



### 3. Measuring and Monitoring Eutrophication and Hypoxia

#### Key measuring and monitoring variables

To establish long-term trends and identify changes including the emergence or intensification of hypoxic sites, regular monitoring of the coastal environment is necessary. To establish the current state of the environment and to track changes, an inventory is required of all inputs reaching the coastal zones and reduction measures within the whole area affecting the coastal zone. For conceptual and practical convenience, a distinction is usually made between point and diffuse sources. Point sources of nutrient inputs include urban settlements with sewer systems and sewage treatment works, industrial discharges including intensive livestock including intensive poultry raising. For these sources, the point of input to the river system (outfall pipes) is identifiable, accessible to load monitoring and can be addressed directly by legal (individual licensing stipulating requirement or restrictions) and technical measures (building or upgrading of treatment plants, changing production practices).

In many highly susceptible areas, such as the Bay of Bengal and Andaman Sea that receive large river runoff and are located close to regions of high population density as well as intense agriculture, baseline data are lacking. In potential hotspots, regular observations at fixed coastal sites are urgently needed under the ongoing and planned initiatives such as the Large Marine Ecosystem projects and in national programs. Monitoring could begin with a basic suite of parameters using just modest funds, infrastructure and facilities (e.g. using fishing boats for sampling). Based on available resources, the next step would be to scale-up monitoring into fully-fledged, permanent programs. For instance, a nation-wide or regionally-coordinated monitoring network or survey program, designed with standardized data collection procedures, would provide an appreciation of the temporal dynamics and spatial distribution of hypoxia. This would provide countries with a more complete representation of the extent of hypoxia in large marine ecosystems and coastal zones.

Key variables that must be measured when monitoring hypoxic conditions are:

- Physical: temperature, salinity and depth.
- Chemical: DO, pH, nutrients (nitrate, nitrite, ammonium, phosphate, and silicate).
- Biological: chlorophyll.

Additional parameters to be measured wherever possible are:

- Physical: currents, bio-optical properties.
- Chemical: hydrogen sulphide, methane, total organic nutrients, particulate and dissolved organic carbon, biological oxygen demand, alkalinity, dissolved inorganic carbon.
- Biological and biodiversity indicators:
  - microbes - total bacterial counts, flow cytometric, molecular (phylogenetic) analysis
  - phytoplankton biomass and composition – size-fractionated chlorophyll, pigments (HPLC), microscopy, flow cytometry
  - zooplankton – macro-, meso- and micro-zooplankton
  - benthos – macro- and meio-benthos: abundance and diversity
  - fish catch – quantity and composition
  - sediment and geochemistry indicators: grain size, total organic carbon



