Proc. Estonian Acad. Sci. Ecol., 1992, 2, 4, 129—136
https://doi.org/10.3176/ecol.1992.4.01

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THE STATE OF THE ESTONIAN COASTAL WATERS IN 1979—1990: SEASONAL, VERTICAL, AND HORIZONTAL VARIATIONS

Abstract. In the paper large-scale spatial and temporal variations in some water quality parameters (water temperature, content of oxygen, nutrients, and oils) in the Estonian coastal waters and in the open part of the Gulf of Finland are discussed. The data were obtained by routine monitoring performed in Estonia. The horizontal pattern of the parameters is presented on maps, which show averaged data for the upper quasihomogeneous layer in 1979—1990 considering also the seasonality. The most polluted areas are Narva, Tallinn, and Pärnu bays; the state is far better in the mouth section of the Gulf of Finland and in the Moonsund. The calculations of total amounts of nutrients in the winter pool of the Gulf of Finland yield about 43 000 t P_{tot} and 440 000 t N_{tot}.

Key words: Gulf of Finland, nutrients, spatial variations.

Introduction

Though episodic and expeditional observations in the Gulf of Finland and Estonian coastal areas have been made since the beginning of the century, regular observations which could be called monitoring were started only in the 1960s. Such monitoring has been carried out by the (former) Estonian Hydrometeorological Service (EHS) using Soviet methods and standards, unfortunately different from the international Baltic Monitoring Programme (BMP) standards. Thanks to its relatively large volume (about 200 000 data fields) and good temporal and spatial resolution, this is so far the only data set which can be used for assessing the state of the coastal waters of Estonia. By now observations have been made for 25 years in nearly 60 stations, usually 3—8 times a year. Variables monitored are water temperature (T), salinity (S), pH; content of oxygen (O_2), nutrients ($N—NO_2$, $N—NO_3$, $N—NH_4$, $P—PO_4$, P_{tot}, $Si—SiO_4$), oils, phenols, detergents, and episodically some other ingredients. In this paper some more important variables have been selected as an example. The period 1979—1990 is discussed, as several changes in analytical methods have been made and earlier data are not strictly comparable.

In connection with such data sets the problem arises of how they describe the real object, i. e. (1) are the data "true" and (2) are they representative. It can be stated that all hydrochemical data are to a smaller or larger extent "false". Usually we do not measure the content of a certain component directly, but only its reaction through some conversion (colour reaction, etc.). The measuring scales are not strictly metric. In intercalibrations differences occur even between the results of respectable

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laboratories. The EHS data seem to be the most "false." Attempts have been made to turn them more comparable to more reliable data sets, for example the BMP ones, by using empirical coefficients, data transformations, and outlier elimination (see e. g. Suursaar, 1991).

As to representativeness, the question is to what extent our discrete and relatively sparse in time and space data can describe continuously changing 3-dimensional fields. Consistence of our estimates depends on how successfully we suppress noise and disturbing variability components and reveal the necessary ones.

In a previous paper (Suursaar, 1992) some statistical properties of the monitoring data and trends in the Gulf of Finland were discussed. The aim of this paper is to describe some typical large-scale temporal (seasonal) and spatial (vertical, horizontal) variations in the coastal waters of Estonia. Also some problems related to eutrophication processes in the whole Gulf of Finland are discussed.

