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# SEDIMENT GEOCHEMISTRY AND USE OF THE SEAFLOOR OF THE GULF OF FINLAND

*by*
*Henry Vallius*

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The Gulf of Finland has during the second half of the last century been under such stress as never seen before. Human activity in its catchment has introduced large amounts of harmful substances and nutrients into the water column. These substances can still be found in the offshore modern soft sediments of the Gulf of Finland. At the same time, all marine activities, except fishing, have expanded many-fold. The shift from the command economy of Soviet times to the current open market economy in Russia has increased marine activities many-fold, but at the same time it has initiated a slow recovery of the seafloor. The condition of the seafloor during the last two decades has clearly improved from the worst times in the early 1980s, but it takes a long time for the submarine environment to fully recover.

In particular, submarine works in connection with various types of new infrastructure, such as pipelines, cables, wind parks and submarine mining, are a new threat for the shallow and sensitive Gulf of Finland.

Keywords (GeoRef Thesaurus, AGI): environmental geology, marine pollution, marine sediments, geochemistry, heavy metals, human activity, Finland, Baltic Sea, Gulf of Finland

*Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland*

*E-mail: henry.vallius@gtk.fi*

## INTRODUCTION

The Geological Survey of Finland (GTK) has a long tradition of marine geological investigations. Since the 1950s, staff from GTK have participated in numerous cruises, especially on the research vessel Aranda, and other research vessels of different nationalities, in the Baltic Sea as well as in other sea areas of the world. Dr Heikki Ignatius initiated marine geology in Finland after a stay in the United States in the mid-1950s. He was followed by Dr Boris Winterhalter, who also gained marine geological knowledge during a relatively long trip to the United States. After their pioneering work, these two initiators were followed by many other geologists specialized in marine geology. Perhaps because the Southern Finland office of the Geological Survey in Espoo, which close to the capital city, Helsinki, is located on the coast of the Gulf of Finland, the majority of the marine geological work has been conducted in the Gulf. The aim of this paper is to summarize the most recent studies on sediment geochemistry and sea floor infrastructure performed from the 1990s until today. These have included internal GTK studies and also national collaborative studies, as well as international collaborative projects such as SAMAGOL and TRANSIT, involving co-operation between GTK and the All-Russia Geological Research Institute (VSEGEI).

This paper summarizes information on the sediment chemistry of selected heavy metals and on the use of the seafloor of the Gulf of Finland, mainly through a review of earlier studies. The metal distribution is presented as composite case maps for nickel, cadmium, mercury and molybdenum, as their distribution is partly controlled by different factors. The data for the maps are from surveys carried out over a period of 7 years (2001–2008). This is a rather satisfactory time period considering the low accumulation rates of the offshore Gulf of Finland, as well as the short annual ship time and large sea areas to map for sampling, making it difficult to complete mapping of larger areas within shorter time periods. The area covered includes Finnish territorial waters and the Exclusive Economic Zone (EEZ) in the Gulf of Finland.

## STUDY AREA: THE GULF OF FINLAND

The Gulf of Finland (Figure 1) is an estuarine-like, rather shallow eastward extension of the Baltic Sea. Its maximum longitudinal extent from the Hanko peninsula to the Neva Bay is some 350 km, while the width of the main gulf outside the Neva Estuary varies between 45 and 110 km. Its depth is slightly over 100 m at maximum and decreases from west to east. Surface salinity decreases from 6 psu to nearly freshwater conditions in the same direction. Because the Gulf of Finland is a direct continuation of the Baltic Proper, the saline water of the Baltic deep flows more or less freely into the Gulf, ensuring that the main hydrographical changes in the Baltic Proper are reflected there. A comparably high freshwater inflow, another important hydrographical factor, is guaranteed by several rivers draining to the Gulf. The most significant inflow is from the east, from the River Neva, which flows through the city of St Petersburg. During the last half century, the Gulf of Finland has been strongly affected by the activities of millions of inhabitants in its drainage basin. In 2002, over 12.6 million people lived in the area (Hannerz & Destouni 2006). Pollution and eutrophication have caused strong loading of harmful substances and nutrients to the seafloor sediments of this very shallow sea area (HELCOM 2007, 2009). The sediments act as reservoirs of emitted elements, recording the concentrations of metals and changes in emissions over the years.

