate concentrations throughout the 1990s, with much lower concentrations maintained through the early 2000s. The situation with nitrate is rather different with high concentrations which occurred in the late 1970s being maintained at substantially lower levels during the 1980s, 1990s and into the 2000s, albeit with an increase again in 2005, corresponding to elevated Danube flows (Figs. 3.1 and 3.2).

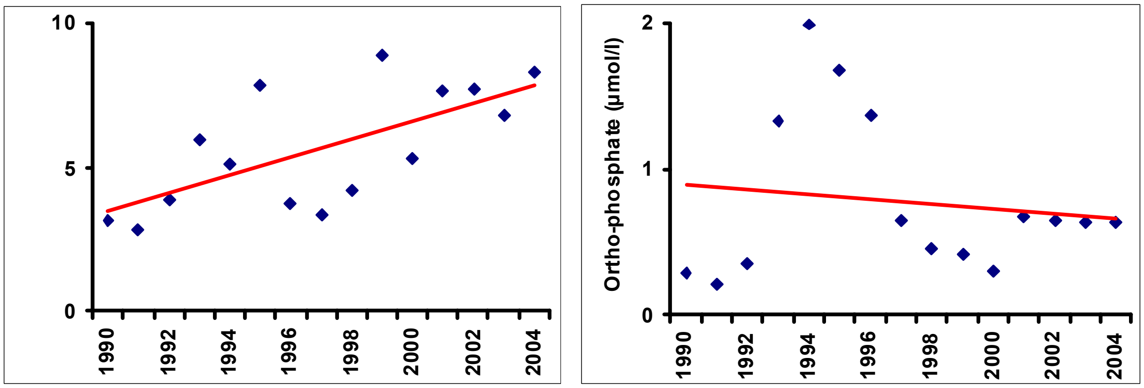
Fig. 5.2 illustrates the problems encountered when trying to amalgamate long-term data from a range of coastal water sites, rather than using data from a single site. Here, available data from all Romanian coastal water sites, sampled at depths shallower than 50m is shown. The overall impression is of decreasing phosphate levels and increasing nitrate levels (as would be inferred from Fig. 5.1, over the same time period), but with much greater inter-annual variability.

Figure 5.1. Annual average nutrient concentrations in surface waters near Constanta, Romania (1975-2005)



Data source: Dr A. Cociasu, National Institute for Marine Research and Development, Constanta, Romania

Figure 5.2. Amalgamated nutrient concentration data from the Romanian part of the Black Sea (1990-2004)



Data source: National Institute for Marine Research and Development, Constanta, Romania; BSERP database

6. Phytoplankton populations in NW Shelf waters

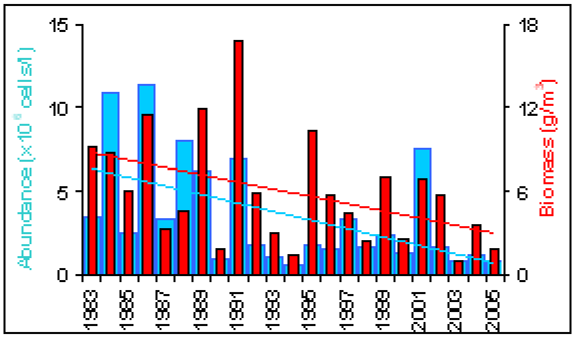
Phytoplankton data can be considered both in terms of major taxonomic groups and in terms of cell density and biomass-related factors. Of the latter two, biomass is the more important indicator, because of the large variability in size between different species and the fact that phytoplankton community composition changes on a seasonal basis.

Biomass is estimated from cell volume (biovolume) measurements. Chlorophyll-a is a pigment present in all photosynthetic phytoplankton, typically comprising 1-2% of dry weight, that is used as a surrogate of biomass. Remote sensing (satellite imagery) data can be used to monitor chlorophyll-like substances in large waterbodies, and this also is used as a surrogate of phytoplankton biomass. However, because different taxonomic groups also contain a mix of other types of chlorophyll (-b and –c) and additional photosynthetic pigments, even though the remote sensing images are calibrated against measured chlorophyll-a concentrations, there is some margin of error. Thus, the images can over- or under-estimate actual data, depending on what species are present, at different times of the year and in different areas of the sea. Remote sensing images are, therefore, a less reliable indicator of phytoplankton biomass than chlorophyll-a measurements.

6.1 Abundance and biomass

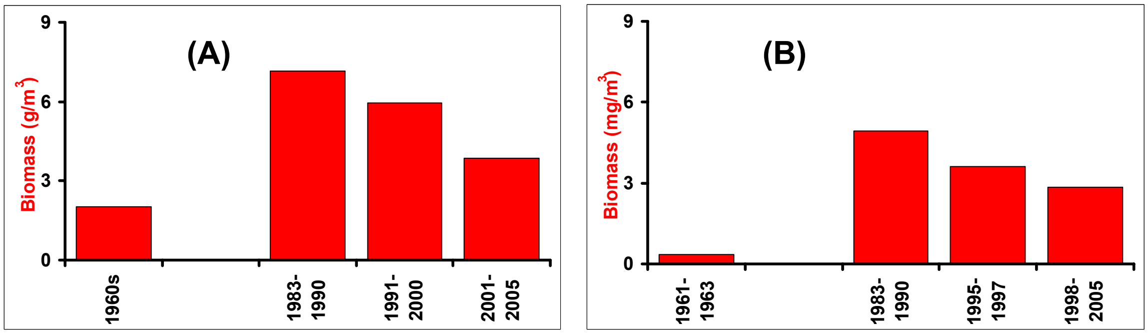
Phytoplankton cell density and biomass have shown considerable inter-annual variability over the last two decades (Fig. 6.1). In 2001, when a temporary return of hypoxic conditions was observed an increase in cell density occurred equivalent to that observed in the 1980s. However, when longer-term averages are considered, an emerging pattern of reducing plankton biomass can be seen, albeit with average levels observed in the last 3 years (2003-2005) at Constanta being typical of those occurring in the 1960s (see Fig. 6.2). Results from Cape Galata, while not as promising as those from Constanta, still show a trend in the right direction, with average phytoplankton biomass levels during 1998-2005 being nearly half of those measured during the 1980s.