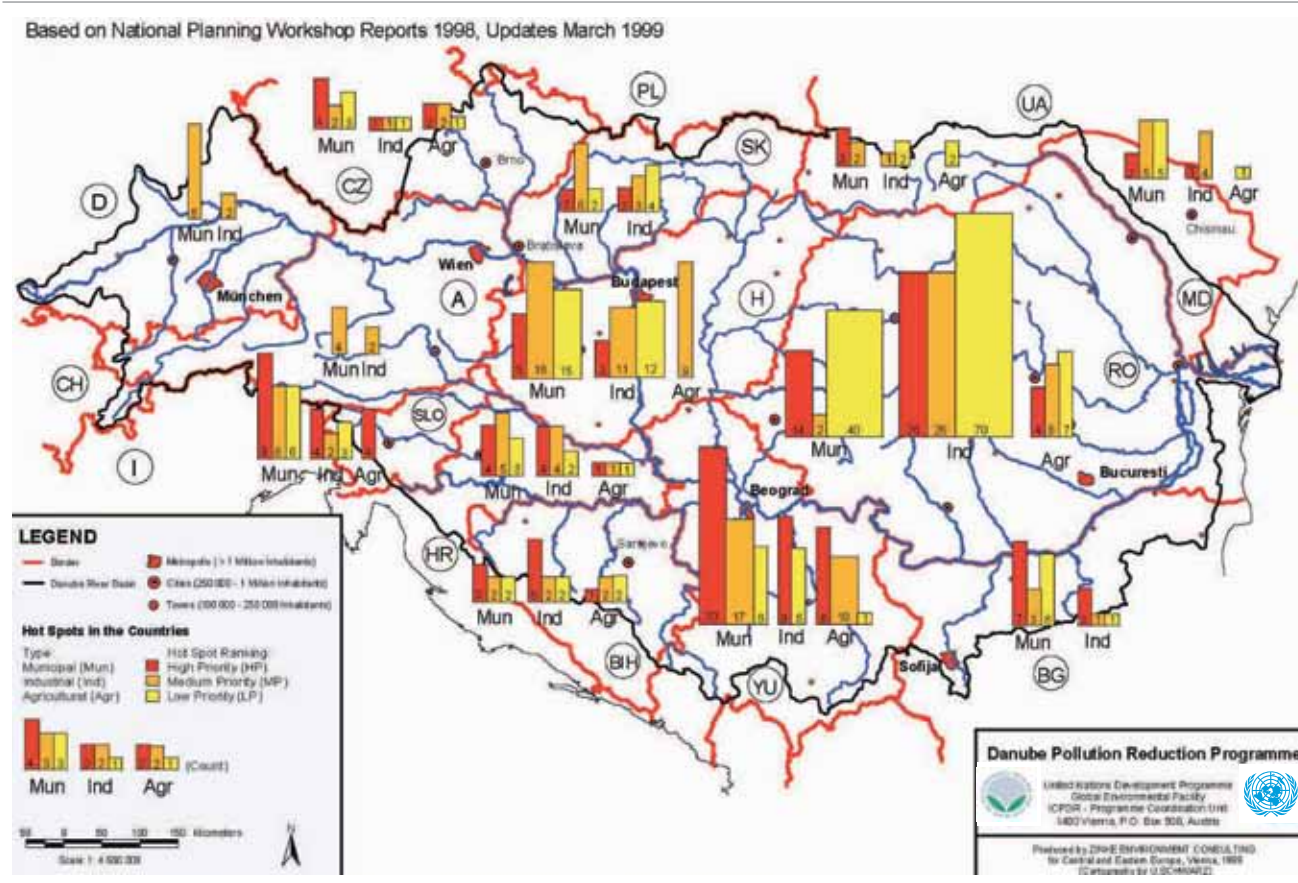
Testing the chlorination level in the water distributed in a camp next to the neighborhood of Cite de Dieu in Port-au-Prince.

## Identifying hypoxic zones

Eutrophication involves an increase in concentrations of macro-nutrients (nitrogenous compounds such as nitrate, ammonium and urea; phosphate and silicate), but the ratios in which these nutrients are delivered to the ocean are vastly different from the ratios in which they occur in seawater (i.e. close to the Redfield (1934) ratio of C:N:P=106:16:1). Anthropogenic nutrients typically have excessive nitrogen and are often relatively deficient in silicate. Coastal eutrophication leads to phytoplankton blooms, but due to the high N:P and N:Si ratios the composition of phytoplankton may be different from that found prior to eutrophication and in less affected areas. Harmful algal blooms, often comprising dinoflagellates, can arise from this anthropogenic nutrient supply.

The threshold oxygen concentration for hypoxia is not well defined, but a value of  $2 \text{ mg l}^{-1}$  ( $63 \text{ } \mu\text{mol}$ ) has been widely used as the behaviour of organisms has been found to be affected at lower oxygen concentrations. Different groups of organisms, however, may have different oxygen thresholds and organisms living in the naturally-formed oxygen-deficient zones are better adapted to low-oxygen concentrations. The thresholds associated with suboxia and anoxia could be better defined as they are associated with changes in modes of biogeochemical cycling. Suboxia is usually taken to represent the prevalence of reducing conditions short of sulfate reduction (mainly denitrification - reduction of nitrate to molecular nitrogen coupled with the mineralization of organic matter by heterotrophic bacteria and similar reduction of oxidized iron (III) and manganese (IV)). The ambient oxygen concentration needed for these processes to occur is very close to zero (sub-micromolar concentrations, probably tens of nanomolars). Due to the errors associated with oxygen concentration measurement at such low levels, the exact oxygen threshold for hypoxia is difficult to identify, but an effective indicator of suboxia is nitrite, an intermediate of denitrification. However, nitrite is also produced by nitrification and assimilatory nitrate reduction by phytoplankton, and so its co-occurrence with near-zero oxygen levels is essential for it to be an indicator of suboxia. Suboxic conditions are also characterized by the accumulation of other reduced chemical species (e.g. Fe (II))

