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ON THE WATER QUALITY OF THE OPEN PART OF THE GULF OF FINLAND AND COASTAL WATERS OF ESTONIA

Abstract. The present study showed the pollution load on the Gulf of Finland to be about 380 000 t BOD_7, 194 000 t N_{tot}, and 9000 t P_{tot} annually. Statistical analysis proved large and manifold variation of the water quality data. It appeared that data of different origin were usually hardly comparable. Negative temperature (—0.1 °C/a) and salinity (—0.1 PSU/a) trends in the deep waters of the Gulf of Finland are evident for the last 15 years. Oxygen and pH trends were respectively about +0.2 ml/l and +0.01 units annually; nutrients exhibited also upward trends, but less obvious.

Key words: Baltic Sea, pollution load, data variability, trends.

Introduction: the Pollution Load

It is a well-known fact that the Baltic Sea has a huge anthropogenic load. The relative load on the Gulf of Finland (load on volume unit) is even 2—3 times higher. The most dangerous ingredients for the Baltic Sea are nutrients, mainly phosphorus and nitrogen salts causing eutrophication of the sea. The pollution load on the Gulf of Finland is probably about 380 000 tons organic matter as BOD_7, 194 000 t total nitrogen (N_{tot}) and some 9000 t total phosphorus (P_{tot}) annually (estimation made on the basis of FSWG, 1984; Pitkänen et al., 1988; Pollution . . ., 1991). It must be mentioned, however, that even if we could take into account all major sources of pollution, the reliability of such compilations would be within a score percent — that is the approximate precision of hydrochemical analyses nowadays. There may be also some gaps in the data. For example, Tallinn is by far not the only main direct waste water contributor from the Estonian side with its 3800 t N_{tot} and 350—320 t P_{tot} annually (Pitkänen et al., 1988; Pollution . . ., 1991). It has been known only since 1989 that annually about 4700 t ammonia has filtrated into the Gulf of Finland from the residue depository of the Chemical and Metallurgy Plant of Sillamäe. The estimate of ammonia pollution from Maardu fertilizer industry was about 820 t in 1990 (data from statistical report of water use). However, bearing in mind that the load from St. Petersburg and the Neva River makes up 60—70% from the total load on the Gulf of Finland, uncertainties in this region affect the reliability of the whole compilation the most strongly.

Statistical Properties of the Monitoring Data on the Gulf of Finland and Estonian Coastal Regions

Hydrochemical data concerning the open part of the Gulf of Finland and Estonian near-shore regions can be found from several sources. Below data gathered by the Baltic Monitoring Programme (BMP) and especially those collected by the Estonian Hydrometeorological Service (EHS) within the monitoring programme of the Soviet Union (ОГСНК

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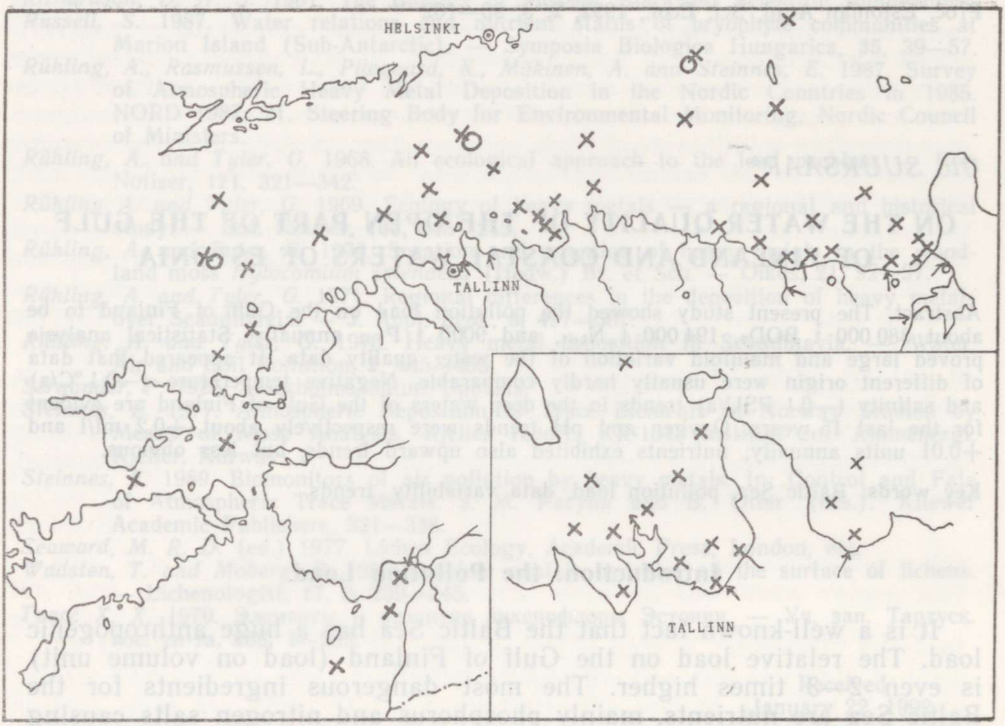


