

Attachment no 2

Summary of Professional Accomplishments

Dr Dominika Maria Saniewska
Faculty of Oceanography and Geography
University of Gdańsk
Al. Piłsudskiego 46
81-378 Gdynia

Gdynia 2024



1. Name:

Dominika Maria Saniewska (maiden name Murawiec)

ORCID: 0000-0002-0630-9602

Scopus: 36247937300

Web of Science ResearcherID: G-1472-2015

2. Diplomas, degrees conferred in specific areas of science or arts, including the name of the institution which conferred the degree, year of degree conferment, title of the PhD dissertation

MSc, major in physical oceanography, Faculty of Biology, Geography and Oceanology, University of Gdańsk, 2007.

Master's thesis *Mercury in open waters of the Baltic Sea* carried out under the direction of prof. dr hab. Lucyna Falkowska.

Doctor of Earth Sciences in Oceanology, Department of Oceanography and Geography, University of Gdańsk, 2013.

Doctoral dissertation *Routes of mercury transport to the coastal zone of the Gulf of Gdańsk* performed under the direction of Prof. Dr. hab. Lucyna Falkowska. Associate Promoter Dr Magdalena Beldowska (now Professor). Doctoral thesis defended with distinction.

3. Information on employment in research institutes or faculties/departments or school of arts

| | |
|------------------|---|
| 2015 - 2017 | Assistant Professor - research associate (postdoc) Faculty of Oceanography and Geography, University of Gdańsk |
| 2017 - 2020 | Assistant Professor - research and teaching staff (0.5 FTE) Faculty of Oceanography and Geography, University of Gdańsk |
| 2020 - currently | Assistant Professor - research and teaching (full-time) Faculty of Oceanography and Geography, University of Gdańsk |

4. Description of the achievements, set out in art. 219 para 1 point 2 of the Act

4.1. Title of scientific achievement

Factors shaping the inflow and transformation of mercury compounds in the sea



4.2. Scientific achievement

My scientific work focuses on issues related to the transformation of mercury (Hg) in nature with a particular focus on the contact zone of land, sea and atmosphere. Mercury is one of the most toxic elements (WHO, 2020), which is why the problem of its emission to the environment, dispersion and transformation has attracted great interest for many years. However, after decades of research and efforts to understand mercury cycling in the ecosystem, some aspects of these processes are still poorly understood (Obrist et al., 2018; Bank, 2020). This is largely due to the scope of the research being conducted. Mercury occurs in nature in low concentrations and in multiple chemical forms. Knowledge of these forms is crucial to understanding the transformations the metal undergoes in the environment, as well as its bioavailability (Lu et al., 2001). However, despite an awareness of the complexity of the mercury cycle in nature, research to date has mainly focused on measuring the concentration of total mercury and methylmercury, one of the most toxic forms of Hg (Boening, 2000). This is due to the time-consuming and high cost of Hg speciation analysis. As a result, the transformation of inorganic mercury, which is the predominant form of Hg in abiotic samples and organisms in the first links of the trophic chain (Fig. 1), remain poorly recognised. In view of this, I consider **my greatest scientific achievement to be the demonstration that all the matrices studied were dominated by labile mercury fractions that were transformed in the environment. I also recognised the factors shaping the influx of mercury compounds into the sea and their transfer in the marine trophic network.** This research has been made possible by the development, by a team of which I am a member, of a simple and relatively fast method of fractionating mercury using a standard mercury analyser and implementing it for testing in a wide range of environmental samples. **I also consider the application of this method to the study of mercury in biological samples to be a success.** Until now, it has only been used for the analysis of soils and sediments. The increasing number of citations of method articles (**publication O1-O4**; Table 1) indicates that the developed method has been noticed by scientists from other research centres.

The basis of this habilitation dissertation is a series of eleven articles published in renowned international journals, which are presented in point 4.3. and in Table 1. In five of these I was first or correspondence author, and in the remaining six I provided substantive supervision during mercury analyses, interpretation of results and manuscript writing. My scientific achievement consists of four publications describing activities undertaken to develop a method for mercury fractionation using thermal desorption and atomic absorption spectroscopy, as well as related problems (**O1-O4**). In the following seven papers, I focus on the transformations of mercury and its compounds (including methylmercury) in the environment (**O5-O11**).

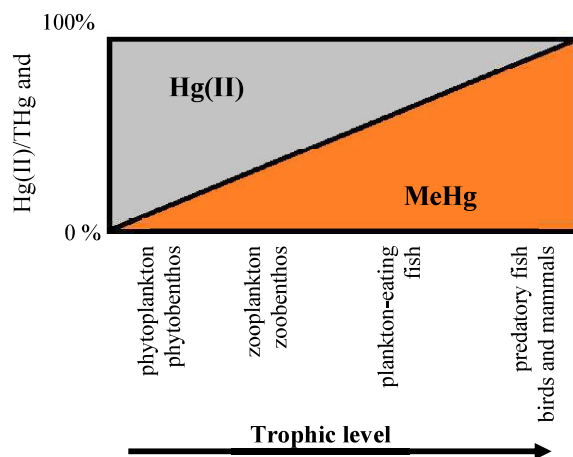



Fig. 1. Percentage of inorganic mercury (Hg(II)) and methylmercury (MeHg) in total mercury (THg) in organisms from different trophic levels (overview figure, own elaboration based on Mason et al., 1995)

4.3. Publications within the framework of academic achievement:

O1. Saniewska D. , Beldowska M., 2017. *Mercury fractionation in soil and sediment samples using thermo-desorption method.* Talanta 168, 152-161. doi: 10.1016/j.talanta.2017.03.026.

My contribution to the scientific publication included: co-development of the research concept and formulation of the research problem, sampling and preparation of the material for chemical analyses, development of the method of mercury fractionation and its implementation in the study of soil and sediment samples, graphical and statistical processing of the results, interpretation of the obtained results, co-authorship of the manuscript, acting as a correspondence author.

O2. Beldowska M., Saniewska D., Gębka K., Kwasigroch U., Korejwo E., Kobos J., 2018. *Simple screening technique for determination of adsorbed and absorbed mercury in particulate matter in atmospheric and aquatic environment.* Talanta 182, 340-347. doi: 10.1016/j.talanta.2018.01.082.

My contribution to the scientific publication included: co-development of the research concept and formulation of the research problem, preparation of the material for chemical analyses, development of the mercury fractionation method and its implementation in the study of suspension and aerosol samples, interpretation of the results obtained, co-authorship of the manuscript.

O3. Jędruch A., Beldowska M., Kwasigroch U., Normant-Saremba M., Saniewska D., 2018. *Mercury fractionation in marine macrofauna using thermodesorption technique: Method and its application.* Talanta 189, 534-542. doi: 10.1016/j.talanta.2018.07.047.

My contribution to the scientific publication included: co-development of the research concept and formulation of the research problem, substantive supervision during the development of the



mercury fractionation method and its implementation in the study of macrofaunal samples, participation in chemical analyses (analysis of methylmercury in selected samples), participation in interpretation of the results obtained (in particular, discussion of the relationship between methylmercury concentrations and labile mercury fraction 1b concentrations and potential use of mercury fractionation for sample typing for methylmercury analysis), co-writing of the manuscript.

- O4.** Wilman B., **Saniewska D.**, Pyta H., Wysiecki D., Beldowska M., 2023. *Mercury fractionation - Problems in method application*. Marine Pollution Bulletin 187, 114560. doi: 10.1016/j.marpolbul.2022.114560.

My contribution to the scientific publication included: participation in the conception of the study and formulation of the research problem, supervision during the development of the mercury fractionation method and its implementation in the study of a wide range of environmental samples, participation in the interpretation of the obtained results (in particular, discussion of the relationship between methylmercury concentrations and labile mercury fraction 1b concentrations and potential use of mercury fractionation for sample typing for methylmercury analysis), co-authorship of the manuscript.

- O5.** Korejwo E., **Saniewska D.** ✉, Beldowska M., 2020. *Fractionation of mercury in aerosols of the southern Baltic coastal zone*. Atmospheric Environment 235, 117623. doi: 10.1016/j.atmosenv.2020.117623.

My contribution to the scientific publication included: creation of the research concept and formulation of the research problem, development and validation of the mercury fractionation method and its implementation in aerosol samples, supervision during chemical analyses, assistance in interpretation of the results obtained, co-authoring of the manuscript, acting as corresponding author.

- O6.** **Saniewska D.** ✉, Gębka K., Beldowska M., Siedlewicz G., Beldowski J., Wilman B., 2019. *Impact of hydrotechnical works on outflow of mercury from the riparian zone to a river and input to the sea*. Marine Pollution Bulletin 142, 361-376. doi: 10.1016/j.marpolbul.2019.03.059.

My contribution to the scientific publication included: conception of the study and formulation of the research problem, sampling and preparation of the material for the study, chemical analyses, graphical and statistical processing of the results, interpretation of the obtained results, co-authorship of the manuscript, acting as correspondence author.



O7. Saniewska D. ✉, Beldowska M., Szymczak E., Kuliński K., Beldowski J., Voss M., Pryputniewicz-Flis D., Burska D., 2022. *Processes affecting the transformation of mercury in the coastal zone in the vicinity of two river mouths in the southern Baltic Sea*. Marine Chemistry 238, 104065. doi: 10.1016/j.marchem.2021.104065.

My contribution to the scientific publication included: creation of the research concept and formulation of the research problem, partial sampling (samples from the Reda river estuary), preparation of the material for the research, chemical analyses, graphical and statistical processing of the results, interpretation of the obtained results, co-authoring the manuscript, acting as a correspondence author.

O8. Korejwo E., Saniewska D. , Beldowski J., Balazy P., Saniewski M., 2022. *Mercury concentration and speciation in benthic organisms from Isfjorden, Svalbard*. Marine Pollution Bulletin 184, 114115. doi: 10.1016/j.marpolbul.2022.114115.

My contribution to the scientific publication included: creation of the research concept and formulation of the research problem, development and validation of the method for mercury fractionation and methylmercury analysis and its implementation in the study of marine sediment and benthic samples, supervision during the preparation of the material for the study and during the chemical analyses, assistance in the interpretation of the obtained results, co-authorship of the manuscript.

O9. Grajewska A., Falkowska L., Saniewska D., Pawliczka I., 2019. Changes in total mercury, methylmercury, and selenium blood levels during different life history stages of the Baltic grey seal (*Halichoerus grypus grypus*). Science of the Total Environment 676, 268-277. doi: 10.1016/j.scitotenv.2019.04.204.


My contribution to the scientific publication included: co-development of the conception of the study and formulation of the research problem, development and validation of the method for methylmercury analysis and implementation of it in the study of blood samples, supervision during the preparation of the material for the study and methylmercury analyses, assistance in the interpretation of the results obtained, co-authorship of the manuscript.

O10. Grajewska A., Falkowska L., Saniewska D., Pawliczka I., 2019. Fur and faeces - Routes of mercury elimination in the Baltic grey seal (*Halichoerus grypus grypus*). Science of the Total Environment 717, 37050. doi: 10.1016/j.scitotenv.2020.137050.

My contribution to the scientific publication included: co-development of the conception of the study and formulation of the research problem, development and validation of the method of mercury fractionation and methylmercury analysis and its implementation in the study of fur and faeces samples, supervision during the preparation of the material for the study and methylmercury analyses,



participation in chemical analyses (determination of 5 mercury fractions in faeces and fur samples), assistance in the interpretation of the results obtained, co-writing of the manuscript.

- O11.** Jarzynowska M., **Saniewska D.** , Fudala K., Wilman B., Bazy P., Płonska P., Saniewski M., 2023. *Mercury and methylmercury in birds and marine mammals inhabiting the coastal zone of the two King George Island's bays Admiralty and King George Bay (maritime Antarctic)*. Marine Pollution Bulletin 193, 115237. doi: 10.1016/j.marpolbul.2023.115237.

My contribution to the scientific publication included: creation of the research concept and formulation of the research problem, sampling and preparation of materials for analysis, development and validation of the method for methylmercury analysis and implementation of the method in the study of shell, feather, fur and faecal samples, supervision of during chemical analyses, assistance in the interpretation of the obtained results, co-authorship of the manuscript, raising funds for the research, acting as corresponding author.