**FIGURE 3 - Hot spots in the Danube Basin countries based on national planning workshop reports of 1998, updated in March 1999**



and Mn (II) which are difficult to measure on a routine basis. One other important aspect of suboxic environments is the cycling of nitrous oxide ( $N_2O$ ), a potent greenhouse gas. For reasons that are not entirely clear, but are obviously related to the fact that  $N_2O$  is both produced and consumed during the reduction sequence of nitrate to  $N_2$ , suboxic environments are distinguished by extreme accumulation as well as depletion of  $N_2O$ . The occurrence of truly anoxic conditions is marked by the accumulation of hydrogen sulfide ( $H_2S$ ) that can be easily detected due to its strong odor even when present in concentrations below  $1 \mu\text{mol}$ . Its occurrence implies complete loss of oxygen and nitrate, and an accumulation of ammonia. Very often, anoxic (sulfidic) aquatic waters are also characterized by the buildup of methane ( $CH_4$ ), another important greenhouse gas, especially in freshwater environments.

The absence of trawling is a very reliable indicator of severe hypoxia/suboxia/anoxia. Sulfidic waters are, of

course, most inhospitable to higher form of marine life. While the motile organisms are either driven away from anoxic zones, or get killed if and when they cannot escape, benthic and demersal (bottom and near bottom dwelling) organisms, with a few exceptions, are completely wiped out. The absence of higher forms of demersal marine life extends to suboxic and even hypoxic zones with variable tolerance to hypoxia from one group to another. Over the Indian shelf that experiences severe bottom-water oxygen-depletion on a seasonal basis primarily caused by the upwelling of deeper offshore water, demersal fish get trapped in inshore areas as the oxygen-deficient layer moves closer to the coast and intensifies. This leads to spurts of heavy catches of demersal species, especially prawns. At this time, a zone extending several tens of kilometers offshore to a water depth of 40-60 m appears which is conspicuous by a complete absence of trawling activity, with very intense fishing activity seaward of this zone probably related to an increase in subsurface oxygen



## 30 Hypoxia and Nutrient Reduction in the Coastal Zone



concentration. In addition to the above-mentioned changes in phytoplankton composition caused by altered macro-nutrient ratios, hypoxia may also modify the relative abundance of primary producers, favoring cyanobacteria (blue-green algae) over larger plankton especially diatoms. The presence of harmful algal blooms (HABs) also serves as a visible indicator of a potential hypoxic area.

Apart from the biogeochemical indicators of hypoxia discussed above, socio-economic indicators of hypoxia need to be more thoroughly developed. These could include specific gauges for indicators of societal benefits and wellbeing (e.g. human and ecosystem health, economic conditions and long term sustainability) and effects on ecosystem services.

## Baseline for remediation

The most important indicator for stress reduction is the annual load entering the coastal areas via riverine inputs. However, a reliable load determination requires a carefully designed monitoring program both on concentrations and run-off and a careful adjustment to a “standard run-off situation” (c.f. the software R-Trend which is used by the OSPAR Commission). A second indicator should be the analyses of the emissions discharged to the river catchment from point and diffuse sources. A useful frequency for this indicator might be approximately every five or six years.

Public information instruments like Pollutant Release and Transfer Registers (as stipulated by the United Nations Economic Commission for Europe (UNECE) Convention on Pollutant Release and Transfer Registers) provide annual updates on pollutant loads discharged by point sources. Building an inventory of point source loadings can be an initial step toward reducing the emissions. In the Danube, this process was initiated in the mid-1990s as an attempt to identify the hot spots which were then addressed by two subsequent action plans. Fig. 3, taken from the Danube Pollution Reduction Program report (ICPDR, 2006), shows the result of the hot spot analyses as a first major step. Normally the identification

and elimination of these hot spots results in the relatively fast reduction in emitted loads as well as in the first positive biological responses, for which indicators are also necessary.