Fig. 1. Monitoring network in the open part of the Gulf of Finland and coastal waters of Estonia.
× — EHS stations, ○ — BMP stations.

in Russian) are discussed. There are three BMP stations in the Gulf of Finland; the time series began in 1979. The series of the EHS data was started in 1968—1974; measurements of up to 14 variables were made by nearly 50 stations (Fig. 1) 3—7 times a year. This is probably the most continuous and extensive data set available for this region. Unfortunately, up to now no sound review has been made of these data. The reasons seem to be that the data are not appreciated among Estonian explorers and in the Soviet Union censorship of such kind of information was common.

The BMP and EHS data are collected using different sampling methods and standards. The EHS data are based on Soviet standards. The BMP data are collected using the methods declared obligatory for each participant country according to special Guidelines (1979). The scope of the EHS data is sufficient enough to allow of certain conclusions about the state of the sea; but wishing to achieve comparability and compatibility with other more reliable sets (such as BMP data, for example) we ought to find out whether and to what extent this is possible. Several intercalibrations have revealed difficulties in the comparison of these data sets, but the results vary sufficiently from one intercalibration to another. Certain indirect intercalibration was made by the author earlier (Suursaar, 1991). The EHS data, the BMP data of the Finnish origin, and the BMP data of other countries were compared. Collated parallel samples from the same area, time interval, seasonal phase, and depth range were sorted out from the data base. Sample averages, standard deviations, ranges of variation, and empirical distribution functions were compared. Shortly about the results:

— From the BMP data on the chemical regime of the Gulf of Finland a critical researcher should use only those of the Finnish origin, which comprise about 80% of the total volume of the BMP-set. The data from other sources are not reliable enough; the Soviet ones (about 15%) are the worst.
— Comparison of the EHS and BMP (Finnish) data shows that in many cases systematic errors or biases (pH, oxygen, ammonia, silicates) occur, which are corrigible by means of a simple coefficient or linear transformation. The forms of transformations have been found empirically and they should not be considered universal. In the case of phosphates, nitrites, and nitrates the comparability depends on the concentrations. Smaller concentrations can differ three to five or even ten times. Bigger concentrations are far better. Several fractional lines or curves are needed for transformations; also outlier elimination is needed.

Unfortunately, the BMP does not include measurements of oils, phenols, and detergents. Precise determination of these contaminants involves substantial methodological difficulties. According to the general opinion of experts, various methods give fairly different results; moreover, no reasonable correlation usually exists between the methods.

Average, typical data are often needed (maps, modelling, assessments of the state of the sea, etc.). Unfortunately, large and manifold data variability appears already in preliminary analysis and it remains even after the removal of such substantial components of variability as seasonality and large-scale horizontal and vertical variability. The behaviour of the parameters of water quality is more or less random, nonpredictable. Sometimes we do not imagine that there might have been another, maybe quite different number instead of the number regarded as a true and reliable value.

In addition to the sources of variability mentioned above, year-to-year variability, catastrophical events, and temporal and spatial variability of microscales and synoptical scales should be born in mind. Unfortunately, it would be almost impossible to distinguish among these monitoring data the processes causing such variability or "patchiness" afterwards. The approximate share of different variability components and scales can be estimated using techniques of ANOVA (analysis of variance) and spectral and component analyses.

The most complete and dense time series is available for the southern part of Tallinn Bay (observations made once in ten days). Fourier' analysis of these data showed that only in temperature a clear one-year harmonic (92% of total variance) could be differentiated among the 36 Fourier' components with periods of 2 months to 6 years. For salinity, oxygen, pH, and nutrients the one-year component is noticeable, but comprises only about 10—30% of the total variance; quite a substantial share remained on shorter scales (Fig. 2). Spectra of oils, phenols, ammonia, and detergents were more similar to the white noise spectrum (zero-continuum 3%). The less frequent occurrence of shorter periods in the detergent spectra could be explained by the effect of the interpolation of gaps.