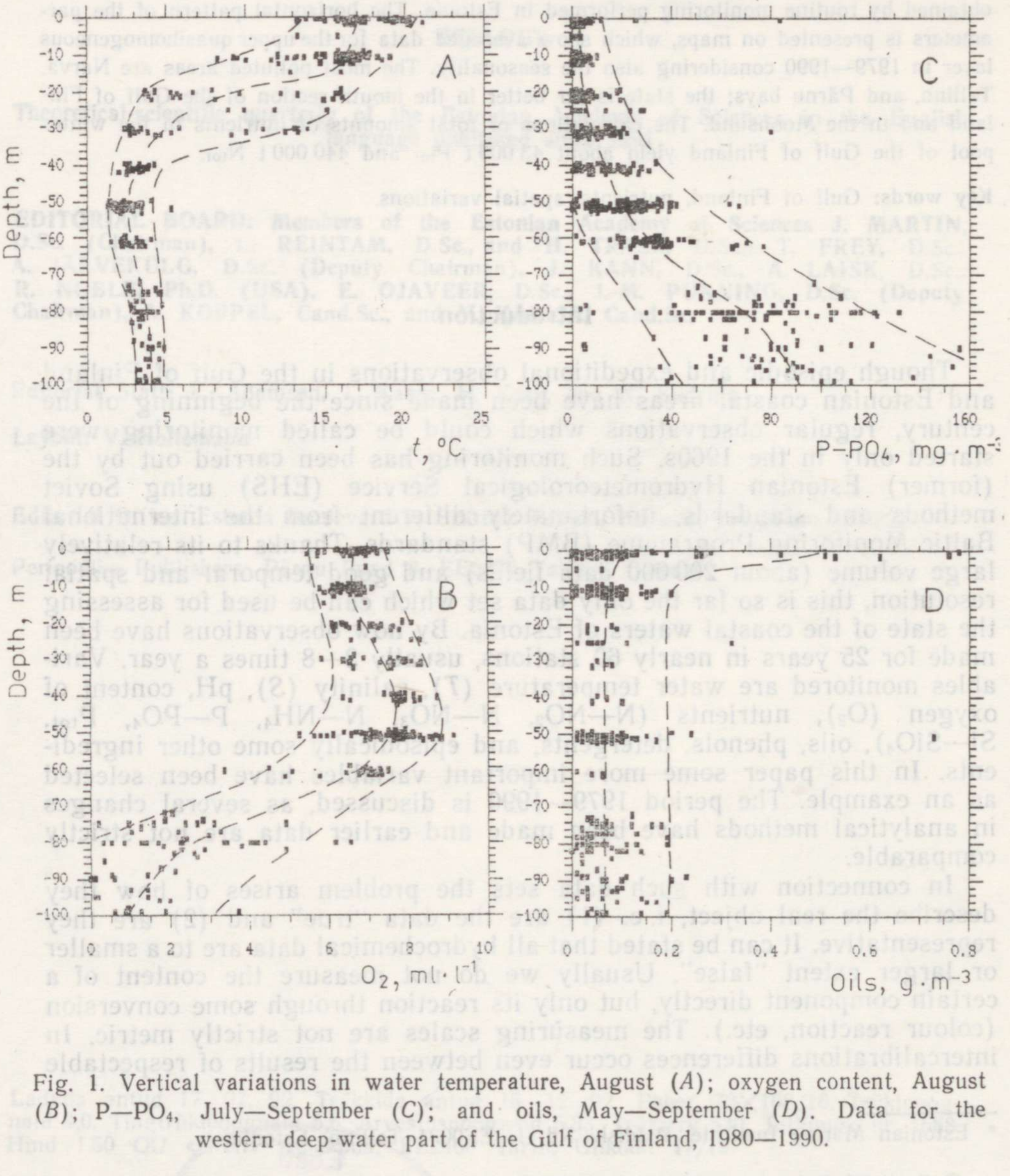

Fig. 1. Vertical variations in water temperature, August (*A*); oxygen content, August (*B*); P—PO_4, July—September (*C*); and oils, May—September (*D*). Data for the western deep-water part of the Gulf of Finland, 1980—1990.

Vertical and Seasonal Variations

The majority of hydrological variables show substantial temporal (especially seasonal) and vertical variability, quite fundamental for the Baltic Sea. It is possible to sort out a number of different vertical and seasonal data selections from the data base. Some most typical of them are shown in Figs. 1 and 2. Measured single values and 50% (medians), 95%, and 5% percentiles are presented as well. Thus, any single curve probably stays within the shown limits under the particular conditions expressed in the legends to the figures. Moreover, such data "envelopes" can be used for example in some forecasting tasks or ecosystem modelling based on Monte-Carlo simulation.