Figure 6.1. Phytoplankton cell density and biomass (average annual data) offshore of Constanta, Romania (1983-2005)



Data source: Dr A. Cociasu, National Institute for Marine Research and Development, Constanta, Romania

Figure 6.2. Long-term (1960s-2000s) average phytoplankton biomass: (A) annual average data offshore of Constanta, Romania and (B) annual September values from three nautical miles offshore of Cape Galata, Bulgaria



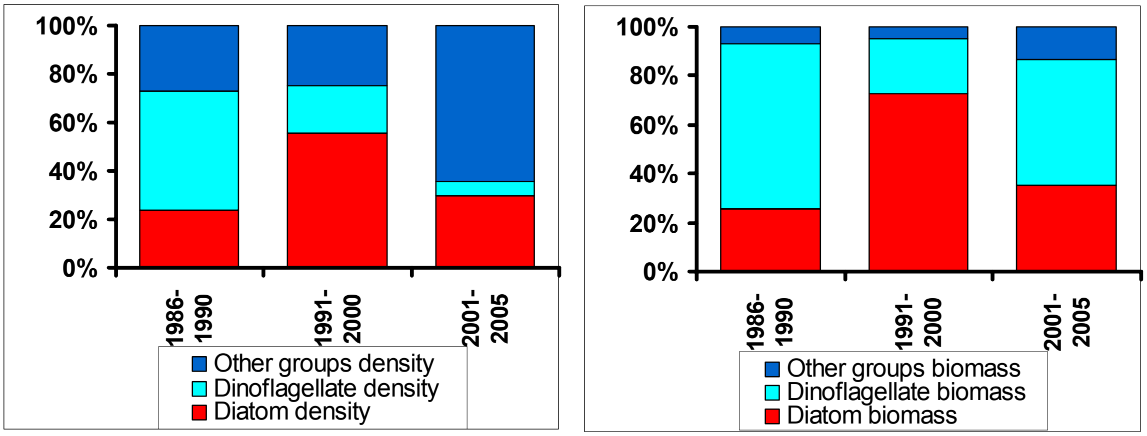
Data source: (A) Dr L. Boicenco, National Institute for Marine Research and Development, Constanta, Romania; (B) Dr S. Moncheva, Institute of Oceanology – Bulgarian Academy of Science, Varna, Bulgaria.

6.2 Community composition

The ratio between major phytoplankton taxonomic groups can also be used as an indicator of ecosystem status. As with phytoplankton biomass/abundance data there is considerable inter-annual variability. Nevertheless, grouping data from longer periods of time together, once again indicates that recovery is once again taking place (Fig. 6.3).

Unfortunately, taxonomic data are not available from the 1960s reference period, but it is clear that in terms of the contribution of major taxonomic groups to total phytoplankton biomass, at least, the situation in recent years has returned to a situation resembling that in the 1980s. Post-2000, the situation with regard to cell counts has been rather less straightforward, since the temporary return of eutrophic conditions in 2001 was reflected very severely in the phytoplankton population, with almost 100% of phytoplankton cell counts in the following year consisting of "other" groups (data not shown).

Figure 6.3. Phytoplankton community composition near Constanta, Romania (1986-2005)



Data source: Dr L. Boicenco, National Institute for Marine Research and Development, Constanta, Romania

6.3 Chlorophyll-like substances

Figure 6.4 shows remote-sensing images of the Black Sea, obtained using Seawifs satellite data. Although there is considerable monthly and yearly variability in the data, high chlorophyll levels were clearly evident in 2001, notably during the period May to September, confirming the temporary return of eutrophic conditions at this time.

However, during 2003, levels of chlorophyll-like substances appeared to be very low, particularly along the NW coastline where the Danube discharges into the Sea. Overall, there appears to have been lower chlorophyll levels in the Black Sea since 2001 than in previous years. November 2004 is particularly noticeable because of the dominance of blue colours, indicating considerably reduced chlorophyll levels (and therefore phytoplankton biomass) compared to the same month in previous years.