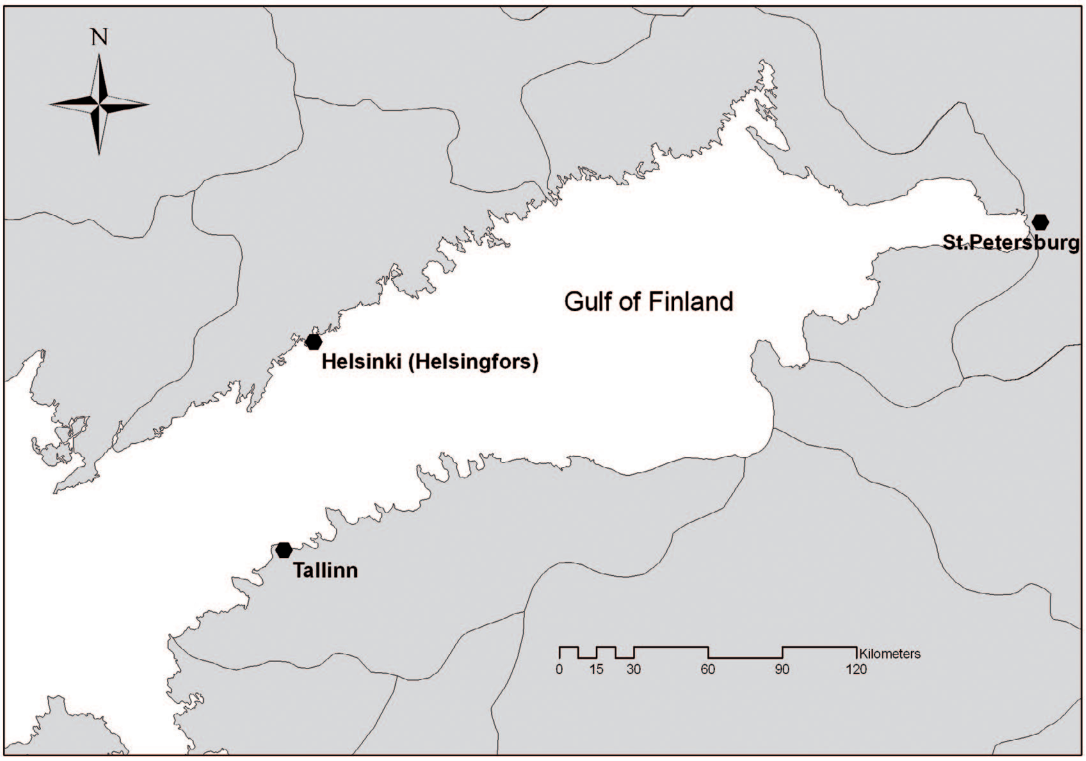


Figure 1. The Gulf of Finland with catchment areas indicated. Source: HELCOM.

## EARLIER STUDIES

In several earlier studies, the distribution or accumulation of heavy metals in the Gulf of Finland has been reported (Jankovski & Pòder 1980, Ott & Jankovski 1980, Tervo & Niemistö 1989, Emelyanov 1995, Borg & Jonsson 1996, Leivuori 1996, Leivuori 1998, Vallius & Lehto 1998, Vallius & Leivuori 1999, Vallius 1999a,b, Leivuori 2000, Vallius & Leivuori 2003). The SAMAGOL project, a collaborative project between GTK and VSEGEI, St Petersburg, collected sediment information from the eastern Gulf of Finland in 2004 to 2006, which was published in a special report by GTK (Vallius 2007, Vallius et al. 2007).

Little has been published in the scientific literature on the infrastructure and the use of the sea floor in the Gulf of Finland. The TRANSIT project of GTK, a recent collaborative project between GTK and VSEGEI, St Petersburg, recognized this gap. The project mapped parts of the offshore sea floor and identified some other published data, in order to obtain a better overview of the situation of the offshore sea floor of the Gulf of Finland. This data will be presented in the final report of the TRANSIT project in 2011, but some data will be included in this paper.

## CHEMISTRY OF MODERN MUDDY CLAYS

The modern soft sediments, muddy clays or muddy/silty clays, cover about one fourth of the sea floor of the Gulf of Finland (Kankaanpää et al. 1997). The distribution of such bottoms varies throughout the Gulf. Differences in basin size and shape correlate well with the number of islands and the complexity of the archipelago in the different sea areas. Small and isolated basins are usually to be found on the northwestern shores of the Gulf, where the archipelago is large and complex. The central northern coast is characterized by an almost complete lack of archipelago, which is reflected in very few sedimentation basins in the area. In the northeastern part of the Gulf, islands are scarce, rather large on average, and separated by larger distances of open sea. As a result of this, the sedimentation basins are usually larger.