Table 1 List of published papers constituting the habilitation achievement with the number of citations according to the Scopus database as of 25.03.2024 (in brackets - the number of citations without self-citation), the MNiSW points and the Impact Factor assigned to the journals in the year of publication.

| No | Magazine | Year | Number of citations | Score of the <u>MNiSW/MEiN</u> | IF |
|-----|----------------------------------|------|---------------------|--------------------------------|-----------------|
| O1 | Talanta | 2017 | 50 (37) | <u>40</u> | 4,224 |
| O2 | Talanta | 2018 | 37 (27) | <u>40</u> | 4,916 |
| O3 | Talanta | 2018 | 23 (17) | <u>40</u> | 4,916 |
| O4 | Marine Pollution Bulletin | 2023 | 6 (5) | 140 | 5.8 |
| O5 | Atmospheric Environment | 2020 | 7 (3) | 100 | 4,039 |
| O6 | Marine Pollution Bulletin | 2019 | 12 (6) | 100 | 4,049 |
| O7 | Marine Chemistry | 2022 | 10 (8) | 140 | 3,0 |
| O8 | Marine Pollution Bulletin | 2022 | 4 (3) | 100 | 5.8 |
| O9 | Science of the Total Environment | 2019 | 22 (19) | 200 | 6,551 |
| O10 | Science of the Total Environment | 2020 | 9 (7) | 200 | 7,963 |
| O11 | Marine Pollution Bulletin | 2023 | 0 (0) | 140 | 5.8 |
| | | | Σ 180 (132) | Σ 1240 | Σ 57,058 |
| | | | | <u>of which 120</u> | |
| | | | | <u>points according</u> | |
| | | | | <u>to the old</u> | |
| | | | | <u>scoring system</u> | |

4.4. Discussion of the scientific objective and results of the work constituting the habilitation achievement

Mercury (Hg) is a highly toxic pollutant present in terrestrial and aquatic ecosystems around the world. This is due to the characteristic properties of this element: volatility, persistence and high toxicity especially of its organic forms. To date, Hg and its compounds have not been shown to have any positive physiological functions in living organisms. What is known is that it is toxic in any form. Mercury exhibits neurotoxic, mutagenic, cytotoxic, nephrotoxic and allergenic properties and can also disrupt the muscle system and many enzymes and proteins. This element is particularly dangerous for pregnant women as it crosses the placental barrier, causing embryotoxic and teratogenic effects on the foetus (Scheuhammer et al., 2007).

Mercury is emitted into the environment mainly in inorganic form (Hg^0). It is a stable form of Hg that is normally volatile and insoluble in water. This means that Hg^0 can stay in the atmosphere for many months and be transported over long distances from the emission source. As a result of atmospheric transformations, Hg^0 is oxidised to the reactive form, Hg^{2+} , which undergoes atmospheric deposition much faster than Hg^0 (Selin, 2009). Mercury deposited on the surface of land or water can undergo microbial methylation. This process produces one of the most toxic forms of mercury, methylmercury (MeHg), which can then biomagnify in the trophic network (Gworek and Rateńska, 2009). Aquatic ecosystems are particularly sensitive to mercury pollution, where Hg bioaccumulates and biomagnifies at every level of the trophic chain. As a consequence of these processes, mercury concentrations measured in predatory fish, birds and marine mammals are up to 1 000 000 times higher than in the surrounding environment (Boening, 2000). On a global scale, the consumption of fish and seafood is the main route of introduction of Hg into the human body. For this reason, the issue of mercury is mainly addressed in the context of the contamination of seas and oceans, as it is from these bodies of water that most of the fish products consumed originate.

Research on mercury in the sea mainly focuses on abiotic samples (water and sediments) and organisms at the higher rungs of the trophic pyramid. The transformation of mercury in the first links of the trophic network is poorly recognised. This is an important knowledge gap, as the metal bioaccumulates most from the environment at this stage (Scheuhammer et al., 2007). Another problem is that most scientists focus on analysing the concentration of total mercury and methylmercury in organisms. While the predominant form of mercury in non-living samples and in the initial links of the trophic network is inorganic mercury (Hg^{2+}) (Fig. 1). Consequently, despite decades of research and effort put into understanding the mercury cycle in nature, some aspects of it are still poorly understood (Obrist et al., 2018; Bank, 2020). Numerous studies have shown that the concentration of total mercury in the atmosphere and in water does not translate into



the concentration of this metal in organisms from higher links of the trophic network living in these environments (Wang et al., 2019; Wu et al., 2019). These discrepancies are largely due to the form in which Hg occurs in nature, as each differs in its physical and chemical properties, i.e. solubility, thermal stability, bioavailability or toxicity (Biester et al., 1999). **This is why the form of the metal has a direct impact on its transport and the transformations taking place in the natural environment.**

A number of methods are known for the speciation analysis of mercury, the most commonly used being sequential extraction, X-ray absorption spectroscopy and thermal desorption combined with atomic absorption spectroscopy. The peculiarities of these methods (time-consuming, costly, high risk of contamination, lack of standardisation of procedures, etc.) have meant that, despite the merit of the results obtained, they are rarely used in routine studies, which greatly limits the understanding of mercury cycling in the environment. Of these three methods, thermal desorption of mercury combined with atomic absorption spectroscopy is the most common and has been used for several decades to study mercury in soil and sediment samples (Windmüller et al, 1996; Biester et al, 1999; Reis et al, 2012; Sedlar et al, 2015). This is a method in which Hg compounds are identified by the temperature at which they are released from the sample. While these measurements were carried out in self-constructed stoves/heaters, under different conditions. As shown in the literature (Biester and Scholz, 1997; Shuvaeva et al., 2008), the conditions prevailing during testing (sample mass, heating rate, flow rate and type of gas, etc.) can contribute to differences in the results obtained. The variety of procedures used by the researchers resulted in a large amount of incomparable data. **Therefore, the main idea of my research was to develop a method for mercury fractionation based on a commercially available automatic mercury analyser, in which the combustion temperature of the sample can be controlled without any software intervention, and to implement this method for the study of a wide range of environmental samples (including for biological samples in which mercury compounds have not yet been studied by this method).** My aim was to standardise the conditions of analysis and thus obtain comparable test results between laboratories. At the same time, I worked on the development and validation of a method for the analysis of methylmercury in our laboratory. I wanted to compare the usefulness of the results obtained by the two methods in interpreting mercury transformations occurring in the environment. The above information led me to put forward the following research hypotheses:

1. Mercury fractionation using thermal desorption coupled with atomic absorption spectroscopy is a method that is applicable to the analysis of mercury forms in a wide range of environmental samples (including biological samples).



2. Measurement of the mercury fraction is a method alternative to the time-consuming and costly analysis of methylmercury.
3. Identification of atmospheric mercury sources and transformations is possible through Hg fractionation in aerosols.
4. The mobility of mercury in river systems, the transformations of its compounds in the aquatic environment and its incorporation into the marine trophic network are determined by the proportion of individual Hg fractions in soil, suspension and sediment.
5. The differential contribution of individual mercury fractions to the ecosystem provides information on the bioavailability of Hg in the environment, as well as serves as an indicator of the pathways of entry and elimination of this metal from living organisms.

In order to verify the above hypotheses, I set the following research tasks:

1. Development of a method for the fractionation of mercury in soil and sediment samples with high organic matter, river and marine suspended solids, aerosols and marine organisms from different trophic levels using a mass-produced automatic Hg analyser.
2. Comparison of the contribution of labile mercury fractions to methylmercury concentrations in biological samples.
3. Recognition of the different mercury fractions present in aerosols and the factors influencing Hg transformations and its entry to the sea.
4. Determination of the contribution of mercury fractions in river systems and the factors shaping their inflow to the sea, as well as the transformations occurring in the coastal zone in the estuarine region.
5. Determination of the main factors controlling bioaccumulation, transfer and transformation of mercury in the marine trophic network.

Development of a method for the fractionation of mercury in environmental samples

To verify the hypotheses, it was necessary to develop a method for fractionating mercury in a wide range of environmental samples (**task 1**). In my research, I decided to use a commercially available automatic mercury analyser, in which the combustion temperature of the sample can be controlled without any software intervention. The first stage of the work was to develop a method for thermal fractionation of mercury in soil and sediment samples. I tried to implement on our analyser the method previously proposed by Reis et al. (2012). It was developed for soil samples with high mercury concentrations (67-126 000 ng/g

d.m.). Unfortunately, in the case of environmental soil samples from northern Poland, characterised by low mercury concentrations ($\text{Hg} < 250 \text{ ng/g d.m.}$), this method failed due to an unsatisfactory recovery of 64% (**publication O1**). The sample heating time needed to be optimised. Research has shown that this time needs to be broken down into two parts - the time it takes to reach the target/target temperature (t_1) and the time it takes to anneal the sample at the target temperature (t_2). The first time (t_1) was crucial to avoid overheating of the sample and spontaneous combustion. It was observed that with too short a time t_1 , the target temperature could be exceeded by up to several tens of degrees Celsius, which interfered with analyses at higher temperatures and made interpretation of the results difficult. In addition, in soil samples with a high organic matter content ($\text{MO} > 20\%$) between 225°C and 250°C , sample spontaneous combustion occurred, leading to a large scatter in the results obtained (as the process occurred at different intensities) and problems with analyses of the Hg fraction at higher temperatures. The second time (t_2) was significant due to the recovery of the analysis. When the t_2 time was too short, the recovery calculated as the sum of all mercury fractions was unsatisfactory compared to the determined total mercury concentration (66.2%). When the t_2 time was increased, the recovery from Hg fractionation increased to 98.5%. Optimisation of heating times t_1 and t_2 yielded satisfactory results for mercury fractionation in soil samples compared to the method proposed by Reis and colleagues (2012) (**publication O1**).

The next step of the study was to test the optimised mercury fractionation method on mercury standards (thirteen synthetic and two natural standards) and environmental samples (three soil samples with different Hg concentrations). It was shown that the 22-step mercury fractionation method did not allow the precise determination of individual Hg compounds in the samples. This was due to the fact that many Hg compounds reached maximum concentrations at the same temperatures (Fig. 2). In addition, the method can be applied to solid samples with mercury concentrations higher than 50 ng/g d.m. (sample mass $\geq 100 \text{ mg}$) (**publication O1**). For environmental samples, this is quite high for Hg concentrations (Jędruch et al., 2021). In addition, the 22-step mercury fractionation method was time-consuming: it took more than 18 hours to analyse one sample in triplicate. Therefore, the next step of the research was to develop an abbreviated fractionation method based on the assessment of the content of specific groups of Hg compounds (fractions) in solid samples. For this purpose, based on the results presented in Figure 2, four limiting temperatures (225 , 325 , 475 and 750°C) were determined, allowing the separation of groups of compounds with similar properties (Fig. 3). The first fraction of mercury to decompose at the lowest temperature (225°C) consisted of labile compounds (mainly mercury halides and nitrate, Hg in combinations with organic matter and methylmercury) (Fig. 3). That is why this group of Hg compounds was called labile-1. At the next temperature (325°C), mercury sulphide (HgS) decayed (Fig. 3). This

compound is considered to be one of the most stable forms of mercury in the environment (Ebinghaus et al., 1999). Therefore, this fraction was defined as stable-1. At 475°C, mercury sulphate and mercury oxide (HgSO₄, HgO) decayed (Fig. 3). Like the first group, these are labile compounds, which is why they have been named the labile-2 fraction. In contrast, in the temperature range 500-750°C, no peak was observed in any of the tested patterns (Fig. 2), it is most likely due to the release of Hg strongly bound to minerals, which was observed in soil samples (Fig. 3). This is why this fraction has been identified as stable-2.

