Restoring the Black Sea in Times of Uncertainty

BY LAURENCE D. MEE, JANA FRIEDRICH, AND MARIAN T. GOMOIU

It was not until the late 1980s that the international community became aware of the magnitude of the ecological crisis underway in the Black Sea. Major components of the ecosystem had begun to collapse as early as 1973 when records show significant areas of summer hypoxia (low oxygen content) on the northwestern shelf as a result of eutrophication (an increase in the water's nutrient content, which enhances plant growth, but leads to oxygen depletion). In a remarkably short space of time, perhaps as little as five years, these hypoxic areas extended over most of the shelf, some 12 percent of the surface of the 420,000 km^2 Black Sea (Zaitsev, 1992). In the late 1980s, the hypoxic events had become so severe that huge quantities of benthic organisms had died and were washed up and rotting on the beaches of Romania and Ukraine. At the same time, commercial yields of the relatively abundant anchovies had plummeted throughout the Black Sea following a decade of decline of fisheries of higher-value predatory species. Then, there was the arrival of the uninvited comb jelly *Mnemiopsis leydi*, transported in ballast water from the eastern seaboard of America. The *Mnemiopsis* population in 1989 was estimated as 800 million tonnes with biomasses as large as 5 kg/m^2 in places (Vinogradov, 1992). By 1992, when the alarm bell was sounded for international support to the Black Sea (Mee, 1992), the future of this unique marine system seemed grim. Social and economic collapse in the countries emerging from communism gave the Black Sea a window of opportunity for recovery and for the countries in the region to put management systems in place to enable recovery and avoid further decline. These systems rely on sound and relevant scientific information. In this article, we shall examine the management systems, discuss the scientific uncertainties, and take a look at some of the actions being taken to reduce these uncertainties.


Signs of health?

Phyllophora attached to mussels sampled at 41-m depth on the Black Sea's northwestern shelf in 2004. Photographs by Laurence Mee.

'But tell me—why is he kicking his heels around here? What is he after?'
'He's studying marine life.'
'No, no, that's not it, old man,' sighed Layevsky.
'From what I gathered from a passenger on the steamer, a scientist, the Black Sea's poor in fauna, and organic life can't exist in its depths owing to the excess of hydrogen sulphide. All serious students of the subject work in the biological stations of Naples or Villefranche. But Von Koren's independent and stubborn. He works on the Black Sea because no one else does.'

– Anton Chekhov, *The Duel*, 1895

RETROSPECTIVE ON A CRISIS IN THE BLACK SEA ECOSYSTEM

Though the catastrophic decline of key Black Sea habitats first occurred in the early 1970s, it followed a series of more subtle but nonetheless significant earlier ecosystem changes. Monk seal populations, for example, began to dwindle early in the twentieth century as sensitive habitats were subjected to development for tourism and human settlements (Zaitsev and Mamaev, 1997). The fertile nearshore seas were particularly vulnerable to opportunistic predators such as the carnivorous sea snail *Rapana thomasiana*, which arrived from the East Asian Seas in the mid 1940s (Zaitsev, 1992). *Rapana* devastated nearshore, hard-bottom benthic communities such as the oyster beds along the Russian and Georgian coasts and fundamentally altered the nature of benthic communities along those coasts. Many nearshore phytobenthos communities were also early victims of change. Eighty-six percent of the biomass of the once abundant brown algae *Cystoseira* was lost from the Romanian coast between 1971 and 1973, during which time it lacked resilience to recover from particularly severe winter ice (Vasiliu, 1984).

The weakening of system resilience (the ability to recover from disturbance) proved particularly fateful for the Black Sea's benthic and pelagic ecosystems; this was most dramatically demonstrated in its response to eutrophication on the northwestern shelf. The shallow shelf covers an area of about 50,000 km^2—12 percent of the Black Sea's surface—and receives the discharge of Europe's second and third largest rivers (the Danube and Dnipro), together draining major areas of 12 countries. As in most parts of the world, agricultural practices were radically transformed in the Black Sea region beginning in the early 1960s by increased use of mechanization, agrochemicals, and by intensification of animal production (up to 1 million pigs in a single farm in Romania!). Inevitably, there was leakage of agricultural wastes (i.e., nutrients) into surface waters and ultimately the Black Sea. Additional nutrients, some new, also arrived from human activities, such as lifestyle-related changes that increased the use of phosphate detergents, of fossil fuel use, and improved sewerage (Figure 2). The outcome was a gradual increase in phytoplankton blooms in the shelf area and the onset of eutrophication.

The open Black Sea is permanently anoxic below about 100-m depth. Prior to eutrophication, however, the shallow northwestern shelf of the Black Sea was host to huge beds of bivalves (mainly mussels) and red algae. The red algae *Phyllophora nervosa* was the keystone species for a benthic ecosystem that covered a huge area, 11,000 km^2 of the shelf. This "red" assemblage provided a habitat for about 118 species of invertebrates and 47 species of fish, some of them commercially important (Zaitsev, 1992). *Phyllophora* was vulnerable to light limitation and hypoxia and its decline in the 1970s was precipitous. The remaining mussel communities were initially more resilient due to their ability to withstand short periods of severe hypoxia.

