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Classification of heavy metal contaminated sediments of the Gulf of Finland

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Heavy metals (cadmium, lead, copper, zinc, and mercury) and carbon were studied from sediment sampling sites around the whole Gulf of Finland. The samples were collected between the years of 1992 and 1996, thus this study reviews the condition of the Gulf in mid-1990's as revealed by a classification of the degree of heavy metal contamination of the surface sediments (0-1 cm). The data comprises earlier published data and new data. They are presented as colour surface maps of the spatial distribution of heavy metals in the recent sediments including a sediment quality classification. Strongest contamination was found at the eastern or north- eastern sites and the metal concentrations decreased towards west. The patterns of the spatial distribution maps are slightly different for each different element. The surface concentrations of the heavy metals are according to this classification within significant or high levels of pollution, which is a non-satisfactory situation.
☐ *Baltic Sea, Gulf of Finland, geochemistry, heavy metals, sediment quality, pollution, contamination, classification.*

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INTRODUCTION

The Baltic Sea is a relatively large sea area with unique character. It is an enclosed sea with brackish water and the only connection to the Atlantic Ocean is through the narrow Danish Sounds. The water depth is moderate, only 52 meters on average (HELCOM 2001). There is no tide and the sea is partly ice covered during the winter months. The Gulf of Finland is an eastward extension of the Baltic Sea and with a mean depth of 35 meters (Vallius 1999b) it is even shallower than the Baltic Sea. Three countries surround the Gulf: Estonia, Russia and Finland. All the capital cities are located on the coast of the Gulf: St. Petersburg, Tallinn and Helsinki, of which St. Petersburg is by far the most populous. The environmental impact from the metropolitan areas, especially the St. Petersburg area, is perceptible. This has contributed to the eutrophication of the sea, which is well visible in the massive algae blooms during hot summers (Rantajärvi 1998). In addition, the load of harmful substances, such as heavy metals, has been massive. In spite of this, until now the state of the offshore sea areas has been considered to be relatively good (Vallius & Leivuori 1999). In the shallower coastal areas the situation has been considered worse, where most areas were classified satisfactory, passable or even poor (Kauppila & Bäck 2001). This is in apparent conflict with the increasing public demands for a cleaner environment.

Sediment quality issues have become an important focus in the environmental assessment, protection, and management of aquatic ecosystems. However, in very few countries around the Baltic Sea detailed presentation on approaches, levels and status of sediment quality criteria have been made (WGMS 2003). Sediment quality guidelines are also important because sediments have a profound influence on the health of aquatic organisms, which may be exposed to chemicals through their immediate interactions with seabed sediments. There are, however, no sediment guidelines or environmental quality criteria for marine sediments in Finland. Thus, in the present paper we try to give a classification of sediment quality in the Gulf of Finland based on Swedish marine sediment quality criteria (Naturvårdsverket 1999, WGMS 2003), where surface concentrations are compared with background values. Quality criteria, which compare total concentrations with a reference or with background provided little insight into the potential ecological impact of sediment contaminants, however, they provide a base from which to evaluate Sediment Quality Guidelines (SQG, Burton 2002).

Some earlier sediment studies have covered the whole Gulf of Finland and most of the data used in this study is earlier published in those studies (Leivuori 1998, Vallius & Lehto 1998, Vallius & Leivuori 1999, Vallius 1999a,b, Leivuori 2000). In the present paper total concentrations of carbon, mercury, lead, cadmium, copper and zinc are presented as colour surface maps of the spatial distribution of heavy metals in the recent surface sediments of the Gulf. Combined with a sediment quality classification this gives a good estimate on the state of the sea floor sediments. On the basis of these maps and other background information we review the level of pollution of the Gulf in mid 1990's in order to contribute to the discussion of the state of the Gulf.

STUDY AREA

The study area comprises the whole Gulf of Finland (Fig. 1). The Gulf is ca. 100 km where widest and ca. 400 km in length. The total area of the Gulf is 29,600 km^2 and the total water volume is 1,100 km^3. The average depth is only 35 meters (Vallius 1999b), but the depth increases towards west, where a maximum depth 121 meters is recorded (Tavast & Donner 1992). The catchment area comprises mostly forested land, 54 %, 17 % of non-productive open land and 13.5 % of inland waters (Sweitzer *et al.* 1996). There are relatively few populated areas in the catchment, but the amount of people living in metropolitan areas (>250,000 inhabitants) is over 6 million (Sweitzer *et al.* 1996). The total annual fresh water discharge to the Gulf is 112 $km^3\ a^{-1}$ (Bergström & Carlsson 1994). The Neva River is by far the largest river in the area. It has a mean annual runoff of some 2460 $m^3\ s^{-1}$ (77.6 $km^3\ a^{-1}$, Bergström & Carlsson 1994). Since there is very limited water exchange from the Atlantic Ocean to the Baltic Sea the water in the distal Gulf of Finland is brackish, with salinity ranging from 0 to 5 in surface waters and 5 to 8 in near bottom waters. The salinity rises from east to west.

