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Mercury and methylmercury in Baltic Sea sediments, and Polish and Lithuanian soils

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We review the current environmental pollution by mercury in the soils of Poland and Lithuania and in the sediments of the Baltic Sea. Mercury is documented to have many negative impacts on the environment as a toxic trace element. In many different chemical forms, it is being released into the environment by both geogenic and anthropogenic activities, with most being released from anthropogenic sources. Methylmercury is considered one of the most toxic forms found in the environment. Mercury levels in sediment and various point sources increased after World War II in the Baltic Sea, which was used as a dumpsite. Previous studies show noticeable differences in total mercury in the Baltic Sea. In the Warta and Odra rivers in Poland, mercury levels are also higher than the background value, though recent findings suggest that river sediments are not the main source of mercury to marine sediments. Concentrations in soils in Poland and Lithuania were below the level of limit values (1 and 1.5 mg/kg^{-1} respectively), but Upper Silesia showed concentrations (up to 4.01 mg · kg^{-1}) above the limit values. Furthermore, between 1992 and 2006, mercury levels in Wrocław dropped dramatically. The dominant trees in the area can affect mercury accumulation. No data were available for comparison with the soils in Estonia and Latvia.

Key words: mercury, methylmercury, soil, sediment, Lithuania, Poland, Baltic Sea.

INTRODUCTION

Mercury is a rare heavy metal found in the Earth's crust whose toxicity is highly dependent on its chemical form (Bernhoft, 2012; Kodamatani and Tomiyasu, 2013). In 2013 the Minimata Convention was written and approved by 128 nations (additional nations have signed on after 2013) to acknowledge, and attempt to reduce the harmful effects of, anthropogenic mercury deposition in the environment (Mercury Convention, 2017).

Additionally, mercury is listed as one of the ten chemicals of major public health concern by the World Health Organization (WHO, 2017). Mercury can be released into the environment by natural and anthropogenic sources and these activities are as various as burning of fossil fuels, cement production, the chloralkaline process, and gold mining (AMAP/UNEP, 2008).

The United Nations Environmental Program (UNEP) Global Mercury Assessment in 2008 found that direct anthropogenic emissions were highest near urban, industrial areas and were generally lower in rural more remote regions (AMAP/UNEP, 2008). In Europe, domestic and foreign anthropogenic sources contribute almost equally to total anthropogenic mercury deposition and contributions from power generation and industrial emission sectors dominate mercury depositions in Europe and central Asia. Anthropogenic activity during the last century has been considered to have increased mercury concentration in the atmosphere between 3 to 5 times and in surface ocean water by at least 3 times (Ilyin et al., 2018).

In this study, we compare published studies on mercury (Hg) pollution in Baltic Sea sediments and in Polish and Lithuanian soils.

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OVERVIEW OF STUDIES IN BALTIC SEA REGION

BALTIC SEA BASIN

The Baltic Sea, in northern Europe, is not a homogeneous body of water, but one that exhibits regional differences in salinity, temperature and the allochthonous to autochthonous organic matter (OM) ratio. Variations in these variables should be the major regulators of MeHg production, bioaccumulation, and biomagnification in specific regions of the Baltic Sea. However, due to the influx of MeHg into the Baltic Sea by river discharge, the aqueous concentrations of MeHg are frequently higher in estuarine coastal areas than in offshore waters (Skrobonja, 2019). Additionally, the presence of anoxic zones may increase Hg levels in the Baltic Sea's water and biota (Kwasigroch et al., 2021). The significant eutrophication of the Baltic Sea, combined with the limited mixing of the Baltic Sea's deep-water layers, results in hypoxic and anoxic zones (Soerensen et al., 2016). Nutrients that are carried by runoff from sewage treatment facilities and agricultural fields cause phytoplankton blooms in coastal ecosystems of the Baltic Sea, resulting in lowered or fully depleted oxygen levels (Skrobonja, 2019). Hg has a 20–30 year average residence time in the oceans, but it has a 0.8–2 year average residence time in the atmosphere; hence, Hg discharged into the ocean is removed far more slowly than it is released into the atmosphere (Gworek et al., 2016) and the water residence time in the Baltic Sea is longer (30–40 years) (Snoeijs-Leijonmalm and Andren, 2017). Preindustrial Holocene background concentrations of THg in Baltic Sea sediment varied between 20 and 50 mg · kg^{-1} (Leipe et al., 2013). Also, natural background concentrations of THg in Bornholm, Gdańsk, Gotland, and the Bothnian Bay are 0.025, 0.03, 0.025, and 0.02 mg · kg^{-1}, respectively (Leipe et al., 2013). Figure 1 shows the geographical locations of the Baltic Sea where these studies were carried out.