In subsequent years, driven by the joint implementation of the EU Water Framework Directive and of European environmental law by countries which joined the European Union in 2004-2005, a much more detailed picture became available. Figure 4, taken from the 2009 Danube River Basin Management Plan (ICPDR, 2009), displays the heterogeneous situation with respect to urban wastewater treatment at the end of 2005. Figure 3 only displays settlements above 100,000 person equivalents (p.e.), whereas the second map covers all settlements with more than 2000 p.e., (the relevant threshold in the underlying EU Urban Waste Water Treatment Directive). This directive has already been implemented in the upper part of the basin (Germany and Austria) and should be fully implemented by all current members of the EU in the Danube Catchment by 2018.

Diffuse or nonpoint sources are inputs resulting from widespread activities like agriculture, traffic, storm water or settlements not connected to sewer systems where the pollution enters the aquatic environment through processes such as erosion, atmospheric deposition or groundwater flow. These processes are strongly dependent on hydrological conditions, which mean that the pollutant load transported to the coastal area is mainly determined by run-off. Quantitative estimates of substance loads from diffuse sources require model calculations and loads have to be extrapolated to a “standard run-off situation” in order to analyze the effects of reduction measures.

Reduction measures for diffuse sources of pollution are far more difficult to implement and enforce as they require significant changes in agricultural and other practices. A further obstacle to implementation of reduction measures is that the effects of remediation measures are difficult to observe in a “politically relevant” time-frame, as the nutrient transport mechanisms may cause delays between reduction measures and observable reductions. In



## Evaluating Responses in the Black Sea

Under planned measures in the Danube, average nitrogen emissions to surface waters will be approximately 12% lower by 2015, compared to the present state (2000-2005). The load to the Black Sea will reach a level that is below the present state but still far above (40%) that of the 1960's. This means that the situation in the Danube River Basin and the Black Sea with respect to nitrogen pollution will improve, but not ensure the achievement of the management objectives and the Water Framework Directive (WFD) environmental objectives on a basin-wide scale by 2015.

Compared to the present state (avg. 2000-2005) the P emissions to surface waters will, through the planned measures, be in 2015 about 21 % lower. The load to the Black Sea

will reach a level which is still 15 % above 1960s levels. Therefore, for phosphorous the respective management objective on the basin-wide scale will not be achieved by 2015, and this is most likely also the case for the WFD environmental objectives. Reductions in nutrient pollution will be achieved as soon as more stringent urban waste water treatment obligations with N and P removal for urban agglomerations of more than 10,000 p.e. are applied for EU member states. This could reduce the discharged emissions in EU members of total N by 37% – 43% and of total P by 45% - 56% compared to the reference situation. However, the knowledge and understanding of the inter-linkages between Danube loads and the ecological response in the North West shelf of the Black Sea still need to be refined and improved.



Wachau



Satellite Image of the Black Sea

the case of ground water polluted by intensive live-stock production, for instance, hydrological conditions may delay the impacts of successful reduction measures by up to several decades, depending on the hydrological conditions. In these cases where changes are slow to show, inventories of pollution loadings can be more infrequently compiled, say on a five-year basis.

Experiences show that reductions in overall inputs achieved over the last 20 years are mostly through point sources, which were dominating emissions at that time. In turn, this means that the relative contribution of diffuse sources has increased and measures to reduce non-point source nutrient pollution are urgently needed.

## Evaluating responses

Since coastal hypoxia is caused by pressures from large geographical areas and from a variety of sources whose contribution to the problem change over time, stress reduction requires an iterative approach. Reduction will be a long-term process and definitions of a vision and of intermediate steps are necessary. To be able to correct and readjust the process over time, the selection of useful feedback indicators is required. These could include:

- Biodiversity indicators (e.g. the presence or absence of certain species).
- Loads entering the affected coastal zone via important river catchments draining into that area.
- The sources and their relative strengths of nutrients in the catchment.
- Intermediate depots both in the catchments and the coastal areas.
- Observed negative effects.
- Limiting factors for eutrophication effects.