The volume of industrial production in the Gulf of Finland catchment area is significant and insufficient cleaning of industrial sewage is one main source of pollution of the Gulf. The catchment area is divided mainly between Finland, Russian and Estonian and it is over ten times the total area of the Gulf (Table 1). Various industries are discharging treated as well as untreated wastewaters into the Gulf. Untreated waters enter mainly from Russia. According to HELCOM's pollution load complication, PLC-2, the sewage from about 52 Russian industrial plants discharged in 1990 without treatment or only partly treated into the Gulf (HELCOM 1993a). In the next pollution load complication, PLC-3, treated direct industrial discharges from 5 Russian industrial plants were reported (Table 1), which clearly underestimate total heavy metal loads into the Gulf (HELCOM 1998). The Neva River is the principal carrier of pollutants. In comparison, the impact of pollution from other areas discharging to the Gulf of Finland is considerably smaller (HELCOM 1993b). However, the Vyborg Bay area and River Kymijoki, with its two main outlet areas, are considerable sources of heavy metals. Additionally, the cities and rural settlements together with airborne load have a negative influence on the state of the Gulf. Estimates of total metal pollution loads into the Gulf are very limited and

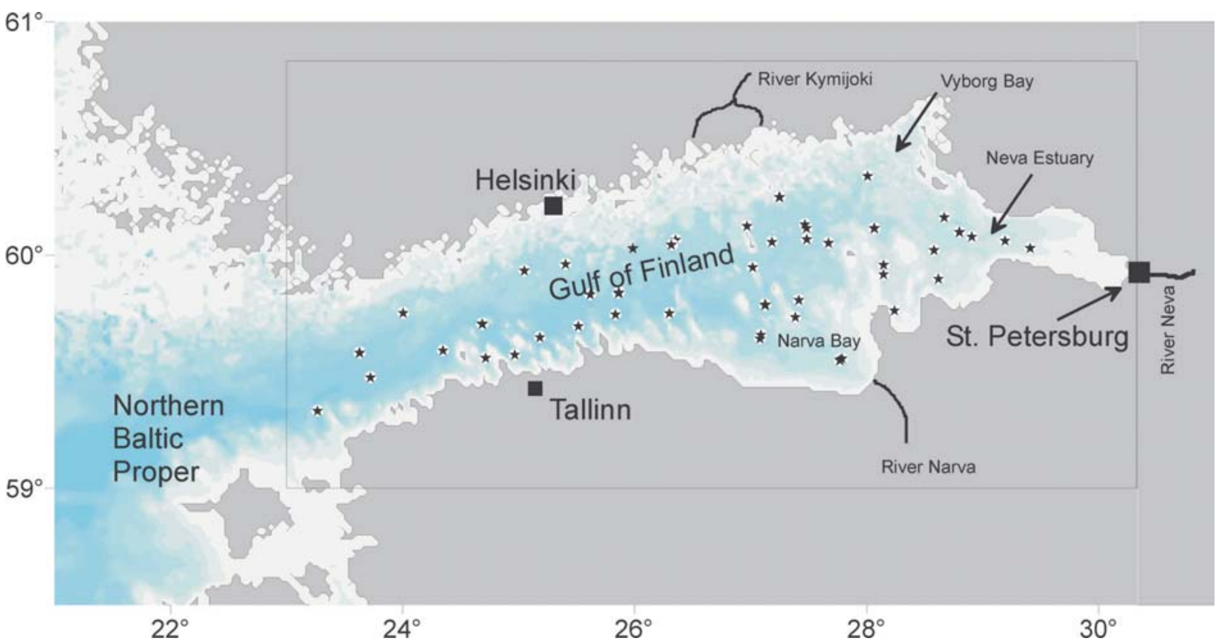

Fig. 1. Study area with sampling sites, rectangle indicates area covered by the geochemical maps (Bathymetric data from Seifert and Kaiser 1995).

Table 1. The catchment area of the Gulf of Finland and discharging industry in 1995 (HELCOM 1998).