According to Bełdowski et al. (2019), as part of Germany's demilitarization effort after WWII, up to 385,000 tons of munitions were dumped into the Baltic Sea, of which 300,000 tons were associated with conventional munitions and the rest are thought to be chemical munitions. These discarded conventional munitions emit more Hg to the environment than chemical munitions and have contaminated the nearby sediments. The concentration of MeHg in the sediments ranged from 17 ±8 pg · g^{-1} (1 pg · g^{-1} = 0.000001 mg · kg^{-1}) to ~68 ±19 pg · g^{-1} and Hg concentrations reported at both dumpsites had different values. In the Bornholm Deep they ranged from 0.034 to 0.092 mg · kg^{-1}, and in Kolberger Heide 0.007 to 0.322 mg · kg^{-1}. In another study of the munition sites, MeHg ranged from 19 to 2362 pg · g^{-1} in the sediments, THg ranged from 0.004 to 0.294 mg · kg^{-1}. In the Arkona Basin, Bornholm Deep, Baltic proper, Gdańsk Bay, Gdańsk Deep, Kolberger Heide, Mecklenburg Bay, and Gotland Deep areas, THg ranged between 0.228–0.255, 0.0504–0.294, 0.0418–0.0753, 0.004–0.146, 0.0676–0.263, 0.0144–0.281, 0.0221–0.159, and 0.0539 mg · kg^{-1}, respectively (Siedlewicz et al., 2020). A similar study was made by Kwasigroch et al. (2021) in the Belt Sea, Arkona Basin, Bornholm Basin, Gdańsk Basin, West Gotland Basin, East Gotland Basin, and the Bothnian Sea. Concentrations of THg in surface sediments ranged from 0.0012 to 0.3408 mg · kg^{-1}. These values were similar to those found in previous studies in surface Baltic sediments by Perttilä et al. (2003), which varied from 0.013 to 0.406 mg · kg^{-1}, and by HELCOM (2010) between 2001–2008, which ranged from 0.04 to 0.3 mg · kg^{-1}, while, between 2003 and 2008, Hg concentrations in sediment dropped in the Bothnian Bay, Land Sea, Eastern Gotland Basin, and Kattegat. MeHg concentrations are elevated across a larger region than just near dumped munitions. The results show that physical processes responsible for movement of sediments and near-bottom water act to diffuse MeHg, making munition dumpsites a diffuse source of MeHg rather than point sources associated with specific munitions (Siedlewicz et al., 2020). Rua-Ibarz et al. (2016) noted that, in 1945, the German submarine U-864 sank, carrying 67 tons of metallic Hg in over 2,000 steel containers in its keel. The submarine was discovered in 2003, with some of the containers cracked and Hg contaminating the surrounding sediments. The concentration of THg in sediments collected near the submarine varied from 60 to 24,000 mg · kg^{-1} (wet weight w.w.). Other research showed that in the southern Baltic Sea, THg concentrations in sediments were between 0.00581 mg · kg^{-1} in the Odra Eustary and 0.225 mg · kg^{-1} in the Gdańsk Deep, the lowest concentration of MeHg being recorded in Odra Estuary, of 61.29 pg · g^{-1}, the highest concentration of MeHg being found in the Vistula Estuary, of 940.07 pg · g^{-1}. These results showed that conditions in the southern Baltic Sea sediments favour Hg methylation (Miotk et al., 2013). THg, MeHg, and organic Hg levels in sediments off the coast of Gdańsk were measured by Bełdowski et al. (2014) who observed concentrations of an average of 0.102 mg · kg^{-1}, 261 pg · g^{-1}, and 425 pg · g^{-1}, respectively, in the Gdańsk Deep. Organic Hg concentrations in sediments were found to be dependent on both MeHg and THg concentrations. The average concentration of MeHg determined in the benthic sediments of the Gulf of Gdańsk was 0.00065 mg · kg^{-1}, which is around 0.5% of THg (Gworek et al., 2016). Organic Hg and MeHg levels were higher in the Gdańsk Bay than in the Gdańsk Deep, according to Manzetti (2020), although THg levels were higher in the Gdańsk Deep. This indicates that biotic metabolism of Hg is higher in the shallow waters of the Gdańsk Bay than in the deep waters of the Gdańsk Deep and that specialized bacteria, such as iron-reducing bacteria that use light in the conversion process, play a role in the transformation of Hg to its organic forms (Manzetti, 2020). Zaborska et al. (2017) measured the levels of Hg and sampled surface sediments at 5 cm depth in the Polish offshore zone, showing that Hg concentrations in sediments were lower, with a range of 0.001–0.019 mg · kg^{-1}.