Figure 6.4. Chlorophyll-like substances in the Black Sea (1997-2005)

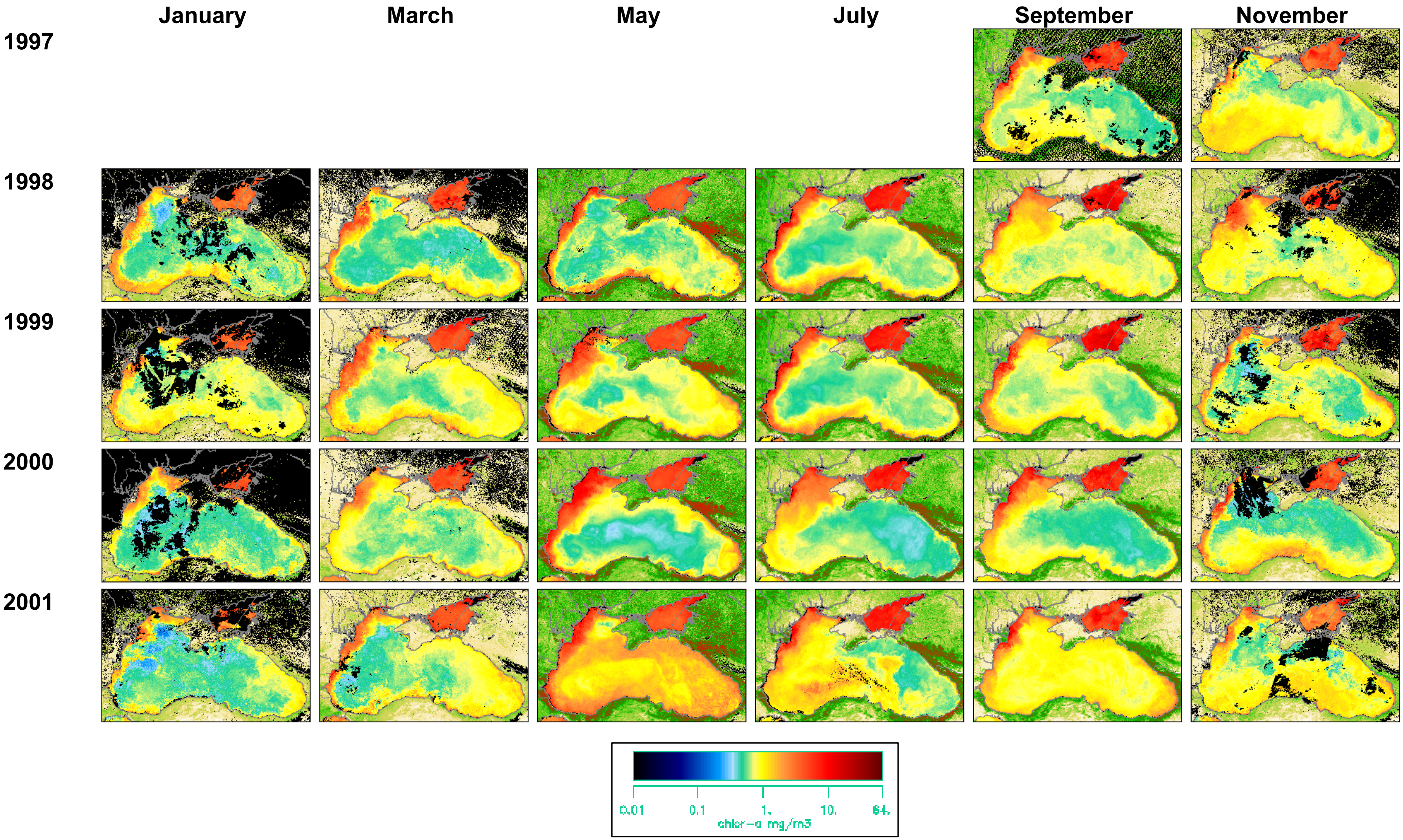
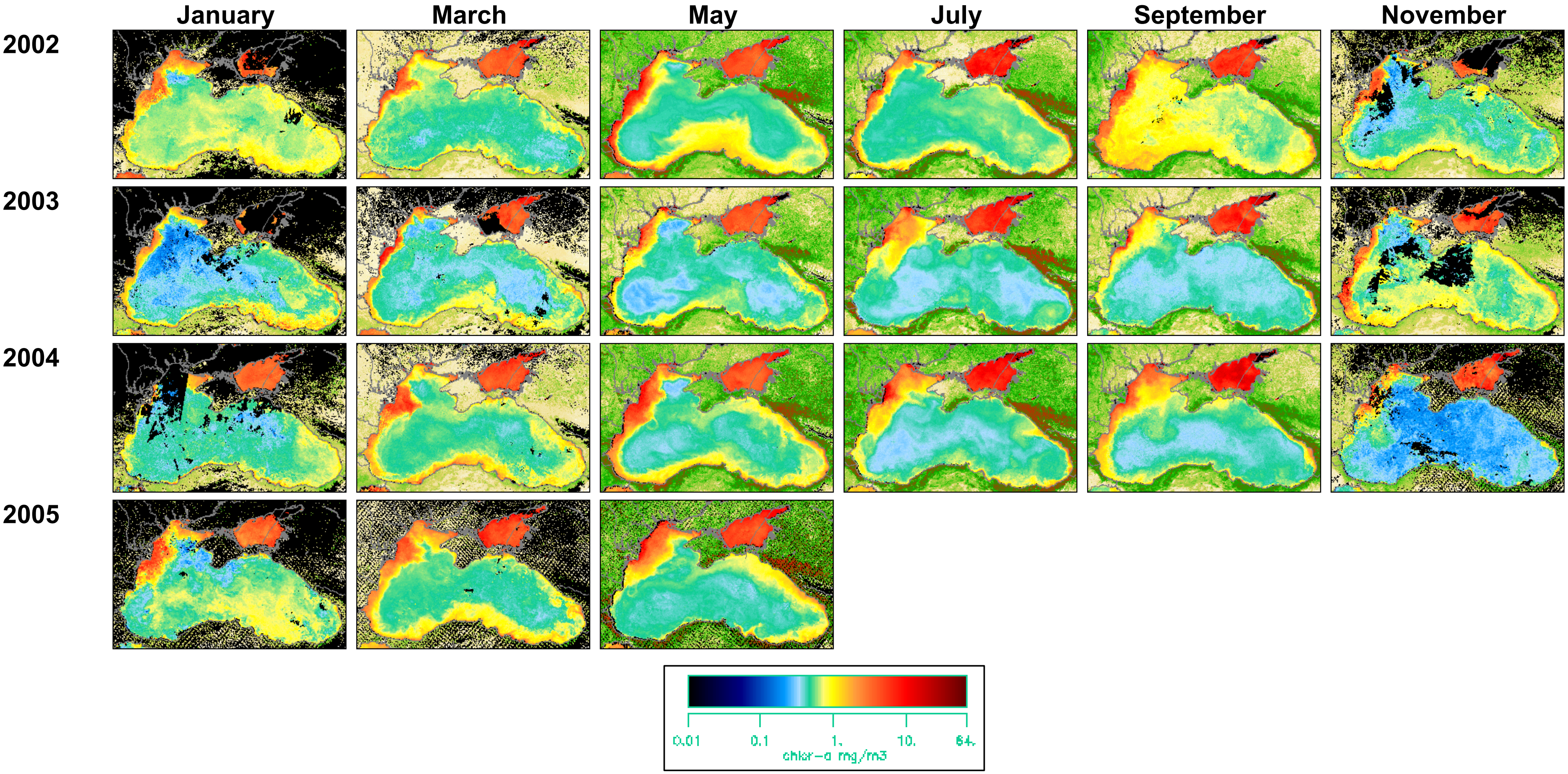