Country	Catchment area of GOF (HELCOM 1998)	Industry discharging into GOF in 1995 (treated direct industrial discharges)
Finland	107 000 km^2 (26%)	18 plants: chemical, iron/steel, mining, food, petrochemical, pulp/paper, others
Russia	276 000 km^2 (67%)	5 plants: chemical, mining, leather/textile, food, pulp/paper, other
Estonia	26 400 km^2 (7%)	3 plants: chemical and pulp/paper
Total	412 900 km^2 (of which 3 400 km^2 (<0.1%) belongs to Latvia	16 plants

uncertain. The figures reported in pollution load compilations for metals are neither comparative nor reliable (HELCOM, 1991, 1993a, 1997, 1998). To get a view of the magnitude of metal loads into the Gulf Leivuori (2000) estimated these to be ca. 20 ta^{-1} of cadmium, 407 ta^{-1} of lead, 675 ta^{-1} of copper, 1405 ta^{-1} of zinc and 1.95 ta^{-1} of mercury. For zinc the estimate is probably too low.

The northern coast of the Gulf has one of the largest archipelagos in the world. This is reflected in the bottom topography of the whole northern part of the Gulf as a mosaic of small, isolated sedimentation basins. The southern coastal bathymetry is smooth and even, with small peninsulas, almost no islands larger, and more homogenous sedimentation basins. In the eastern part of the southern coast the islands are combined with the mainland by nearly continuous submarine ridges. The deposits are mainly glacial till and sorted sediments of glacial or postglacial age. In areas where conditions are favourable, the fine sediments (silts and clays) have been overlain by subrecent, or recent organic-matter rich clays. These are capable of binding and releasing metals depending on the physicochemical conditions in the near bottom water. They thus act as metal reservoirs. Bottom topography of the Gulf of Finland has been more thoroughly discussed by Vallius (1999b) and Leivuori (2000).

The hydrography in the Gulf is controlled by the Coriolis force, which forces the currents into anticlockwise movement (Palme'n 1930, Alenius & Myrberg 1998), further influenced by geomorphology and meteorological factors. Especially the near-bottom currents are difficult to model in a sea area like the Gulf of Finland, due to the complicated bottom topography. Models that cover the whole area and include also the near-bottom water indicate that bottom currents in general follow the surface current directions (Lehmann & Hinrichsen 2000), but there are local deviations up to 180 degrees from the surface current directions (A. Lehmann, pers. comm.). The sedimentation in the Gulf of Finland is to a large degree controlled by the hydrography. Salinity gradients and changes in oxygen content of the near bottom waters is another important factor when dealing with the stability of the metals in the Gulf of Finland.

In the water column metals (e.g. copper, zinc, and cadmium) are influenced by biological uptake-regeneration cycles and by adsorption-sorption onto particles (e.g. copper, lead). Metals occur in their higher oxidation states as oxyhydroxides or as complexes with organic and inorganic ligands accumulating partly in the coastal area or transported further to open sea areas. Beside organic matter, iron and manganese oxyhydroxides have been reported to be the main scavengers of metals in the Gulf of Finland (Leivuori 2000).

MATERIALS AND METHODS

Sampling and sample handling

The bottom sediments for this study were sampled during cruises of different Russian research vessels rented by All-Russia Geological Research Institute (VSEGEI) for the Marine Ecological Patrol (MEP), two cruises of R/V Muikku from the Finnish Environment Institute (FEI), and several cruises of R/V Aranda of the Finnish Institute of Marine Research (FIMR). All samples were taken between the years 1992 and 1996. The total amount of sampling locations for this study is 47 (Fig. 1). From some sampling areas, however, there are cores from parallel sites from which only mercury data is presented. Thus mercury data covers totally 55 sites. New data are presented mainly from the western and northern parts of the Gulf, where there were gaps in the earlier data.

Sampling was usually preceded by thorough echo-sounder investigation of the area to be sampled, unless the basin had been studied earlier. In each basin usually the site with thickest cover of recent sediments was chosen for sampling. Positioning of the sampling sites were always performed by GPS and on the Finnish vessels by DGPS.

The samples are relatively short gravity cores from recent soft sediments taken with different kinds of gravity corers with inner diameters of 60 to 90 mm. Most samples were taken with a Niemistö or a Gemini corer. The Niemistö corer has the disadvantage of small diameter, with risk of core shortening, smearing and edge effect. The Gemini corer on the other hand is a twin corer with low risk of smearing, tilting or core shortening. In general the Gemini corer yields undisturbed surface samples (Ilus 2000). The core length varied usually between 15 cm and 25 cm. The cores were sliced into 1 cm thick subsamples on board and packed in plastic bags or containers that immediately were stored in -18 °C until they were freeze dried (Leivuori 1998, Vallius & Lehto 1998, Vallius & Leivuori 1999, Vallius 1999a,b, Leivuori 2000). Only the uppermost 0-1 cm samples are evaluated in this study.

