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5 **Analytical studies on the environmental state of the Svalbard archipelago - critical source of information about anthropogenic global**
6 **impact**

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18 Keywords: Arctic; environmental chemistry; pollutants; analytical studies; remediation

19

20 **Abstract**

21 The Svalbard archipelago differs from other polar regions due to its specific environmental conditions and geographic location which make the
22 area gather pollution from long-range transport. Due to the recent development in analytical techniques it is possible to determine the
23 concentration of pollutants at the level present there. This paper collates and discusses the information from the literature about: pollutants
24 present in various components of the ecosystem, the number and kind of research centers conducting analytical studies, and remediation



25 programs and projects realized in the area of the Svalbard archipelago. Monitoring the state of the environment of the Arctic region is extremely
26 important because of the unique opportunity to observe the direct influence of pollutants on processes in the studied area. Active participation of
27 many countries in research, international actions aimed at protecting the polar region, and highlighting the scale of the problem have helped
28 decrease the concentration of some toxic compounds in the Arctic environment. The data obtained in that way do not only constitute a source of
29 information about the changes in the polar environment but also enable an evaluation of the influence of particular pollutants on the global
30 ecosystem.

31 List of abbreviations:

| Abbreviation | Full name in english |
|---------------------|--|
| AAA | Atomic absorption analyzer (determined Hg) |
| AAS | Atomic absorption spectroscopy |
| Ace | Acenaphthylene |
| Acp | Acenaphthene |
| AFS | Atomfluorescence spectrophotometer |
| An | Anthracene |
| BaA | Benzo(a)anthracene |
| BaP | Benzo(a)pyrene |
| BbF | Benzo(b)fluoranthene |
| BDE | Brominated diphenyl ethers |
| BghiP | Benzo(ghi)perylene |
| BkF | Benzo(k)fluoranthene |
| CHB | Chlorobornanes |
| CHL | Chlordane |
| Chr | Chrysene |
| CN | Chlorinated naphthalenes |



| | |
|----------------|---|
| CVAFS | Cold vapor atomic fluorescence spectrophotometry |
| DbA | Dibenzo(a,h)anthracene |
| DDD | Dichlorodiphenyldichloroethane |
| DDE | Dichlorodiphenyldichloro-ethylene |
| DDT | Dichlorodiphenyltrichloroethane |
| DIEL | Dieldrin |
| Fl | Fluorene |
| Flu | Fluoranthene |
| GC-ECD | Gas chromatography, electron capture detection |
| GC-MS-NCI | Gas chromatography, mass spectrometry, negative chemical ionization |
| GC-MS-NICI | Gas chromatography, mass spectrometry, negative ion chemical ionization |
| GC-FID | Gas chromatography, flame ionization detector |
| GC-TOF-ESI | Gas Chromatography, time-of-flight, electrospray ionization in the negative ion |
| HBCD | Hexabromocyclododecane |
| HCH | Hexachlorocyclohexane |
| Hepta | Heptachlorepoxyde |
| HGAAS | Hydride generator atomic absorption spectroscopy |
| HPLC-MS/MS-ESI | High-performance liquid chromatography, tandem mass spectrometer, negative electrospray ionization |
| HRGC-HRMS-EI | Gas chromatography, high-resolution mass spectrometry, electron impact |
| HRGC-LRMS-ECNI | High-resolution gas chromatography, low-resolution mass spectrometer, electron capture negative ion |
| IC | Ionic chromatography |
| ICP-AES | Inductively coupled plasma atomic emission spectrometry |
| ICP-MS | Inductively coupled plasma mass spectrometry |
| ICP-QMS | Inductively coupled plasma quadrupole mass spectrometry |
| InP | Indeno(1,2,3-cd)pyrene |
| MeHg | Metylo Hg |