Figure 6.4 Continued…

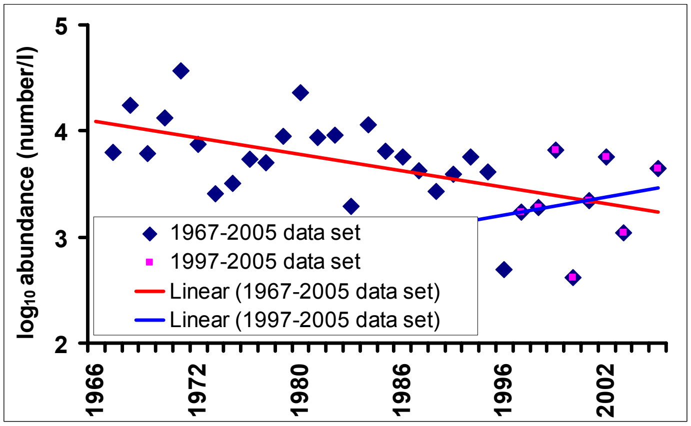


Data source: http://marine.jrc.cec.eu.int/frames/archive_seawifs.htm

7. Zooplankton

Microzooplankton in the Black Sea are dominated by Cladocera and Copepoda, long-term data for which present a fascinating reflection of the biological changes that have occurred since the 1960s. Fig. 7.1 shows a clear long-term trend of declining abundance, with extrapolation of the long-term linear regression line suggesting that in 2006, zooplankton abundance would be a full order of magnitude lower than that in 1967. However, there is a great deal of inter-annual variability in the figures, and when only more recent data are considered (e.g. a trend line for data from 1997-2005 is shown in Fig 7.1), these suggest that zooplankton abundance has actually levelled off or increased over the last decade.

Figure 7.1 Long-term summer abundance of Cladocera and Copepoda three nautical miles offshore of Cape Galata, Bulgaria (1967-2005)



Data source: 1967-1994, Prof. A. Konsulov, 1994-2002, Dr. L. Kamburska; 2003-2005, Dr K Stefanova, IO-BAS. All data provided by Dr Stefanova, Institute of Oceanology – Bulgarian Academy of Sciences, Varna.

8. Zoobenthos populations of the NW Shelf

The status of zoobenthos (sediment invertebrates) communities can be assessed using a range of reporting metrics:

- Abundance (the total number of all species per m^2 of sediment)
- Biomass (the total number of individual invertebrates (of all species) per m^2 of sediment
- Number of species present (the total number of species present at any one site)
- Zoobenthos indices

Sampled were collected during one of the Phase I BSERP research cruises (2003), and it is intended to re-sample these sites in the Phase II cruises during 2006 for comparative purposes to see whether/how the situation has changed

8.1 Abundance and biomass

A large area of increased abundance/biomass was present in front of the Danube delta and Constanta (Romania), with decreased abundance in front of Odessa (Ukraine) - possibly due to contamination by pesticides – and at more southerly Bulgarian sites.

Abundance/biomass clearly decreases offshore. The pattern of decreasing abundance/biomass in southerly waters is due to the reduced influence of major rivers (the Danube and Dniester) which provide an import source of nutrients and organic carbon which are cycled through the food chain.