Chemical analyses

All chemical analyses were done at the laboratories of the FIMR and the Geological Survey of Finland (GSF). The samples were first weighed for wet weight then freeze-dried and weighed again for dry weight before sieving to obtain the <2 mm fraction (GSF) or removing large objects by tweezers (FIMR). The samples were then mechanically homogenised and analysed for total concentrations of heavy metals and carbon.

The sediment samples were analysed for heavy metals with comparable ICP-AES, ICP-MS and GF-AAS techniques at the laboratories of GSF and FIMR (Vallius & Leivuori 1999). Measurements were done after total dissolution with different acid combinations (hydrofluoric acid-perchloric acid or aqua regia and hydrofluoric acid with boric acid, Vallius & Leivuori 1999). Mercury was measured using FIMS- techniques after nitric acid digestion (Vallius & Leivuori 1999). Total carbon was analysed using a Leco CHN-600 instrument at GSF. Additionally, total carbon data of six stations analysed by Carman (1996) were included.

The analytical methods were accredited (FIMR accredited by the Centre of Metrology and Accreditation as testing laboratory T040) or the quality was ensured otherwise. The analytical reliability was in both laboratories checked using commercial standard reference materials. The analytical results of the both laboratories are comparable as reported earlier by Vallius and Leivuori (1999). Minimum recovery was obtained for cadmium (91%) at the FIMR and maximum recovery for mercury (113%) at GSF. All other recoveries were between these values, and they could thus be considered as satisfactory (Vallius & Leivuori 1999).

Data analysis and map production

This paper combines old published and new unpublished data from the surface sediments of the Gulf of Finland. Since the aim of this paper is to classify the quality of these sediments the data is presented as colored surface maps, from which it is easier to divide the Gulf in different zones according to Swedish environmental quality criteria. The metal and carbon data from the studied sites were combined into one data set that was statistically tested before map production. For most elements the frequency distribution was normal, only copper and cadmium shoved a bimodal distribution. Version 1.2.1 of the GEOEAS program by the U.S. Environment Protection Agency (EPA) was used for the variogram tests (EPA 1988). The variogram was determined for each element separately, and was checked for best model, taking into account range of the variogram, possible nugget effect, sill height and vertical scale of the variogram. For all elements a spherical model was chosen, but the parameters varied markedly between elements. In three cases (mercury, cadmium and zinc) a nugget effect was taken into account. The number of samples is rather low, which is best visible as a ring-pattern in the black and white maps of the kriging standard deviations.

Point kriging was chosen as gridding method and the maps were produced using the Golden Software Surfer 7© software and the chosen variogram model. On every map the variogram for the data as well as a graphical presentation of the kriging standard deviation is plotted. The extension of the maps is limited to the data limits thus white areas are plotted on the maps.

RESULTS AND DISCUSSION

The data set has a slight skewness toward higher concentration values for mercury and zinc, indicated by somewhat lower median values than mean values (Table 2). In spite of that, the metals are statistically relatively smoothly distributed along the Gulf of Finland

Table 2. Concentrations and descriptive statistics for studied elements in the surface sediments (0-1 cm). Concentrations of metals in mg kg –1 and carbon in % on dry weight basis. See the explanations of classes in Table 3.

	C	Pb		Hg		Cu		Cd		Zn	
	(%)	(mg kg $^{-1}$)	Class	(mg kg $^{-1}$)	Class	(mg kg $^{-1}$)	Class	(mg kg $^{-1}$)	Class	(mg kg $^{-1}$)	Class
Mean	4.0	51	3	0.18	3	43	3	1.2	3	199	4
Median	3.8	49	3	0.17	3	43	3	1.2	3	183	3
SD	1.1	16		0.09		9.3		0.57		68	
Minimum	2.1	25	1	0.05	2	25	2	0.28	2	77	1
Maximum	6.7	88	4	0.39	4	63	4	2.2	4	391	5
Count	47	47		55		47		47		46*	

SD = standard deviation * One outlier removed with a steadily decreasing trend towards the west and with no clearly isolated populations in any areas of the Gulf.

Copper, lead, cadmium, zinc and mercury exhibit noticeable correlation with each other in the Gulf (Leivuori 1998). These elements are transported in association with organic material, but at least copper, cadmium and zinc are also released by decomposition of organic substances from freshly deposited material under oxic conditions. Zinc, lead and cadmium further have the ability to co-precipitate with manganese and iron oxyhydroxides (Salmons & Förstner 1984), which influences greatly to the distribution of these elements.