It must be mentioned, however, that these spectra represent the variability of water parameters in the heavily loaded near-shore regions. The variability in the off-shore regions is evidently smaller and seasonal cycles should be more significant there.

The role of different variability components was also analysed using ANOVA techniques. In case of temperature, salinity, pH, oxygen, and some nutrients large-scale and seasonal variability are dominant. Phenols, oils, detergents, and ammonia, however, have more substantial

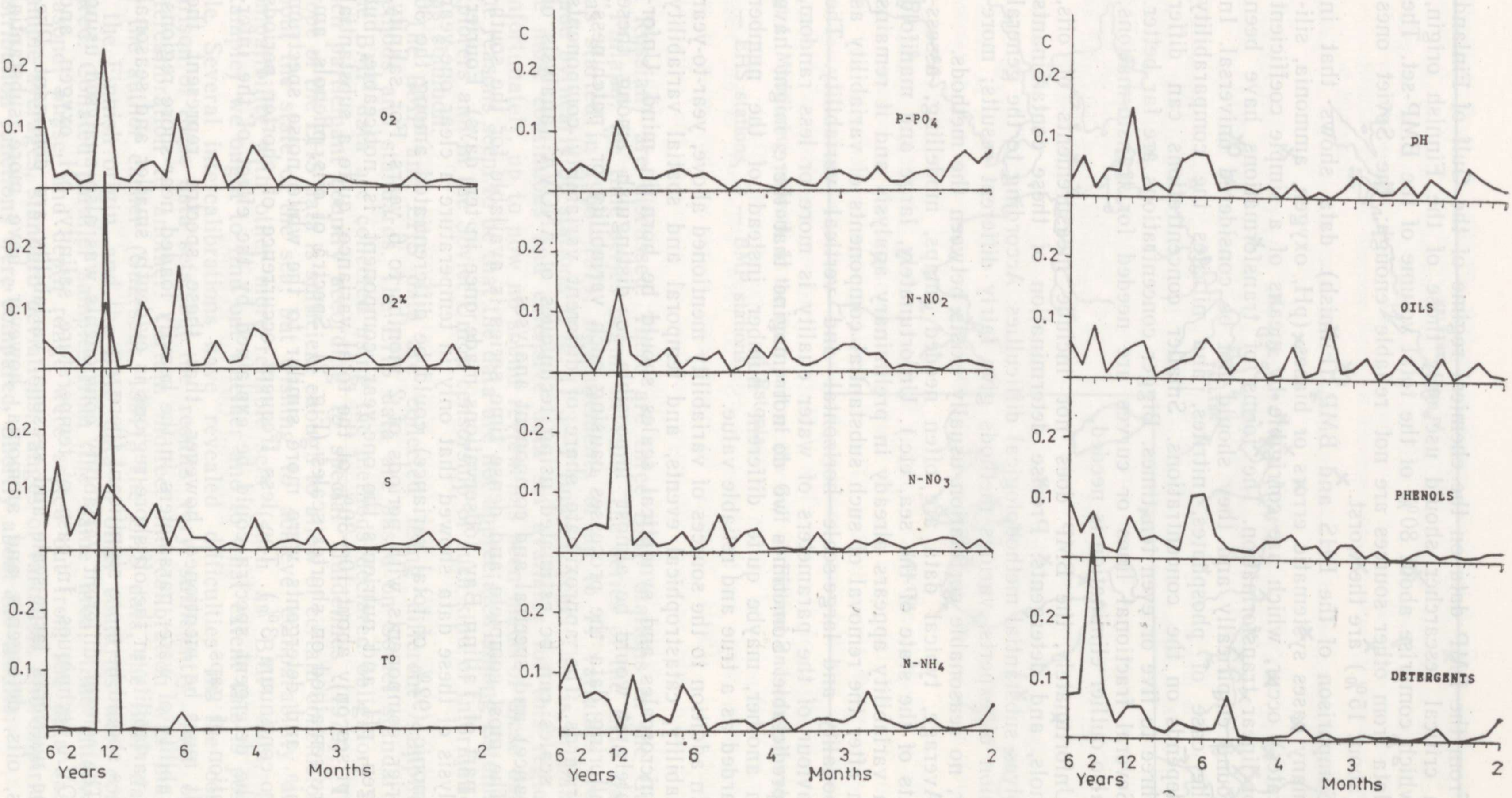


Fig. 2. Standardized spectra of the water quality data in the southern part of Tallinn Bay (0 m, 1982—1987).