The surfaces of these sedimentation basins are usually covered by a generally thin sheet of modern muddy clay with a rather high organic content. This material easily binds heavy metals and clearly reflects temporal changes in the anthropogenic input of harmful substances in the hydrosphere.

## DISTRIBUTION OF NICKEL, CADMIUM, MERCURY AND MOLYBDENUM

The distribution of metals in the surface sediments is controlled by several factors, such as natural inputs, the anthropogenic load, hydrography and local physico-chemical conditions.

Natural inputs are rather strongly controlled by the chemistry of the local bedrock (Vallius 2009). Of all the heavy metals, nickel (Ni) perhaps best reflects the local natural input (Figure 2). It reflects the shale and amphibolite areas of the central coast, where these metals are present at slightly higher concentrations than in the surrounding rocks (Rasilainen et al. 2008). The soft sea floor sediments of the rapakivi area of the northeastern Gulf, on the other hand, seem to have slightly lower Ni concentrations.

Many heavy metals show clear anomalies, which are probably attributable to anthropogenic activity. Cadmium (Cd) has been found out to be present at rather high concentrations in the Gulf of Finland (Vallius 2009). Figure 3 illustrates the horizontal distribution of Cd in the study area. It shows a clear anomaly in the easternmost part of the area and some sites with slightly higher concentrations along the southern border of the Finnish EEZ (Exclusive Economic Zone). The rest of the northern Gulf seems to have lower and rather even Cd concentrations. As natural Cd concentrations are usually <0.2 mg $kg^{-1}$ (Vallius 2007, Naturvårdsverket 1999), and only two surface samples in the study area were below this value, most sites in the Gulf of Finland have to be considered as relatively highly contaminated with Cd. Consequently, the distribution of Cd in the study area does not seem to correlate with any geological provinces, but instead with the availability of anthropogenically released Cd.

Mercury (Hg) is a special case in the eastern Gulf of Finland, as it is a significant contaminant of the sea floor off the outlets of the River Kymijoki. It has been known for decades to be present in high concentrations in the river environment, which is easily seen in the sea floor sediments outside the river outlets. The source of the Hg is release from industrial plants on the upper reaches of the river. The main contamination took place in the 1950s and 1960s, but the contaminated sediments are also a future source of Hg in the Gulf.

When looking at the map of Hg distribution in the northern Gulf of Finland (Figure 4), it can easily be verified that the River Kymijoki, with outlets between the longitudes of 26.4 degrees and 27 degrees east, is the main source of Hg. Sites near the Finnish–Russian border also show slightly higher concentrations compared to the western Gulf of Finland, which implies that these sites might have another source of Hg in the east, as the concentrations slightly increase towards the border.

Molybdenum is a metal usually present in rather low concentrations in modern sea floor sediments. Mean and median values of 2.47 mg $kg^{-1}$ and 1.64 mg $kg^{-1}$, respectively, have been reported from the Gulf of Finland (Vallius 2009). The majority of the samples in the present dataset are close to those values, but there is an anomaly at the Finnish–Russian border and some strongly anomalous sites along the southern border of the Finnish EEZ (Figure 5).