The data are in most cases highly scattered, those on oils, phenols, detergents, and ammonia being especially random. Data on oils are presented as an example of this group (Figs. 1*D* and 2*D*). As can be seen, different variables show quite diverse behaviour, which must be considered dealing with the data.

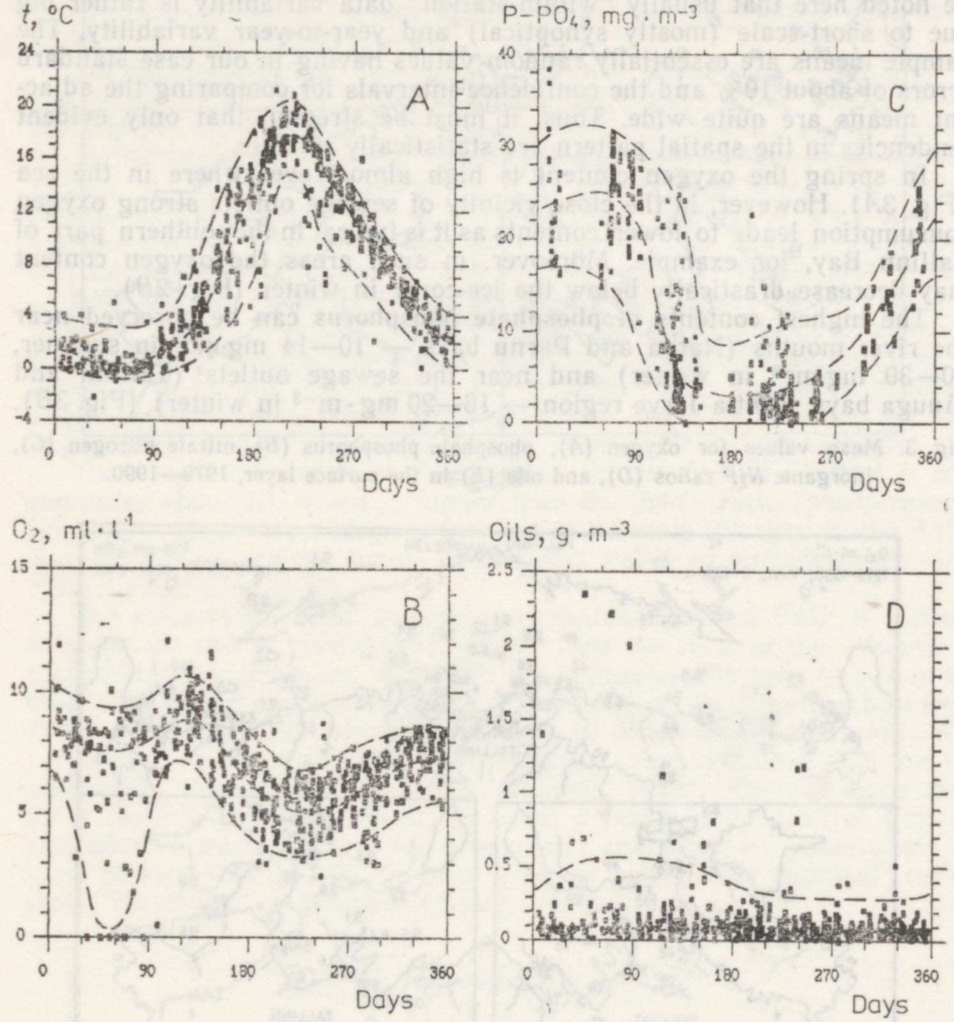

Fig. 2. Seasonal variations in water temperature (*A*), oxygen content (*B*), P—PO_4 (*C*), and oils (*D*). *A*, *B*, and *D* — data for the southern part of Tallinn Bay, 0 m, 1980—1990; *C* — Gulf of Finland, BMP data, 0 m, 1979—1987.