Table 1 shows the concentrations of Hg in sediments and surface waters in various parts of the Baltic Sea and Table 2 shows that concentrations of Hg according to place/regions. Because of flawed analytical processes, Hg levels were commonly overestimated. When we compare these results with recent studies, there are changes in THg levels in the sediments of the Baltic Sea.

In Gulf of Riga, across the entire bay, several samples were taken in the deepest sites of the bay for Hg measurement, where the average concentration in sediments was 1.5 mg · kg^{-1}. These analyses were made of the uppermost sediments within a 5 cm depth range and traced back to their source; Hg was distributed more generally in the entire southern area originating from the Gauja River (Leivuori et al., 2000). Another study was carried out in the Tallinn region. The bays of Kopli, Tallinn, Muuga, and Ihasalu were all sampled. According to the study, the Minister of the Environment of Estonia's Regulations set a target of 0.5 mg · kg^{-1} and a limit value of 2 mg · kg^{-1} for Hg, with Muuga and Ihasalu suffering the most from pollution. Maximum Hg concentrations were clearly determined at 6.5–10 cm within the sediment layer. Hg values were relatively low at most of locations; however, five stations had higher Hg concentrations than the limit value (Erm et al., 2014). These results show that in the Baltic Sea areas such as Bornholm, Gotland and Gdańsk Hg concentrations exceeded background levels.

Fig. 1. The locations where the previous studies were performed

Table 1

Concentrations of THg in Baltic sediments (1984–2002) (Gworek et al., 2016)

Location (marine sediment)	THg [mg · kg^{-1}]
Baltic Sea	2–340
Baltic Sea proper	100 ±50
Baltic Sea (Aland Sea)	180 ±60
Baltic Sea (Bothnian Sea)	100 ±30
Bothnian Bay	400 ±240
Gulf of Puck	0.74–5.7
Gulf of Gdańsk	3.5–160
Gulf of Puck	2.8–180
Danish Straits	60–220
Baltic Sea (Bosex Area)	140–190
South Baltic Sea	30 ±10
Baltic Sea proper	20–360
Gulf of Gdańsk	310 ±310
Gulf of Riga	30–790