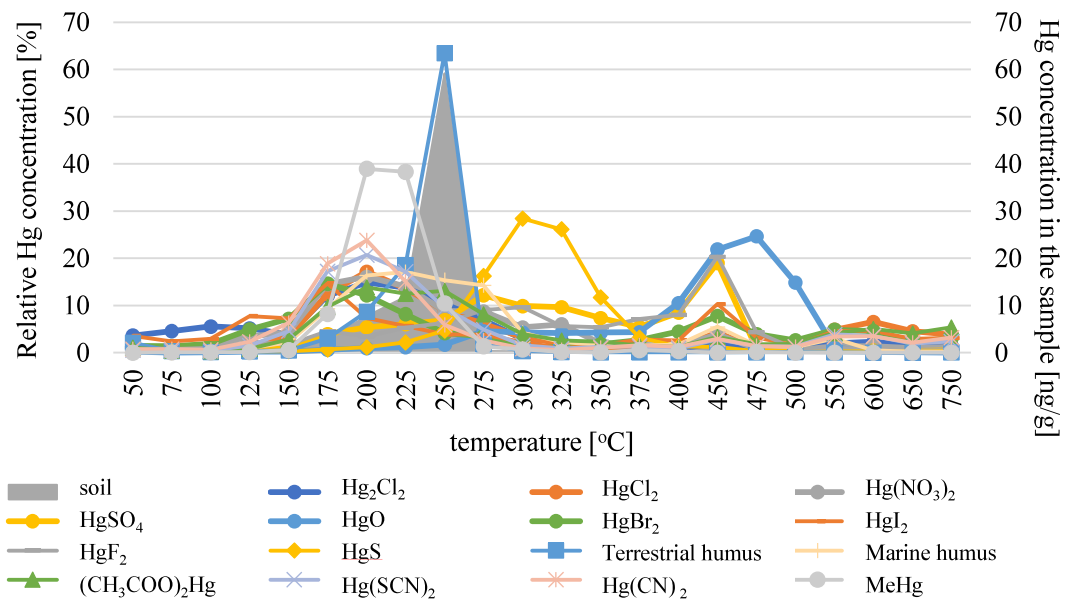


Fig. 2. Thermogram for soil samples and mercury standards obtained by the 22-step fractionation method (own elaboration based on publication O1)

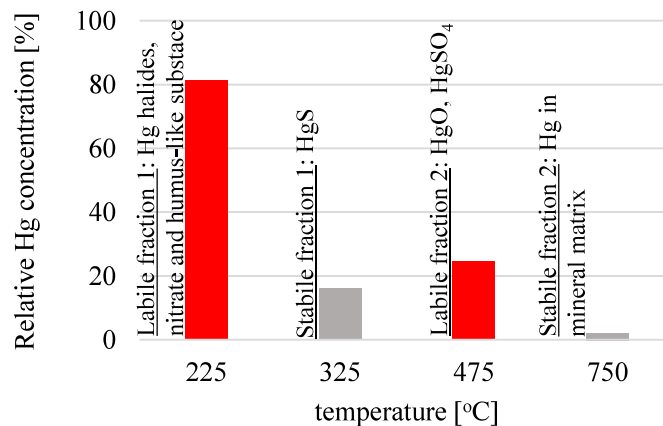


Fig. 3. Thermogram for soil samples obtained by the 4-stage fractionation method (own elaboration based on publication O1)

The method was then tested on environmental samples (soil samples, beach sand, cliff and marine sediments) (**publication O1**). It has been shown that the 4-step fractionation method we developed can be used to analyse the concentration of four groups of mercury compounds (fractions) with similar properties in solid samples with Hg concentrations of 2.4 ng/g d.m. or higher (with a 100-400 mg weight). This method has a satisfactory recovery (>90%) and a detection limit of 0.26 ng/g d.m. The method described is faster (analysis of one sample in triplicate takes approximately 3 h) and cheaper (no reagents are required, which also reduces the possibility of sample contamination) than alternative mercury speciation methods. **However, from my point of view, the key advantage of this method is that it was implemented on a mercury analyser commonly used in research laboratories.** This allows standardisation of the analytical procedure and, consequently, the results obtained by this method in different laboratories can be compared with each other. This makes the method widely applicable to laboratories dealing with the biogeochemical transformations of mercury in the environment (**publication O1**).

The next step of the ongoing research was to verify whether the 4-step Hg fractionation method we developed could also be used in the analysis of river and marine suspensions and aerosols (**task 1**). Both aerosols in the atmosphere and suspended particles in water are very important carriers of mercury. Therefore, identifying the fractions in which mercury is present in these samples is key to recognising their source and understanding the transformations of Hg in them (**tasks 3 and 4**). Unfortunately, the results obtained using the 4-step method for Hg fractionation in river and marine suspension and aerosol samples were not satisfactory. These samples were dominated by the labile-1 mercury fraction (89 - 98%) (Fig. 4a and 5a). It follows that the 4-step Hg fractionation method proved to be of little use in suspension and aerosol studies. Therefore, the aim of further research was to develop and validate a thermal desorption method for the assessment of mercury fractions in suspension and aerosols (**task 1**). Based on the results of analyses using the 22-step Hg fractionation method, carried out in a wide range of environmental samples (river and marine suspended solids, phytoplankton, macrophytobenthos), five temperature limits (175, 225, 325, 475 and 750°) were determined (Fig. 4b; **publication O2**). It has been shown that at temperatures up to 175°C, mainly particle-adsorbed mercury (Hg_{ADS1}) is released and consists mainly of mercury halides. These are the most labile Hg compounds, which mostly form loose surface compounds with suspension and can be partially absorbed through the gastrointestinal tract, which is related to the solubility of these compounds in water (Broussard et al., 2002). In the temperature range from 175°C to 225°C, mercury in combinations with organic matter, methylmercury and mercury nitrate decomposed. These are mercury compounds formed by ligands with strong complexing properties that are usually found inside cells (Le Faucheur et al. 2014). The absorption of these compounds into the body occurs more efficiently than

inorganic salts, as they are more soluble in lipids and bind to sulfhydryl groups (Broussard et al., 2002). This fraction was therefore referred to as absorbed mercury (Hg_{ABS}). The peak in the temperature range from 225°C to 325°C was associated with the presence of mercury sulphide (HgS), while in the range from 325°C to 475°C, Hg oxide and sulphate (Hg_{ADS2}) decayed. At temperatures between 475°C and 750°C, mainly residual mercury, strongly bound to minerals (Hg_{RES}), is released. **I believe that the great advantage of this method is the separation of mercury adsorbed on the surface of the particles from that absorbed inside.** This information offers great potential for discussion on the pathways of mercury entry into the first links of the trophic network (**publications O2 and O4**).

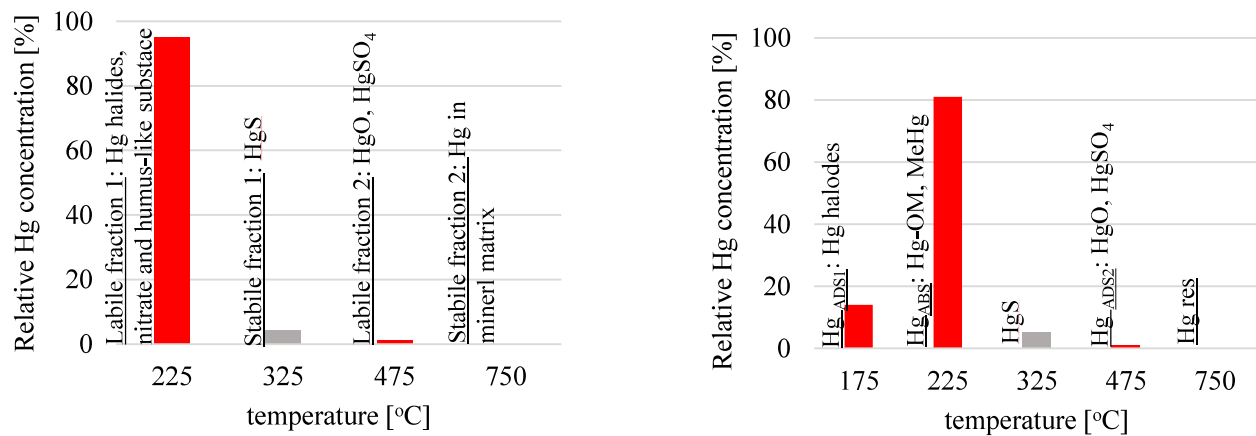


Fig. 4. Thermogram for marine suspended solids samples obtained by (a) 4-stage and (b) 5-stage fractionation methods (own elaboration based on O2 publications)

At the same time, I developed and validated a thermal desorption method for the assessment of mercury fractions in aerosols (**task 1**). For aerosols, the method developed was based on six temperature limits (125, 175, 225, 325, 475 and 750°C) (**O2 publication**). In addition to the five temperature steps, analogous to the Hg fractionation in suspension, one more was added: 125°C, at which gaseous mercury (Hg_{GAS}) is released (Fig. 5b) (Biester and Scholz, 1997, Reis et al., 2015). Given that no single unquestionable method for the speciation of mercury in the atmosphere has been developed to date (Gustin et al., 2021), our proposed method for the fractionation of mercury in aerosols could become an important tool to provide information on the sources of this metal in aerosols and the processes occurring on the particles (**publication O2 and O4**).

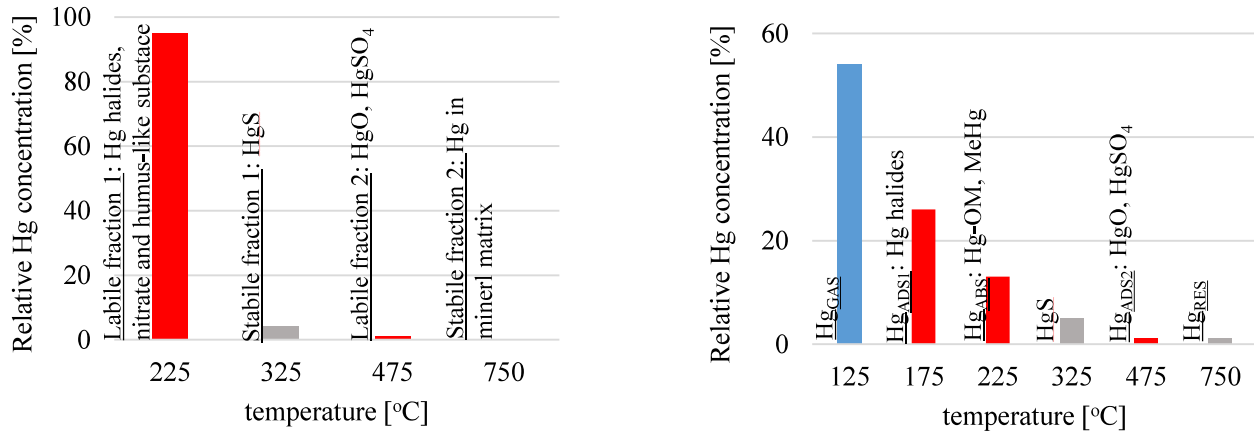


Fig. 5. Thermogram for aerosol samples obtained by (a) 4-stage and (b) 6-stage fractionation method (own elaboration based on O2 publication)

The method for fractionating mercury in suspension and in aerosols, has been tested on environmental samples and certified reference materials. The 5-step suspension mercury fractionation method and 6-step aerosol mercury fractionation method we developed can be used to analyse groups of Hg compounds with similar properties in samples with Hg concentrations of 2 ng/sample or higher. These methods have satisfactory recoveries (<90% and <85% respectively). The detection limit of the 5-stage mercury fractionation method in suspension is 0.06 ng/g d.m., and the detection limit of the 6-stage mercury fractionation method in aerosols 1.41 $\mu\text{g}/\text{m}^3$ (**O2 publication**).

The next stage of the research was to check whether the 5-stage method of Hg fractionation in suspension developed by us can also be used in samples of organisms from different trophic levels (**task 1**). Recognition of the Hg fraction in organisms can help determine the main factors influencing the incorporation of this metal into the marine trophic network and its accumulation and biomagnification in living organisms (**task 5**). It is worth noting that the thermal desorption method has not previously been used to fractionate Hg in organisms. Studies have shown that the 5-step Hg fractionation method developed for suspension samples also works well for mercury fractionation in organisms. This method had a satisfactory recovery (94%) and a low limit of detection (1 μg Hg) (**O3 publication**). **Thus, I confirmed hypothesis 1, stating that mercury fractionation using thermal desorption coupled with atomic absorption spectroscopy is a method that is applicable to the analysis of mercury forms in a broad spectrum of environmental samples (including for biological samples).** However, the specificity of the biological samples forced us to change the nomenclature of the fractions. In the case of animal tissues, it is not possible to speak of adsorption, which occurs when Hg binds to suspension particles. In benthic organisms such as crustaceans, bivalves and gastropods, Hg can adsorb to the surface of the exoskeleton,

but the significance of this process is low (Hare, 1992). It was therefore proposed to revert to the names labile and stable fraction by analogy with **publication O1**. Hg released at temperatures up to 175°C (mainly Hg halides) should be referred to as Hg labile 1a, the fraction released between 175 and 225°C (mercury contained in organic matter, methylmercury and other Hg compounds formed with ligands with strong complexing properties) as labile 1b. Between 225 and 325°C, mercury sulphide (stable fraction 1) decayed. At 475°C the labile fraction 2 (Hg oxide and sulphate) decayed, while in the temperature range 500-750°C the residual fraction (stable 2) decayed.