The summer dead zone itself extended from 3,500 km^2 in 1973 (the first major recorded appearance) to 30,000 km^2 by 1978, a remarkable rate of development (Zaitsev, 1992). As the phenomenon gradually extended in time and space, large areas of mussel bed and associated fauna eventually succumbed. By 1989,

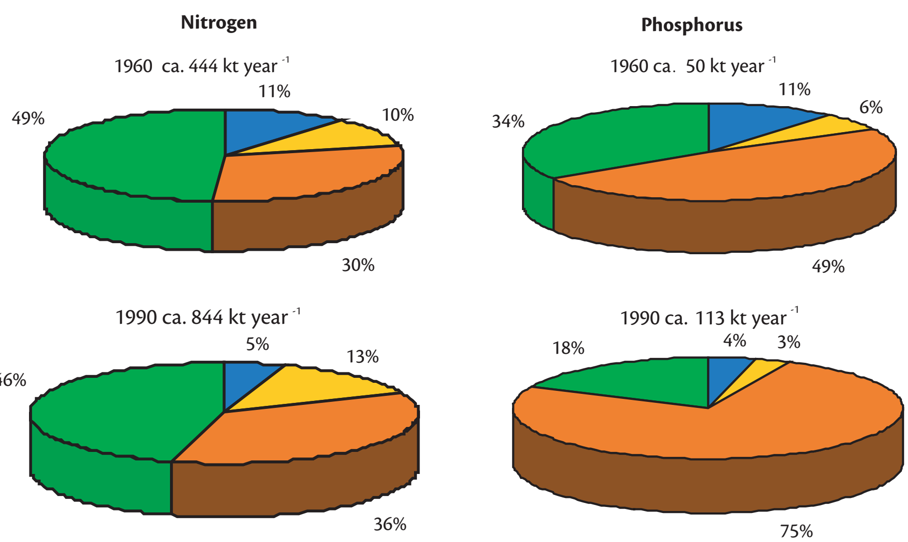

Figure 2. Total nutrient emissions by human sources and background values for the Danube River basin in 1960 and 1990, based on Schreiber et al. (2004).

there had been several massive mortalities of benthos resulting in thousands of tons of dead animals.

CONCEPTUAL MODEL OF SYSTEM STATE CHANGE

A simple conceptual model illustrates the non-linear response of the benthic system to increasing nutrient loads (Figure 3). Initial conditions consist of a phytobenthos-(*Phyllophora*) dominated system (in which bivalves are usually also present). The system demonstrates resilience until a critical threshold (point "1") is reached. Resilience is provided by the filtering capacity of bivalves (*Mytilus*) together with the nutrient assimilation and net oxygen production by the algae. These act as a self-regulatory system. At threshold 1, the system becomes shaded by the increased water-column phytoplankton and the algal mats decline sharply. Components of the system relying on a keystone phytobenthos species would also be lost leaving a bivalve-dominated benthic system. At some point, the bivalve community is unable to cope with sudden food supplies from heavy blooms and detritus, and the excessive supply creates a huge oxygen demand leading to bottom hypoxia. Under hypoxic conditions, mussels close and rely on their glycogen supply, and their filtering capacity is lost. Furthermore, when conditions become anoxic, phosphorus and ammonia pools in the near surface sediments are released, further contributing to the nutrient loading of the system. At threshold 2, where hypoxia persists longer than mussels can be sustained by their glycogen supply, resilience is lost and the system collapses. At this stage, the overall ecology of the shelf is entirely dominated by the pelagic system, a system that may also demonstrate thresholds and non-linearities with increasing nutrient loading (as evidenced by Zaitsev, 1992 or modelled by Kemp et al., 2001). Moreover, in the case of the Black Sea, the pelagic system has also suffered major alterations as a result of overfishing of predators and the massive development of the opportunistic comb jelly, *Mnemiopsis leydi*.

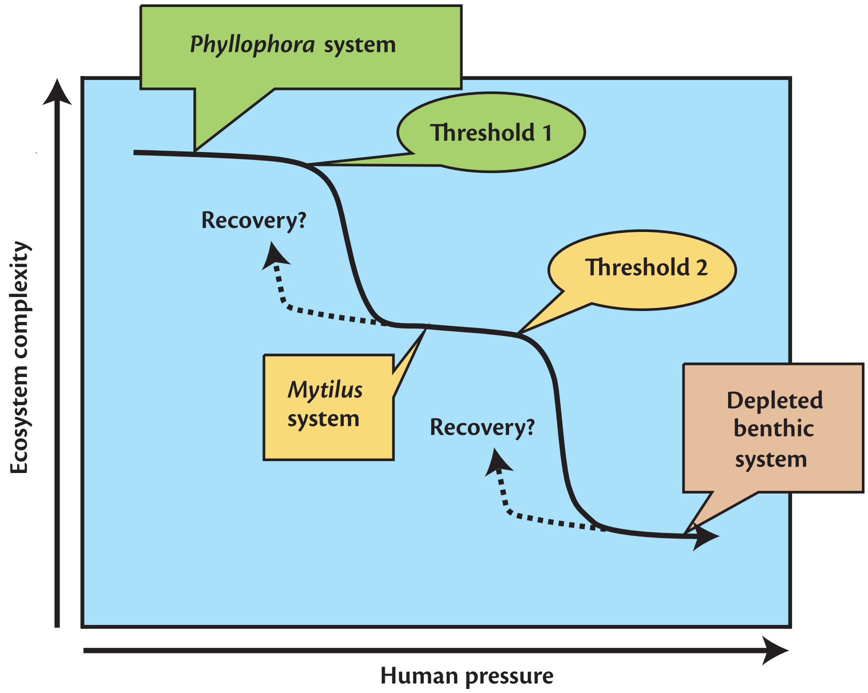

Figure 3. Conceptual model of decline of the benthic systems in the northwestern shelf of the Black Sea. The system declined through a series of resilient steady states indicated here by characteristic assemblages. The thresholds for the collapse of each steady state are discussed in the text. Note that the system may exhibit hysteresis or even irreversibility when the human pressure is removed.