RIVERS AND LAKES

After rivers and precipitation, increasing coastal zone abrasion in the Gulf of Gdańsk becomes the third most important source of Hg (Bełdowska et al., 2016). The background content of Hg varies significantly between different types of bottom sediments. Because rivers have a substantially higher proportion of suspended particles, the background concentration of Hg in unpolluted river sediments is around 0.2 mg · kg^{-1} and the overall background THg level in lake sediments is around 0.1–0.3 mg · kg^{-1} (Gworek et al., 2016). The amounts of Hg in bottom sediments from streams, lakes, rivers, and channels in Poland were 0.012 mg · kg^{-1}, 0.011–0.05 mg · kg^{-1}, 0.021–0.07 mg · kg^{-1}, and 0.016–0.044 mg · kg^{-1} respectively (Boszke and Kowalski, 2007b). Baralkiewicz et al. (2007) conducted studies in Swarzędzkie Lake, a post-glacial lake near Poznań. Concentrations of THg in the lake sediments varied between 0.082–2.21 mg · kg^{-1} with a high variability in different parts of the lake; the greatest Hg levels were found near the Mielcuch Stream and Cybina River, which brought pollutants into the lake. Koniarz et al. (2015) found that concentrations of Hg in sediments were between 0.01–0.18 mg · kg^{-1}. Hg concentrations in bottom sediments were highest in the Rybnik, organic matter being possibly the most important factor affecting Hg concentrations and diffusion in the sediments investigated, while low Hg levels were generally related to the absence of anthropogenic activities. The Odra River is the second largest river in Poland, and anthropogenic emissions have significantly contaminated its catchment area before it reaches Baltic Sea; in bottom sediments, concentrations of Hg were between 0.12 to 2.99 mg · kg^{-1} (Boszke et al., 2004). In a study carried out in the Poznań region, a relatively high concentration was determined in pond sediments, at 0.154 ±0.08 mg · kg^{-1}, and in the Warta River sediments it was 0.118 ±0.096 mg · kg^{-1}. Concentrations of Hg in lake sediments were the lowest (Boszke and Kowalski, 2007). Sedimentary Hg concentrations ranged from 0.001 to 15.4 mg · kg^{-1}, with higher concentrations found in the upper Warta River and below Poznań (Bojakowska and Gliwicz, 2008). The Reda and Gizdepka rivers, near Gdynia, showed a typical period, a drought period, a rain/flood period, and a thaw period in a year: 15.3, 3.7, 12.2, and 1.4 mgHg/period were carried to Puck Bay, respectively. The highest Hg was in a typical period, but only because it was long. Thaws and floods were brief but strong, increasing concentrations of Hg in sediment over a short period of time. The typical, downpours, drought, and thaw period, contributed <1% of the Hg load introduced into the Baltic Sea (Gębka et al., 2019). Vorumaa county in the southern Estonia, home to Liinjarv Lake has little direct industrial activity, the lake's Hg inflow being mostly via agricultural activities and the atmosphere. Concentrations of Hg in lake sediment cores ranged from 0.08 to 0.24 mg · kg^{-1} and organic matter is the most important element controlling the sedimentary Hg distribution (Lepane et al., 2007). Hg concentrations in the sediment of Babrukas Lake in Lithuania ranged from 0 to 10.25 mg · kg^{-1}, indicating that anthropogenic activity (wastewater discharge) had an impact on the lake (Raulinaitis et al., 2012). National monitoring data from 2004 showed that the chemical state of eight river stations in Lithuania did not meet the criteria for favourable status in terms of Hg content. The average concentration of Hg in the Nemunas River (flowing through Belarus, Lithuania and the Lithuanian-Russian border), the Šešupė River (at the border between Kaliningrad and Lithuania), the Šelmenta River (located in Marijampolė County), the Mūša River (located in the Pakruojo district and Latvia), the Skirvytė River (situated south-west of Rusnė) and the Lėvuo River (in Northern Lithuania) exceeded the limit values of Environmental Quality Standard (EQS) (Valentukevičienė et al., 2013). For major rivers such as the Odra and Warta, Hg concentrations exceed the background level though, according to Gębka et al. (2019), river sediments are not primary source of Hg to the Baltic Sea.

SOIL

Concentration of Hg in soils mostly depends on the underlying geology and on anthropogenic activities. Soils are so important to ecological processes that when pollution or other factors weaken this ecosystem, the entire ecosystem suffers and may collapse (Robles et al., 2014). The average concentration of Hg in Polish soil is <0.05 mg · kg^{-1} (Pasieczna, 2012b). Higher THg concentrations in soil (>0.06 mg · kg^{-1}) in southern Poland have been linked to excessive Hg levels in bedrock but the contamination level of topsoil is low, at <0.011 mg · kg^{-1} (FOREGS, 2005). Local Hg anomalies in the Polish Lowlands are linked to various industrial and fuel combustion processes. The textile sector (which use Hg as a catalyst in fibre manufacture), as well as the chemical, engineering, and electrical industries, all represent a severe threat (Lis and Pasieczna, 1995). The European Union LUCAS Topsoil Survey collected ~23,000 topsoil samples from land across all European Union countries. The average Hg concentration in European topsoil was 0.04 mg · kg^{-1}, with a range of 0–159 mg · kg^{-1}. Mining for gold and Hg has historically resulted in high Hg concentrations at various mining locations, which could explain the high Hg concentrations in some samples from the Krompachy area in eastern Slovakia caused by mineralization (Hg is a minor component in the Fe and Cu mineralization zone), with mining and pollution caused by ore processing leading to increasing Hg emissions (Ottesen et al., 2013; Gworek et al., 2020).