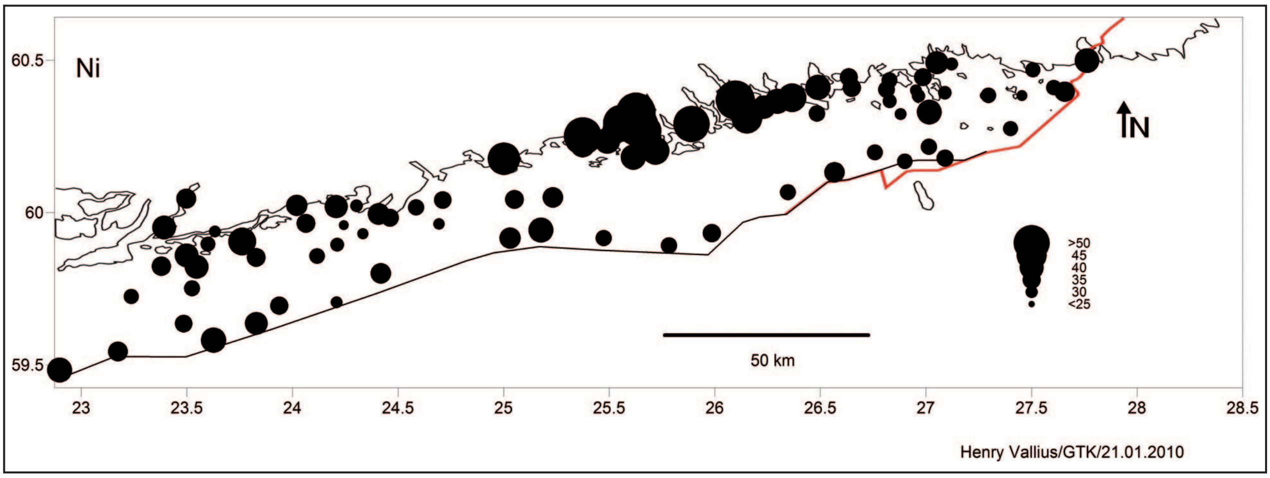


Figure 2. Circular symbol map of nickel concentrations in the soft surface sediments of the Gulf of Finland. Concentrations in mg kg-1 DW.

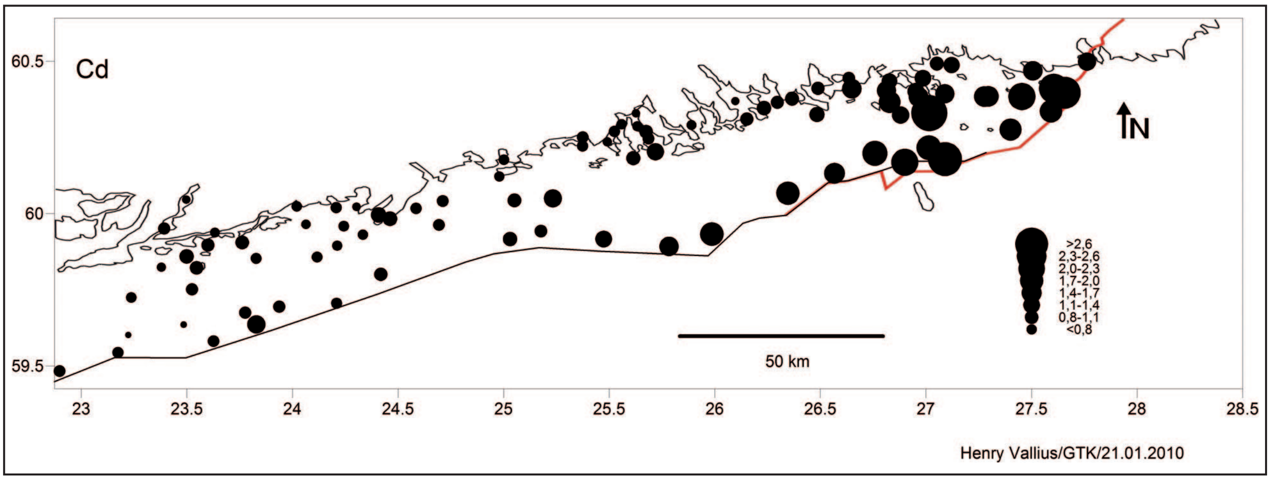


Figure 3. Circular symbol map of cadmium concentrations in the soft surface sediments of the Gulf of Finland. Concentrations in mg kg-1 DW.