Publication O3 showed that the proportion of labile mercury fractions (labile 1a+labile 1b+labile 2) in the tissues of the animal organisms studied was very high, ranging from 92% to 100%. It was also observed that the proportion of labile fraction 1b increased with increasing trophic level, ranging from 64% in consumers at lower trophic levels (clams) to 98% in consumers at the highest trophic level (seals). In the literature, an analogous trend is described for methylmercury (Wu et al., 2019). The organic form of mercury, methylmercury, biomagnifies along the trophic chain, reaching its highest concentrations in the last links (marine mammals and humans) (Perrot et al., 2016). I assumed that mercury fractionation using thermal desorption coupled with atomic absorption spectroscopy is a method alternative to the time-consuming and costly analysis of methylmercury in biological samples (**hypothesis 2**). Therefore, in order to verify this hypothesis, it was necessary to include methylmercury analysis in the study (**task 2**). **Publication O3** indicated a coincidence between the proportion of the Hg labile 1b fraction in total mercury and the proportion of MeHg/THg in selected tissues of animals from different trophic levels (tissues with the highest proportion of Hg labile 1b were selected for analysis). However, in the next stage of the study (**publication O4**), it was shown that despite this relationship, the concentrations of both forms of mercury (MeHg and Hg_{lab 1b}) differed among each other in individual samples (**publication O4**). **It follows that the mercury fractionation method cannot be used as an alternative for the analysis of methylmercury in organism samples (rejection of hypothesis 2)**, which is undoubtedly a significant drawback of the proposed method. But information on the labile fraction content of samples can be used to pre-select samples for MeHg analysis, thus reducing the time-consuming analysis of material with low labile mercury fractions (**publication O4**).

Use of the mercury fractionation method to identify factors shaping inflow and the transformation of this metal in the sea

The next stage of the research was to identify mercury fractions occurring in a wide range of environmental samples. I used the information obtained to identify the drivers of the influx of labile fractions into the sea and to elucidate the mechanisms controlling Hg accumulation and biomagnification in the trophic network.

Sources of mercury in aerosols and atmospheric transformations of this metal

As part of **task 3**, the contribution of the mercury fraction in aerosols collected in the coastal zone of the Gulf of Gdańsk (in Gdynia) and in Silesia (in Zabrze) was analysed (**publications O4 and O5**). The research showed that the aerosols in Gdynia were dominated by a gaseous form of mercury adsorbed on particles (Hg_{GAS} – 37% of total mercury in aerosols (TPM)) and Hg in combination with halides and organic matter (Hg_{LAB1} – 56% TPM). At the same time, data from the winter of 2016/2017 showed that the Hg_{LAB1} fraction was dominated by mercury halides adsorbed on aerosols (Hg_{LAB1A}), whose share in TPM was twice as high as mercury in connections with organic matter (Hg_{LAB1B}). Mercury sulphide accounted for 6% of TPM in aerosols in Gdynia (**publication O5**). The percentage of the two remaining mercury fractions (Hg_{LAB2} and Hg_{RES}) together included less than 1% TPM. In the aerosols in Silesia, the percentage of individual mercury fractions differed significantly from that measured in Gdynia. The particles collected in Zabrze were dominated by mercury in combination with organic matter (Hg_{LAB2}), which accounted for more than 50% of Hg in aerosols (**publication O4**). The proportion of other fractions in the aerosols varied over a wide range and was dependent on the size of the aerosols. In particles smaller than 1 μm (PM_{10}), mercury sulfide accounted for 30% of $Hg_{PM_{10}}$, mercury halides accounted for 12% of $Hg_{PM_{10}}$, and the gas form adsorbed on the particles was in the range of up to 4% $Hg_{PM_{10}}$ (**publication O4**). With increasing particle size, an increase in the proportion of gaseous mercury adsorbed on the aerosols was observed, while the proportion of halides and mercury sulphide decreased. This was probably due to the increasing sorption area of the particles (**publication O4**).

The main factor determining the proportion of individual mercury fractions in aerosols was the origin of the air masses and the characteristics of the Hg sources in the study area (publication O4 and O5). This was visible both on a local and regional scale. In Gdynia, land air masses were characterized by a greater share of gaseous mercury and HgS adsorbed on aerosols than air of maritime origin. In contrast, marine air masses were dominated by mercury halides and Hg in combination with organic matter contained in aerosols (**publication O5**). In contrast, the lower proportion of mercury halides in the aerosol samples

from Silesia, compared to the results obtained in Gdynia, may have been due to the characteristics of Hg sources in the research area (**publication O4**). In Gdynia, marine aerosols dominate, characterised by a high proportion of sea salt (Lewandowska and Falkowska, 2013). In Zabrze, on the other hand, there are mainly aerosols of anthropogenic origin, consisting of fossil fuel combustion products such as soot, dust, sulphur and nitrogen droplets, organic and inorganic carbon compounds (Pyta et al., 2020). **I believe that this is a very important aspect of the study, as the contribution of individual mercury fractions in aerosols can help to identify sources of mercury in the air in the research area.**

Air temperature was another factor influencing the proportion of individual mercury fractions in aerosols. As air temperature increased, the proportion of mercury in combinations with halides and organic matter increased, while the proportion of the gaseous form adsorbed on particles decreased (**publication O5**). On the one hand, this can be explained by the oxidation of elemental mercury to the reactive form and its adsorption onto aerosols (Malcolm et al., 2009). This process occurs particularly intensively in the marine coastal zone (Beldowska et al., 2012; Saniewska et al., 2014) and results in a shorter period of Hg residence time in this region (10-100 days) than that assumed for the general atmosphere (0.5 - 1 year), resulting in an increased mercury load reaching the sea (Holmes et al., 2009). However, on the other hand, the decrease in the proportion of the gaseous form of Hg adsorbed on aerosols with increasing air temperature could also be due to the evaporation of gaseous mercury from the surface of the particles (Lu et al., 1998). In summer, the high air temperature stimulates this process. As the ambient temperature decreased, this process lost significance, resulting in the highest proportion of gaseous form mercury in aerosols measured in winter (**publication O5**).

Wet precipitation was an important factor influencing the concentration of mercury in aerosols and the entry of this metal to the sea. When comparing the percentage of Hg fraction in particles before and after precipitation, no statistically significant difference was observed (**publication O5**). However, after the rains in late December and early January, the lowest aerosol Hg concentrations were found in winter. These values were 6.7 times lower than the average concentration of mercury in aerosols this season (**O5 publication**). This allowed the conclusion that wet precipitation effectively cleans the atmosphere of suspended mercury and cleanses all Hg fractions uniformly. Thus, atmospheric precipitation must be considered as a significant source of all the mercury compounds studied into the sea.

To my knowledge, the research presented in **publication O5** is the first such comprehensive study of mercury compounds in aerosols. It has been shown that fractionation of mercury using thermal desorption combined with atomic absorption spectroscopy is a method that is applicable to the analysis of Hg compounds in aerosols (**confirmed hypothesis 1**), and the obtained results can be used as an indicator of

sources of Hg origin in aerosols and changes taking place in the atmosphere (**confirmed hypothesis 3**). In addition, the factors influencing the form of mercury in aerosols are general in nature and can provide a reference point for other regions of the world.

Mobility of mercury in river systems and its entry to the sea

As part of **task 4**, I analysed the contribution of mercury fractions in soils, suspended matter and sediments from three river systems located in northern Poland - the Płutnica, Gizdepka and Reda rivers (**publication O6**). This study showed that the soils, taken from the catchments of the rivers in question, were dominated by labile fractions of mercury - Hg absorbed in organic matter and mercury halides, which together accounted for more than 50% of the total mercury in the soil. Another compound that was commonly found in the soils studied was mercuric sulphide, which averaged around 20% of total mercury, but under specific conditions could constitute the dominant Hg fraction in the soil (86%). The proportion of the other two mercury fractions (Hg_{ADS2} and Hg_{RES}) varied over a wide range, but usually did not exceed 10% of Hg in the soil. Mercury fractions in the river suspension largely reflected the fractionation of Hg in the soil. Predominant were Hg absorbed in organic matter and mercury halides, which together accounted for about 80% of the total mercury in suspension. The proportion of mercury sulphide averaged several per cent of total mercury in suspension, and the average proportion of the other two mercury fractions (Hg_{ADS2} and Hg_{RES}) did not exceed 6%. The river sediments were also dominated by labile mercury fractions. The content of the different groups of mercury compounds varied over a very wide range and depended on both the forms of Hg runoff from the soil and the conditions in the water and sediment (**publication O6**). However, it is noteworthy that the river sediments were characterised by a significantly higher proportion of the labile fraction associated with sulphate and mercuric oxide (Hg_{ADS2}), which on average accounted for 14% of the total mercury in the sediments (**publication O6**), compared to soil and suspended solids.

The main determinant of the proportion of individual mercury fractions in the soil and its mobility in the river system was the organic matter content (publication O6). The low organic matter content limited the ability of the soil to complex Hg (Ravichandran, 2004). Therefore, in soils poor in organic matter, mercury was mainly present in water-soluble fractions, i.e. halides (Hg_{ADS1}), sulfate and mercury oxide (Hg_{ADS2}) (**publication O6**). These compounds can be washed from the soil into the river during precipitation and then transported to the sea. This was particularly evident in the case of flooded soils (located close to the river bed), where the outflow of soluble fractions (Hg_{ADS1} and Hg_{ADS2}) from the soil into the river water resulted in a decrease in the concentration of mercury in the soil with a concomitant increase in the proportion of mercury fraction bound to organic matter (Hg_{ABS}), which is less soluble in

water (**publication O6**). The organic matter present in the soil contains functional groups in its structure, which include sulphur in reduced form (sulphide, sulphhydryl and thiol groups). It is these functional groups that are responsible for the formation of stable complexes of mercury with organic matter. Therefore, in soils with a high organic matter content, water-soluble mercury compounds account for only a few percent of the total mercury concentration in the soil (Boszke et al., 2008). Thus, only a small proportion of mercury in this form can be washed out of the catchment into aquatic ecosystems. Normally, this metal can be released from the soil by erosion with the slurry. For this reason, the complexation process of mercury by organic matter has an important impact on the circulation of Hg in river systems, as it reduces the solubility, mobility and toxicity of mercury in soils (Ravichandran, 2004).

Ongoing research has also shown that human activities affect the circulation of mercury compounds in river systems (publication O6). The obtained results proved that hydrotechnical works, i.e. dredging and reconstruction of the riverbed, increased the outflow of Hg from the soil to the river. As a result of these works, the vegetation growing on the riverbank has been damaged or in some places completely destroyed, and the soil in the riparian zone has been disturbed. This contributed to the intensification of soil erosion, thus accelerating the export of eroded particles and associated mercury to the river (Kozłowski, 1999; Eklöf et al., 2012). The mercury that reached the watercourses underwent further transformations, the direction of which depended on the river conditions. In places where there were reducing conditions (slowed water flow, large influx of organic matter), some of the labile mercury released from the soil was transformed into HgS and deposited into sediments. This process largely reduced the mobility and bioavailability of mercury. The situation was different in areas with intense river flows. At these sites, oxidising conditions prevailed in the sediment, and mercury leached from the soil occurred mainly in dissolved form, which was only marginally deposited into the sediment. This resulted in the transport of Hg downstream and then into the sea (**publication O6**). In contrast, hydraulic engineering works involving the removal of reeds and aquatic vegetation from the riverbed and riparian zone did not significantly affect mercury concentrations in soil, water or river sediment (**publication O6**). Nevertheless, the work was a significant source of soil organic matter. The outflow of fresh organic matter from the soil into the river stimulated the formation of reducing conditions in the sediments. As a result, some of the labile mercury deposited in the sediment was transformed into the sulphide fraction, reducing its mobility and limiting its negative environmental impact. However, over time the organic matter deposited on the riverbank decomposed. This contributed to an increase in mobility and bioavailability of Hg in complexes with organic matter, and these areas became regions where mercury methylation could occur intensively (Skjllberg et al., 2006; Šípková et al., 2016).



Studies have shown that fractionation of mercury using thermal desorption combined with atomic absorption spectroscopy is a method that is applicable to the analysis of Hg compounds in soil and river slurry (**confirmed hypothesis 1**), and the obtained results can be used as an indicator of changes occurring in river systems (**confirmed hypothesis 3**). Given the plans to intensify hydrotechnical work in Poland (e.g. expansion of waterways) and the increase in the intensity and frequency of downpours and floods (associated with climate change), an increase in the load of labile mercury flowing out of the soil and transported by the river to the sea can be expected. This can increase Hg concentrations in coastal and estuarine organisms. **I believe that this is a very important aspect of the research that needs to be continued, as rational management of river catchments and the riparian zone appears to be an important method of reducing Hg input to the sea.**

Mercury transformations in the marine coastal zone in the estuarine region

As part of **task 4**, I analysed the contribution of mercury fractions in suspended matter and surface sediment from the Gulf of Gdańsk in areas influenced by the waters of the Vistula (suspended matter) and Reda (suspended matter and surface sediment). Samples were taken at varying distances from the estuary. Studies have shown that in the area in question, between 26% and 43% of mercury in seawater occurred in suspended form (Hg_{SPM}) (**publication O7**). This is relatively high compared to oceanic waters, where Hg_{SPM} is typically less than 20% (Horvat et al., 2003). This allows us to conclude that suspended matter plays an important role in the circulation of mercury in estuaries and constitutes a 'carrier' of mercury in the marine environment. Mercury in suspension occurred mainly in labile fractions, especially those associated with mercury halides (Hg_{ADS1}) and in complexes with organic matter (Hg_{ABS}). The two fractions together typically accounted for more than 80% of Hg_{SPM} . HgS comprised only 15% of Hg_{SPM} . The contribution of the other two mercury fractions (Hg_{ADS2} and Hg_{RES}) did not exceed 2% of Hg_{SPM} (**publication O7**). The proportion of the Hg fraction in the marine suspension taken closest to the river mouth was similar to that measured in the river suspension. However, the farther away from land, the fractionation of Hg in the particles varied over a wide range without a uniform trend. This was a consequence of numerous processes occurring in the coastal zone of the sea (**publication O7**).