Water quality in the open part of the Gulf of Finland. Analysis of variance

Source of variability	*Ms*								
	pH	O_2 %	PO_4	NO_2	NO_3	NH_4	SiO_4	Oils	Phenols
Geographical	0.017	2	17.9	6.7	238	161	0.024	3.3	12.0
Vertical	0.023	99	7.5	0.9	100	66	0.001	4.0	2.5
Temporal	0.510	708	22.6	10.1	303	2470	0.057	8.8	50.0
(Residual)	0.010	16	5.7	2.2	220	265	0.005	1.4	7.4

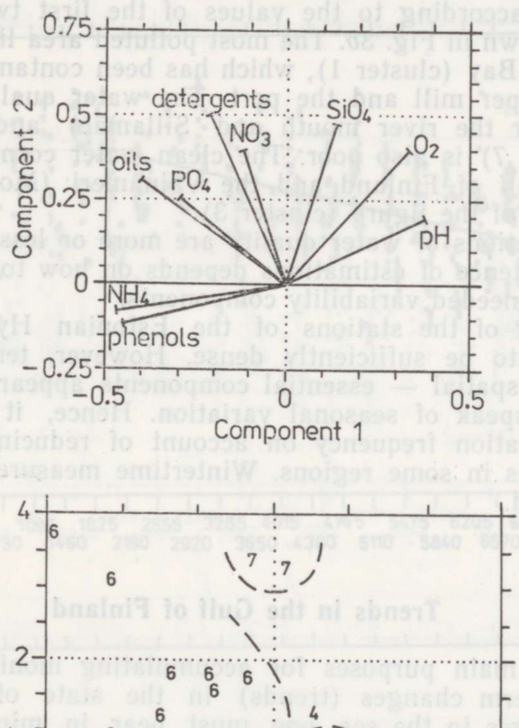


Fig. 3. Component (*a*) and cluster analyses (*b*) of the water quality data in the Gulf of Finland and Estonian near-shore areas.
Stations: *1* — southern part of Tallinn Bay, *2* — Tallinn Bay, *3* — the mouth section of the Gulf of Finland, *4* — central part of the Gulf of Finland, *5* — Kolga and Muuga bays, *6* — Narva Bay, *7* — Pärnu Bay.

variability within the quasihomogeneous layer than in the vertical curve and the variability within a season is stronger than seasonal variability. The results of two-factor analysis are presented in the Table; the final estimates — the mean squares (*Ms* — sums of squares divided by degrees of freedom for each group) — are given. Attempts were made to evaluate the relative importance of geographical (6 points in the central part of the Gulf of Finland), vertical (within the 0—20 m layer), and temporal (within 2—3 summer months) variability. In all cases temporal variability (though not seasonal) is the greatest. Surprisingly, spatial variability in general is not significant at all although the stations are about 30 km from one another within the total distance of 150 km. Thus, the spatial distribution of the water quality in the central part of the Gulf of Finland is relatively homogeneous. Spatial heterogeneity increases in the coastal and more polluted regions, as also component and cluster analyses indicate. The share of nine original components in the first two principal components, which make up 34+26% of the total variance, can be seen in Fig. 3*a*. Observation points plotted according to the values of the first two principal components are shown in Fig. 3*b*. The most polluted area lies in the southern part of Tallinn Bay (cluster 1), which has been contaminated for a long time by the paper mill and the port. The water quality in Narva Bay (especially near the river mouth and Sillamäe) and in Pärnu Bay (clusters 6 and 7) is also poor. The clean water corner — the western part of the Gulf of Finland and the Väinameri (Moonsund) — is in the lower right of the figure (cluster 3).