The conceptual model helps to appreciate the management conundrum. It is important not to exceed any threshold because the overall system may demonstrate hysteresis or even irreversibility; lowering nutrient loading does not automatically imply that the system will return to earlier levels of organization. The problem is that current science has not been very effective at identifying thresholds and we lack sufficient experience to predict how most non-linear marine systems will respond to management actions.

Social and economic circumstances in the Black Sea may be giving the system a window of opportunity for recovery and enabling us to understand how a eutro-

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phied system responds to change. The collapse of communist regimes characterized by central planning led to economic failure. This failure, in turn, resulted in dramatic decreases in emissions of nitrogen and phosphorus compounds and a decrease in their discharge to the Black Sea (in the case of phosphate, almost to 1960s levels). These political events are providing a unique opportunity to study the system for early signs of recovery, some of which we report in this article. First though, we will explain how the countries in the region are preparing a new management framework and discuss the science needed to support it.

AN ADAPTIVE MANAGEMENT FRAMEWORK

Managing a severely damaged ecosystem—including the human dimension—in countries with economic hardships is difficult, but doing this with high levels of uncertainty regarding likelihood of recovery is a daunting challenge. Fortunately, in the case of the Black Sea, national environmental authorities have shown considerable willingness to develop the necessary management tools, and support for these has been forthcoming from the Global Environment Facility (GEF) and the European Union. Without considerable investment, these tools will not solve the problem of course, but they do provide a mechanism for change to happen. The six Black Sea coastal countries (Bulgaria, Georgia, Romania, Russia, Turkey, and Ukraine) signed the *Bucharest Convention for the Protection of the Black Sea* in 1992 (it entered into force in 1994), and the *Black Sea Action Plan* in 1996. Subsequently, jointly with the eleven Danube countries that established the International Commission for the Protection of the Danube River, they agreed on overall objectives and initial targets for limiting nutrient discharge into the Black Sea. Implementation of these objectives will require increased action at all levels of society.

The conceptual basis underlying these objectives and targets is "adaptive management." Adaptive management, originally termed "adaptive environmental assessment and management" (Holling, 1978), recognizes that the level of scientific uncertainties in natural systems is often too great to permit long-term management decisions based upon conceptual modeling or knowledge of a limited part of the system. Adaptive management offers a practical means of integrating knowledge over social and economic as well as ecological scales (Walker et al., 2002). It can accommodate unexpected events by encouraging approaches that build system resilience. Adaptive management will only be effective if all the key actors remain engaged and are fully aware of the need for good science to reduce the inherent uncertainties of managing non-linear systems.

Figure 4 illustrates the implementation and scientific requirements of adaptive management. The process starts with the completion of an overall assessment of the state of the marine environment and the social and economic reasons for its decline (the procedure is termed a "Transboundary Diagnostic Analysis" and is now applied in most GEF international waters projects). Having agreed on "the facts" as well as recognizing the uncertainties, all of the stakeholders involved agree upon a long-term vision of how they would like to see the environment in the future. This vision is supported by measurable "Ecosystem

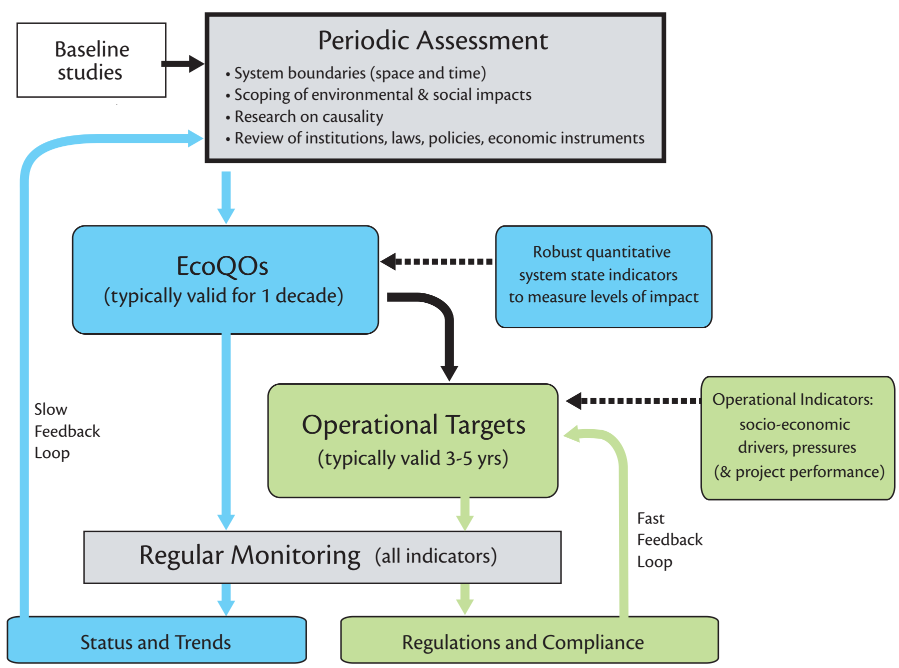

Figure 4. Framework for adaptive management for the Black Sea. Figure based on Mee (2004).