8.2 Species diversity

The higher species richness in shallower waters (Fig. 8.1) is associated with good dissolved oxygen conditions. The observed lower diversity in deeper areas was fully expected due to natural oxygen depletion with increasing depth in the Black Sea. (e.g. Fig. 8.1). In the shallow Danube delta and Odessa areas low benthic diversity is preconditioned by the highest content of silt/clay fraction in sediments and aggravated by the decreased oxygen concentration associated with anthropogenic eutrophication. The effect of toxic substances may also play a role in the Odessa area (data not shown).

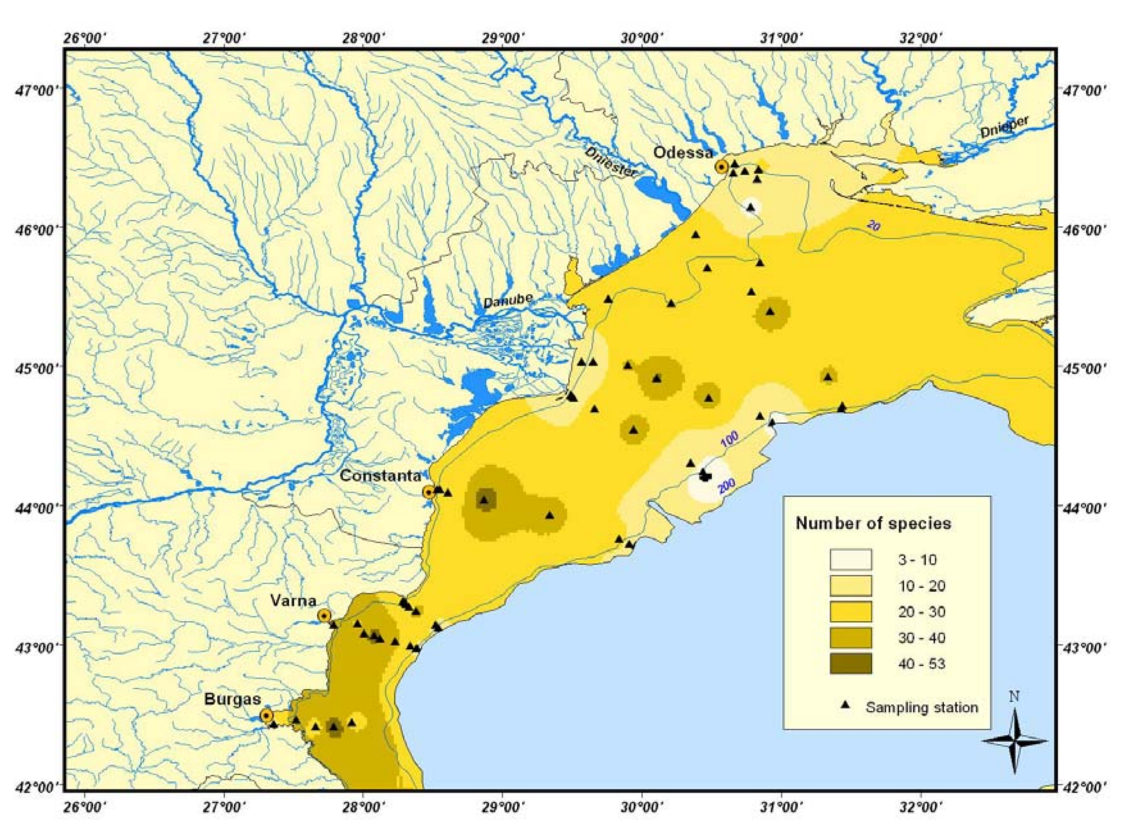
While the 2003 data provide a good snapshot of zoobenthos biodiversity, an example of trends in biodiversity is given in Fig 8.2. Here, the improving situation can be seen clearly – the number of species has doubled since the mid-1990s, albeit with some way to go before the "reference" situation of the1960s can be re-established.

8.3 Zoobenthos indices

A range of zoobenthos indices exist for report purposes. Fig 8.3 shows results for the NW Shelf using the AZTI Marine Biotic Index (AMBI) – one which provides rather optimistic results compared to other zoobenthos indices:

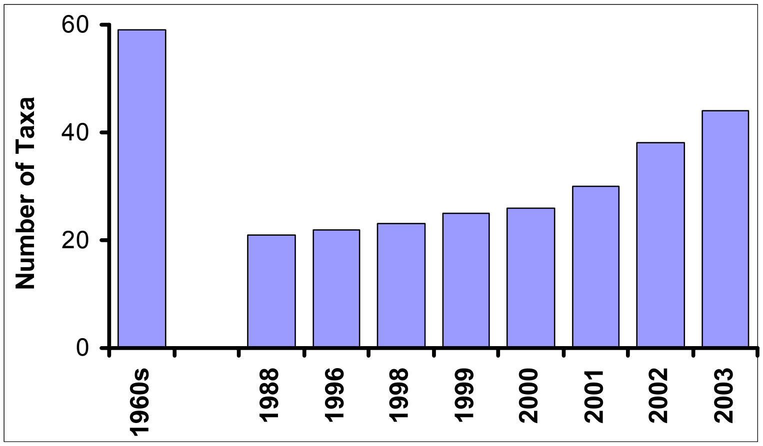
- The Bulgarian coastal area is distinguished by good, occasionally high zoobenthic status.
- The Danube plume area is characterised by moderate to poor zoobenthic status, although improving status is evident in more southerly Romanian wasters (with increasing distance from the Danube).
- The Dniester area coastal stations are moderately disturbed with an improving situation offshore.
- The AMBI results for most Odessa area stations (only slightly disturbed) contradict those of other zoobenthic indicators (lowest abundance of crustaceans, lowest species richness, absence of adult molluscs, etc.).
- Deep area stations are generally considered to be undisturbed.