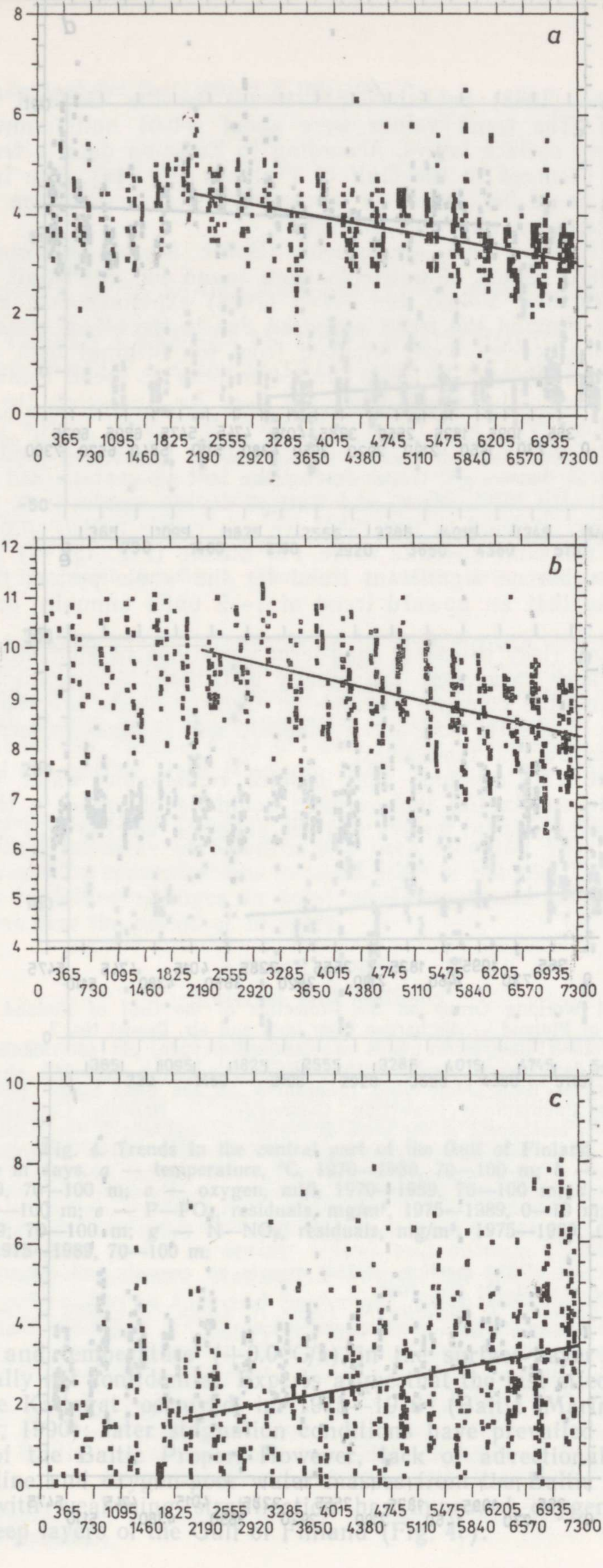
Thus, estimations of water quality are more or less approximate and random. Consistence of estimations depends on how to suppress disturbing and reveal needed variability components.

The network of the stations of the Estonian Hydrometeorological Service seems to be sufficiently dense. However, temporal variability is bigger than spatial — essential components appear within days and weeks, not to speak of seasonal variation. Hence, it is advisable to increase observation frequency on account of reducing the number of observation sites in some regions. Wintertime measurement of nutrients is highly needed.

Trends in the Gulf of Finland

One of the main purposes for accumulating monitoring data is to discover long-term changes (trends) in the state of the sea. When assessing changes in the sea one must bear in mind, however, that changes caused by human activities are superimposed by natural changes in the marine environment, which may be connected with global climatic changes. Moreover, about 10 years ago it was noticed that "something is wrong" with the Earth's climate. Climatic extremes have become more frequent, supposable global trends are overshadowed by increasing fickleness (ISC, 1980). Thus, attempts at the extrapolation of trends or long-term cycles far into the future seem to be quite risky.

In most subbasins of the Baltic Sea, the temperature and salinity in the deep layer have decreased gradually during the last 10—15 years (Baltic Marine Environment..., 1987, 1990). This is connected with the baric situation in the North Atlantic and the occurrence of water inflows from the North Sea. Trend estimate in the 70—100 m layer of the Gulf of Finland according to EHS data is about —0.1 °C for temperature and —0.1 PSU (Practical Saline Unit = per mille) for salinity annually (Fig. 4*a* and 4*b*). Trend estimates for salinity (—0.02