Quality Objectives" (EcoQOs) that are understandable to all stakeholders involved (usually including the general public). Setting EcoQOs is not a simple process—what is desirable may not be achievable— and they must be supported by sound science and good ecological indicators. There are no presumptions on exactly how the long-term EcoQOs are to be reached, however. All stakeholders agree on a first pragmatic step towards the EcoQOs, planned within a politically sensible timeframe and defined by an operational target (Figure 4). Achievement of this target is monitored carefully and scientific research is conducted to see how the socio-ecological system responds. The research gradually reduces uncertainty about management outcomes and helps policy-makers to define the next step. From time to time, the overall vision can also be revisited as the perception of environmental quality gradually changes.

In the Black Sea, the first integrated assessment, completed in 1996 with the support of a U.S.-funded GEF project ($7 million) (Black Sea Environmental Programme, 1996a), was based on information from existing research and monitoring. From the outset, it was clear that there were many knowledge gaps in our understanding of the socio-ecological system but there were enough hard facts to enable governments to agree on an overall vision and the initial actions towards its accomplishment. For the long-term vision, underwritten by all six governments, it was agreed to strive for

a biologically diverse Black Sea ecosystem with viable natural populations of higher organisms, including marine mammals and sturgeons, and which will support livelihoods based on sustainable activities such as fishing, aquaculture and tourism in all Black Sea countries (Black Sea Environmental Programme, 1996b, p. 5).

This political statement had many nuances in a system where sturgeons were disappearing, monk seals were on the verge of extinction, and fishing and tourism were in steep decline! Of course, it would be naive to imagine that the Black Sea could ever return to a pristine state—especially following the arrival of so many opportunistic species—but this is not the intention of the vision statement. Nevertheless, it does open up deeper and yet unanswered ethical questions about exactly what we mean by sustainable use of the marine environment.

For the priority issue of overcoming eutrophication, a joint memorandum by the Black Sea and Danube Commissions clarified further the EcoQO and first operational targets (Table 1). These targets endeavor to return the Black Sea to its pre-eutrophic conditions in the long-term while holding the nutrient discharges at their mid-1990s low in the short term in order to see whether or not the system recovers and to what extent. In effect, this is a large-scale experiment and the governments in the region are eager to see its results; there is justified pressure for renewed economic development and the short-term costs of nutrient reduction are high.

Table 1: Current Adaptive Management Targets for the Black Sea and Danube Basin

Long-term Objective (EcoQO)	"to take measures to reduce the loads of nutrients and hazardous substances discharged to such levels necessary to permit Black Sea ecosystems to recover to conditions similar to those observed in the 1960s"
First Operational Target	"urgent measures should be taken in the wider Black Sea Basin in order to avoid that the loads of nutrients and hazardous substances discharged into the Seas exceed those that existed in the mid 1990s (these discharges are only incompletely known)"

Source: Memorandum of Understanding between the International Commission for the Protection of the Black Sea (ICPBS) and the International Commission for the Protection of the Danube River (ICPDR) on common strategic goals. Signed in Brussels, 26 November 2001. 3 pp. ([Online] Available at: http://europa.eu.int/comm/environment/enlarg/pdf/danube_memorandum.pdf).

OVERCOMING SCIENTIFIC UNCERTAINTIES FOR FUTURE MANAGEMENT OF EUTROPHICATION

The International Study Group on the Black Sea

Until now, the first operational target for the adaptive management of eutrophication appears to have been achieved, not by human interventions but by economic failure. This situation cannot continue for long: six of the eleven Danube basin countries are now members of the European Union and three more will soon be joining. The economies of Ukraine and Russia are also strengthening and Turkey has maintained high economic growth for over a decade. It is now an urgent matter to set more carefully defined adaptive management goals, but this requires better knowledge of how the system is functioning and the dynamics of current recovery. Unfortunately, the economic and social crisis in the region seriously impaired scientific capacity. In 1990, for example, there were over 20 local medium-sized research ships in the region, but now even the two or three that remain have aging gear and operate infrequently due to restricted operational budgets. Except for Romania, most regular environmental monitoring effectively ceased around 1990. Without the occasional support of visiting ships and international cooperative projects such as CoMSBlack, NATO-TU, and the EU's EROS-21 and daNUbs, there would exist few data at all over the last 15 years.

The GEF, which does not normally support oceanographic research, recognized the shortage in research and monitoring as a serious obstacle to progress in implementing the adaptive management framework. Its new support to the Black Sea Commission (a project termed the Black Sea Ecosystem Recovery Project) included modest provisions for cooperative international research using local vessels and established an International Study Group (ISG) to coordinate the work. Restarting local research has not been easy, but two cruises have already been carried out (in 2003 and 2004) using R/V *Akademik* of the Bulgarian Academy of Science. Further work is planned in 2005 and 2006. Cost-shared cooperation with partner institutions, such as Germany's Alfred Wegener Institute for Polar and Marine Research and the University of Plymouth, has helped to ensure the transfer of new techniques to the region. But, further outside support will be needed to meet the goals that the ISG has set. The ISG is examining the main uncertainties:

Uncertainty I: Limited Information on Nutrient Flows and Budget

Remarkably little information exists regarding fluxes of dissolved and particulate inorganic and, especially, organic nutrients into the Black Sea, and there are contradictions among existing data sets. The International Commission on the Danube River has now established a quality-controlled monitoring system, but the frequency of measurements at lower Danube stations remains rather low. The nature of organic matter along the river course of the Danube was studied in detail during EROS-21 (Reschke et al., 2002). However, we do not have time-series information on how this has changed following human interventions such as the construction of the Iron Gates I and II dams on the Danube. Inputs from the Dnipro, Dniester, and other rivers discharging to the northwestern shelf are even less certain. Recent attempts to reconstruct historical inputs of the Danube by the EU-funded daNUbs project (H. Kroiss, TU Vienna, pers. comm., 2004) have relied upon application of a diffuse and point-source model (the MONERIS model) in the absence of reliable field data. Similarly, atmospheric inputs have been calculated using models, though thanks to GEF funding, the ISG has sponsored an emergent network of ground stations.