Figure 8.1. Macrozoobenthic species distribution in the NW Shelf (2003)



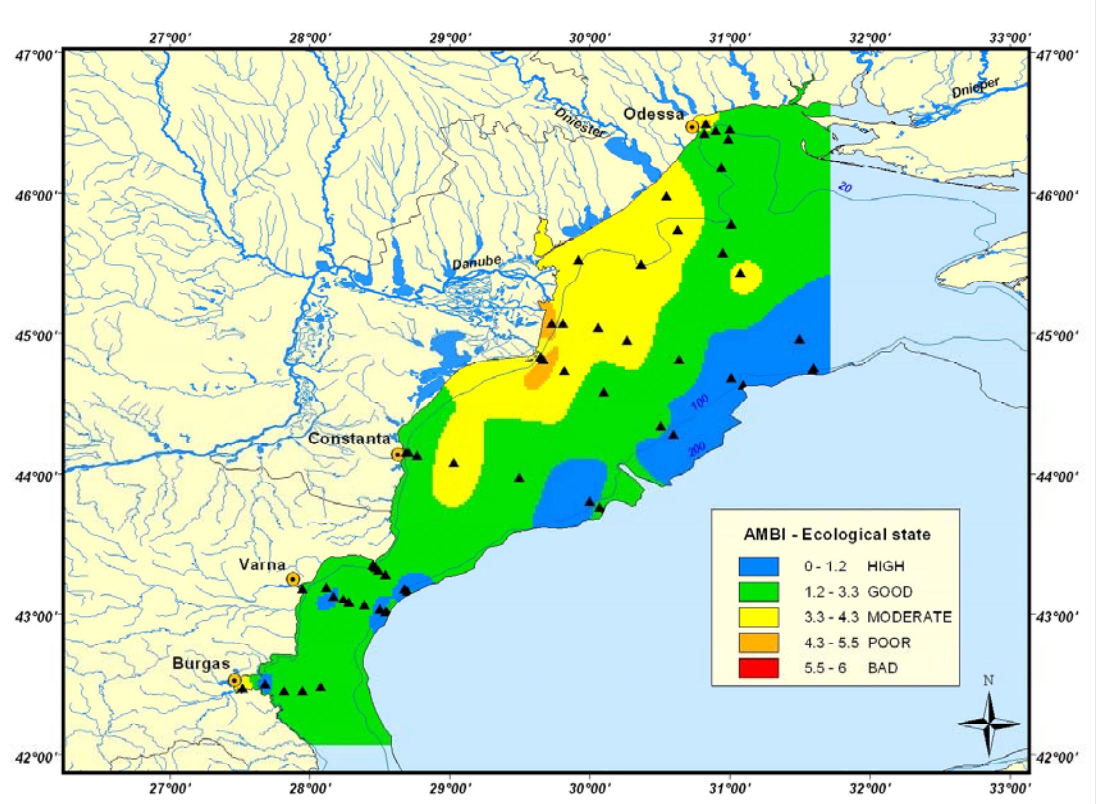
Data source: Todorova, V and Konsulova, T., IO-BAS (2006) Ecological state assessment of zoobenthic communities on the North-Western Black Sea Shelf – the performance of multivariate and univariate approaches. Presentation made at the Black Sea Scientific Conference, 8-10 May 2006, Istanbul.

Figure 8.2. Number of macrozoobenthos species near Constanta, Romania (1960s-2003)



Data source: Dr C. Dumitrache, National Institute for Marine Research and Development, Constanta, Romania

Figure 8.3. AZTI marine biotic index results - geographic distribution (2003)



Data source: Todorova, V and Konsulova, T. (2006) Ecological state assessment of zoobenthic communities on the North-Western Black Sea Shelf – the performance of multivariate and univariate approaches. Presentation made at the Black Sea Scientific Conference, 8-10 May 2006, Istanbul