a
b
c
0 2 4 6 8
4 5 6 7 8 9 10 11 12
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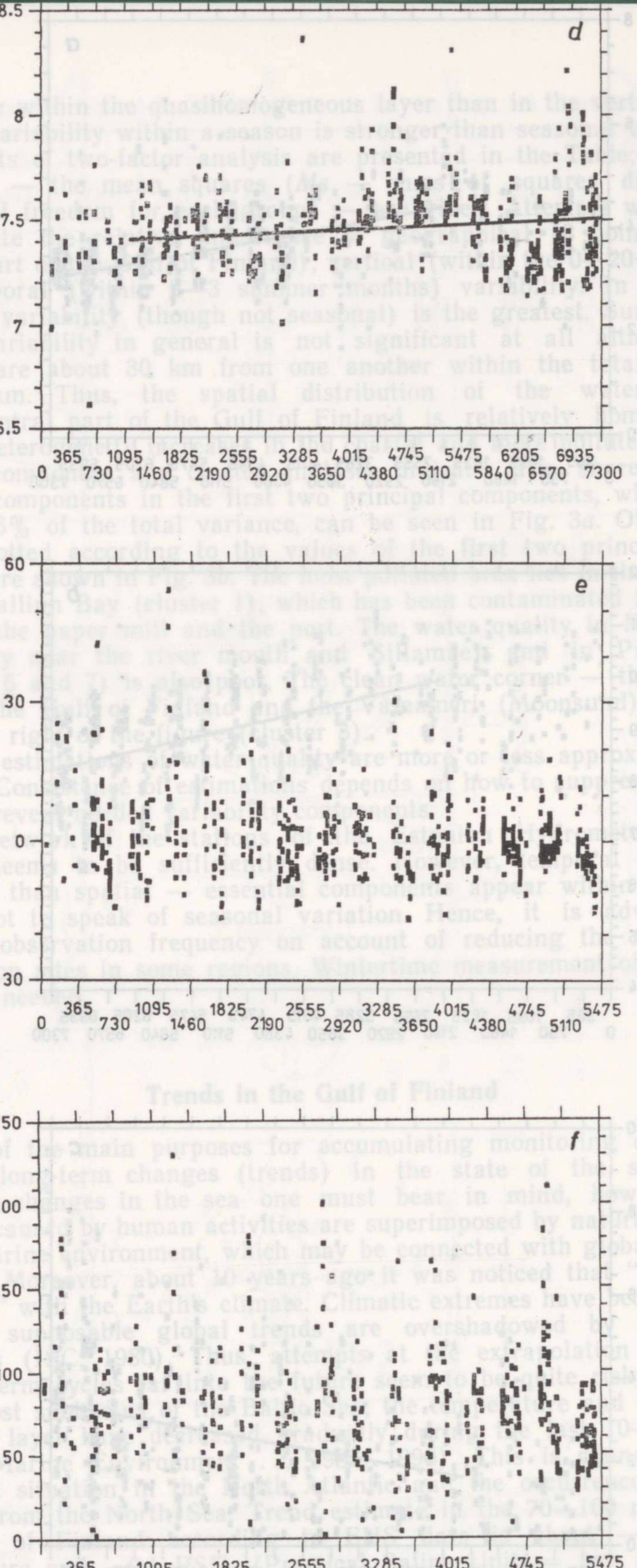