| | |
|--------------|-----------------------------------|
| Nap | Naphthalene |
| OCPs | Organochlorine pesticides |
| OHCs | Organohalogen compounds |
| Oxy | Oxychlordane |
| PAHs | Polycyclic aromatic hydrocarbons |
| PBDE | Polybrominated diphenyl ethers |
| PCDD | Polychlorinated dibenzo-p-dioxins |
| PCDF | Dibenzofurans |
| PCN | Polychlorinated naphthalenes |
| PFAS | Perfluorinated alkyl substances |
| PFCAs | Perfluorocarboxylic acids |
| PFHxS | Perfluorohexane sulfonate |
| PFOS | Perfluorooctane sulfonate |
| PFOSA | Perfluorooctane sulfonamide |
| Phe | Phenanthrene |
| POP | Persistent organic pollutants |
| Pyr | Pyrene |
| SpC | Specific conductivity |
| TEQ | Toxic equivalents |
| TOC | Total organic carbon |
| TPH | Total petroleum hydrocarbons |
| Σ CHL | Total chlordane levels |
| Σ DDT | Total DDT levels |
| Σ HCH | Total HCH levels |

32

33

34 1. Introduction

35 For many decades the Arctic was considered to be one of the last pristine regions free of the symptoms of anthropopressure [1] – this
36 concept has been weakened as a result of thorough environmental chemistry studies undertaken in the recent years. Due to improvements in
37 analytical techniques for water, air, soil and biological material pollution, it is possible to recognize the considerably low, but still harmful and
38 persisting levels of contamination present there. The phenomenon of Arctic pollution arises from a combination of long range transport of
39 pollutants and the Arctic haze phenomenon(locking contaminated air in the area for months [1]). Once supplied with even small amount of
40 pollution, Svalbard will store them for a long time, as an environment with slow decomposition processes. Being an area of well-developed
41 scientific research, Svalbard can be considered a model for international cooperation on pollution understanding and control in pristine areas.
42 However, even in this area there are still challenges remaning.

43 A particular class of pollution is of special concern in the Arctic: the persistent organic pollutants, characterized by durability and
44 resistance to degradation. The residence time of those pollutants is long enough for them to be transported thousands of kilometers by air and
45 ocean water [2,3]. Consequently, the compounds that have not been produced for the past few decades still appear in the environment (including
46 the polar regions). The quantities of those still present there may cause impact negatively the functioning of ecosystems, animal and human
47 health. Over the recent years it was reported that the Arctic has become a strongly polluted region [1,4]. The negative effects of pollution have
48 been seen very clearly in the area of Svalbard archipelago [1].

49 Located between 74 - 81° N, and 10-35° E, and separated from Greenland and Franz Josef Land by wide straits, the archipelago of
50 Svalbard is a gateway to the Arctic. In winter the atmospheric circulation concentrates a flux of pollutants from Central Europe, Scandinavia and
51 northwestern Russia into the Arctic. Svalbard, being the first landmass on the way of polluted airmasses, receives a strong contamination “blast”
52 [1]. Over a half of the area of the archipelago is protected in nature reserves, national parks, and plant sanctuaries due to both unique and
53 sensitive flora and fauna.. Not surprisingly, specialists from numerous research centers conduct studies in the region, the results of which can be
54 the basis for:



- 55
- An exact diagnosis of the state of the environment and the processes within;
- 56
- finding and implementing appropriate systems of both passive (conservationist) and active protection.

57

58 **2. Svalbard - a vulnerable area of the Arctic**

59 Pollutants from distant sources of emission are a growing threat to the Arctic region. An especially vulnerable part is the Svalbard
60 archipelago. The deposition of pollutants there is conditioned by the location of the archipelago and climatic factors. The key features of the
61 location of the archipelago which determine the deposition of pollutants in that place are:

- 62
- a relatively short distance from continental Europe (800 km north of the Scandinavian Peninsula, from the area where crude oil is
63 extracted in the North Sea, and from the Kola Peninsula and Sweden where minerals (including heavy metals) are mined - all those areas
64 are potential sources of emissions of pollutants;
 - less sea ice formation around Svalbard, as compared to the rest of the Arctic, which makes the archipelago the northernmost area
65 available for shipping and increases tourist traffic there (the existence of small local sources of pollutants);
 - the land relief dominated by mountains: these constitute a natural barrier for the contaminated airmasses coming from Europe and
66 northwestern Asia;
 - the location in the gap between the continents surrounding the Arctic Basin which facilitates the exchange of oceanic waters between the
67 moderate and high latitudes, as well as longitudinal circulation of air [1].
- 68
- 69
- 70