9. Dissolved oxygen status of NW Shelf waters

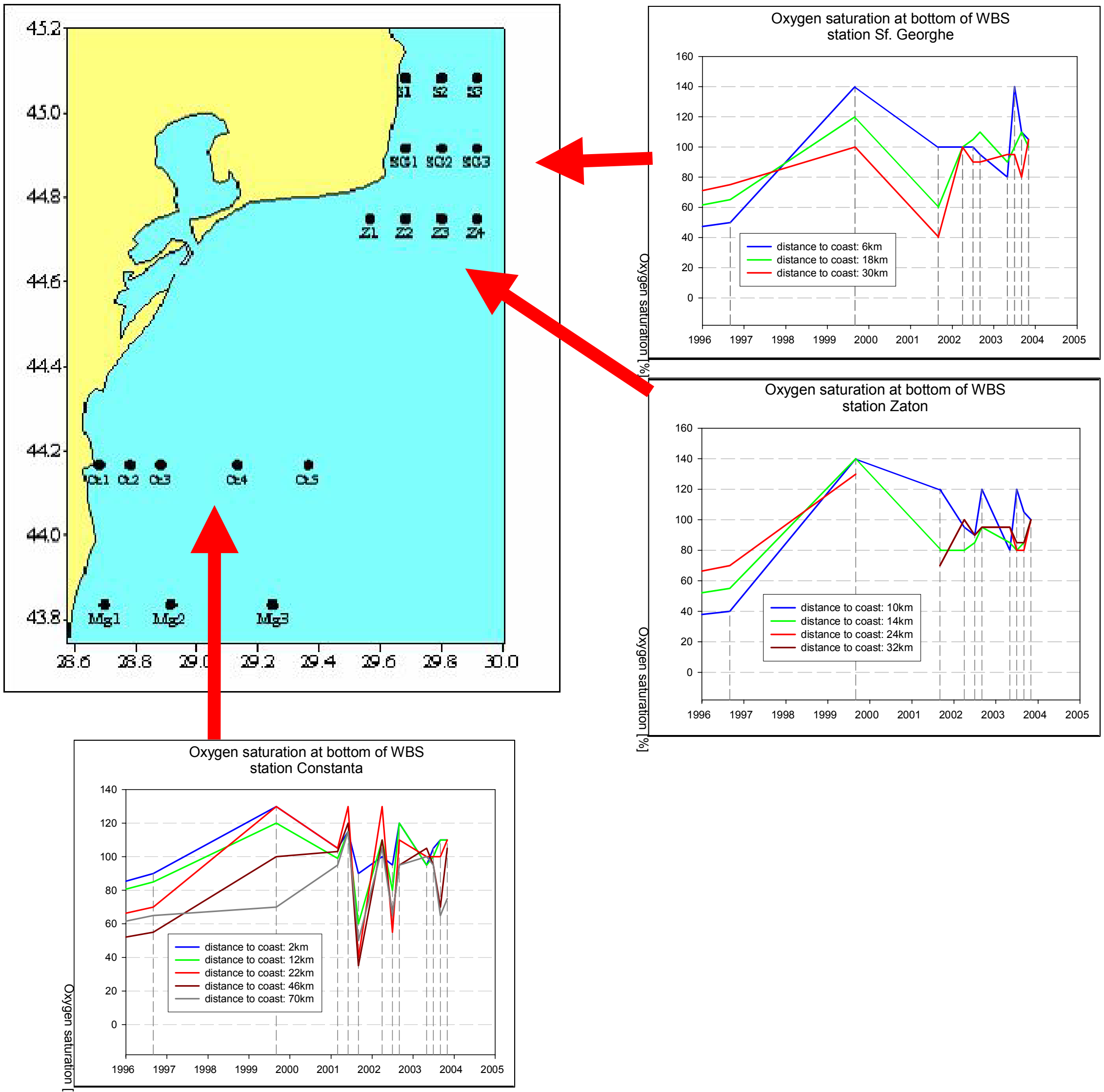
Between the early 1970s and early-mid 1980s, the area of the NW shelf affected by low dissolved oxygen conditions (hypoxia) increased in size (data not shown). However, by the mid 1990s the situation was beginning to recover and had improved further by 1999 (Fig. 9.1).

A return of hypoxic conditions in 2001 was clearly recorded in mussel population age structure statistics (mussels form annual growth rings, similar to trees). Thus, samples collected from coastal waters between the Danube delta and Odessa (Ukraine) regions (at 25 m depth) during 2003 contained very few older (>2 years) mussels, since these has died during the 2001 event (data not shown).

Fig. 9.1 reveals that while DO levels fell substantially in Romanian coastal during summer 2001, the overall trend since 1996 has been one of improving status. A transient hypoxic event occurred close to Constanta in summer, 2005, resulting in a fishkill. While, the affected area appears to have been highly localized within Romanian coastal waters, a hypoxic event was also reported in the Ukrainian part of the NW Shelf during summer of the same year.

Dissolved oxygen measurements taken just above the sediment should be one of the best indicators of trophic status. However, robust data are very expensive to collect. In reality, such monitoring needs to be continuous (e.g. measurements taken every 30 minutes to account for diurnal fluctuations in dissolved oxygen levels), with very good spatial resolution. Manual monitoring is, therefore, not pragmatic. Thus, a network of buoy-mounted sondes/probes is required to produce robust data, with regular (perhaps fortnightly) servicing/re-calibration of the instruments, rather than the series of snapshot values illustrated in Fig. 9.1. Clearly this is not possible, given the current financial restraints. A single day of hypoxia will strongly affect zoobenthos populations for years in the future.

Figure 9.1. Dissolved oxygen content of Romanian coastal waters (1996-2004)



Data source: Cociasu *et al.* (2003-2005) Deliverables: D7.1 Romanian report; D7.3 Romanian annual reports 2001-2002; and D7.6 "Summary report on field and laboratory work in 2001-2003 in comparison with previous observations in the Western Black Sea" from the project "Nutrient Management in the Danube Basin and its impact on the Black Sea" supported under contract EVK1-CT-2000-000 of the 5th EU Framework Programme, http://danubs.tuwien.ac.at

10. Discussion

10.1 Nutrient loads and levels

As discussed in Section 5, there is a paucity of data to illustrate trends in nutrient concentrations within the NW shelf as a whole, though there is one particularly useful dataset from Romanian waters, albeit likely to be influenced to a large extent by changing local nutrient loads from land. NIMRD data (not shown) suggest a major decrease in nutrient levels at Sulina, close to where the Danube discharges into the Black Sea, but this is a coastal site which again is likely to reflect changes in local nutrient discharges from land. The extent of the decrease in nutrient levels at this site certainly cannot be explained by the relatively small decreases in Danube loads observed at Reni, particularly with regard to nitrate, since about half of the flow in the Danube is groundwater–derived, with available groundwater nitrate data (not shown) failing to show a major decrease in concentration.