As with the suspended matter, mercury in the bottom sediments also occurred in the labile fraction, but the percentage of individual Hg fractions in the sediments differed significantly from those in the suspended matter (**publication O7**). Between 50% and 60% of mercury in the sediments of both estuaries was present in complexes with organic matter (Hg_{ABS}) and mercury oxides and sulfates (Hg_{ADS2}). The stable fraction of HgS was 36% Hg_{SED} in the Vistula estuary (Kwasigroch et al., 2018) and 25% Hg_{SED} in the Red estuary,

which was much higher than in the case of the suspension (**publication O7**). It is noteworthy that, as in the case of river sediments (**publication O6**), a high proportion of the labile fraction of Hg associated with sulphate and mercuric oxide (Hg_{ADS2}) was also measured in the surface layer of marine sediments (**publication O7**). A similar trend was also observed in sediments taken from Isfjorden (Svalbard Archipelago) (**publication 8**). This may indicate the presence of conditions in these sediments that stimulate the transformation of Hg to sulphate or oxide.

The main process influencing the contribution of individual mercury fractions to suspended solids and marine sediments in the estuarine region was the deposition of suspended solids to the sediments (publication O7). Depending on the distance from the estuary, this process occurred in different ways. At the junction of land and sea, where the flow of water in the river slows down, the coarse fraction of the river slurry is sedimented to sediments in the coastal zone of the sea. The proportion of the HgS fraction in marine sediments taken close to the estuary was significantly higher than in areas away from the land. **This allows us to conclude that HgS carried by rivers was the first fraction to be sedimented into marine sediments (publication O7).** HgS is a stable and low-toxic form of mercury that is deposited into sediments characterised by high Eh potential and low organic matter content. This greatly reduces the transformation of Hg to the more toxic form of mercury, methylmercury. This means that surface sediments in estuaries can be considered a relatively safe area in terms of mercury.

As it moved away from the mouth of the river, the share of HgS in sediments decreased, and the content of labile mercury in complexes with organic matter (Hg_{ABS}) increased. At the same time, the concentration of total mercury (Hg_{SED}) and the content of organic matter in sediments also increased. In the Reda estuary, it was observed that the increase in the concentration of Hg in the sediments occurred with a decrease in the concentration of Hg in the suspension (**publication O7**). **This allows us to conclude that the sedimentation of mercury absorbed in suspension (Hg_{ABS}) was an important source of this metal in sediments.** This process took place most intensively in the place where the highest salinity gradient occurred. Therefore, we believe that deposition of fine-grained particles, rich in mercury and organic matter occurred by flocculation (Szymczak and Galinska, 2013). This process is important because it significantly reduces the transport of mercury to the open sea. This makes it necessary to consider coastal zones as a 'storehouse of mercury' transported by rivers. In addition, these sediments, with their low redox potential and high organic content, are potential sites for mercury methylation.

Another process affecting the transformation of mercury in the coastal zone in the area of estuaries was the activity of plankton (publication O7). This phenomenon was particularly evident in the outer part of the estuary, which is significantly influenced by marine waters. In this region, mercury in

complexes with organic matter (Hg_{ABS}) dominated in the suspension. Studies have shown that with the increase in water salinity, the share of Hg_{ABS} in the suspension increased (**publication O7**). This allows us to conclude that in the outermost part of the estuary, part of the Hg_{ABS} fraction may have been of marine origin. This theory was confirmed by low values of C_{ORG}/N_{TOT} weight ratios, which are typical for marine organic matter (**publication O7**). Nutrients, transported to the sea by rivers, stimulate the growth of marine phytoplankton, which can actively accumulate river-derived mercury (mainly Hg_{ADS1}). As a result of this process, the mercury accumulated by the plankton is converted to the fraction absorbed inside the cells (Hg_{ABS}). In addition, rivers are also a source of Hg_{ABS} . This form of mercury can also be incorporated into the marine trophic network by consumers, i.e. zooplankton. Both of these processes are crucial in the circulation of mercury in the sea, as Hg in complexes with marine organic matter is more bioavailable than Hg in association with terrestrial organic matter (Chakraborty et al., 2015; Schartup et al., 2015), which stimulates the transfer of this metal to higher trophic levels. **Rivers are therefore an important source of the labile form of Hg, bioavailable to marine organisms.**

Processes such as mixing of river and seawater or sediment resuspension were not observed to influence the variability of the proportion of Hg fraction in suspended solids and sediments in the estuarine region (**publication O7**). Also, the river flow (Vistula vs. Reda) and hydrological conditions (i.e. periodic fluctuations in the river water level) did not affect the contribution of individual mercury fractions to suspended solids in the sea shore zone. Regardless of the mercury load transported by rivers, the Hg fractions in both areas were similar. **It follows that the factors influencing the form of mercury in the coastal zone in the estuarine region are of a general nature and can provide a reference point for other regions of the world.**

Studies have shown that fractionation of mercury using thermal desorption combined with atomic absorption spectroscopy is a method that is applicable to the analysis of Hg compounds in suspension and marine sediments (**confirmed hypothesis 1**), and the obtained results can be used as an indicator of the transformation of this metal at the land-sea boundary, which may result in Hg being included in the trophic network (**confirmed hypothesis 4**).

Processes controlling bioaccumulation, transfer and transformation of mercury in the marine trophic network

As part of **task 5**, I analysed the proportion of mercury fractions and methylmercury concentrations in biological samples:

- phyto- and zoobenthos from Isfjorden (Svalbard Archipelago) (**publication O8**),

- blood from the seals at the seal centre of the Prof. Krzysztof Skóra's Marine Station in Hel (**publication O9**¹),
- hair and faeces from seals at the seal centre of Prof. Krzysztof Skóra's Marine Station in Hel (**publication O10**),
- shells, egg membranes, penguin feathers and droppings, sea elephant hair and droppings, and tail droppings inhabiting the west coast of the Gulf of Admiralty (Antarctica) (**publication O11**¹).

The research carried out showed that the proportion of mercury compounds in the biological samples examined varied over a wide range. **The main factor determining the proportion of individual mercury fractions in biological samples was the position of the organism concerned in the trophic network (publications O3, O4 and O8).** For both the Baltic organism samples (**publications O3 and O4**) and the Arctic macrobenthos (**publication O8**), an increase in the proportion of the labile Hg_{LAB1B} fraction was observed as the trophic level of the organisms studied increased, with a concomitant decrease in the proportion of the Hg_{LAB1A} fraction (**publications O3, O4 and O8**). This trend was particularly evident in the first links of the food chain. In phytoplankton and macroalgae, mercury adsorbed on the surface of particles or loosely bound to the matrix (Hg_{LAB1A}) typically accounted for less than 20% of THg, and Hg adsorbed in particles (Hg_{LAB1B}) comprised more than 60% of THg (**publications O2, O4 and O8**). It is also worth noting that in the organisms at the base of the trophic network, three other mercury fractions (Hg_{LAB2}, Hg_S and Hg_{RES}) also had a relatively large share in the total mercury (up to 30%) (**publications O2, O4 and O8**). In the tissues of animal organisms, an increase in the proportion of Hg_{LAB1B} (mercury incorporated into organic matter, including MeHg) was observed, ranging from 64% in fauna at lower trophic levels to 98% in consumers at the highest trophic levels (**publications O3, O4 and O8**). The opposite trend was observed for the Hg_{LAB1A} fraction, with the highest proportion in detritivores and filter feeders (15-25% THg) and the lowest (2% to 15%) in predators (**publications O3, O4 and O8**). A similar trend as for Hg_{LAB1B} is also observed in the case of methylmercury. MeHg biomagnifies along the trophic chain, reaching its highest concentrations in the last links of the chain (Wu et al., 2019). It could follow that not only methylmercury, but also mercury embedded in organic matter (Hg_{LAB1B}), undergoes biomagnification in the marine trophic chain (**publications O3, O4 and O8**). However, the interpretation of the results obtained is not straightforward. The high proportion of Hg_{LAB1B} with a concomitant low proportion of MeHg in the samples may also be the result of detoxification and/or demethylation processes. This was evident in the grey seal droppings. Mercury entered the seals' bodies with food (herring - 92%

¹ In publications 9 and 11, in the course of the review and publication work, decisions were made not to include information on the mercury fraction in the manuscripts. Therefore, they will be presented as unpublished data in the self-reference.

Hg_{LAB1B} and 75% MeHg) (**publication O10**). In the faeces, 78% of the mercury was in the form of Hg_{LAB1B}, while MeHg accounted for only about 20% of THg (**publication O10**). It follows that as a result of the digestion process, methylmercury in food was accumulated in the body or transformed into an inorganic form (demethylation), which significantly less translated into Hg fractionation (**publication O10**). Thus, this confirms the previous finding that **Hg_{LAB1B} fraction analysis cannot be used as an alternative to measure methylmercury concentrations in biological samples (rejection of hypothesis 2)**. In low methylmercury samples, where the inorganic form of Hg predominates, mercury fractionation is an excellent tool, providing information on the incorporation of this metal into the trophic network and the transformations taking place in organisms (**hypothesis 4 and 5 confirmed**). In contrast, in samples with high MeHg content, labile fractions typically account for around 100% of THg, with values varying within a narrow range. In this case, a methylmercury analysis is warranted. Such a situation occurred during a study based on blood and milk samples of seals from the Prof. Krzysztof Skóra's Marine Station in Hel (**publication O9**). In these samples, >98% THg were labile mercury fractions, whose share ranged from 94 to 100% THg (**publication O9 – unpublished data**). Hg fractionation therefore did not provide sufficient information to understand the transfer of mercury along the female-puppy pathway across the placenta and also with breast milk during lactation. Only the MeHg results in combination with THg allowed recognition of how mercury transfer took place during the early life phase of the seal (**publication O9**). The study showed that maternal transfer of methylmercury across the placenta was the most efficient form of mercury transport to the offspring. As a result of continuous exposure to MeHg in prenatal life, its highest concentration in the blood of puppies was observed immediately after birth. In the following weeks of the seals' lives, THg concentrations and the proportion of MeHg in the blood decreased. This was due to two factors. On the one hand, milk was a minor source of methylmercury in puppies. On the other hand, methylmercury elimination in juveniles occurred surprisingly quickly after parturition via transport of mercury to new fur and with faeces (**publication O9**). In addition, during the lactation period, high doses of selenium, an element that potentially reduces mercury toxicity, are delivered to the puppies' bodies with the mother's milk. It has thus been shown that the postnatal development of young grey seals can reduce the potential risks associated with mercury exposure during fetal life.

Another factor influencing the proportion of individual mercury fractions in biological samples was the tissue-building material (publications O3, O4 and O8). The lowest proportion of labile fractions was characterised by samples of hair including skin dropped by sea elephants from Admiralty Bay. These samples were dominated by the sulphide fraction, which averaged 58% THg. 40% of the mercury in the hair and skin of sea elephants was present as complexes with organic matter (Hg_{LAB1B}). The three other

mercury fractions (Hg_{LAB1A} , Hg_{LAB2} and Hg_{RES}) comprised less than 2% THg (**publication O11 - unpublished data**). A high proportion of mercury sulphide was measured in the feathers of penguins from Admiralty Bay (24%; **publication O11 - unpublished data**) and in the fur of grey seals from the Robert L. H. Smith Marine Station. Prof. Christopher Skin in Hel (12% and 6% in adult seal hair and lanugo, respectively) (**publication O10**). The high HgS content in feathers and fur is due to the structure of these tissues (Phelps et al., 1980). Feathers and fur are made up of approximately 90% keratin, a protein characterised by a high content of the sulphur amino acids cysteine and methionine. These are substances with which mercury forms stable complexes. A relatively high proportion of stable fractions (20% THg) was also measured in macrophytobenthos samples from Isfjorden (**publication O8**) and penguin eggshells from Admiralty Bay (**publication O11 - unpublished data**). In both cases, the predominant group of stable mercury compounds was the residual form, which included 18% THg in the macrophytobenthos and 15% THg in the shells. This is a specific situation, as in biological samples Hg_{RES} usually accounts for less than 3% of THg (**publications O3, O4, O8, O10**). In the case of algae, the presence of mercury in the residual fraction may have been related to the fact that these organisms take nutrients from the sediments in which this form of mercury may be present (**publication O8**). In eggshells, on the other hand, the presence of Hg_{RES} was most likely due to their mineral structure. In the inner membrane of eggs, which is composed to a much greater extent of proteins than the shell, the residual mercury is only 3% THg (**publication O11 - unpublished data**). In the other biological samples studied, labile fractions accounted for more than 90% of the mercury, with labile mercury accounting for more than 98% of THg in samples of organisms from higher trophic levels (starfish and snakeheads, muscles of woolly crab, herring, salmon, cod and grey seal, grey seal blood and faeces of grey seals, penguins and sea elephants) (**publications O3, O4, O8, O9, O10 and O11**).