71 Climate is another factor contributing to the transport of pollutants over the area of Svalbard. The climatic factors in question are:

- 72
- low temperatures (the inflow of cold masses of air from the north):
73 - they significantly influence the vapor pressure and the numerical value of Henry's law constant of stable chemical compounds;
74 - they increase the tendency of pollutants to condense and contribute to their collection in various components of the environment;
- 75
- the frontal system running through the region:



76 - causes an increased cyclonic activity and frequent movement of low pressure areas as well as the related areas of huge cloudiness,
77 precipitation, and strong winds; together with an increase in the association of pollutants with the particles in the atmosphere , their removal
78 from the atmosphere, in the process of dry and wet deposition, becomes more rapid;

79 • the Icelandic Low in the vicinity of the archipelago which is a typical moving low pressure area of the moderate latitudes of the northern
80 hemisphere – atmospheric activity is the main media spreading the stable pollutants

81 • the wind speed grows together with the pressure gradient; as a result the pollutants in the air are subject to circulation (advective
82 movement and vertical movement in the atmosphere) and can be transferred across long distances:

83 - local winds (along the East-West axis) affect the redistribution of pollutants in the Svalbard region;

84 - in the archipelago there often occur katabatic winds caused by radiative cooling of masses of air lingering over the elevated areas, and
85 the cooled air flows down and creates a very strong wind; again, this increases the spreading potential of once deposited contaminants;

86 • the variable location of the upper tropospheric jet stream:

87 - Svalbard is subject to variable directions of air inflow, from stationary atmosphere with the Arctic haze to external transport;

88 • ocean currents:

89 - the warm West Spitsbergen Current on one side and the cool East Spitsbergen Current on the other cause a significant difference in sea
90 ice formation to the east from the archipelago as compared to the western side (also, this influences the pressure system);

91 - undercurrents and surface currents allow more efficient mixing of water transported from a long distance [1,5].

92 The ocean plays an important role in the circulation and removal of persistent organic pollutants. Less volatile and more hydrophobic organic
93 compounds (e.g. PAHs) can undergo sorption by microorganisms. In this way a fraction of pollutants is removed from the surface of water, but
94 harmful substances are not decomposed - they are collected in seabed sediment [1]. Moreover, the contaminated water masses and sea ice are
95 transferred far by surface currents and undercurrents [6]. It is a common opinion that oceans are media in which contaminants are diluted which
96 can decrease the concentration of xenobiotics to levels not exceeding the norms provided for particular elements of the environment - even as the
97 overall pollutant load does not change. Nevertheless, the distribution of pollutants is not homogeneous, due to the currents and the sedimentation



98 process of the suspension. What is more, the penetration of stable organic compounds into the food chain makes them spread over long distances
99 and cross the boundaries between ecosystems.

100 Contamination emitted from distant sources can have a negative impact on the environment even a few thousand kilometers away, that is
101 why for a long time the harmful effects of chemical compounds introduced into the environment were underestimated. The mere presence of
102 xenobiotics in the environment does not pose a threat but many of them have a strong tendency to bioaccumulation and biotransformation, and
103 they are characterized by a high probability of toxicity [5]. Due to the global migration of contaminants, especially persistent organic pollutants,
104 there is an accumulation of those compounds in higher latitudes. Consequently, the concentration of contaminants in some polar ecosystems is
105 comparable to that of regions with high anthropopressure (urbanized areas). The Arctic ecosystem is particularly vulnerable to the negative
106 impact of anthropogenic contaminants [7]. The vulnerability is in direct relationship with the simplicity of the structure of that ecosystem in
107 which there are only a few key species [8]. The state of the ecosystem is influenced by the following parameters:

- 108 • extreme climatic conditions: low temperatures, strong winds, a limited amount of solar radiation, and a short growing season (about 2,5
109 months) contribute to a low biodiversity. Scarcity of water and arid land (together with nutrient limitation) are the main causes of
110 unequal distribution of vegetation. On the western shore and in the middle of the land vegetation is more varied than in the east where ice
111 deserts prevail. The processes of regeneration of nature are slow so all anthropogenic changes persistently influence the quality of the
112 environment;
- 113 • decreased microbiological activity aggravates the slowing down of the nutrient circulation in nature (about 300 years for 95% of organic
114 matter). A large amount of nutrients is stored in the soil where they are unavailable for organisms. The process of slow degradation leads
115 to a deficit of key nutrients, both on the land surface and beneath the water surface.

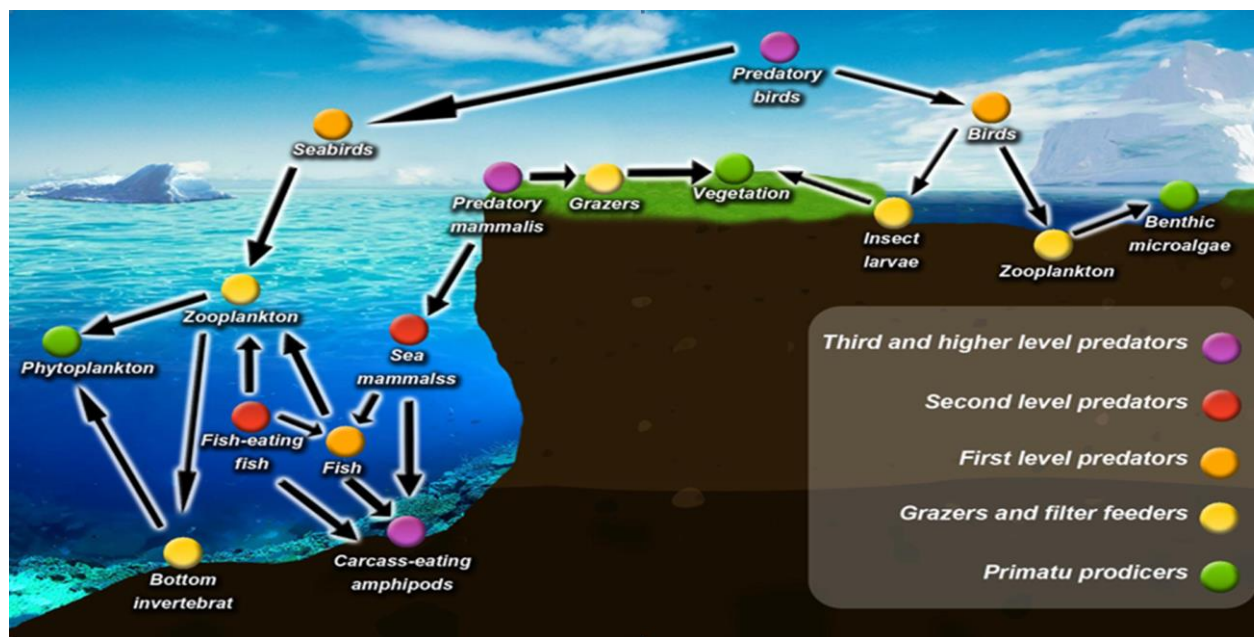
116 Additionally, cold air impedes biological processes. In such difficult conditions the only surviving organisms are those of simple structure,
117 capable of storing and recreating energy reserves in a short period of time, and with a low demand for solar energy. Still, the organisms develop
118 decidedly more slowly than in other climates [7].



119 In the Svalbard archipelago the green areas consist of low grasses, herbs, mosses, and lichens (vegetation characteristic of tundra). Nearly
120 40% of that region is covered with meadows. There are few species of trees present in some areas: polar willows and dwarf birches. Of the
121 animals, birds deserve special attention. Many birds migrate to the archipelago in summer. Sea species, such as Glaucous gulls, Kittiwakes and
122 fulmars, preponderate on the islands. The most common birds, though, are Little auks and Guillemots. Colonies of these birds have their
123 dwellings along the cliff shores. On the flat shores there live Common Eiders and Barnacle geese. Due to the low grass the main specimen of
124 land animals are the reindeer (a pasture animal); on bird colonies preys the arctic fox. Another significant group of animals are those living on
125 the boundary of the land and the sea. Those are seals, walruses, and polar bears which are also the greatest land predator in the archipelago [9].

