

1 Introduction

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1.1 Background

During recent decades, large-scale effects of pollution on the entire Baltic Sea have become apparent. The prevalence of anoxic deep basins, decreases in the large populations of grey seals and increased frequency of toxic phytoplankton blooms (Horstmann 1975; Kahru et al. 1994) are examples of phenomena governed by large-scale processes. Marine resources, like fish for consumption, are endangered due to overall high levels of toxic substances and overfishing. Measures must be implemented to reduce the loads of pollutant to such levels that the environmental quality of the Baltic is restored. At the same time, the costs of different measures should be weighted against the results achieved (see HELCOM 1991; Wulff and Niemi 1992; Gren et al. 1997). Consequently, demand for strong scientific argument increases when international measures need to be motivated (see e.g. Wikner et al. 1996).

So far, most scientific studies have concentrated on local recipients in the coastal zone, hence our understanding of the factors controlling large-scale effects is limited. It is now obvious that these effects arise as a result of a complex interplay between pollutant loads from many sources. They originate from all the countries in the Baltic drainage basin and, in the case of atmospheric deposition, from sources even further away. A complex interplay between physical, biogeochemical and ecological processes governs concentration levels and effects. Large-scale interdisciplinary efforts on an international level are needed to understand and remedy these effects.

Assessments (e.g. HELCOM 1996) show that concentrations of both eutrophication and toxic substances are still high in the Baltic Sea although for several substances the increasing trends have ceased during the last decades. Although there are clear relationships between increasing anthropogenic inputs and increasing concentrations and ecological effects on a long-term (50-year) time scale, these relationships are less obvious and

even absent on a decade scale or less. In fact, the concentration of nutrients in the sediments of the Baltic proper did not start to increase until the middle of the nineteenth century (e.g. Carman et al. 2000) parallel with increases in population, agriculture and industrialization. There is now a growing understanding that variations in concentration and effects of various pollutants are caused by a complex interplay between inputs, climate forcing and processes in the sea. This book is an attempt to synthesize our current understanding of the processes governing large-scale effects and ecological processes, critical for the distribution and effects of pollutants in the Baltic Sea. It is also an attempt to summarize some of the results gained in a Baltic Sea research project 'Large-scale environmental effects and ecological processes in the Baltic Sea' which was initiated by the Swedish Environmental Protection Agency (SEPA) with connections with several Baltic states. Some of the work presented in this book has subsequently been funded within the Baltic Sea System Study (BASYS), an international EU/MAST (Marine Science and Technology) program.

Models synthesize and evaluate our understanding of external forcing and internal biogeochemical and physical processes controlling distributions, concentrations and effects of eutrophication and toxic substances. Models are also tools to evaluate various management strategies. Therefore we have organized the chapters in this book by starting with descriptions of physical transports and external forcing by climate and by loads of nutrients and some selected toxic substances. We then describe various critical processes governing plankton growth, sedimentation and transformation in sediments. The next chapters describe quantities and distributions of nutrients, organic matter and toxic substances. The book concludes with chapters in which both budgets and dynamic models of nutrient and toxic substances are developed, based on the information presented in previous chapters.

1.2 Physical Transports and External Forcing

In Chapter 2, Stigebrandt describes the physical transport systems of the Baltic, and the various current and mixing processes. The Baltic has strong salinity gradients both vertically and horizontally. This chapter provides an extensive overview of the physical oceanography of the Baltic Sea and the processes governing the distribution of sea salt and thus many other dissolved substances in this large estuary. In addition, the overall distributions of temperature, currents, oxygen and optical properties are described and related to forcing functions.

With a drainage basin area that is four times larger than the surface of the sea, the Baltic is highly affected by inputs from the surrounding land. The freshwater outflow through the Danish straits is large, comparable to the Mississippi River. Variations in weather affect to a high degree the supply of nutrients, seasonally, interannually and on a climate scale. In Chapter 3, Bergström et al. describe the processes governing freshwater inputs and spatial and temporal characteristics of climate variations. They illustrate the large regional variations in climate and also in hydrology. The latter depends on climate as well as on variations in topography and soils in the different subregions.

In Chapter 4, Grimvall and Stålnacke have assembled an extensive database of nutrient concentrations in rivers from all Baltic countries and have estimated riverine inputs for the period 1970–1993. They show that the large variations in freshwater runoff to the Baltic, reported by Bergström et al. (Chap. 3), are also reflected in large variations in nutrient inputs. If the variations in freshwater flows were accounted for, there were no clear trends in riverine nutrient inputs during the studied period. The major increases in nutrient loads occurred earlier, probably in the 1950–1960s, when drastic changes in land use and increases in fertilizer applications occurred. Despite significant changes in land use, point source emissions and atmospheric emissions in certain parts of the Baltic drainage basin, the total annual riverine load of both nitrogen and phosphorus to the sea has been fairly constant between 1970 and 1993.

Runoff from agricultural land has been estimated to account for about half the total N load and a fifth the P load to the Baltic. After independence in 1990, fertilizer use in Estonia, Latvia and Lithuania dropped drastically to 1950 levels and the yield of most agricultural products decreased by almost 50 %. In spite of these drastic changes, there have been almost no changes in nutrient runoff to the Baltic, at least until 1998. Löfgren et al. (1999) attribute this to large nutrient pools still remaining in the previously heavily fertilized soils that will continue to leak nutrients for many decades, before substantial decreases in runoff will be seen.