d
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0 365 730 1095 1460 1825 2190 2555 2920 3285 3650 4015 4380 4745 5110 5475 5840 6205 6570 6935 7300
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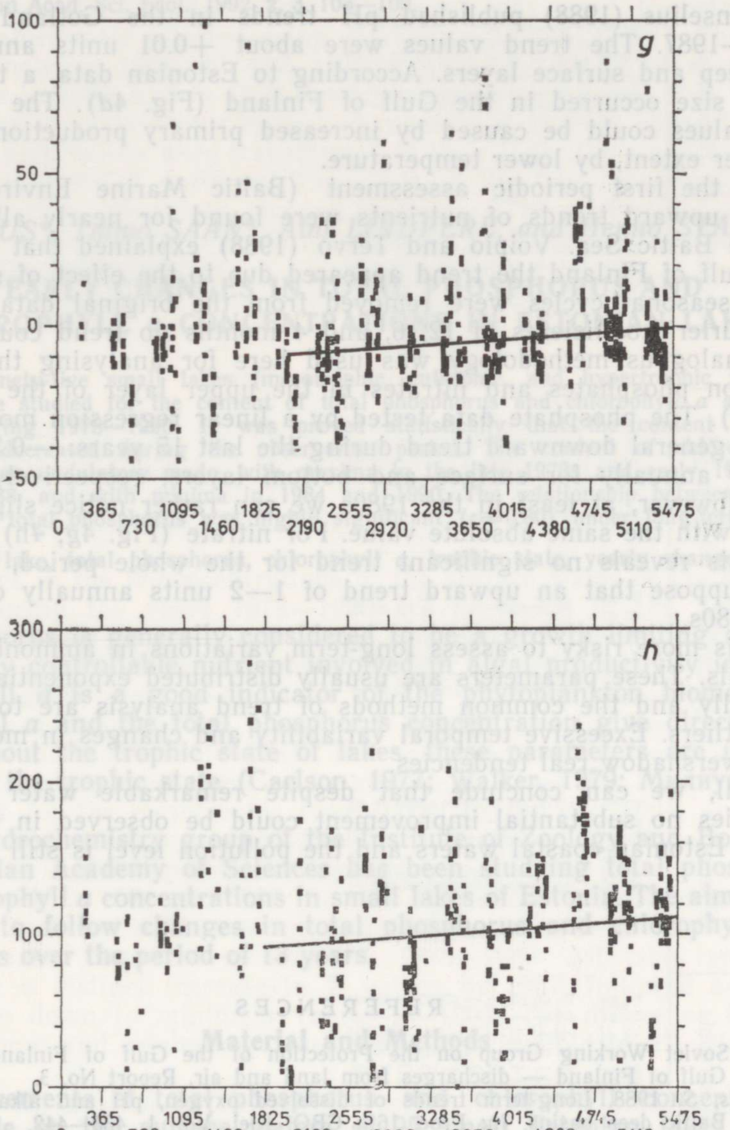

Fig. 4. Trends in the central part of the Gulf of Finland.

Time scale in days. *a* — temperature, °C, 1970—1989, 70—100 m; *b* — salinity, PSU, 1970—1989, 70—100 m; *c* — oxygen, ml/l, 1970—1989, 70—100 m; *d* — pH, 1970—1989, 70—100 m; *e* — P—PO_4, residuals, mg/m³, 1975—1989, 0—10 m; *f* — P—PO_4, 1975—1989; 70—100 m; *g* — N—NO_3, residuals, mg/m³, 1975—1989, 0—10 m, *h* — N—NO_3, 1975—1989, 70—100 m.

PSU/a) and temperature (+0.0 °C/a) in the surface layer seem to be statistically not confidential. Experts argue that the last effective inflows from the Kattegat occurred in 1975–1976 (Baltic Marine Environment . . ., 1990); later stagnation conditions have prevailed in the deep basins of the Baltic Proper. However, lack of advectional inflows of more saline and oxygen-poor water masses from the Baltic Proper connected with weakening stratification has improved oxygen conditions in the deep layers of the Gulf of Finland (Fig. 4*c*).

Fonselius (1988) published pH trends in the Gotland basin for 1964—1987. The trend values were about +0.01 units annually both for deep and surface layers. According to Estonian data, a trend of the same size occurred in the Gulf of Finland (Fig. 4*d*). The increase in pH values could be caused by increased primary production and, to a smaller extent, by lower temperature.

In the first periodic assessment (Baltic Marine Environment..., 1987) upward trends of nutrients were found for nearly all subbasins of the Baltic Sea. Voipio and Tervo (1988) explained that at least in the Gulf of Finland the trend appeared due to the effect of seasonality; after seasonal cycles were removed from the original data by means of Fourier' coefficients of 12, 6, and 4 months no trend could be seen. An analogous methodology was used here for analysing the Estonian data on phosphates and nitrates in the upper layer of the Gulf (Fig. 4*e*, 4*g*). The phosphate data tested by a linear regression model show a slight general downward trend during the last 15 years: —0.3 and —1.0 mg/m³ annually for surface and bottom layers, respectively (Fig. 4*e*, 4*f*). However, at least in the 1980s we can rather notice slight upward trend with the same absolute value. For nitrate (Fig. 4*g*, 4h) regression analysis reveals no significant trend for the whole period, though we can suppose that an upward trend of 1—2 units annually occurred in the 1980s.

It is more risky to assess long-term variations in ammonia, phenols, and oils. These parameters are usually distributed exponentially or log-normally and the common methods of trend analysis are too sensitive for outliers. Excessive temporal variability and changes in methods may also overshadow real tendencies.

Still, we can conclude that despite remarkable water protection activities no substantial improvement could be observed in the quality of the Estonian coastal waters and the pollution level is still alarmingly high.

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