126 The ability to collect and store energy is of vital importance for animals living in the Arctic as it enables survival in freezing winters without
127 light; yet the way the animals gain food makes them vulnerable as well. The food rich in fats is the basic element of diet and the main source of
128 energy for organisms living in polar regions. On the one hand, lipids condition the survival of many species of animals, on the other hand,
129 though, they pose a threat [5]. Stable organic contaminants (occurring both in the water and the land environment in Svalbard) frequently have a
130 tendency to accumulate in adipose tissue. The level of contaminants depends on the processes occurring in organisms: bioaccumulation and
131 biomagnification. As harmful substances move to subsequent trophic levels, the concentration of the toxic substances in organisms on higher
132 levels in the food chain grows. The high content of harmful substances can impact negatively both on an animal and a human organism, despite
133 the low concentrations of those compounds in the environment. Biomagnification causes the spread of contaminants in the entire food chain,
134 endangering the highest-placed organisms the most. Figure no. 1 shows the scheme of the food chain characteristic for the area of the Arctic
135 tundra and of the sea ecosystem of the Svalbard archipelago.





136

137 **Figure 1.** The food chain of the polar ecosystem [7].

138 The introduction of contaminants contributing to the degradation of the environment disturbs the mechanism of homeostasis of polluted
 139 ecosystems. That, in turn, can lead to toxic effects among organisms and even to a collapse of ecological balance. Chemical exposure to various
 140 xenobiotics, even in low concentrations, can seriously affect health and functioning of organisms, especially when the exposure:

- 141
- occurs at a critical stage of development (fetal, newborn). The young offspring of polar mammals (the polar bear, the ringed seal) is at
 142 especial risk of exposure to toxic substances because they feed on mother's milk rich in fat and lipophilic contaminants.
 - is long-lasting. Many Arctic organisms are characterized by great longevity (whale, the Little Auk) and are exposed to pollutants for
 143 many years, so their tissues and organs are highly contaminated.
- 144

145 Table 1 presents data from literature about the influence of various groups of contaminants on living organisms in the Svalbard region.

146 **Table 1.** Types of contaminants and their negative influence on living organisms in the Svalbard region [1, 4, 10, 11, 12, 13]

| Contaminants | Species | Observed biological changes |
|--|---|---|
| OHCs (including PCBs) | Arctic char (<i>Salvelinus alpinus</i>) | - changes in the liver; - impact on the immune system; - disturbances of the adaptation to changes in salinity; |
| OHCs | Ivory gull (<i>Pagophila eburnea</i>) | - disturbances of the vitamin metabolism; |
| PCBs | Arctic fox (<i>Vulpes lagopus</i>) | - impairment of reproductive functions; - impact on the vitamin metabolism; - - weakening of bones; |
| PCBs | Arctic Tern (<i>Sterna paradisaea</i>) | - decreased reproductive success; |
| PCBs, PCNs, PBDEs, HBCDs | Glaucous Gull (<i>Larus hyperboreus</i>) | - impairment of reproductive functions; - decreased survival rate of adult gulls; - impact on hormone production; - increased number of dead eggs; - impact on the size and composition (the amount of proteins and fats) of the eggs; - decreased immunity; |
| Numerous OCPs (PCBs, PBDEs, HBCD, DDTs, HCHs and others) | Polar bear (<i>Thalarctos maritimus</i>) | - impairment of reproductive functions; - impact on hormone production and decreased reproductive health; - decreased production of antibodies; - - kidney deformations; - weakening of teeth (<i>periodontosis</i>); |
| PCBs, PBDEs, HBCD, HCHs | Ringed seal (<i>Pusa hispida</i>) | - impairment of reproductive functions; |
| PBDEs | Beluga whale (<i>Delphinapterus leucas</i>) | - increased incidence of digestive system cancers; - decreased immunity. |

147

148 Large amounts of stable compounds are stored in snow and ice, constituting a potential source of toxic emission into the environment.