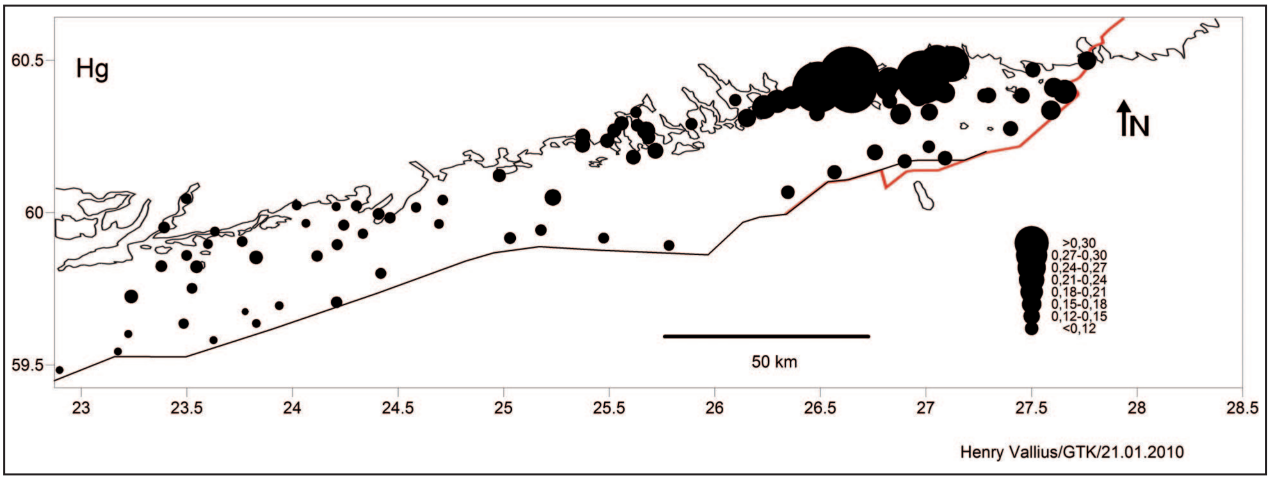


Figure 4. Circular symbol map of mercury concentrations in the soft surface sediments of the Gulf of Finland. Concentrations in mg kg-1 DW.

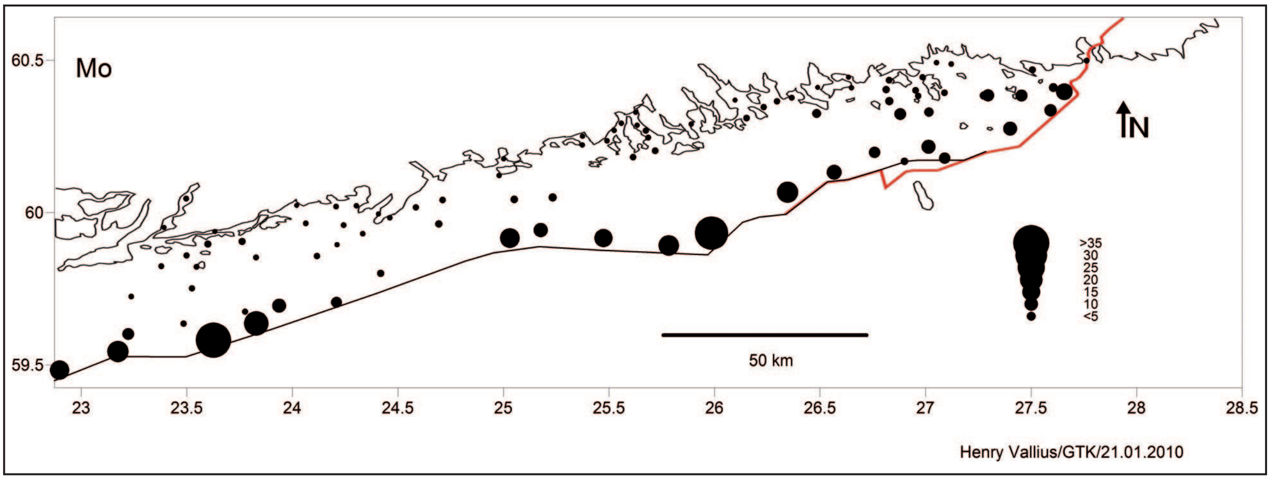


Figure 5. Circular symbol map of molybdenum concentrations in the soft surface sediments of the Gulf of Finland. Concentrations in mg kg-1 DW.

The anomaly in the east is difficult to explain, but is most certainly of anthropogenic origin, and the Mo at least partly originates in Russia. The anomalous sites along the EEZ border are very interesting and perhaps easier to explain. There is a more or less permanent halocline in the Gulf of Finland at a depth of about 60 m, which hinders water exchange from upper oxidized water layers to the bottom layers. This easily leads to oxygen depletion and hypoxic/anoxic bottoms below the halocline. Some bottoms above the halocline also suffer from hypoxia, as most bottoms in the Gulf of Finland suffer from seasonal oxygen depletion. In many cases, periods of water exchange from surface layers to these bottoms are too short to promote life. Mo is widely regarded as an anoxia indicator (Hallberg 1974). When plotting Mo concentrations of the present study against with the depth of the sampled station, an interesting pattern is seen (Figure 6). Higher levels of Mo (> 10 mg $kg^{-1}$) start to be found in bottom sediments at depths of 50 m or more, and the concentrations increase with depth. At the same time, no concentrations below 15 mg $kg^{-1}$ are to be found at depths of over 80 m. As virtually all the bottoms of over 50 m depth suffer from poor oxygen conditions, and the deepest bottoms probably from permanent anoxia, the correlation between Mo content and anoxia seems to be rather clear. However, as there have been no actual oxygen measurements from these sampling sites, the relationship is still speculative. On the other hand, all samples of this study have undergone thorough macroscopic investigation to provide a description of the cores. Virtually all samples from the deep sites have shown black surfaces indicating anoxia, often reeking of hydrogen sulphide and often even covered with a white bacterial mat, indicating reducing conditions. The Pearson correlation coefficient between bottom depth and the Mo content of the 90 samples is 0.72.