Fractionation of mercury in biological samples is a relatively new approach, so interpretation of the results obtained by this method can be difficult. **However, ongoing research has shown that the results obtained can help to understand the transfer of mercury in the trophic chain.** It is important to know all forms of mercury, especially the labile forms that can be bioavailable to organisms (not just methylmercury). The form in which Hg occurs in nature affects its physical and chemical properties. This is why **the proportion of different Hg fractions can indicate the different origins of the metal in the samples and influence its rate of accumulation.**



Impact of my research on the development of the discipline

I consider my greatest scientific achievement presented in this habilitation thesis **to be the identification of factors shaping the influx of mercury fractions into the sea and their transfer in the marine trophic network**. All the matrices studied were dominated by labile mercury fractions, the proportion of which varied over a wide range and depended on a number of factors and processes in a given environment.

The main factor determining the distribution of mercury fractions in aerosols was the origin of the air masses and the characteristics of the Hg sources in the study area. This resulted in a difference in the percentage fraction of mercury in aerosols taken on the Coast and in Silesia. This is an important aspect of the conducted research, because the participation of individual mercury fractions in aerosols can help in determining the sources of mercury in the air in the studied area. Also, air temperature influenced the fractionation of mercury in aerosols due to transformations occurring in the atmosphere. In contrast, the occurrence of wet precipitation did not result in changes in the proportion of the Hg fraction in the particles. Rain contributed to the purification of air from mercury in suspended form. Thus, atmospheric precipitation should be considered as a significant source of all marine mercury compounds studied.

The main factor determining the proportion of individual mercury fractions in the soil and its mobility in river systems was the organic matter content. In soils with low organic matter content, mercury was found mainly in fractions that are easily soluble in water, which can be leached from the soil into the river during precipitation and then transported to the sea. In soils with a high organic matter content, water-soluble mercury compounds accounted for only a few per cent of THg, so only a small amount of mercury in this form was washed out of the catchment into aquatic ecosystems. For this reason, complexation of mercury by organic matter reduced the solubility, mobility and toxicity of mercury in the soil. Hydrotechnical work carried out within the riverbed has also had an impact on the circulation of mercury compounds in river systems. However, the effect of this activity was highly dependent on the type of work carried out and the environmental conditions of the river.

The main process influencing the contribution of the different mercury fractions in suspended solids and marine sediments was the sedimentation of the suspended solids into the sediments. Depending on the distance from the estuary, this process occurred in different ways. At the junction of land and sea, the dominant fraction of mercury sedimented into marine sediments was HgS. In contrast, as the river moved away from the estuary, deposition of mercury absorbed in suspension was a significant source of this metal in the sediment. Sedimentation of Hg from the water column to the sediment was important in the circulation of this metal in the sea, as it significantly reduced its transport to open waters and made it



necessary to consider coastal zones as a 'storehouse of mercury' transported by rivers. Another process influencing mercury fractionation in the coastal zone in the estuarine region was the presence of plankton, whereby mercury transported by the rivers was converted into an absorbed fraction inside the cells. This process is crucial in the circulation of mercury in the sea, as Hg in complexes with marine organic matter is more bioavailable than Hg in combination with terrestrial organic matter, which stimulates the transfer of this metal to higher trophic levels.

The main factor determining the share of individual mercury fractions in biological samples was the position of a given organism in the trophic network. It was observed that the proportion of the labile fraction of mercury absorbed inside the cells increased with increasing trophic level of the organisms studied. An analogous trend is shown by methylmercury. However, no statistically significant positive relationship between the discussed Hg fraction and MeHg was observed. This could have been due to a number of factors. The proportion of individual mercury fractions in biological samples also depended on the material of the tissue. A high proportion of HgS was measured in tissues composed of keratin. In contrast, the increased proportion of the residual mercury fraction in eggshells relative to the other biological samples was most likely due to their mineral structure. In the remaining tested biological samples, more than 90% of mercury are labile fractions, while in the samples of organisms from higher trophic levels, labile mercury accounted for more than 98% of THg.

This research was made possible by the development of a mercury fractionation method by a team from the UG Department of Oceanography and Geography and its implementation in the study of a wide range of environmental samples. The developed mercury fractionation method is a fast and relatively cheap method to determine the percentage of specific groups of mercury compounds with similar properties in samples with low Hg concentrations. This method does not require special sample preparation (apart from lyophilisation and homogenisation) and the use of reagents, which reduces the possibility of sample contamination and significantly reduces the cost of analysis. In addition, the method utilises a mercury analyser commonly used in testing laboratories, which allows standardisation of the analytical procedure. Therefore, the results obtained using this method in different laboratories can be compared with each other. This makes the developed mercury fractionation method widely applicable to laboratories dealing with biogeochemical transformations of mercury in the environment. This is confirmed by the increasing number of citations of our publications (Table 1). I believe that it is a great achievement to demonstrate that the developed method is also suitable for mercury fractionation in biological samples. To my knowledge, this is the first time that thermal desorption combined with atomic absorption spectroscopy has been used to fractionate mercury in this type of sample. The undoubted disadvantage of the developed method is that it

cannot be used as an alternative for methylmercury analysis. However, the information on the content of labile Hg fractions in the samples can be used to pre-select material for MeHg analysis, thus reducing the time-consuming analysis of material with a low content of labile mercury fractions.

4.5. Literature

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5. Presentation of significant scientific or artistic activity carried out at more than one university, scientific or cultural institution, especially at foreign institutions

Since the beginning of my scientific work, I have been cooperating with scientists from various research centres in Poland (Institute of Oceanology PAS in Sopot, Institute of Meteorology and Water Management - PIB in Gdynia, Institute of Environmental Protection - PIB in Warsaw, Provincial Inspectorate for Environmental Protection in Gdańsk) and abroad (Jožef Stefan Institute in Ljubljana, Slovenia, Leibniz Institute for Baltic Sea Research in Warnemünde, Germany) (appendix. 3, II.11). This collaboration translates into interdisciplinary research that we conduct together. At the same time, it allows me to obtain unique research material or data that I would not have been able to obtain on my own.

In my first year of doctoral studies, I applied for a grant called *Atmospheric Deposition and Terrestrial Runoff of Mercury into the Coastal Zone of the Gulf of Gdańsk* to the Provincial Fund for Environmental Protection and Water Management in Gdańsk. My application was successful (app. 3, II.9, P3), and the



research was conducted in cooperation with the Institute of Oceanology of the Polish Academy of Sciences (IO PAS) in Sopot and the Institute of Meteorology and Water Management - National Research Institute in Gdynia (IMGW-PIB). I am still conducting joint scientific work with both centers to this day. Thanks to the cooperation with IMGW-PIB, my research has been extended to include hydrological measurements in rivers. On the other hand, the cooperation with the IO PAS has enabled me to analyse total and ionic mercury in river water and precipitation in the mercury laboratory run within their structures. This collaboration has resulted in two publications (app. 3, II.4, **A7 and A8**), in which it was shown that in untransformed areas, most of the mercury reaching the catchment areas of the Kacza and Potok Oliwski rivers was retained in the soil as a result of atmospheric deposition. In contrast, any anthropogenic changes in the catchment (development of agricultural land or urban areas with impermeable surfaces) accelerated the outflow of mercury from the catchment, resulting in an increase in the concentration of this metal in the river. The results clearly indicated that anthropogenic catchment areas are a significant source of mercury in rivers. Consequently, catchment management has a significant impact on the mercury load reaching the sea.

The continuation of the above research was the River Rafting project *as the main source of mercury to the waters of the Gulf of Gdańsk* financed by the University of Gdańsk (my second original grant, app. 3, II.15, **UG3**). I carried it out in cooperation with the Provincial Inspectorate for Environmental Protection in Gdańsk (WIOŚ), the Institute of Oceanology PAS in Sopot and the Institute of Meteorology and Water Management - PIB in Gdynia. Collaboration with the WIOŚ has made it possible to obtain unique material - water samples from the Vistula River taken regularly every month in 2010. It was a very valuable cooperation, because that year there was the largest flood in 160 years; then samples were collected every day. In turn, IMGW provided me with samples from a cruise in the southern Baltic from June 2010. As a result, the Hg load entering the sea with the waters of the Vistula - the second largest river entering the Baltic Sea after the Neva - was determined. It has also been shown that during the flood, the water in the Vistula and Gulf of Gdańsk contained several times higher concentrations of Hg than outside the flood period. Elevated mercury concentrations in seawater resulted in increased Hg concentrations in surface sediments. It was visible for three years after the flood. The huge mercury load (75% of the annual load) introduced into the sea during the month-long flood was largely incorporated into the trophic network, which translated into a fourfold increase in Hg concentrations in phytoplankton compared to pre-flood values. Mercury transported with the waters of the Vistula reached distant parts of the Baltic Sea, thus making the flooding a potential transboundary source (app. 3, II.4, **A6**). In addition, the research I have been conducting (app. 3, II.4, **A6-A8**) made it possible to estimate the actual monthly and annual mercury



loads reaching the Gulf of Gdańsk due to atmospheric deposition and river run-off. I have shown there that the values presented in international reports (HELCOM, EMEP) of mercury loads discharged by Poland into the sea are significantly overestimated. I therefore consider it a success that the Baltic Marine Environment Protection Commission (HELCOM) has used the results of my research as source data to correct (reduce) the amount of mercury loads entering the Baltic Sea from the Polish area.

In 2008, in the second year of my doctoral studies, I did a one-month internship in the Climate Change Unit laboratory at the Joint Research Centre in Ispra (Italy) (app. 3, II.11, **S1**). This trip took place as part of the EU project *Determination of organic and elemental carbon in atmospheric PM10 aerosol samples* (app. 3, II.9, **P1**), of which I was a contractor. During this trip I worked with Dr Jean-Philippe Putaud, head of the European Commission Atmospheric Observatory and Global Atmosphere Watch Regional Station in Ispra, Italy. He is a scientist with research interests across a broad spectrum of atmospheric chemistry and physics. Dr Putaud introduced me to the thermo-optical method developed at his centre for measuring organic and elemental carbon in aerosols (according to the EUSAAR protocol). As part of this internship, I intercalibrated the method of determining various carbon fractions in aerosols used in UG laboratories with the EUSAAR method. I also carried out chemical analyses of a series of aerosol samples collected in the coastal zone of the southern Baltic Sea. A wealth of analytical material was produced there, which was published in the journal *Science of the Total Environment* (app. 3, II.4, **A3**). The knowledge and skills I gained enabled me to implement a thermo-optical method for the analysis of carbon compounds in aerosols that follows the EUSAAR protocol, which is still in use today at the Faculty of Oceanography and Geography of UG.

In 2010, I attended the European Research Course in Atmospheric Chemistry and Physics (ERCA), organised by Prof. Claude Boutron of the Laboratoire de Glaciologie et Géophysique de l'Environnement in Grenoble, France (app. 3, II.11, **S2**). Only two Polish women qualified for this prestigious training and the cost of attending this event was funded by the French Ministry of National Education. During this trip, I significantly deepened my knowledge of atmospheric transformations, which in turn enabled me to carry out a more detailed discussion in two manuscripts on atmospheric mercury transformations (app. 3, II.4, **A4 and A7**) and in the dissertation.