149 Chemical substances, including the compounds the production of which has been stopped, are "trapped" in the permafrost, snow, and ice and are

150 gradually released into the environment. As a result, living organisms are continuously exposed to them [14].



151

152 **3. The history of analytical studies conducted in the Arctic region**

153 The problem of the transport of pollutants and their impact on the Arctic environment is not new. Table 2 presents the most important
154 events related to the analytical studies of samples collected in the region.

155 **Table 2.** Milestones in the field of analytical studies of samples collected in Arctic region

| Action/ year | Description |
|---|--|
| The first signals about the influence of chemical compounds on the state of the environment in the polar region / 1883. | <ul style="list-style-type: none">• The first signals about the influence of chemical compounds on the state of the environment in the polar region are given by geologist Adolf Erik Nordenskiöld. During one of his expeditions he noticed a thin layer (0,1-1 mm) of gray dust over the surface of ice in Greenland. The traveler was not conscious of the fact that the powder which he called "cosmic" could be partly anthropogenic;• The results of the studies of ice cores from Greenland prove that anthropogenic compounds are present in the analyzed material and their emission is dated back to late 1800s . The effect of the industrial revolution in the late 18th and early 19th centuries was the emission of huge pollutant loads into the environment [15]. |
| The first report about the contamination of the Arctic region (Mitchell) / 1957. | <ul style="list-style-type: none">• The report described the phenomenon of the Arctic haze which was first observed by pilots flying over the Arctic;• The aerosols in a layer of the haze, when the sky is cloudless and humidity is low, can reduce visibility by up to ten times. The Arctic haze consists mainly of aerosols described as secondary. They are created in the photochemical processes of gas contaminants in the atmosphere [16]. |
| The first evidence of the presence of organic contaminants in elevated ecosystems / 1970s | <ul style="list-style-type: none">• The report proves the presence of organic contaminants in polar ecosystems;• However, complex studies were only conducted around 1990, when the studies of the process of POP transportation in high mountain regions began [4]. |

156

157 Still, the growth of consciousness and knowledge about the presence of anthropopressure in areas far from significant sources of pollution
 158 has contributed to the increase, over the last few years, of scientists' and politicians' interest in the problems of polar regions. The results of the
 159 studies of the state and quality of the Arctic environment catalyzed changes in politics and international law. Governmental bodies of many
 160 countries as well as groups of experts of numerous organizations and associations have undertaken various actions, including:

- 161 • the introduction of a ban on or limit of the emission into the environment of compounds posing a threat for the environment (so-
 162 called priority pollutants);
- 163 • monitoring the process of introducing new xenobiotics by industrial companies;
- 164 • monitoring the quality of various elements of the environment for the purpose of identification of sources of pollution,
 165 determining the location of strongly contaminated places, and defining unknown/new xenobiotics;
- 166 • beginning the process of cleaning (remediation) strongly contaminated places.

167
 168 Table 3 presents the information about the most important memorandums and international agreements, within the framework of which
 169 studies are conducted to aid the protection of the Arctic.

170 **Table 3.** The most important memorandums and international agreements concerning the protection of the Arctic region

| Program/international agreement | Subject |
|--|---|
| Stockholm Convention on Persistent Organic Pollutants | A Convention concerning persistent organic pollutants from 2001 |
| LRTAP | A convention concerning long-range transboundary air pollution transmitted across long distances |
| UNEP | A global program of actions on behalf of the protection of maritime environment against activities on land |
| The Vienna Convention from 1885 | The Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete Ozone Layer |
| The London Convention on the prevention of pollutants | Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter |

| | |
|-------------------------------|---|
| The Climate Change Convention | A United Nations Framework Convention on Climate Change, adopted at a conference in Rio in 1992 |
| OSPAR | Convention for the Protection of the Marine Environment of the North-East Atlantic, from 1992 |
| MARPOL73/78 | The International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978 |

171

172 Table 4 shows the information about the main organizations currently interested in conducting scientific research in the Arctic region.