Classification of surface sediments in the Gulf of Finland based on heavy metal data

Sediment classification

In 1999 the Swedish Environmental Protection Agency (EPA) established the Swedish Environmental Quality Criteria (EQC) of marine sediments (Naturvårdsverket 1999). The purpose of these criteria is to enable local and regional authorities and others to make accurate assessments of environmental quality on the basis of available data on the state of the environment and thus obtain a better basis for environmental planning and management by objectives. The assessment of metals is based on the deviation from a comparative value representing pre-industrial concentration levels (Table 3). Sediment samples collected at about 55 cm depth of burial are believed to represent pre-industrial time (Naturvårdsverket 1999). Vallius and Leivuori (1999) estimate background values of heavy metals based on samples collected at 25 cm in the GOF. They were lead 21, mercury 0.018, copper 25, cadmium 0.11 and zinc 100 mg kg-1. These values are in good agreement with the Swedish ones, with exceptions for Cu and Zn, the background values of which might have been overestimated because of too short sampling depth. Thus in this classification Swedish pre-industrial values (limit value of Class 1, Table 3) have been used.

In the Swedish EQC the class boundary between classes 1 and 2 should represent a "natural" normal value. One objective with the classification system is that the system should make it possible to detect if a local point source exits within and affect a restricted sea area. Thus the boundary between the classes 4 and 5 is put at a level where point sources clearly affect the concentration. The classes 2, 3 and 4 are intended to successively show the effect of increased diffuse pollution (WGMS2003, Naturvårdsverket 1999).

Table 2 includes also the quality criteria classification for mean, median, minimum and maximum values of metals in the GOF. Mean values of lead, mercury, copper and cadmium indicate significant and zinc large effect of (increased) pollution. Maximum values indicate large and very large point source pollution, while minimum values show none (Pb) or slight (Hg, Cu, Cd) influence of pollution. This classification indicates that the situation in the surface sediments of the GOF is not good. However, a classification based on single values of metals does not give an over-all picture of the situation over the whole Gulf. In order to get a better result we used geochemical maps over the whole study area as a basis for classification.

Geochemistry and classification of the surface sediments

Concentrations of the heavy metals have earlier been reported to increase from west to east along the Gulf of Finland (Leivuori 1998, Vallius & Lehto 1998, Vallius & Leivuori 1999, Vallius 1999a,b, Leivuori 2000), and the addition of new data in this study has not changed this trend. The most contaminated sediments are found at the eastern or northeastern stations. However, the patterns of the horizontal distribution of the elements in the surface sediments are slightly different for each different element (Figs. 2a-c and 3a-c).

Carbon is a very active element and is often involved in biochemical processes that affect metal binding and fixation. In the Baltic Sea usually more than 99% of the total carbon is of organic origin (Carman 1996). In a study from the Gulf of Finland Conley *et al.* (1997) report inorganic carbon to have percentages between 0.7% and 1.8% of total carbon. Thus the total carbon presented here can be considered as of organic origin. Similar to the findings by Leivuori (1998) and Vallius & Leivuori (1999) no significant correlation between the carbon content and the different metal contents was found.

Table 3. Ranges used for classification of sediment heavy metal contamination according to the Swedish Environmental Protection Agency (mg kg^{-1} dry weight, total analysis, WGMS 2003).

Metal	Class 1	Class 2	Class 3	Class 4	Class 5
(mg kg^{-1})	Little or none	Slight	Significant	Large	Very large
Pb	< 31	31–47	47–68	68–102	> 102
Hg	< 0.04	0.04–0.10	0.10–0.27	0.27–0.72	> 0.72
Cu	< 15	15–30	30–60	60–120	> 120
Cd	< 0.2	0.2–0.5	0.5–1.2	1.2–3	> 3
Zn	< 85	85–125	125–196	196–298	> 298