Within the Black Sea, it has been difficult to establish reliable nutrient budgets, partly due to uncertainties in major components of the budgets such as particle flux to the sediment, benthic nutrient recycling, and nutrient exchange between the shelf and open-sea regions. The latter has been examined for nitrogen in a modeling experiment by Gregoire and Lacroix (2003). The importance of benthic fluxes as a significant internal source fueling eutrophication and, therefore, a key component of nutrient budgets on the shallow shelf, was revealed by flux chamber measurements and three-dimensional modeling, integrating the information obtained during the EU-funded EROS-21 cruises and INTAS 99-01710 project (Gregoire and Friedrich, 2004; Friedrich et al., 2002) (Figure 5). This work is continuing through the ISG cruises employing the same sampling equipment as was deployed in the earlier studies. Current resources are insufficient to support reliable particle sedimentation studies using long-term sediment trap moorings, hence, estimates can only be obtained from models and proxy observations. The ISG cruises are examining exchange between the shelf and open-sea areas. For example, the cruise in May 2004 aboard the R/V *Akademik* employed Lagrangian methods, satellite-tracked drifters, and an acoustic Doppler current profiler, to investigate to role of shelf-edge mesoscale eddies.

There is very little information on winter conditions in the Black Sea because frequent storms limit winter cruises. During cold winters, relatively nutrient-rich water from the northern continental slope and shelf probably feeds the cold intermediate layer (CIL) that extends over much of the Black Sea and has a residence time of about 5.5 years (Stanev et al., 2003). Vertical mixing from the CIL may feed productivity over large areas of the Black Sea and thus the variations in winter temperatures on the shelf should have a profound effect over offshore primary production in the summer. Satellite data have also revealed significant winter phytoplankton blooms in the southern part of the sea, presumably as a result of mixing of deeper waters (Figure 6). Earlier studies suggest that this winter production may make a greater overall contribution to the offshore primary production in the Black Sea than eutrophication (Sorokin, 2002). Much remains to be learned about this process. The "natural" conditions of the Black Sea remain something of an enigma.

Uncertainty II: Gaps in Knowledge of the Pelagic System

For some years there has been some disagreement as to whether phosphorus or nitrogen limits primary production in the Black Sea, and also the role altered silicate flux plays in decreased diatom populations. This is not merely an academic debate; the cost of reducing nitrate loads to the sea far exceeds that of measures to reduce phosphorus. Studies carried out during the EROS-21 project (Ragueneau et al., 2002; Lancelot et al., 2002a) show seasonal and regional differences in nutrient limitation. In particular, diatom growth in the coastal and the open Black Sea has been regulated over the last decade by ambient phosphorus in spring, and phosphorus plus nitrogen in summer, with silicon concentrations remaining undepleted. Compared to the Redfield ratio (mean Si/N/P molar ratio in phytoplankton of 16/16/1) (Redfield et al., 1963), the winter nutrient signal of the open Black Sea shows silicon-excess, but phosphorus and nitrogen deficiency, while in the Danube, mixing plume nitrogen is in excess compared to phosphorus. These studies have also demonstrated that where silicate remained sufficient, an imbalance in either nitrogen or phosphorus could favor a bacterial- and microzooplankton-dominated food web rather than a diatom-copepod trophic chain. In other words, reduction of phosphorus without corre-