Of the metals discussed here, two are strongly controlled by anthropogenic loading and sources (Cd and Hg), while Ni is controlled by the anthropogenic load but also rather strongly by the natural input. Molybdenum, on the other hand, is an element that is strongly controlled by local physicochemical conditions, and the input source is of secondary importance.

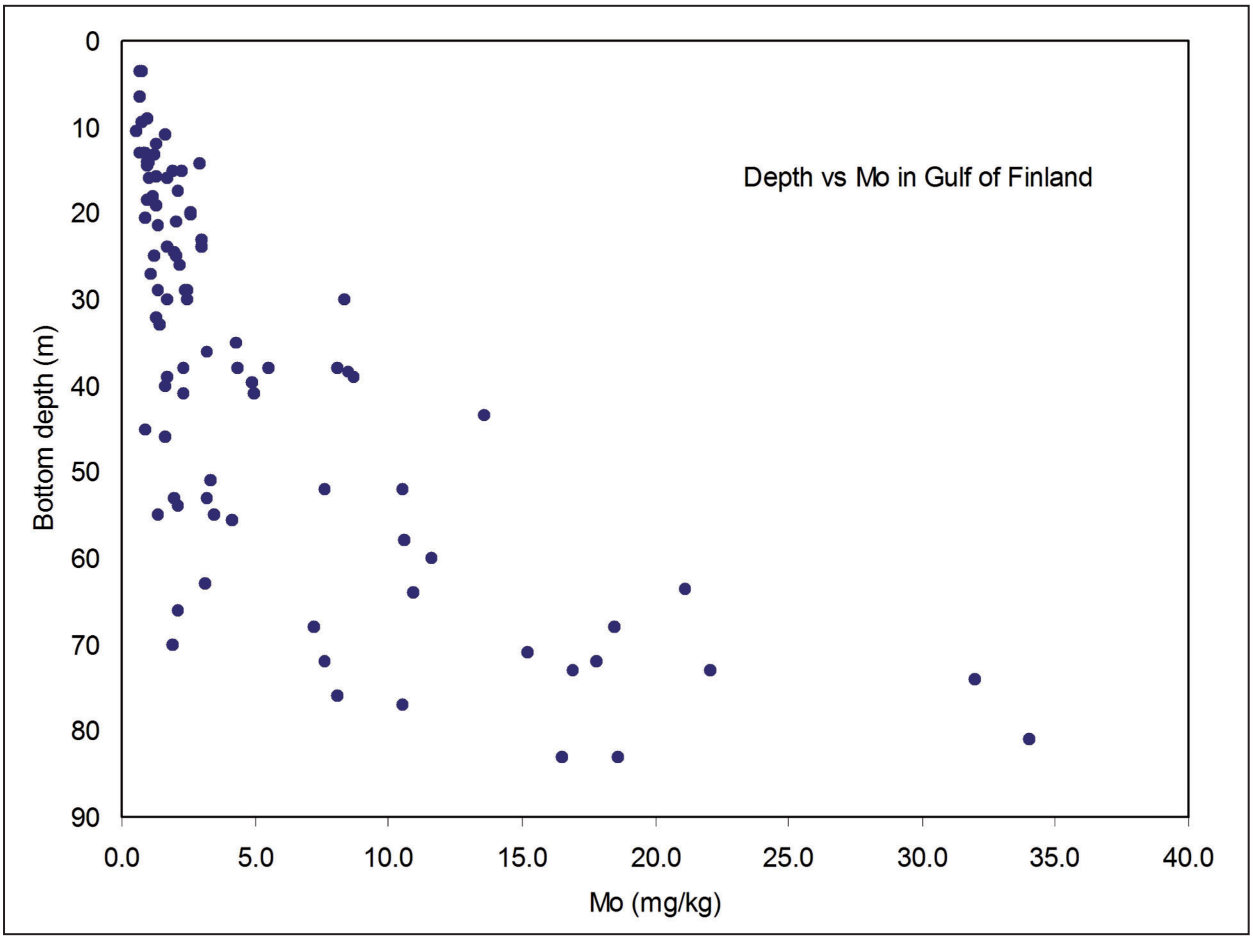


Figure 6. Molybdenum concentrations in relation to depth in the Gulf of Finland.