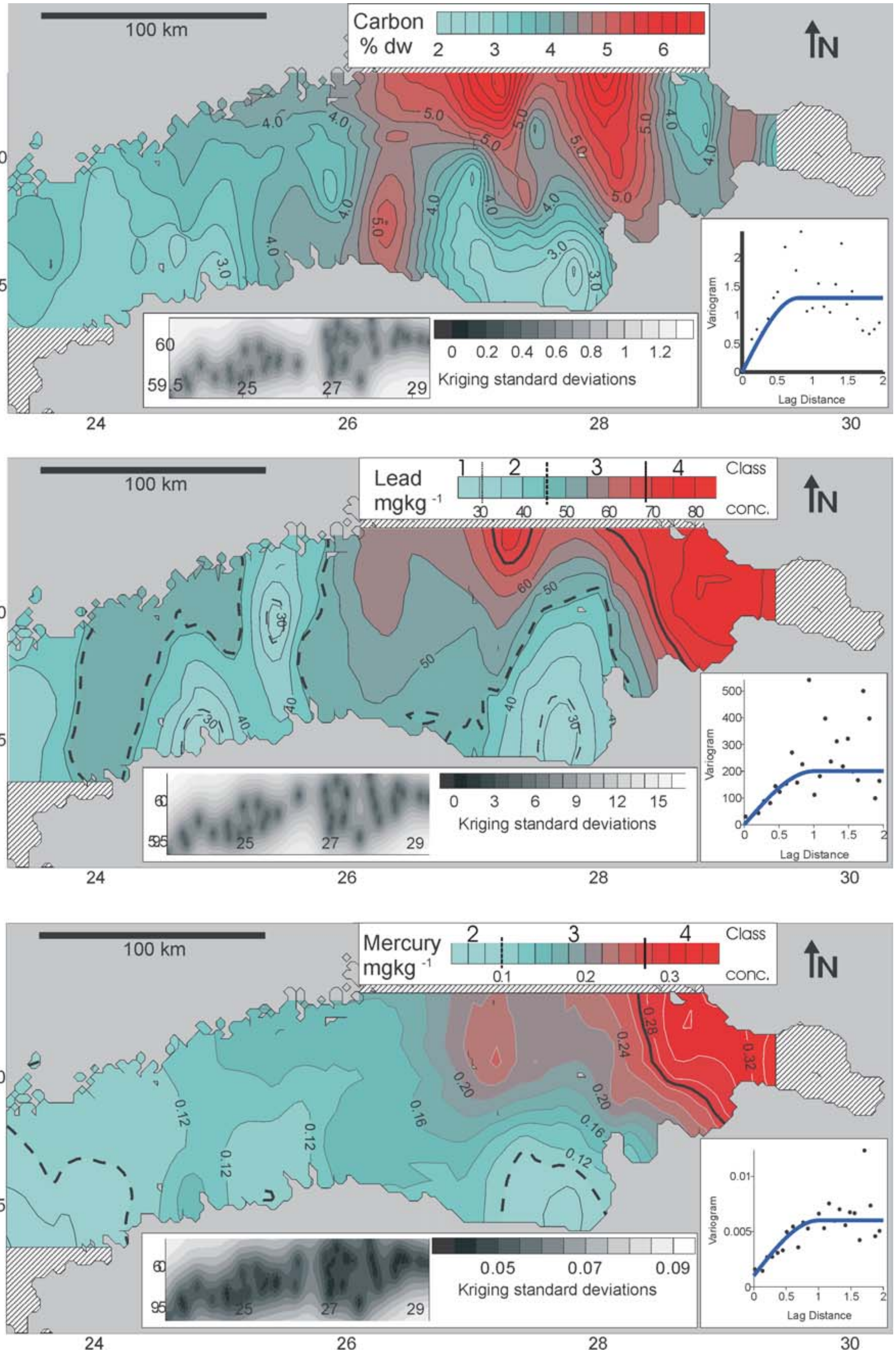

Fig. 2a-c. Surface sediment concentrations, variograms and kriging standard deviations of carbon, lead and mercury as well as classification of heavy metal contamination (Shoreline data from Seifert and Kaiser 1995).