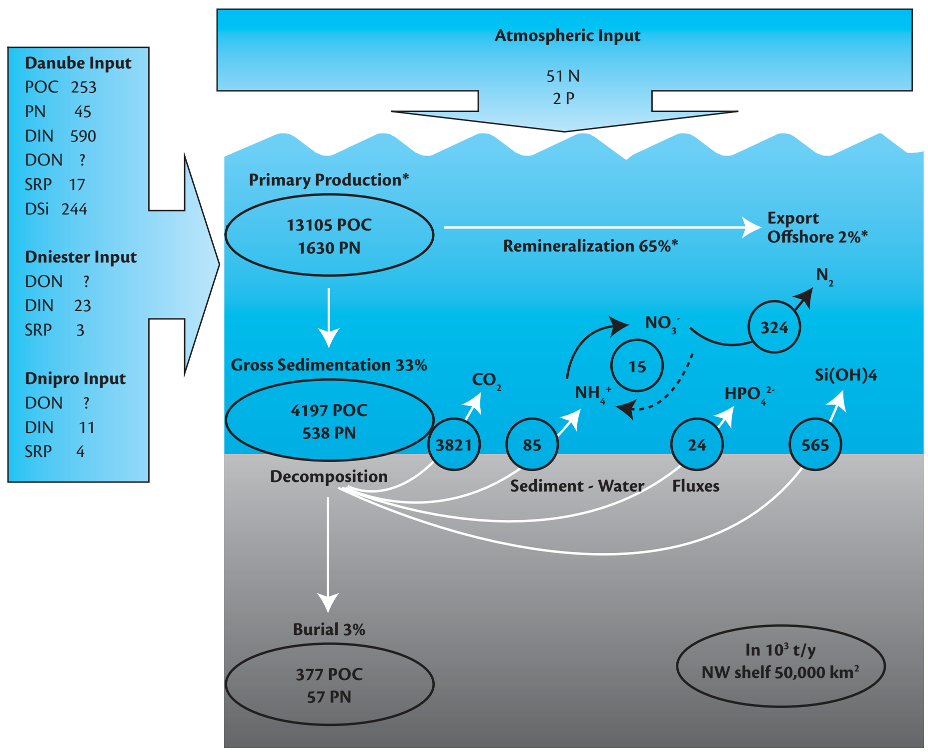

Figure 5. Nutrient budget for the northwestern Black Sea shelf area for the mid-1990s. POC = Particulate Organic Carbon, PN = Particulate Nitrogen, DIN = Dissolved Inorganic Nitrogen, DON = Dissolved Organic Nitrogen, SRP = Soluble Reactive Phosphorus, DSi = Dissolved Silicate. According to model estimates, about 65 percent of the shelf primary production is remineralized within the euphotic layer. Two percent of the material is transported off the shelf. Thirty-three percent of the primary production reaches the sediment. Benthic nutrient recycling is a significant internal nutrient source for the pelagic system, sustaining high productivity by the release of phosphorus and nitrogen from the sediment in the same range as river inputs. The shelf sediments release about twice as much silicon than is discharged by the Danube, however, the shelf acts also as a sink for nutrients. After benthic decomposition 3 percent of the model primary production remains buried in the sediment. Model estimated atmospheric nutrient deposition seems to be of minor importance as it amounts roughly to only 4 and 8 percent of the river SRP and DIN inputs, respectively. All values are given in thousand tons per year. All fluxes, except for measured river inputs, are calculated for a 50,000 km^2 shelf area. Data marked with * are taken from model calculations in Gregoire and Friedrich (2004) and Gregoire and Lacroix (2003). Danube input represents the average input of 1991 to 1995 (Cociasu et al., 1996) except for POC and PN (Reschke et al., 2002). Dniester and Dnipro inputs were taken from Topping et al. (1999). Literature data on atmospheric inputs reflect high uncertainties; values here are taken from EMEP (Sofief et al., 1994).

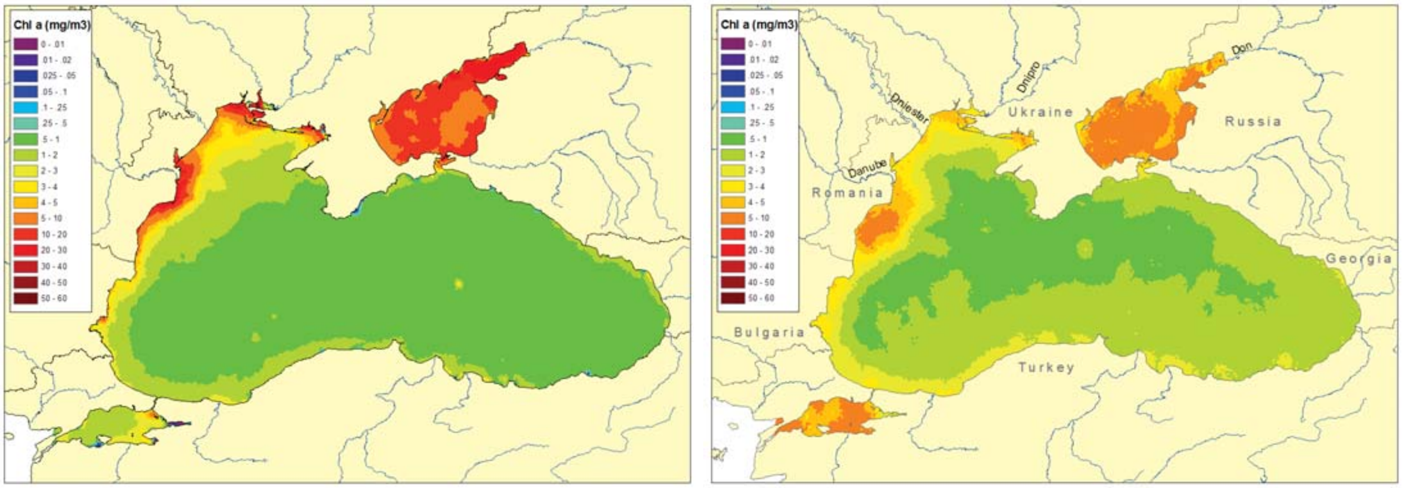

Figure 6. Summer (July, left) and winter (January, right) surface chlorophyll concentrations in the Black Sea derived from SeaWiFS satellite data averaged from 1997 to 2003. Note the intense summer bloom on the northwestern shelf and the winter bloom along the Turkish and Georgian coasts.

sponding cuts to nitrogen would simply move the problem somewhere else!

The situation is further complicated by the non-linear changes in the pelagic food chain. The onset of eutrophication was accompanied by heavy fishing pressure, leading to a decrease of fish stocks. Together with eutrophication, this favored the development of "trophic dead ends"—species such as the gelatinous *Noctiluca* and *Aurelia* that have little food value for higher predators. *Aurelia* and the introduced species *Mnemiopsis* were then competing with fish for copepods (Gucu, 2002). The decline of top predator stocks has severely altered the food chain, reducing grazing on primary producers (Daskalov, 2003).