## TEMPORAL TRENDS IN HEAVY METAL ACCUMULATION

Based on older studies (Vallius & Lehto 1998, Vallius 1999 a,b, Vallius & Leivuori 1999, Vallius et al. 2007), it is known that the concentrations of heavy metals in the soft surface sediments have declined from the highest levels of the early 1980s. There are several reasons for the decrease, but increasing environmental awareness together with improved environmental legislation has played the most important role here. A clear decrease in the concentration of Pb and Zn was already observed during the 1990s throughout the Gulf of Finland, but especially in the eastern Gulf (Vallius & Leivuori 1999). In the same data, Cd showed a rather clear decrease in the western Gulf of Finland, but an uncertain decrease in the eastern Gulf of Finland (Vallius & Leivuori 1999). However, according to the report from the SAMAGOL project, Cd concentrations seem to have been slowly decreasing in the easternmost part of Finnish territorial waters (Vallius et al. 2007). The offshore Gulf of Finland has also been rather well sampled during the ongoing TRANSIT project. Preliminary data from this project show that a similar decreasing trend is still going on and new samples (August 2009) from Russian territorial waters show that in addition to other heavy metals, Cd is also decreasing in the eastern Gulf of Finland. This is a very welcome finding from an area not so easily or often accessed. Figure 7 illustrates the vertical distribution of Cd, Pb, and Zn from a short surface core taken at station F40, 25 km ENE of the island of Seiskari (Seskar), in the outer Neva estuary just 80 km from the shores of St Petersburg. According to the chemistry data from this core, the highest concentrations are still very close to the sediment surface, at a depth of only 6–8 cm, but the surface concentrations are clearly lower.