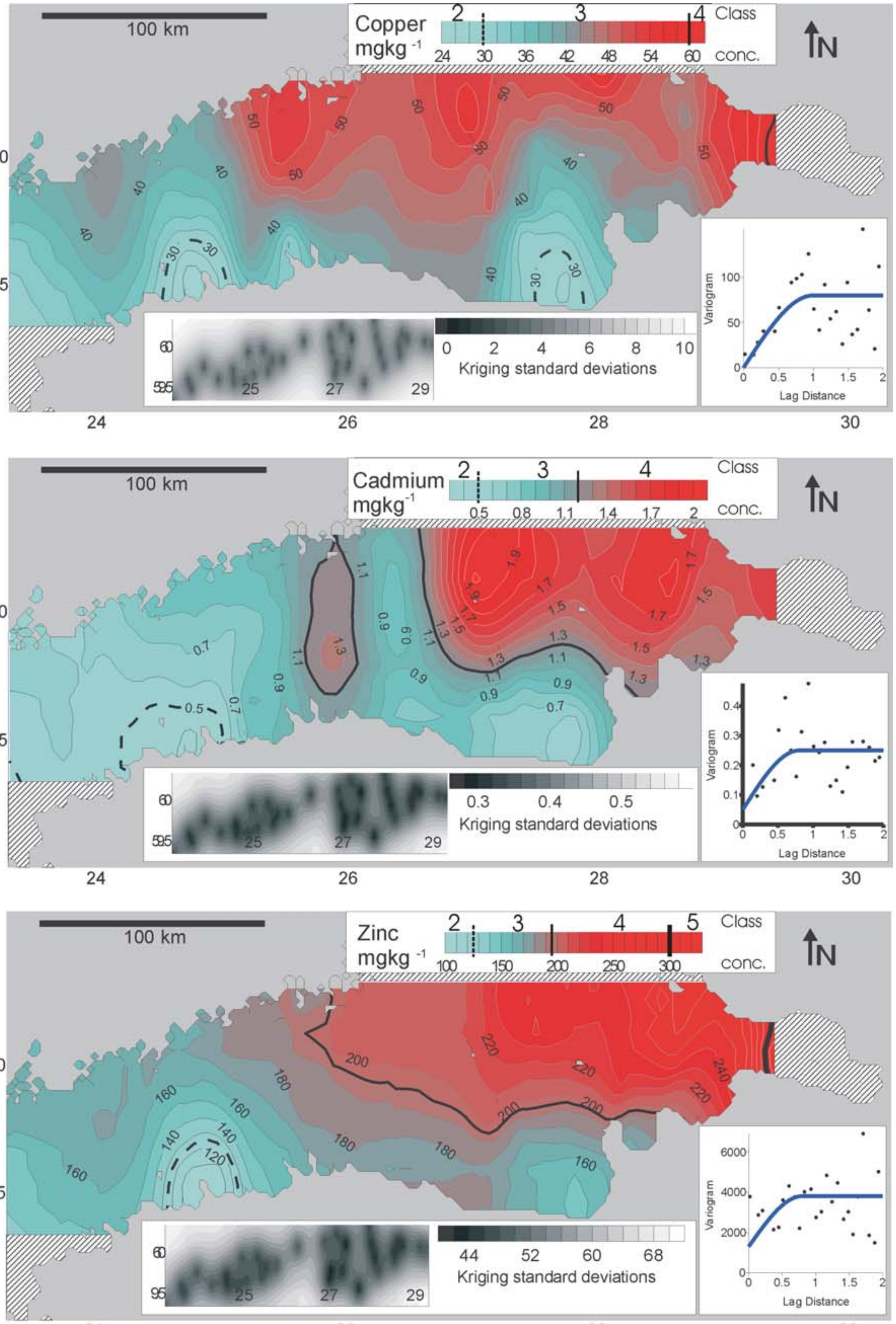

Fig. 3a-c. Surface sediment concentrations, variograms and kriging standard deviations of copper, cadmium, and zinc as well as classification of heavy metal contamination (Shoreline data from Seifert and Kaiser 1995).

Map in Fig. 2a shows that carbon concentrations are higher in the northeastern and part of the Gulf of Finland, with an extension southwest towards the coast of Estonia. The Narva Bay area in southeast is low in carbon, as is the whole western part. Although carbon shows a clear anomaly in the north- east, these concentrations are not particularly high.

Lead (Fig. 2b) contamination is large (class 4) in the Neva Estuary and outside the Vyborg Bay. The rest of the Gulf shows increased diffuse pollution with in classes 2 and 3. Especially in the eastern part of the Gulf lead concentrations are more than double the background values. It is readily well trapped in accumulating sediments under oxic conditions, which has favoured the accumulation of lead in the Neva Estuary. According to PLC-3 lead loads from the Neva River is almost 20 times higher than loads from the Kymijoki River (HELCOM 1998). It is clear, that the Neva River is a point source for lead on that area. In western areas the lead concentrations show only small or clear deviation from the background value.

Like lead also mercury contamination (Fig. 2c) is large in the Neva Estuary (class 4) and shows clear contamination also in the open sea area, slightly higher in the northeastern part of the Gulf (class 3). Almost all the rest of the Gulf is significantly (class 3) contaminated by mercury. Only sediments in the outlet towards the Baltic Proper are somewhat cleaner (class 2). In the northern part of the Gulf the mercury outside the outlet of River Kymijoki is known to be originating from discharges during late 1950's (Kokko & Turunen, 1988, Anttila-Huhtinen & Heitto 1998, and Verta *et al.* 1999).

Copper (Fig. 3a) contamination is quite even throughout the whole Gulf. Only the Neva Bay shows large contamination (class 4) and almost all of the rest Gulf shows significant contamination (class 3). HELCOM (1993b) reported many plating industry plants in the St. Petersburg area, which discharge at least copper and also in some degree zinc into the Gulf. These loads explain partly the high copper contamination in the Neva Bay. Organic matter, iron/ manganese hydroxides or oxyhydroxides probably are the main scavengers of copper in the water and act as carriers, allowing widespread occurrence in the sediments.