Fixed nitrogen (organic and inorganic) applied to land as fertiliser (including livestock manure) is more rapidly exported to rivers/sea in surface runoff than via groundwater. (Groundwater is a relatively unimportant supply route of phosphorus to surface waters.) So, in the years following the economic collapse of the late-80s-early 90s when regional livestock numbers and inorganic fertiliser sales rapidly declined, it is possible that nutrient loads to the sea via surface water runoff/soil erosion) did decline substantially, but data to support, such a theory is mixed. Certainly, data from Reni show flow-corrected inorganic nitrogen loads from the Danube hardly to have changed since 1988; but the trend in total phosphorus loads is very different, illustrating an obvious decrease since 1998, and with a particularly rapid fall in 1992/1993 compared to previous years.

Much greater success has been achieved with reducing phosphorus than inorganic nitrogen loads to the Black Sea. This success appears primarily to have been the result of reducing phosphate loads to land as both inorganic fertiliser and as livestock manure. However, in many countries a shift away from intensive livestock units to more extensive livestock production techniques has almost certainly contributed to the long-term trend.

10.2 Ecology, organic carbon and oxygen balance

The microzooplankton results (Section 7) suggest that a huge change in Black Sea ecology has occurred since the late 1960s, and it would be almost impossible to argue otherwise. However, the trend is in the opposite direction to that which would be expected if eutrophication was the only environmental problem, since higher nutrient levels typically result in higher abundance and biomass of phytoplankton, zooplankton and higher predators; not a 10-fold decrease, as Fig. 7.1 could suggest. Clearly, then, the zooplankton results need to be viewed in the light of wider environmental issues:

The **phytoplankton** results (Section 6) are very interesting. Biomass levels have been on a downwards trend since the worst eutrophic period of the 1980s, as would be expected if nutrient levels within the Sea had fallen. Supporting evidence for the downwards trend in phytoplankton biomass levels in the whole of the Black Sea (not just two sites, relatively close to land) is provided by remote sensing images (Fig. 6.4).

Recent unpublished data from the BSERP July/Sept 2006 research cruise suggests that along a transect within 15-20 miles of the Dniester River mouth, organic loading and inefficient cycling of organic matter still allow hypoxic conditions to occur. This cruise also found *Noctiluca*[3], a heterotrophic phytoplankter to be present in large densities at the outer edge of influence of the Danube inflow. *Noctiluca* is recognized as an indicator of eutrophic conditions in the Black Sea, and a gradual shift towards non-photosynthetic phytoplankton (*Noctiluca* and other taxa) could help explain, in part at least, the observed trend of decreasing chlorophyll levels. Fig 6.3, while not including data for the 1960s, still demonstrates the huge changes that have taken place in major phytoplankton taxonomic groups, since the phytoplankton community during this period was dominated completely by dinoflagellates and diatoms.

Over-fishing is still considered one of the most important environmental problems facing the Black Sea. It doesn't matter whether a relative reduction in the abundance/biomass of top-level predators (e.g. horse mackerel) or lower level consumers is the consequence, the result is reduced grazing pressure on zooplankton, and therefore an increase in grazing pressure on phytoplankton. Fig. 6.4, showing a trend of decreasing levels of chlorophyll-like substance, supports the theory that zooplankton grazing pressure has increased since 1997. However changing chlorophyll levels can also be interpreted in another way: that zooplankton levels mirror the "carrying capacity" of the sea for phytoplankton, so reducing chlorophyll levels (as an indicator of phytoplankton biomass) would be expected to result in lower zooplankton biomass. Unfortunately, microzooplankton biomass data are not available, only abundance data.

Mnemiopsis leidyi. This fast-reproducing comb jelly was first identified in the Black Sea during the early 1980s and its impact on native biota and fisheries has been devastating. By the mid 1990s, estimates of its total biomass in the Black Sea and Sea of Azov approached 1 billion tonnes. *Mnemiopsis* actively feeds on fish larvae and zooplankton, but only passively on phytoplankton. The issue here is the relative feeding pressure *Mnemiopsis* exerts on fish larvae compared to zooplankton, which is not fully understood. Certainly the downwards trend in cladocerans and copepods (Fig. 7.1) started a long time before *Mnemiopsis* was first identified in the Sea. Now that a major predator of *Mnemiopsis* (another invasive comb jelly, *Beroe ovata*) is abundant in the Black Sea, increasing in numbers since the mid-1990s, this could have helped microzooplankton populations to recover to higher levels than those observed in the 1990s.

The overall picture that emerges of ecology is one of recovery. However, the presence of alien species may have had a greater and more long-term impact than previously thought. There is evidence of a new "type" of ecosystem having established in the NW Shelf at least, leading some experts to consider that a full return to 1960s ecological conditions may prove to be even more challenging than originally thought, despite further planned reductions in nutrient loads.

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[3] *Noctiluca* enumeration is undertaken as part of microzooplankton monitoring, because of the relatively large size of this dinoflagellate genus (typically 400-600 μm).