Kowalski and Frankowski (2016) studied the Poznań area with industrial and municipal emission sources and where coal is a primary fossil fuel, other sources being wastes from hospitals, cement plants, sewage treatment plants and factories. The concentration of Hg (0.0955 ±0.0391 mg · kg^{-1}) in soil in central Poznań was two times higher than in other areas of the city. In general, the concentration of Hg in urban soil is two to four times higher than in non-urban soil (Pasieczna, 2012a). In 1992, Hg concentrations were measured in Wrocław (6.60 mg · kg^{-1}), Gdańsk (5.50 mg · kg^{-1}; Lis and Pasieczna, 1995) and in 2006, Boszke and Kowalski (2007a) reported the highest concentrations of Hg (up to 0.746 mg · kg^{-1}) from 61 samples in the centre of Poznań, perhaps reflecting emissions released from the coal combustion plant. Warszawa (up to 1.08 mg · kg^{-1}), Wrocław (up to 1.14 mg · kg^{-1}), Kraków (up to 1.38 mg · kg^{-1}), and Upper Silesia (up to 4.01 mg · kg^{-1}) had the highest concentrations of Hg in urban soil. Elevated Hg concentrations were also found in other European city centers, such as Stockholm (on average 0.86 ±0.96 mg · kg^{-1}). Warsaw Thermometer Factory surface soil layer contamination with THg, examined in 2005, showed a mean result of 147 mg · kg^{-1} (Gworek et al., 2020). In lawns in Wrocław examined by Dradrach and Karczewska (2013), concentrations of Hg in soil samples were in the range of 0.046–1.144 mg · kg^{-1}. Moreover, Boszke and Kowalski (2007a) noted, in their study in Poland, Hg concentrations in urban soil from parks and lawns of 0.16 mg · kg^{-1}. Such concentrations mostly depend on its location and purpose. Małuszyński and Małuszyńska (2022) analysed Hg in the Mazowiecki Landscape Park, where THg concentrations in the soils ranged from 0.082 to 0.362 mg · kg^{-1}: levels that regulations in Poland suggest indicate unpolluted soils.

Regardless of whether the soil is polluted or not, Hg is a volatile element that can migrate rapidly if certain conditions exist. Ottesen et al. (2013) observed that mineralization is the key to Hg anomalies in Poland's Western Sudetes, which can be Rote Fäule-related (Wierchowiec and Zielinski, 2016). In 2007, the concentration of THg in soil samples obtained from a chlor-alkali plant in the south-east of Poland was 261 ±9 mg · kg^{-1}, exceeding the industrial site's allowable limit of 30 mg · kg^{-1} dry soil (Sas-Nowosielska et al., 2008). Forest soil in Europe has far less Hg than agricultural soil, typically 0.05–0.15 mg · kg^{-1} and in Poland, forest soil has an average concentration of 0.095 mg · kg^{-1} (Boszke and Kowalski, 2007). Gruba et al. (2019), investigated if specific tree species affect Hg concentration in forest soil in Poland. They analysed seven dominant tree species: THg concentrations in forest soil varied due to natural differences in organic matter, sand content, and altitude. Hg stocks in the soil profiles analysed rose in the following order: pine (12 mg · m^{-2}), birch (15 mg · m^{-2}), oak (21 mg · m^{-2}), alder (24 mg · m^{-2}), beech (45 mg · m^{-2}), spruce (50 mg · m^{-2}), and fir (66 mg · m^{-2}) and in concentration: birch (0.06 mg · kg^{-1}), oak (0.06 mg · kg^{-1}), alder (0.08 mg · kg^{-1}), pine (0.12 mg · kg^{-1}), beech (0.12 mg · kg^{-1}), spruce (0.17 mg · kg^{-1}) and fir (0.13 mg · kg^{-1}). Tree