Cadmium (Fig. 3b) shows a similar pattern to copper and mercury, but the degree of contamination is higher. Its contamination is large in the whole northeastern Gulf, as well as in the central areas (class 4). The rest of the Gulf (except off Tallinn) is still significantly contaminated by cadmium (class 3). Evidently cadmium is partly transported with organic carriers (e.g. humic substances), but also the massive algae blooms in the easternmost part of the Gulf could promote the accumulation of cadmium into sediments, since there is a relationship between eutrophication and the removal of metals, as noted by Jonsson (1992). There seems to be various sources of cadmium pollution in the Gulf and it seems to be easily transported over a larger area. Cadmium and zinc together show the highest contamination in the sediments of the Gulf.

The distribution of zinc (Fig. 3c) is almost similar to that of cadmium. It is largely contaminating the northeastern Gulf (class 4) and the Neva Bay is very highly polluted (class 5). It could be assumed, that the discharges from plating industries in St. Petersburg (HELCOM 1993a) have partly contaminated the Neva Bay. The rest of Gulf is significantly polluted (class 3). Zinc has similar interaction with organic matter, iron/ manganese hydroxides or oxyhydroxides as copper causing a wide-range uniform distribution of the metal.

State of the Gulf

The surface concentrations of all the studied metals are roughly two to ten times higher than the pre-industrial values depending on metal. The amount of anthropogenically-derived metals differs at different sites and depths. Vallius (1999a, 1999b) and Leivuori (2000) has estimated the anthropogenic part of the accumulating metals to be more than 90% for mercury, ca. 80% for cadmium, and between 40% and 60% for zinc, copper and lead. Contamination falls often into classes 3 and 4 of the Swedish environmental criteria, that is, the sediments are significantly or largely polluted. The metals originate from different sources, mostly in the River Neva, River Kymijoki and the Vyborg Bay drainage areas. Additionally to the anthropogenic sources there is also a natural difference in the metal levels in the sediments of the Gulf. The sediments on the northern side of the Gulf have slightly higher heavy metal contents than the sediments on the southern side simply because of the differences in the source rocks. The geological background provides the sediments along the northern coast with higher heavy metal concentrations (Vallius 1999b). Most metal backgrounds are only slightly higher, but lead, cadmium and mercury concentrations are two to nearly four times higher on the northern side compared with the southern side. As the background values of these metals are very low compared to the total concentrations in the surface sediments this does not too much deviate the classification of the sediments. In fact, the sediments of the southern coast are slightly more contaminated than what the classification describes. This explains partly the cleaner areas off the Estonian coast.

The state of the Gulf of Finland has drastically changed to the worse during the 20th century due to an extensive anthropogenic impact. During the last decade of the century the situation improved though especially in the most polluted eastern end of the Gulf, which was mainly related to the decrease in Russian industrial production (Vallius & Leivuori 1999). During the cleaner conditions of the last decade the Gulf of Finland, especially the eastern area, has gone through an environmental self-purification as cleaner sediment has accumulated on top of the more polluted sediment from the decades before. This process will continue if the conditions remain stable. As this study shows the surface concentrations of all metals (except lead in some cases) are, though, still highly elevated in the whole Gulf and especially in the northeastern parts.

The state of the Gulf according to this study is not good. As the input of metals has decreased, eutrophication of this area has become problem number one (Kauppila & Bäck 2001, HELCOM 2001). Additionally, there is a concern that through bottom water anoxia the risks of metal release from the bottom sediments will increase. However, there is no information how well the criteria used fit to sediment classification in areas where varying oxygen conditions are prevailing. Thus, the sediment quality classification should take into account many variables effecting heavy metal processes in the water-sediment interface. Burton (2002) suggests, that sediment quality guidelines (SQGs) should be used as part of a holistic assessment in a screening manner or in a "weight-of evidence approach", in which multiple components are assessed (e.g. habitat, hydrodynamics, resident biota, toxicity, and physicochemistry, including SQGs) using integrated approaches.

As already stated the number of samples in this study is rather low for this kind of presentation. We believe, however, that it does not severely misrepresent the situation in reality, and want to add this perspective to the discussion of the state of this polluted sea area. As a matter of fact collection of even such a data set is close to impossible today.

CONCLUSIONS

Based on the used sediment quality criteria the state of sediments in the Gulf of Finland is not satisfactory. In most areas sediments are significantly or largely polluted. The used criteria seem to be useful also for classification of sediments in the Gulf of Finland, however criteria for classification should be validated for this specific area, if this method will be applied nationally.

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