In 2015, after a four-year maternity and parental leave, I was hired at UG as an assistant professor. During this time, I established a partnership with Prof. Milena Horvat, Head of the Department of Environmental Sciences at the Jožef Stefan Institute in Ljubljana (Slovenia). She is an expert when it comes to researching organic forms of mercury. Cooperation with prof. Horvat and her team proved to be instrumental in my scientific development. I initially made contact to learn about the current method of



measuring methylmercury in environmental samples and the state-of-the-art equipment for mercury analysis. In 2016, I did a month-long internship at the Jožef Stefan Institute (app. 3, II.11, **S3**) funded by the Foundation for Polish Science (within the START grant) and the National Science Centre (app. 3, II.9, **P8**). From the first day of my stay in Ljubljana, I was given the opportunity to work in the laboratory on methylmercury analysis. There I worked with samples of very different matrices, using different mercury analysers (TEKRAN, Brooks Rand). I also carried out methylmercury analysis in a series of Baltic samples, which served as internal reference material for our later studies. The knowledge and skills gained during this internship, enabled me to implement methods for the analysis of methylmercury at the Department of Oceanography and Geography of UG and helped to co-found one of the first centres in Poland dedicated to the study of organic mercury compounds in the environment.

In 2020, I completed another research internship at the Jožef Stefan Institute (app. 3, II.11, **S5**). This trip was financed under the PROM – International Scholarship Exchange of Doctoral Students and Academic Staff funded by the National Agency for Academic Exchange. The main objective of this internship was to learn about the current method of measuring mercury isotopes in environmental samples and the state-of-the-art equipment used for these analyses. During my stay at the Jožef Stefan Institute, in cooperation with Dr. Igor Živkovič, we tried to refine the method of preparing samples from the Antarctic, which I took for research on mercury isotopes. Our activities have proved fruitful. I therefore decided to incorporate these analyses into the project *Benthic Organisms as an indicator of mercury sources in the Antarctic coastal zone (Admiralty Bay)*. It has received NCN funding (app. 3, II.9, **P10**) and I am currently implementing it in collaboration with, among others, researchers from the Jožef Stefan Institute. In 2022, I visited Ljubljana again as part of the project implementation (app. 3, II.11, **S6**). The purpose of the trip was to continue the analysis of mercury isotopes in samples from Antarctica. I conducted the research with Dominik Božič, M.Sc. Our work in the laboratory has resulted in a unique database - there are few Hg isotope results in samples from the polar regions. We are currently in the process of compiling the results and writing the manuscript. During this stay, thanks to discussions with prof. Horvat, Dr Igor Živkovič and Domonik Božič, I have significantly expanded my knowledge of mercury isotopic transformations in the environment, which I hope will help in the discussion of the results obtained.

At the end of 2018 and the beginning of 2019, I participated in a two-month scientific expedition to the H. Arctowski Polish Antarctic Station (app. 3, II.11, **S4**). This trip was funded by NCN as part of the project *Distribution of ⁹⁰Sr and ¹³⁷Cs in biota of polar areas in the aspect of melting glaciers as a secondary source of isotopes of anthropogenic origin* (app. 3, II.9, **P9**). The main goal of the trip was to obtain research material necessary for the implementation of the project. Sampling turned out to be a very good opportunity



to learn about the processes taking place in the polar regions. Therefore, I believe that this trip proved to be a milestone in my career - it allowed me to extend the study of mercury in material collected in the Antarctic. I returned from the trip with unique research material (terrestrial and marine samples from the Admiralty Bay coastal zone) and a head full of ideas. This prompted me to write my project *Benthic Organisms as an Indicator of Mercury Sources in the Antarctic Coastal Zone (Admiralty Bay)*, which received funding from NCN (app. 3, II.9, **P10**). I am currently carrying out this project in a consortium with IO PAN. This material is part of the dissertation of Ewa Korejwo, M.Sc., in which I act as assistant supervisor.

During the stay at the H. Arctowski Polish Antarctic Station, I have established cooperation with the Institute of Biochemistry and Biophysics of the Polish Academy of Sciences. This cooperation made it possible to continue sampling, which we began to collect during our scientific expedition. We were able to determine how mercury and methylmercury concentrations change in penguin feathers and faeces during different developmental periods (egg laying, chick care, foraging) (app. 3, II.4, **A36**).

The fruit of quite extensive cooperation, the publication *Processes affecting the transformation of mercury in the coastal zone in the vicinity of two river mouths in the southern Baltic Sea* (app. 3, II.4, **A33**). I obtained samples for research as part of two projects: Remobilization of mercury from land to sea under the influence of intense meteorological and hydrological phenomena (app. 3, II.9, **P7**) funded by the National Science Centre, headed by Prof. Dr. hab. Magdalena Beldowska from the University of Gdańsk and *BONUS-COCOA* (03F0683A) funded by the German Ministry of Science and Education and headed by prof. Maren Voss from the Leibniz Institute for Baltic Sea Research in Warnemünde (Germany), and contractors on behalf of the UG, Dr. hab. Dorota Burska, Prof. UG and Dr Dorota Pryputniewicz-Flis. This research has also involved Dr. Karol Kulinski, prof. IO PAN, which performed measurements of stable isotopes of carbon and nitrogen in suspension samples. He also supported me substantively during the development of results on the transformation of organic matter in the sea. Meanwhile, Dr Ewa Szymczak, Prof. UG from the Marine Geology lab helped me interpret the results in terms of geological processes in estuaries.

The aforementioned extensive cooperation enabled me to significantly broaden the spectrum of research. Without them, I would not be where I am today.

6. Presentation of teaching and organizational achievements as well as achievements in popularization of science or art

I started teaching during my doctoral studies. Since the second year of doctoral studies (i.e. since 2008), I have been preparing and conducting courses in chemical oceanography and hydrochemistry of the marine



environment in the following fields: Oceanography, Aquaculture – Business and Technology, Water Management and Protection of Water Resources and Marine Hydrography. These include both laboratory classes: Hydrochemistry (90 h/year), Water Chemistry (30 h/year), Chemical Oceanography (60 h/year), original lectures: Protection of the marine environment (15 h/year), as well as field workshops: Specialist workshops in the sea and coastal zone (10 h/year). Since 2015, when I was hired at the University of Gdańsk, I have also been running a Diploma Lab and a Master's Lab (30 h/year). To date, I have been the supervisor of seven Master's theses and eleven Bachelor's theses. I am also the associate supervisor of five doctoral dissertations (two completed, both with distinction, three are in progress):

- I. Agnieszka Grajewska, *Pathways of mercury ingress and elimination in the Baltic grey seal (Halichoerus grypus grypus)*, University of Gdańsk. Supervisor Prof. dr hab. Lucyna Falkowska. Doctoral thesis defended with distinction in 2020.
- II. Karolina Gębka, *Meteorological and hydrological determinants of the inflow of labile forms of mercury to the Gulf of Gdańsk*, University of Gdańsk. Supervisor Prof. Dr. hab. Magdalena Beldowska. Doctoral thesis defended with distinction in 2020.
- III. Ewa Korejwo, *Mercury and methylmercury in polar regions*, Institute of Oceanology PAS. Supervisor Prof. dr hab. Jacek Beldowski. The planned date for the dissertation defence is 2024.
- IV. Patrycja Płońska, *Impact of geological structure and meteorological conditions on the outflow of mercury from soils*, University of Gdańsk. Supervisor Prof. dr hab. Magdalena Beldowska. The planned date for the dissertation defence is 2025.
- V. Dominik Narwojsz, *Effects of climate change on the concentration and bioavailability of mercury in the Arctic*, Institute of Oceanology PAS. Supervisor Prof. dr hab. Jacek Beldowski. The planned date for the dissertation defence is 2025.

I am constantly trying to improve my teaching skills and increase my knowledge of new teaching methods. I regularly participate in teaching workshops and training courses, i.e.:

- I. Workshop *Process and outcome orientation in the assessment of student work - between developmentally supportive assessment and control*,
- II. Workshop *Creatively and actively working with scientific text - i.e. how to support students in reading difficult content*,
- III. Workshop *Empathy in teacher-student communication. Introduction to NVC (Non Violent Communication)*,
- IV. Workshop *Tools used to prepare presentations and teaching materials*,
- V. Workshop *Gamification in academic education*,



VI. Workshop *Strategies for giving feedback - grading, appreciation, feed - back, feed -forward,*

VII. Training *Comprehensive programme to remove barriers to education for people with disabilities.*

This has resulted in the use of activity-based teaching methods, which are designed to make students solve the problem raised in class themselves. In the field workshops, I work using the project method. These methods have been highly appreciated by students for many years.

I also try to innovate in education. An example of this is the co-authorship of two case study courses *Plastic pollution - a global problem for the 21st century* and *Nuclear energy - a panacea for global warming*, which were developed in collaboration with staff from IMGW-PIB in Gdynia and the Experiment Science Centre in Gdynia. I am co-author of the academic textbook *Physico-chemical studies of natural waters - a guide to laboratory exercises.*

In my teaching, I try to infect students with a passion for oceanography and scientific work. This causes many of my mentees to actively participate in research in our department. This results in awards, prizes and scholarships that students receive for their academic achievements. Four students I have mentored are winners of the Minister of Science and Higher Education Scholarship for Outstanding Achievement. My undergraduate received an honourable mention at the 13th *Marine Chemistry, Geochemistry and Conservation* Conference for his poster *Factors influencing the outflow of total mercury from soil to river and sea* (appendix. 3, II.7, **W50**), presenting the results of his undergraduate thesis. Two students for whom I was a supervisor applied for a Diamond Grant.

My teaching activities were recognised by the community, resulting in my being awarded the 2023. Medal of the National Education Commission.

I am also involved in organizational activities both at the University of Gdańsk and in scientific circles outside the university. Currently, I am a member of the Commission for Awards and Decorations at the Faculty of Oceanography and Geography. I have also actively participated in the work of the Team for the development of a remediation plan for the quality of scientific activity in the discipline of Earth and Environmental Sciences for the Faculty of Oceanography and Geography at UG. In 2017, I was the Chair of the Faculty Recruitment Committee for the courses: Oceanography, Geology, Aquaculture - Business and Technology and Water Management and Conservation. I was a member of the Organising Committee of the National Scientific Conference *Mercury in the Environment - Identification of Threats to Human Health* four times in 2007, 2010, 2013, 2016, I was also Vice-Chair of the Organising Committee of the 15th Conference on *Chemistry, Geochemistry and Protection of the Marine Environment*, held on 20 October 2023 in Gdynia (app. 3, II.8). I co-organised a workshop at the 14th International Conference on



Mercury as a Global Pollutant (app. 3, II.8). Since 2013, I have been a member of the Gdańsk Scientific Society (app. 3, II.10) and I get involved in groups/organisations that promote knowledge about the seas and oceans. Since 2023, I have been a representative of the University of Gdańsk in the Polish Scientific Diving Committee - PKNN (app. 3, III.6). The committee currently comprises nine institutions (Institute of Oceanology of the Polish Academy of Sciences in Sopot, Faculty of Archaeology of the University of Warsaw, National Maritime Museum in Gdańsk, Institute of Meteorology and Water Management National Research Institute, Institute of Biochemistry and Biophysics of the Polish Academy of Sciences in Warsaw, Centre for Underwater Archaeology of the Nicolaus Copernicus University in Toruń, Faculty of Biology of the Adam Mickiewicz University in Poznań, University of Gdańsk, Technical University of Gdańsk). The aim of the committee is to create the necessary regulations allowing scientific institutions to use diving techniques in scientific research. Since 2024, I have been an expert of the Polish Section of the Committee for The International Maritime Organisation's Marine Environment Protection Committee (IMO MEPC) at the Marine Environment Protection Centre (MEPC). IMO at the Polish Register of Shipping S.A. The MEPC Section develops national regulations related to the protection of the marine environment, as well as monitors their implementation. On several occasions I was the scientific cruise director on the research vessel Oceanograf in the southern Baltic.

I have also tried to get involved in activities that popularise science. I am the author/co-author of popular science articles:

- I. Saniewski M., Bazy P., Borszcz T., Kukliński P., **Saniewska D.**, Kostrzyńska A., 2012. Spitsbergen - in the land of polar bears. *Nuras* 11, 1-12.
- II. **Saniewska D.**, Saniewski M., 2014. Mauritius - in search of paradise. *Nuras* 5, 42-47.
- III. **Saniewska D.**, 2015. Flood and the quality of the marine environment. *Universe* 116(4-6), 148.
- IV. Balaza P., **Saniewska D.**, Saniewski M., 2019. Humpback whale, giant sponges and the 'dive of a lifetime'. *Salamander* 47(1-2), 43-48.

I have co-organised lectures, demonstrations and competitions during the Baltic Science Festivals and Oceanography Weekends on many occasions, as well as leading oceanography workshops in kindergartens and primary schools. In 2021, I also took part in the *European Blue Schools Network* project coordinated by the Gdynia Aquarium MIR-PIB. The aim of all these actions was to promote natural knowledge of the seas and oceans, with particular emphasis on the Baltic Sea, and to awaken scientific interest in children, young people and adults.

- I. V Baltic Science Festival, popularisation stand entitled *Metal Face of the Sea*. 25 May 2007, contractor.