Table 2

Concentrations of Hg according to place/regions

Place/region	Sediment or soil	Concentration [mg · kg^{-1}]	References
Arkona Basin	sediment	0.228–0.255	Siedlewicz et al., 2020
Bornholm Deep	sediment	0.0504–0.294	Siedlewicz et al., 2020
Baltic Proper	sediment	0.0418–0.0753	Siedlewicz et al., 2020
Gdańsk Bay	sediment	0.004–0.146	Siedlewicz et al., 2020
Gdańsk Deep	sediment	0.0676–0.263	Siedlewicz et al., 2020
Kolberger Heide	sediment	0.0144–0.281	Siedlewicz et al., 2020
Mecklenburg Bay	sediment	0.0221–0.159	Siedlewicz et al., 2020
Gotland Deep	sediment	0.0539	Siedlewicz et al., 2020
Baltic Sea sediment (various places)	sediment	0.0012–0.3408	Kwasigroch et al., 2021
Baltic Sea sediment (various places)	sediment	0.013–0.406	Perttilä et al., 2003
Baltic Sea sediment (various places)	sediment	0.04–0.3	HELCOM, 2010
Odra Eustary	sediment	0.00581	Miotk et al., 2013
Gdańsk Deep	sediment	0.225	Miotk et al., 2013
Gdańsk Deep	sediment	0.102	Bełdowski et al., 2014
Gulf of Riga	sediment	1.5	Leivuori et al., 2000
Swarzędzkie Lake	sediment	0.082–2.21	Baralkiewicz et al., 2007
Rybnik	sediment	0.01–0.18	Koniarz et al., 2015
Odra River	sediment	0.12–2.99	Boszke et al., 2004
Poznan region: Ponds, Warta River	sediment	0.154 ±0.08 0.118 ±0.096	Boszke and Kowalski, 2007a
Liinjarv Lake	sediment	0.08–0.24	Lepane et al., 2007
Babrukas Lake	sediment	0–10.25	Raulinaitis et al., 2012
Poznań	soil	0.0955 ±0.0391	Kowalski and Frankowski, 2016
Wrocław	soil	6.60	Lis and Pasieczna, 1995
Gdańsk	soil	5.50	Lis and Pasieczna, 1995
Poznań	soil	<0.746	Boszke and Kowalski, 2007b
Wrocław	soil	<1.14	Boszke and Kowalski, 2007b
Kraków	soil	<1.38	Boszke and Kowalski, 2007b
Upper Silesia	soil	<4.01	Boszke and Kowalski, 2007b
Warszawa Thermometer Factory	soil	147	Gworek et al., 2020
Wrocław of municipal lawns	soil	0.046–1.144	Dradrach and Karczewska, 2013
Mazowiecki Landscape Park	soil	0.082–0.362	Małuszyński and Małuszyńska, 2022
Chlor-alkali plant in the south-east of Poland	soil	261 ±9	Sas-Nowosielska et al., 2008
Former military bases, in Lithuania	soil	<0.05 and 2.1	Paukstys et al., 1997

species have a substantial impact on Hg stocks only in the organic horizon, and higher concentrations of Hg were determined beneath pine, fir, spruce, and beech than beneath oak, alder and birch.

The average concentration of Hg in Lithuanian soil is <0.03 mg · kg^{-1} (Panagos et al., 2021). In former military bases, in Lithuania, Hg concentrations ranged between <0.05 and 2.1 mg · kg^{-1} (Paukstys et al., 1997). According to Salminen et al. (2011) concentrations of Hg of organic layer samples (188 samples from 3 Baltic countries) are mostly within the range of natural variation, with a Hg anomaly in central Lithuania due to emissions from a fertilizer factory, while high Hg values in southwestern Lithuania may be explained by industrial emissions from Kaliningrad. No anomaly has been observed in Latvia and Estonia. According to the information provided by the Lithuanian Geological Survey, the 2011–2017 cycle of state soil monitoring, 71 plots of soil in cultivated fields showed Hg contents of the topsoil A samples below the sensitivity limit of the laboratory method of <0.005 mg · kg^{-1}, 21 samples ranged from 0.006 to 0.168 mg · kg^{-1}, with a mean of 0.033 mg · kg^{-1}. In soil horizon C, Hg was detected in 23 samples and ranged from 0.006 to 0.023 mg · kg^{-1}, with a mean of 0.013 mg · kg^{-1}. Hg concentrations in all Lithuanian ecosystems are only of anthropogenic origin, being sorbed by organic matter and accumulating in organic bottom sediments and organically fertilized soil. In the upper arable A horizon, there is about 4 times more than in the soil. Lithuania's Hg stock is less due to its Hg density, while being 1.3 times greater than that of Slovakia and nearly 3 times larger than that of Slovenia (Panagos et al., 2021).