Horizontal Spatial Variations

In order to get statistically reliable long-term mean estimates it is useful to enlarge the data selections and, at the same time, to avoid the growth of variances of the selections (to minimize standard errors of samples). Therefore, temporally and vertically as homogeneous and stable data as possible have been chosen for calculations of maps (Fig. 3). In general they represent either the winter- or summertime regime in the upper quasihomogeneous layer (0—10 . . . 40 m). The most informative data for nutrient calculations are those collected in winter (e. g., Nehring and Francke, 1985; Astok et al., 1986). Unfortunately, since genuine wintertime data are too rare in the EHS data set, data obtained in November—December were used. One should, however, bear in mind that the nutrient data in offshore regions should be about 50% higher in February—March (see also Fig. 2*C*).

Every single value in the maps represents the mean value (or median) of some 30—150 observations. However, in many cases the spatial distribution of averaged values seems still quite uneven and "patchy". It should be noted here that usually "within-station" data variability is rather big due to short-scale (mostly synoptical) and year-to-year variability. The sample means are essentially random values having in our case standard errors of about 10% and the confidence intervals for comparing the adjacent means are quite wide. Thus, it must be stressed that only evident tendencies in the spatial pattern are statistically reliable.

In spring the **oxygen** content is high almost everywhere in the sea (Fig. 3*A*). However, in the close vicinity of sewage outlets strong oxygen consumption leads to lower contents as it is typical in the southern part of Tallinn Bay, for example. Moreover, in such areas the oxygen content may decrease drastically below the ice-cover in winter (Fig. 2*B*).

The highest contents of **phosphate phosphorus** can be observed near the river mouths (Narva and Pärnu bays — 10—14 mg·m^{-3} in summer, 20—30 mg·m^{-3} in winter) and near the sewage outlets (Tallinn and Muuga bays, Kohtla-Järve region — 16—20 mg · m^{-3} in winter) (Fig. 3*B*).

Fig. 3. Mean values for oxygen (*A*), phosphate phosphorus (*B*), nitrate nitrogen (*C*), inorganic *N*/*P* ratios (*D*), and oils (*E*) in the surface layer, 1979—1990.

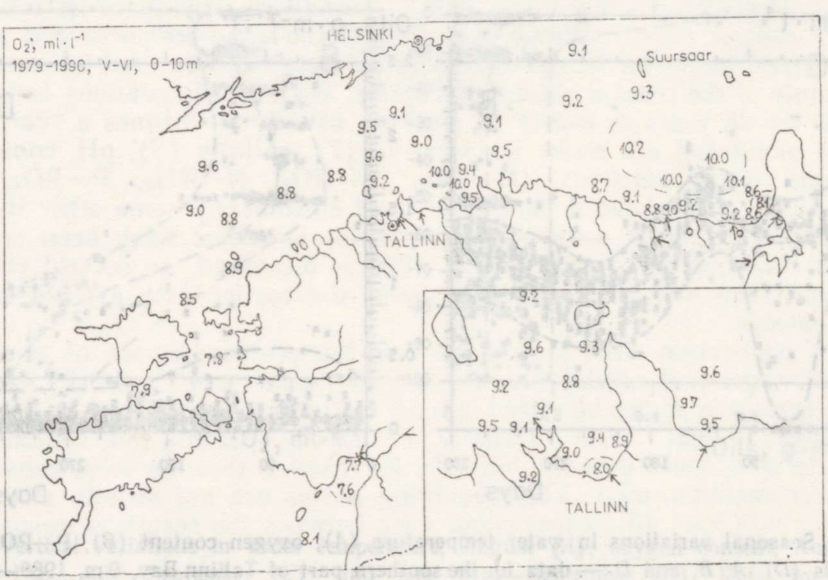

Fig. 3*A*.

The average concentrations were the lowest in the mouth section of the Gulf of Finland and in the Moonsund (1.5–3 mg·m^{-3} in summer, 8—14 mg·m^{-3} in early winter).