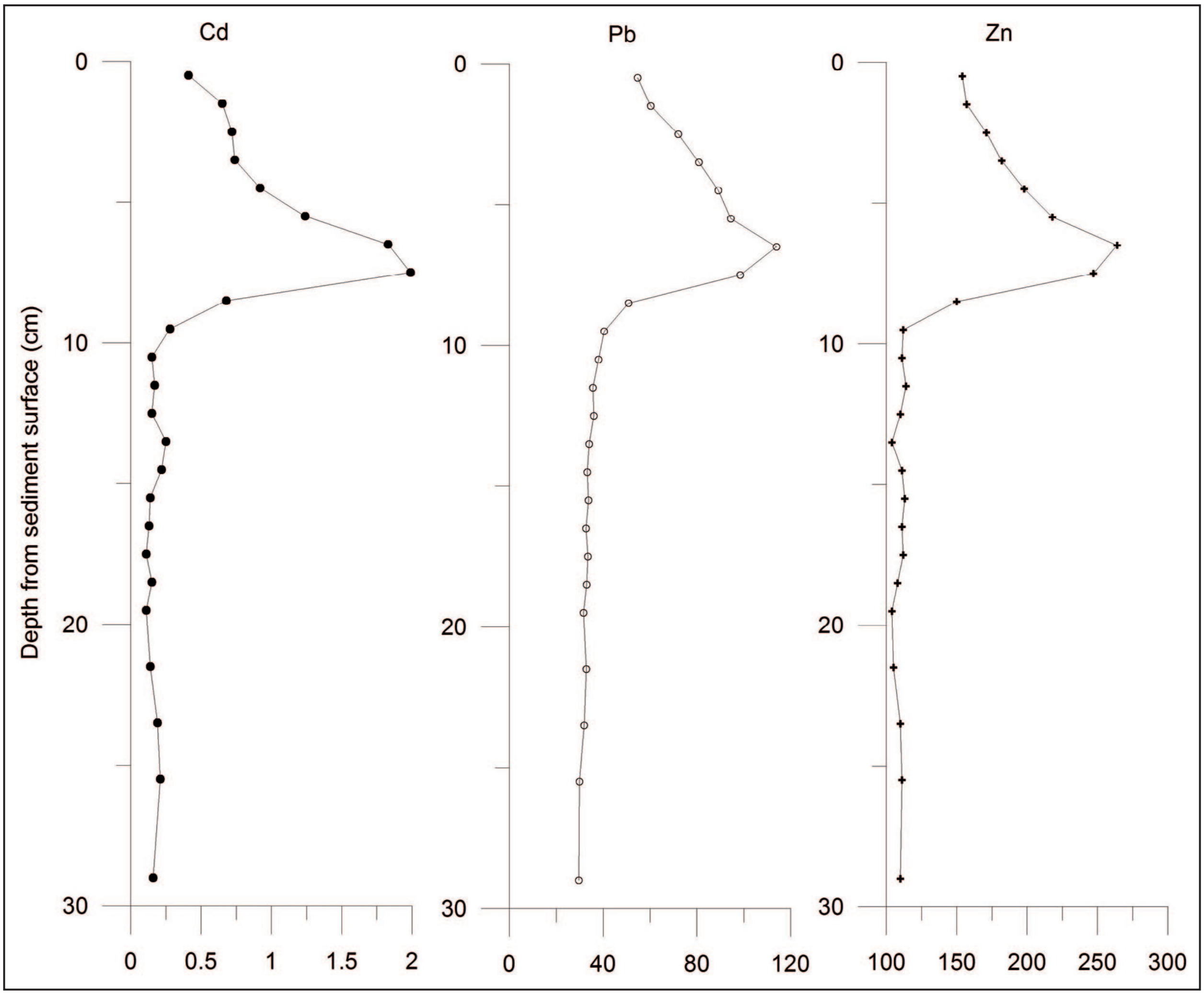


Figure 7. Vertical profiles of cadmium, lead, and zinc at site F40 in the eastern Gulf of Finland, Russian territorial waters.

## INFRASTRUCTURE AND USE OF THE SEA FLOOR OF THE GULF OF FINLAND

The Gulf of Finland is currently affected by many types of human activity on a magnitude never seen before. Shipping and various offshore infrastructures are considerably increasing. During investigations of the sea floor in connection with the Nord Stream gas pipeline, an inventory of offshore infrastructure was published (Nord Stream Espoo Report 2009). In the Finnish EEZ, a total of 10 cables were found in the pipeline corridor, all of which are in use. Nine of them are communications cables and one, the Estlink between Finland and Estonia, is a power cable. In addition to these, several unidentified cables were found. Most of the cables are situated in the western Gulf of Finland, crossing the Gulf in a north–south direction.

While old activities in the Gulf of Finland, such as fishing and hunting, are declining, it is clear that the Gulf will in the future be even more exploited in the sense of infrastructure. Already today there are ongoing or planned pipeline projects, in Russia the Fe/Mn concretions are being mined and wind parks will certainly be constructed in the near future. Marine sand and gravel extraction, especially in the Russian sector, has been a threat to the marine environment, as it has caused coastal erosion especially along the northern coast of the Neva estuary. Clear signals of increased human activity also include the large harbours that have recently been built, especially in Russia, but also in Finland and Estonia. Increasing ship traffic with larger vessels and especially off-shore anchorage is affecting the sea floor. At the same time, risks of ship collisions and other marine accidents are increasing alarmingly. Any larger accident would have severe impacts on the seafloor and ecosystems of this shallow and sensitive sea.

## CONCLUSIONS

The Gulf of Finland has suffered from strong human activity during the past century. Intense industrial activity has caused pollution and the accumulation of harmful substances on the seafloor. The magnitude of accumulation of such substances, as well as their concentration in the soft surface muddy clays, has recently started to decrease. This positive trend has continued for the last two or three decades. The reason is probably the better awareness of the sensitive nature of our shallow sea, followed by environmentally-friendly legislation and regulations. The shift from the Soviet command economy to the current market economy in Russia probably forced many of the worst polluting industrial plants to shut down, while many marine activities have increased considerably.

During the last two decades, marine activities in the Gulf of Finland have grown many-fold. Ship traffic is accelerating as never seen before, new harbours are being constructed in all countries surrounding the Gulf, and large infrastructure projects are being realized. At the same time, however, fishing is in decline. It seems that the Gulf of Finland of today serves mankind more as a means of transportation than as a source of food.

As the Gulf of Finland is so shallow and affected by the activities of more than 12 million people living in its catchment area, it is very important to consider all new planned activities in relation to what the sensitive sea and its ecosystems can withstand.

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