- II. VI Baltic Festival of Science, popularisation stand under the title *Adventure with Oceanography*. 30.05.2008, contractor.
- III. VII Baltic Science Festival, popularisation stand entitled *In the Land of Oceanography*. 29 May 2009, contractor.
- IV. VII Baltic Science Festival, presentation entitled *Mercury in the Environment*. 29 May 2009, speaker.
- V. VII Baltic Science Festival, popularisation stand entitled *In the Land of Oceanography*. 29 May 2009, contractor.
- VI. Kasztanowe Kindergarten number 19 in Gdynia, *oceanographic workshop for schoolchildren*. 14 May 2014, contractor.
- VII. Kasztanowe Kindergarten number 19 in Gdynia, *diving workshop for pupils*. 19 May 2015, contractor.
- VIII. No. 34 Leonid Teliga Primary School in Gdynia, *an oceanographic workshop for schoolchildren*. 15 VI 2018, contractor.
- IX. Weekend with Oceanography, presentation entitled *Mercury in the Southern Baltic*. 29 III 2019, speaker.
- X. Weekend with Oceanography, a popularisation stand entitled *Marine Chemist*. 29-31 III 2019, contractor.
- XI. Scientific Circle of Oceanographers, presentation entitled *Distribution of mercury in the fauna and flora of polar areas in the aspect of melting glaciers*. 11 IV 2019, speaker.
- XII. Green hub, presentation entitled *Mercury in the environment*. 8 IV 2021, speaker.
- XIII. Young Scientists UG, interview under the title *Melting glaciers a secondary source of mercury in the Antarctic coastal zone?*. 18 August 2022.

7. Apart from information set out in 1-6 above, the applicant may include other information about her professional career, which she deems important.

A detailed list of my scientific achievements is presented in Appendix 3 'List of scientific achievements making a significant contribution to the discipline of Earth and Environmental Sciences'. At this point I would like to briefly describe my achievements, which have not yet been listed in the self-referral.



7.1. Other research issues

Before obtaining a doctoral degree

During my studies, I became interested in issues related to mercury transformations in the marine environment. As part of my master's thesis, I conducted research on *Mercury in the open waters of the Baltic Sea* based on original, independently analyzed material collected during research expeditions. I demonstrated that the main factor determining the distribution of mercury in the water column is suspended matter. I also emphasized the importance of density stratification in the southern Baltic Sea in the circulation of Hg in the sea. In layers such as the thermocline or halocline, where organic matter accumulates, mercury in the form associated with suspended matter undergoes biochemical transformations into the dissolved form, facilitating its return to circulation. In the southern Baltic Sea, which is a relatively shallow basin, only a small part of the sedimenting suspended matter, along with mercury, reaches the bottom, where it is temporarily excluded from circulation. This suggests that the estimated mercury load deposited in sediment may be overestimated. The results of these studies were published in the *Oceanological and Hydrobiological Studies* journal (app. 3, II.4, **A1**).

In 2007, I commenced my doctoral studies in Oceanography and Geography at the University of Gdańsk. My doctoral dissertation on *the Mercury Transport Pathways to the Coastal Zone of the Gulf of Gdańsk* was based on three research projects - *Carcinogenic and neurotoxic compounds in aerosols in inhaled air near and distant from pollution emitters* funded by the Ministry of Science and Higher Education (app. 3, II.9, **P2**), *Atmospheric deposition and land runoff of mercury to the coastal zone of the Gulf of Gdańsk* funded by the Voivodeship Fund for Environmental Protection and Water Management in Gdańsk (app. 3, II.9, **P3**), and *River runoff as the main source of mercury to the waters of the Gulf of Gdańsk* funded by the University of Gdańsk (app. 3, II.15, **UG3**). In this work, I identified the pathways of mercury transport to the southern Baltic Sea and described in detail the factors influencing the variability of mercury loads introduced into the sea through these pathways. I demonstrated that the most efficient transport route for mercury to the coastal zone of the Gulf of Gdańsk was river runoff. The mercury load transported by rivers depended on the amount of precipitation and the type of catchment area. The second source of mercury - dry and wet atmospheric deposition, accounted for only a few percent of the total mercury load reaching the southern Baltic Sea. Mercury influx with rainwater predominated in summer and depended on the origin of air masses. Meanwhile, during the heating season, dry deposition of mercury associated with aerosols prevailed. This extensive work was published in the form of five scientific articles (app. 3, II.4, **A4, A6-A9**).



After obtaining a doctoral degree

In 2015, I was employed at UG as an assistant professor. I served as the principal investigator of the research project *Remobilization of mercury from land to sea under the influence of intense meteorological-hydrological phenomena* funded by the National Science Centre (app. 3, II.9, **P7**). This project constituted a continuation of my research conducted in river systems. I indicated that under the influence of intense meteorological-hydrological phenomena, mercury deposited on land for decades is remobilized and transported to the sea. This process is particularly unfavorable as a relatively large toxic mercury load enters the coastal zone in a short period, potentially endangering organisms thriving in this area. The research findings were published in the form of five articles in reputable scientific journals (app. 3, II.4, **A16, A20, A24, A28, and A29**).

At the same time, I participated in the project *Transfer of endocrine-active compounds at the highest trophic level* funded by the National Science Centre (app. 3, II.9, **P8**). These were experimental studies conducted at the Professor Krzysztof Skóra Marine Station in Hel, involving the Baltic grey seal (*Halichoerus grypus*). In this work, we determined the quantities of selected endocrine-active compounds (mercury and phenol derivatives) transported from fish diet to seals and their offspring, and subsequently eliminated from the body. The research also provided information on the components of the flow of endocrine-active compounds through the food chain-consumer-feces, as well as on the kinetics and conditions of processes, which are poorly understood links in the circulation of mercury and phenol derivatives in the marine trophic web (app. 3, II.4, **A14, A15**). This project was the culmination of years of research on the mercury cycle in the southern Baltic trophic web, and also served as the basis for writing three review articles - *Status and trends of mercury pollution of the atmosphere and terrestrial ecosystems in Poland* (app. 3, II.4, **A31**), *Mercury in the Polish part of the Baltic Sea: a response to decreased atmospheric deposition and changing environment* (app. 3, II.4, **A37**), and *Mercury Cycling in the Gulf of Gdańsk (Southern Baltic Sea)* (app. 3, II.2, **RM15**).

I was also one of the investigators involved in the project *Distribution of ⁹⁰Sr and ¹³⁷Cs in organisms of fauna and flora of polar regions in the aspect of melting glaciers as a secondary source of anthropogenic-origin isotopes* funded by the National Science Centre (app. 3, II.9, **P9**). As part of the research, I participated in a two-month scientific expedition to the Polish Antarctic Station named after H. Arctowski. From this expedition, I brought back a wealth of research material, which served as the basis for writing the project *Benthic organisms as indicators of mercury sources in the coastal zone of Antarctica (Admiralty Bay)* (ap. 3, II.9, **P10**) of which I am the principal investigator. The aim of the research is to identify mercury



sources in Antarctica and determine their potential for accumulation and biomagnification in the marine food chain. Currently, the project is ongoing.

7.2. Scientific publications

I am co-author of forty-two scientific publications in journals from the Journal Citation Reports database (in sixteen articles I am the first or corresponding author) (appendix 3, II.4) (as of 25.03.2024 total IF=189.454, total ministerial points 3464 points., including 664 points according to the old scoring system). Five of these included material I had accumulated during my doctoral studies (total IF=11,268, total ministerial points 119 points), while the remaining thirty-seven publications appeared after I obtained my doctoral degree (total IF=178,186 and total ministerial points 3345 points, of which IF=57,058 points and 1240 ministerial points were contributed by publications constituting scientific achievements) (app. 3, IV.1 and 4). My works are starting to be cited - the total number of citations according to the Scopus database as of 25.03.2024 is 711 (including 534 without self-citations), and the Hirsch index: 17 (app. 3, IV.2 and 3). I am also the author and co-author of twenty-one peer-reviewed chapters in scientific monographs outside the Journal Citation Reports database (app. 3, II.2).

7.3. Participation in projects

I have experience in project management. I was the manager of four projects funded by: National Science Centre, Provincial Fund for Environmental Protection and University of Gdańsk (app. 3, II.9 and 15). Two of them took place before I obtained my doctoral degree and two after. I have also been involved as a contractor in ten research projects funded through national or international competitions (app. 3, II.9 and 14). Five of these took place during my doctoral studies, while the other five were completed after obtaining a doctoral degree. Prior to my PhD, I also participated as a contractor in two projects funded by the University of Gdańsk (app. 3, II.15).

7.4. Participation in conferences and invited lectures

I have presented the results of my research at forty-five scientific conferences - nineteen national and twenty-six international (app. 3, II.7). In total, I have co-authored ninety-five conference presentations (nineteen of which were prior to my PhD). I also gave a lecture at the invitation of *Mercury and Antarctic* at the Jožef Stefan Institute in Ljubljana (Slovenia).

7.5. Expertise activities



Since obtaining the PhD, I have regularly reviewed scientific publications. In ten years I have reviewed more than twenty articles in journals such as *Science of the Total Environment*, *Marine Pollution Bulletin*, *Analytica Chimica Acta*, *Atmospheric Pollution Research*, *Chemosphere*, *Ecotoxicology and Environmental Safety*, *Environmental Sciences Europe*, *Environmental Science and Pollution Research*, *Journal of Environmental and Occupational Science*, *Scientific Reports*, *Water Research*, *Water* (app. 3, II.13), as well as in monographs outside the Journal Citation Reports database. I also co-authored the expert report *Mercury air pollution at regional background stations - assessment for 2015*, commissioned by the Chief Inspectorate of Environmental Protection (app. 3, III.5). I am currently a representative of the University of Gdańsk in the Polish Committee for Scientific Diving (app. 3, III.6), as part of which we create the necessary regulations allowing scientific institutions to use diving techniques in their research. More recently, I have also been an expert of the Polish Section of the Committee for the Promotion of the Environment. The International Maritime Organisation's Marine Environment Protection Committee (IMO MEPC) at the Marine Environment Protection Centre (MEPC). IMO at the Polish Register of Shipping. (app. 3, III.6). The section's remit is to develop national legislation related to the protection of the marine environment, and to monitor its implementation.

7.6. Prizes and awards

My scientific activities have already been recognised by the scientific community on several occasions:

- I. Scholarship for outstanding doctoral students and young employees of the University of Gdańsk, XI 2009, University of Gdańsk Development Foundation.
- II. Scholarship to finance participation in the European Research Course in Atmospheric Sciences (ERCA), I 2010, French Ministry of National Education, Paris (France).
- III. Distinction for doctoral thesis *Transport routes of mercury to the coastal zone of the Gulf of Gdańsk*, X 2013, Council of the Faculty of Oceanography and Geography, University of Gdańsk.
- IV. Award for Young Scientists for Outstanding Achievements in the Field of Earth Sciences for PhD thesis *Pathways of Mercury Transport to the Coastal Zone of the Gulf of Gdańsk*, XII 2013, Gdańsk Scientific Society.
- V. START Scholarship for outstanding young scholars at the beginning of their scientific career with proven achievements in their field of research, V 2015, Foundation for Polish Science.
- VI. First Degree Rector's Team Award for a series of scientific publications covering issues related to the transformation of mercury in the Earth's atmosphere, its leaching and deposition



- in the sea, distribution, bioaccumulation and biomagnification of endocrine substances in the marine trophic chain, X 2015, University of Gdańsk.
- VII. Scientific scholarship for an outstanding young scientist, X 2016, Ministry of Science and Higher Education.
- VIII. Travel Award, VI 2017, Organising Committee of the International Conference *Mercury as a Global Pollutant*, Providence (USA).
- IX. Rector's Second Degree Team Award for a series of closely related scientific publications on the occurrence of phenol and mercury derivatives in the marine environment, X 2018, University of Gdańsk.
- X. Dean's Award for Research Achievements and Particularly Valuable Scientific Publications in 2018, X 2019, Faculty of Oceanography and Geography, University of Gdańsk.
- XI. Dean's Award for Research Achievements and Particularly Valuable Scientific Publications in 2019, X 2020, Faculty of Oceanography and Geography, University of Gdańsk.
- XII. Team Prize of the Rector of the first degree for a series of scientific publications presenting the problem of mercury and bisphenol A and alkylphenols in the marine environment, X 2021, University of Gdańsk.
- XIII. Medal of the Commission of National Education for special services to education and upbringing, VIII 2023, Commission of National Education.
- XIV. Team Prize of the Rector of the first degree for leading contribution to publications presenting the problem of mercury in the marine environment on the example of the highly urbanised Baltic Sea and remote pollution source Isfjorden, X 2023, University of Gdańsk.

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(Applicant's signature)