Nitrate nitrogen (Fig. 3*C*) shows in general a similar spatial pattern to phosphates. High concentrations occur in the polluted areas such as Pärnu and Narva bays (60—150 mg·m^{-3} in winter). In the open sea the average values are 30—60 mg·m^{-3} in early winter, 5—20 mg·m^{-3} in summer. (Here means from transformed data are presented, which show somewhat reduced values compared to the original but erroneously elevated values.)

In Fig. 3*D* the **inorganic N/P ratio** ($NO_3+NO_2+NH_4/PO_4$) is presented. In the Gulf of Finland the weight ratio is 3.5–5.5, which is some-

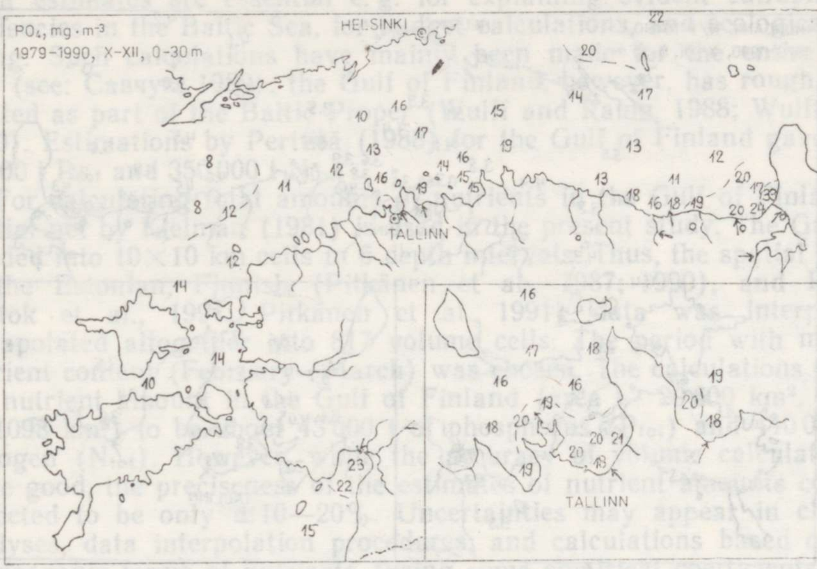

Fig. 3*B*.

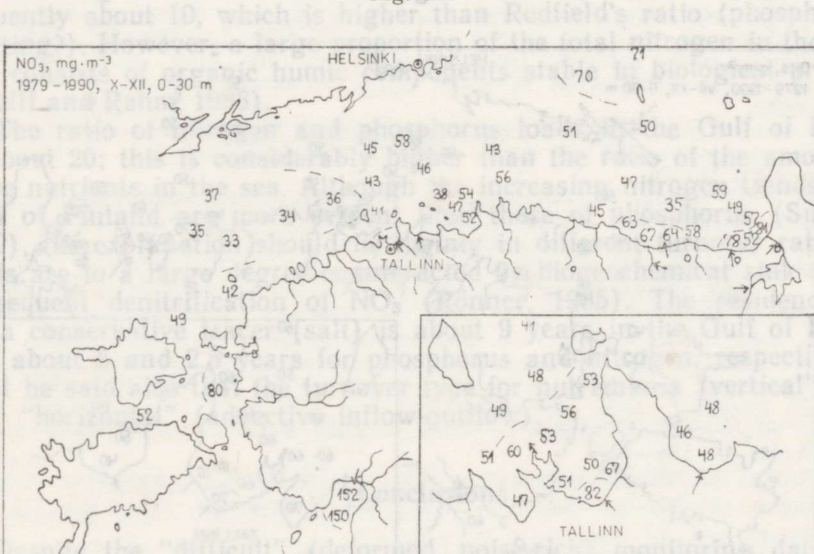

Fig. 3*C*.

what higher than in the Baltic Proper (about 3 in the trophogenic layer; Wulff and Rahm, 1988). In the coastal areas the ratio varies from 3.2 to 12 (excess of nitrogen loads). Weight ratio of 6—9 (molar ratio about 16:1) is considered optimum for primary producers (Redfield et al., 1963). Thus, the present analysis supports the opinion that nitrogen is the limiting factor for vernal primary production in the Gulf of Finland as well as in the Baltic Proper (e.g., Voipio, 1981; Pitkänen et al., 1987). However, the processes related to the bloom of phytoplankton are more complicated. In many cases it is hard to speak about any limitation — the loads are heavy and zero-concentrations are rare for both N and P even in summer.