Table 3 shows the limit values for Hg in Baltic Sea region countries. According to this table, Polish and Lithuanian Hg levels in soil are generally below the limit value and only Upper Silesia in Poland exceeds the limit, being almost 3 times higher. Indeed, the limit levels differ greatly from one country to another. As a result, comparing outcomes to limit values is not a viable basis for analysis. There seem to be no Hg deposits in Poland, Lithuania, Latvia, and Estonia. Slovakian dense deposits are close to Upper Silesia in the south of Poland (Panagos et al., 2021). This may be one of the reasons why Hg levels thee are higher than in other areas. Moreover, Lis and Pasieczna (1995) noted Hg geochemical anomalies (>0.10 mg · kg^{-1}) in the Wałbrzych region of cinnabar and metacinnabar deposits, in coal seams in Lower Silesia while for Upper Silesia, the source of Hg is thought to be emissions from coal-fired power stations. In addition, the concentration of Hg in hard coal from the Lower Silesia coal basin deposit is 0.399 mg · kg^{-1} and from the Upper Silesia coal basin deposit it is 0.06 mg · kg^{-1} (Bojakowska and Sokołowska, 2001). Furthermore, the metal industry in this region may be the key factor in the area (Ballabio et al., 2021). Comparison of studies carried out in 1992 and 2006 revealed that, for Wrocław, concentrations of Hg drastically changed. Unfortunately, there is little data available concerning Hg data in the soils of Lithuania, Latvia, and Estonia.

Table 3

Baltic Sea region countries limit values for Hg in soil (Eunomia, 2018; Bauer et al., 2020)

	Limit values for Hg (mg · kg^{-1})
EU (max.)	1.5
Lithuania	1
Latvia	0.5
Estonia	1.5
Sweden	0.3
Finland	0.2
Denmark	0.5
Poland	1.5

CONCLUSIONS

Anthropogenic emissions of Hg strongly affect the environment and therefore, pose an elevated risk on human beings as well as nature via sediment and soil. This overview compiles recent Hg and MeHg studies of soil and sediment.

After World War II, many basins in the Baltic Sea were used as munition dump sites. This practice, in addition to sunken ships and submarines therefore increased Hg concentrations in the sediments. Point sources near the shores and rivers further contribute to the increasing Hg inflows to the Baltic Sea, which includes several shallow bays with mineral-rich clays and sand bottoms. Clays are used for decontamination and remediation in polluted waters and soil because of their high sorption capacity, and such a process can happen naturally. Pollutants from both organic and inorganic sources can be absorbed by the Baltic Sea sediment. Furthermore, biotic metabolism is higher in shallow water than in deep water and this enhances the conversion process of MeHg. Hg has a residence duration of 20–30 years in the oceans and 30–40 years in the Baltic Sea, but only 0.8–2 years in the atmosphere. As a result, Hg released into the water diminishes far more slowly than Hg released into the atmosphere. Toxic substances circulate for an extended period in the sea, contributing to its sensitivity. Comparison of previous THg levels with recent studies showed ongoing changes in Baltic Sea sediments. In the case of rivers, Hg in sediment surpass the background Hg concentrations in the Odra and Warta rivers in Poland. Despite this, another recent study demonstrated that river sediments are not the primary source of Hg into the marine environment, though some older results may have yielded overestimated results.

Studies of soils in Poland and Lithuania revealed concentrations of Hg above limit levels only in the Upper Silesia region, and here they were three times higher. This may be derived from Slovakian Hg deposits and/or coal-combustion plants and metal industry located close to this area. Moreover, the concentrations of Hg in Wrocław showed an substantial decrease between 1992 and 2006. In addition, dominant trees, such as fir and spruce, can variously affect soil accumulation of Hg. According to the Lithuanian Geological Survey, Hg levels in Lithuanian soils are among the lowest in Europe. There are many causes for increases of Hg pollution, such as agricultural techniques, but the most impactful are mining and coal combustion processes. We could not find any data or study on concentrations of Hg in the soils of Estonia and Latvia, and further studies are needed in order to discover recent trends of Hg in the soils of Lithuania, Latvia, and Estonia. Thus, Hg monitoring remains crucial.

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