The clear gradient in nutrient inputs, with an increase from north to south, is explained by the increasing population densities and the area of agricultural land, as shown by Sweitzer et al. (1996). Poland contributes most to the nutrient load but is inhabited by only approximately half of the 85 million people that live in the area of the Baltic drainage basin. The per capita load is not dramatically different between, for example, Sweden and Poland, in spite of much more advanced sewage treatment in the former country. Today, the major source of nutrients to the Baltic is, as mentioned above, leakage from agricultural land; Stålnacke (1996) estimates this to be roughly 50 % of the total load. Presently, the former East-block countries

are using less fertilizer per unit of land. They have soil properties and more wetlands that favor nutrient retention to a higher degree than elsewhere in the drainage basin, including the more 'developed' Baltic EU countries.

Although the riverine input is the major source of nutrients, the atmospheric deposition of nitrogen directly over the sea could represent about a third of the total input. Consequently, better estimates are urgently needed for nitrogen (see e.g. Rosenberg et al. 1990). Only a minor fraction of the phosphorus load comes from atmospheric deposition. In Chapter 5, Granat presents a thorough examination of existing data and interpolated wet and dry depositions of nitrate and ammonium with a high resolution over the Baltic. The nitrogen concentrations are averaged over 1986–1990 for the entire Baltic Sea. He reports large regional and seasonal variations and even doubled nitrogen deposition in the last decades, compared to data from before 1965. Recent calculations of nitrogen deposition to the Baltic with the EMEP model for the period 1986–1996 show a downward trend in deposition after 1989. The calculated deposition for the last 3 years is thus about 20 % lower than during 1986–1990 (Barret et al. 1998).

There has been a decrease in the levels of some toxic persistent halogenated pollutants in the Baltic biota [Bignert et al. 1998; for example herring (*Clupea harengus*), cod (*Gadus morhua*) and guillemot (*Uria aalga*)] during the last decades (Fig. 1.1), although the levels are still high. Health authorities are still cautioning extensive consumption of Baltic fish. There has been a recovery in top predator populations, e.g. the breeding success of white-tailed eagles is almost back to the level of the 1950s before the extensive contamination by persistent pollutants of the Baltic started (Fig. 1.1). Some of this population recovery in these birds of prey is also attributed to winter feeding on food free of persistent pollutants. The rapid recovery of the seal populations, which previously showed a high degree of reproduction disturbance due to PCBs, has now urged fishery organizations to legalize hunting again.

Although trends in persistent pollutants in some Baltic biota are well documented (Bignert et al. 1998), little has been known about the origin of these pollutants and their flows between different components of the ecosystem. Inputs of chlorinated hydrocarbons, specifically atmospheric and river inputs of PCBs, DDTs and HCHs to the Baltic, are described by Agrell et al. in Chapter 6. An extensive sampling program was set up, covering the entire Baltic region, and with participation of scientists from many countries around the Baltic. The same techniques were used at all sites to obtain comparable data. Agrell et al. (Chap. 6) found that the rivers and the atmosphere contribute almost equally to the PCB load, while atmospheric deposition of HCHs and DDTs was about five to seven times more important. Large-scale, even global, redistribution of pesticides via

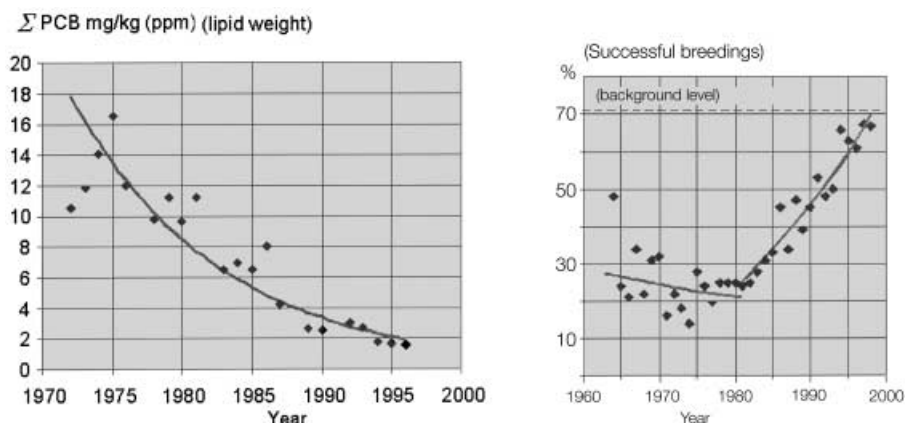


Fig. 1.1. Σ PCB in herring muscle (ppm, lipid weight) in the southern Baltic proper (*left*) and percentage of successful breeding of sea eagles in Sweden (*right*). (Data from the Swedish National Contaminant Monitoring Program, Swedish Museum of Natural History; see <http://www.nrm.se/mg>)

the atmosphere is probably now a major contribution to the pollution of the Baltic, now that local or regional contributions have diminished due to regional bans. However, former usage of some substances is still reflected in the fact that soils and water may act as sources, leaking DDTs and highly chlorinated PCBs into the environment.

Although the effects of some toxic substances are now well documented, there is still a danger that new contaminants may be introduced. The M74 syndrome, which causes high mortality in newly hatched salmon fry, was initially suspected to be caused by toxic substances of unknown origin. Recent studies (Bengtsson et al. 1999) show a more complex picture, where the drastic changes in the Baltic food web and the diet of salmon are shown as explanations of the syndrome.

1.3 Critical Processes

An understanding of forcing functions and sources, controlling the inputs and physical distribution of nutrients and toxic substances, should be supplemented by an understanding of the biogeochemical processes that are responsible for redistributions, internal transfers, sources and sinks in the water column and sediments. A challenge to the understanding of Baltic biogeochemistry is that this sea experiences large temporal and spatial

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