Much of the advance of pelagic-system knowledge was gained during the past decade as a result of proxies and improved modeling rather than through comprehensive field data. Conceptual and mechanistic ecosystem models such as BIOGEN (Lancelot et al., 2002b), ECOPATH (Gucu, 2002), and the six-compartment ecosystem model coupled with the general circulation model of GeoHydrodynamics and Environment Research (GHER) (Gregoire et al., 2004) have been very useful for explaining the existing data, filling data gaps, and examining the effects of anthropogenic forcing, including opportunistic species. They have yet to predict the factors influencing system thresholds, which is the key uncertainty of interest to managers. Indeed, in the absence of a more comprehensive database derived from systematic monitoring and focused research, such predictions may be inaccessible. This is why we are encouraging the countries in the region, assisted by the international community, to renew monitoring efforts guided by model outputs.

The summer of 2001 provided an unfortunate surprise that illustrates this need. Just when researchers were becoming satisfied that the system was moving towards recovery, late rainfall and high temperatures triggered a new large-scale hypoxic event. For a season, the pelagic system of the northwestern shelf showed clear signs of a return to eutrophication, but these were only captured by a small number of observers, such as Bodeanu (Figure 7), who monitored the Romanian shelf area for almost 40 years. Mostly though, it was a lost opportunity to conduct wider research on system response and to validate model predictions.

Uncertainty III: Poor Understanding of the Status and Trends in the Benthic Marine Ecosystem

The limited recent observational data on the Black Sea shelf's benthic ecosystem is particularly problematic for understanding the rate of recovery of benthic systems since the late 1980s. Previously, particularly in the 1950s and 1960s, there was a very large effort on research and monitoring in all coastal and shelf habitats except for those in Turkey. Since 1990, we have only seen sporadic snapshots of parts of the system during cruises that were pursuing other objectives. During the EROS-21 cruises, extended benthic studies have been carried out, but conclusions have yet to be drawn on the state of the benthic ecosystem in the mid-1990s.

The ISG R/V *Akademik* cruise in autumn 2003 was specifically designed to map the current distribution of meiobenthos (very small animals living within seafloor sediments) and macrobenthos (plants and large animals) and covered most of the northwestern shelf of the Black Sea. This cruise revisited many sites monitored prior to and during the worst period of eutrophication. Early results (Figure 8) suggest that the northwestern shelf is in a process of gradual recovery, though the hypoxic event in 2001 clearly affected mussel populations on the northern part of the shelf. However, the existence of two-year-old mussels in this area is promising and contrasts with the situation in the late 1980s where all new recruits were killed by the annual appearance of the dead zone.

In May 2004, we revisited a small area where the previous cruise had revealed a *Phyllophora* population. This relict population was growing on mussel beds in 41 m of water on the outer shelf close to their limit of light tolerance (see opening spread photos). Currently, it is not possible to establish whether this population is growing or simply a remnant of the earlier field, but it should be monitored carefully in the future. Though we saw little evidence of a return of the complex red *Phyllophora* ecosystem first described 92 years ago by the Russian scientist Zernov, the continued presence of at least one species of these algae is a symbol of hope that the *Phyllophora*

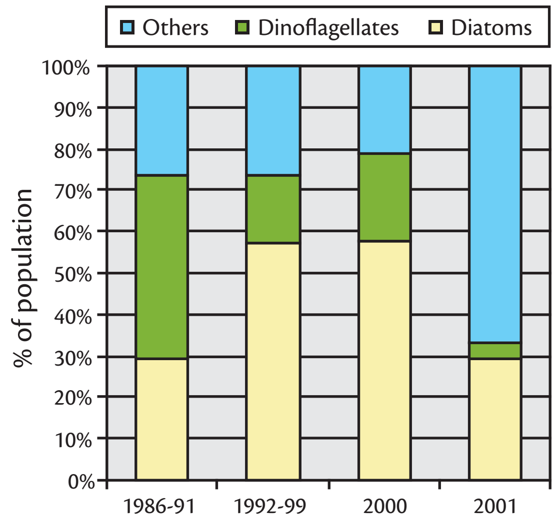

Figure 7. Phytoplankton population off the Romanian coast during severe eutrophication (1986-1991), recovery (1992-2000), and the unexpected return of eutrophic conditions in late summer 2001. The system has since returned to a status characteristic of recovery. Data from settling counts by Bodeanu et al. (2002); "others" includes green and blue-green algae.

field may return again.

Much work remains to be done to evaluate recovery of the benthic system in the Black Sea. Much of the capacity for taxonomic studies in the region has been lost. Careful investigation is needed to examine current community structures and their ecology. Opportunistic species have joined the fauna and some previous nearshore species appear to have disappeared entirely, a factor that may lead to further changes in the resilience of the system. Re-evaluation of historical data through painstaking research and modeling is also necessary in order to provide a context for current results.

WILL THE BLACK SEA DEAD ZONE RETURN?

Now that many central and eastern European countries have joined the European Community or are in the process of joining, and Turkey will begin negotiations to join, the fate of the Black Sea will be heavily influenced by the Community's common policies and regulations. New members seek the economic prosperity and social welfare that the Community has achieved and are keen to develop new industries and modernize their agriculture. Even at the height of the Black Sea dead zone in the mid 1980s, the average fertilizer application rate in the Danube basin was below the current rates of most western European countries. There is growing awareness that redevelopment of agriculture along those lines in the lower Danube basin would endanger the gradual recovery of the Black Sea's northwestern shelf. Furthermore, the application of the EU's Urban Waste Water Directive will improve public health as it will require sewerage and treatment plants for all towns with over 2000 inhabitants, but it will also increase nutrient loading in rivers, given that it only requires 35 percent nitrogen and 30 percent phosphorus removal.