Oil products were determined by means of infrared spectrophotometry.

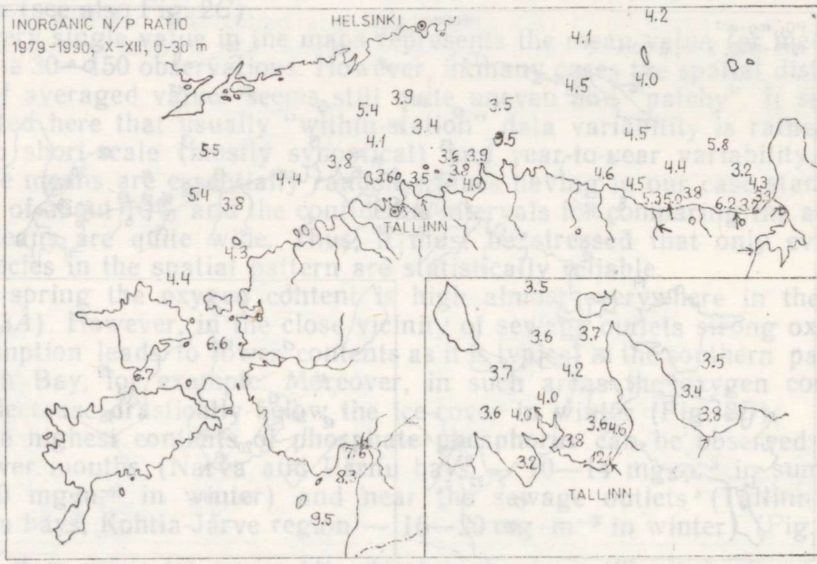

Fig. 3*D*.

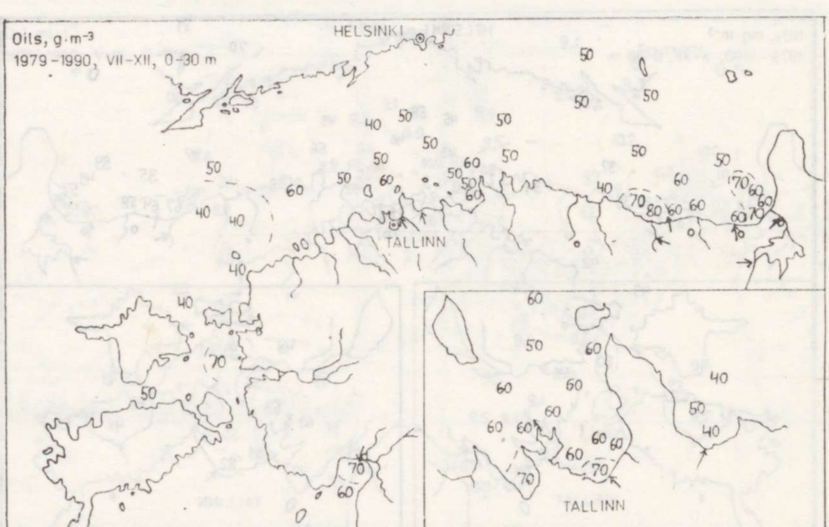

Fig. 3*E*. (Note: the unit is mg · m^{-3}.)

Unfortunately, the results seem to be incomparable with the values achieved by more up-to-date methods. The distribution of oils is highly skewed; thus, to avoid the influence of outliers and errors, sample medians (50%) are represented in Fig. 3*E*. The spatial distribution of medians shows that the most polluted areas are Tallinn and Narva bays. However, Figs. 1*D*, 2*D* and 3*E* suggest that the useful information carried by these data is too scanty. To continue the monitoring of oils, phenols, and detergents in this way is of questionable use.

Total Amounts of Nutrients in the Gulf of Finland

Total amounts of nutrients are regarded as basic properties of the sea. Their estimates are essential e. g. for explaining evident eutrophication tendencies in the Baltic Sea, for budget calculations, and ecological modelling. Such calculations have mainly been made for the entire Baltic Sea (see: Савчук, 1989); the Gulf of Finland, however, has roughly been treated as part of the Baltic Proper (Wulff and Rahm, 1988; Wulff et al., 1990). Estimations by Perttilä (1988) for the Gulf of Finland gave about 50 000 t P_{tot} and 350 000 t N_{tot}.

For calculating total amounts of nutrients in the Gulf of Finland the spatial net by Kielman (1981) is used in the present study. The Gulf was divided into 10×10 km cells in 6 depth intervals. Thus, the spatial pattern of the Estonian, Finnish (Pitkänen et al., 1987; 1990), and Russian (Astok et al., 1991; Pitkänen et al., 1991) data was interpolated-extrapolated altogether into 817 volume cells. The period with maximal nutrient content (February—March) was chosen. The calculations showed the nutrient amount in the Gulf of Finland (area — 29 600 km^2, volume — 1098 km^3) to be about 43 000 t of phosphorus (P_{tot}) and 440 000 t of nitrogen (N_{tot}). However, while the accuracy of volume calculations is quite good, the preciseness of the estimates of nutrient amounts could be expected to be only ±10—20%. Uncertainties may appear in chemical analyses, data interpolation procedures, and calculations based on data of inorganic forms of nutrients (using some empirical coefficients).

The weight ratio of total N/P amounts in the Gulf of Finland is consequently about 10, which is higher than Redfield's ratio (phosphorus is limiting?). However, a large proportion of the total nitrogen in the Baltic Sea consists of organic humic components stable in biological processes (Wulff and Rahm, 1988).

The ratio of nitrogen and phosphorus loads in the Gulf of Finland is about 20; this is considerably higher than the ratio of the amounts of these nutrients in the sea. Although the increasing nitrogen trends in the Gulf of Finland are more evident than those of phosphorus (Suursaar, 1992), the explanation should lie mainly in different turnover rates. The loads are to a large degree counteracted by biogeochemical sink and the subsequent denitrification of NO_3 (Rönner, 1985). The residence time for a conservative tracer (salt) is about 9 years in the Gulf of Finland and about 5 and 2.5 years for phosphorus and nitrogen, respectively. It must be said also that the turnover type for nutrients is "vertical" rather than "horizontal" (advective inflow-outflow).

Conclusions

Despite the "difficult" (deformed, noise-rich) monitoring data, it is possible to get some information about the state of the Estonian coastal waters. The amount of data is abundant allowing statistically quite founded assessment on long-term and large-scale distributions. However, the compatibility with other sets is problematic; the realization of the sea-monitoring in Estonia needs some reconstruction.

The pollution level in the Gulf of Finland is relatively high being determined by a large overall load. Still, the water quality in the coastal areas is determined mainly by the local polluters, whose direct influence decreases rapidly when receding from a certain pollution source. In the Estonian coastal waters the most polluted areas are Narva, Tallinn, and Pärnu bays, where the inflow from rivers and sewers is the most plentiful, and the nutrient contents are in general about 2—3-fold higher than in the mouth section of the Gulf.

Continuous eutrophication is the main problem for the Gulf of Finland. It is necessary to reduce the nutrient load on the Gulf. As nitrogen seems to be the limiting factor for producers, reducing excessive nitrogen loads should be the most effective.

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Presented by J.-M. Punning, D.Sc.

Received
May 18, 1992