A new EU-funded project, European Lifestyles and Marine Ecosystems (ELME) (for more information about this project go to www.elme-eu.org) is

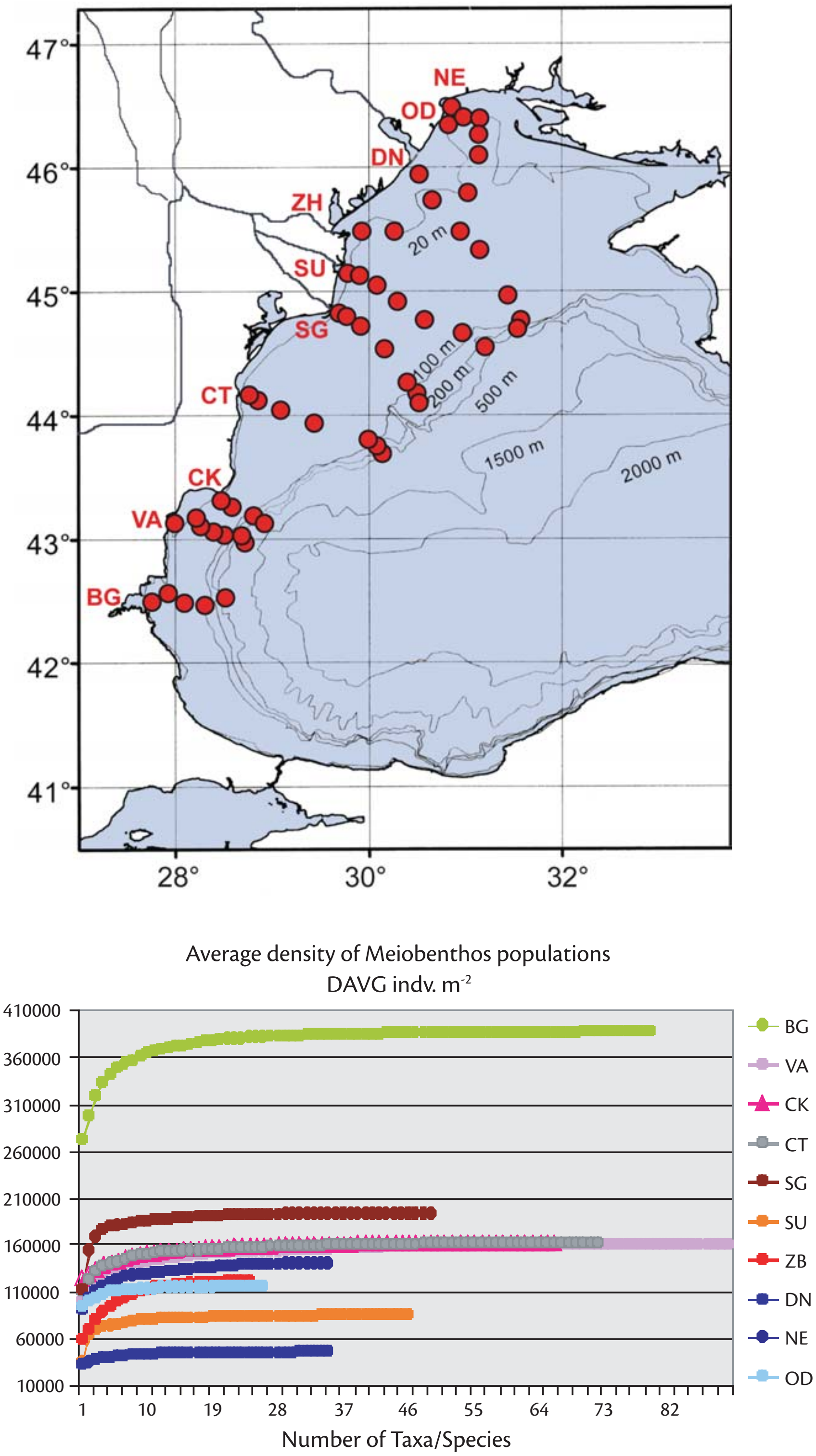

Figure 8. Top: Sampling area during the ISG cruise in autumn 2003 showing the geographical location of transects. Bottom: General average cumulative curves for density of meiobenthos (small animals who live buried within the sediment) populations along transects. The abundance of the animals (and to a certain extent their diversity) increases from the ecologically stressed northern areas to the southern ones, which had been least impacted by hypoxia. Recurrence of species, considered to be extinct two to three decades ago was observed, particularly in the Danube Delta (SG, SU) transects.

currently seeking to model the future consequences of policies on Europe's regional seas—such as the Common Agricultural Policy—that ultimately determine the emissions from land to sea. ELME is employing probabilistic techniques such as Bayesian network modeling in order to move between social and natural ecosystem scales. Convincing politicians to take preventative rather than remedial action requires strong scientific evidence, perhaps more than current research and monitoring efforts can provide. Conceptual and quantitative models are useful as a means of focusing the attention of field research on key uncertainties, enabling the best use of limited resources. By using models along with the reassuring stepwise approach of adaptive management, it is hoped to trigger the management actions necessary to prevent a return to the past.

You have heard all the facts about Tartars and Saracens as far as they can be told, and about their customs, and about the other countries in the world as far as they can be explored or known, except that we have not spoken to you of the Black Sea ... it seems to me that it would be tedious to recount what is neither needful nor useful and what is daily recounted by others. For there are so many who explore these waters ... that everybody knows what is to be found there.

Marco Polo, *The Travels* (Epilogue), c. 1300

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