173 **Table 4.** The main organizations conducting scientific research in the Arctic region

| Organization | Establishment date |
|--|--------------------|
| The Arctic Ocean Sciences Board (AOSB) | 1984 |
| The International Arctic Science Committee (IASC) | 1990 |
| The Arctic Monitoring and Assessment Programme (AMAP) | 1991 |
| The European Polar Board (EPB) | 1995 |
| Svalbard Science Forum (SSF) | 1997 |
| Forum of Arctic Research Operators (FARO) | 1998 |
| The University Arctic (UArctic) | 2001 |
| Circumarctic Environmental Observatories Network (CEON) | 2002 |
| Circumpolar Biodiversity Monitoring Program (CBMP) | 2004 |
| Arctic Regional Ocean Observing System (Arctic ROOS) | 2006 |
| Sustained Arctic Observing Network (SAON) | 2007 |
| The European Multidisciplinary Seafloor Observatory (EMSO) | 2008 |

174

175 What is more, in the Arctic region many stations for specific purposes and research centers have been created by a number of countries. Stations
176 for specific purposes play an important role in the protection of the Arctic, because they provide resources for research, enabling continuous
177 measurements which give a reliable image of the state of the environment.

178 For many years the Svalbard archipelago has been drawing research organizations from the whole world. The complex infrastructure
179 forms the basis for research and scientific studies. In comparison with the rest of the Arctic, the Svalbard archipelago has the largest number of
180 stations and research units. Table 5 collates basic information about the stations and research units situated in the Svalbard archipelago.



181 **Table 5.** Research units situated in the Svalbard archipelago.

| Region | Research unit | Country |
|--|--|--------------------|
| Ny-Alesund | Himadri Station | India |
| | AWIPEV Arctic Research Base | Germany, France |
| | Harlandhuset | The United Kingdom |
| | Netherlands Arctic Station | The Netherlands |
| | Dirigibile Italia | Italy |
| | Rabben Station | Japan |
| | Yellow River Station | China |
| | DASAN Station | Korea |
| | Zeppelin mountain station | Sweden, Norway |
| | Sverdrup Station | Norway |
| | SvalRak | |
| | The Kings Bay Marine Laboratory | |
| Space Geodetic Observatory | | |
| Svea | Meteorological station | Norway |
| Hopen | Norwegian Meteorologisk Institutt | |
| Bjornoya | Herwighamna is a meteorological station | |
| Longyearbyen | The University Centre in Svalbard | Norway |
| | Norwegian Polar Institute | |
| | SvalSat, Kongsberg Satellite Services | |
| | Stiftelsen for industriell og teknisk forskning | |
| | Nansen Environmental and Remote Sensing Center | |
| | Storage facilities for cultural historical objects | |
| | Svalbardporten | |
| | KHL in Longyearbyen | |
| European Incoherent SCATter Scientific Association | Sweden | |

| | | |
|------------------------|---|--------------------|
| | National Institute of Polar Research | Japan |
| Barentsburg | Archaeological Institute in Moscow | Russia |
| | Kola Science Centre | |
| | Institute of Geography | |
| | Arctic and Antarctic Research Institute | |
| | Polar Marine Geological Research Expedition | |
| | The Murmansk branch of the Russian State Committee for Hydrometeorology | |
| Hornsund | the Institute of Geophysics, Polish Academy of Sciences, Polar Station (named after Stanisław Siedlecki, at Isbjørnhamna) | Poland |
| Kaffiøyra | Nicolaus Copernicus University, Polar Station | |
| Bellsund (Calypsobyen) | Maria Curie-Skłodowska University in Lublin (seasonal) | |
| Petuniabukta | Adam Mickiewicz University in Poznań (seasonal) | |
| Palffyodden | Jagiellonian University (seasonal) | |
| Werenhus | University of Wrocław | |
| Pyramiden | The Czech Republic camp | The Czech Republic |

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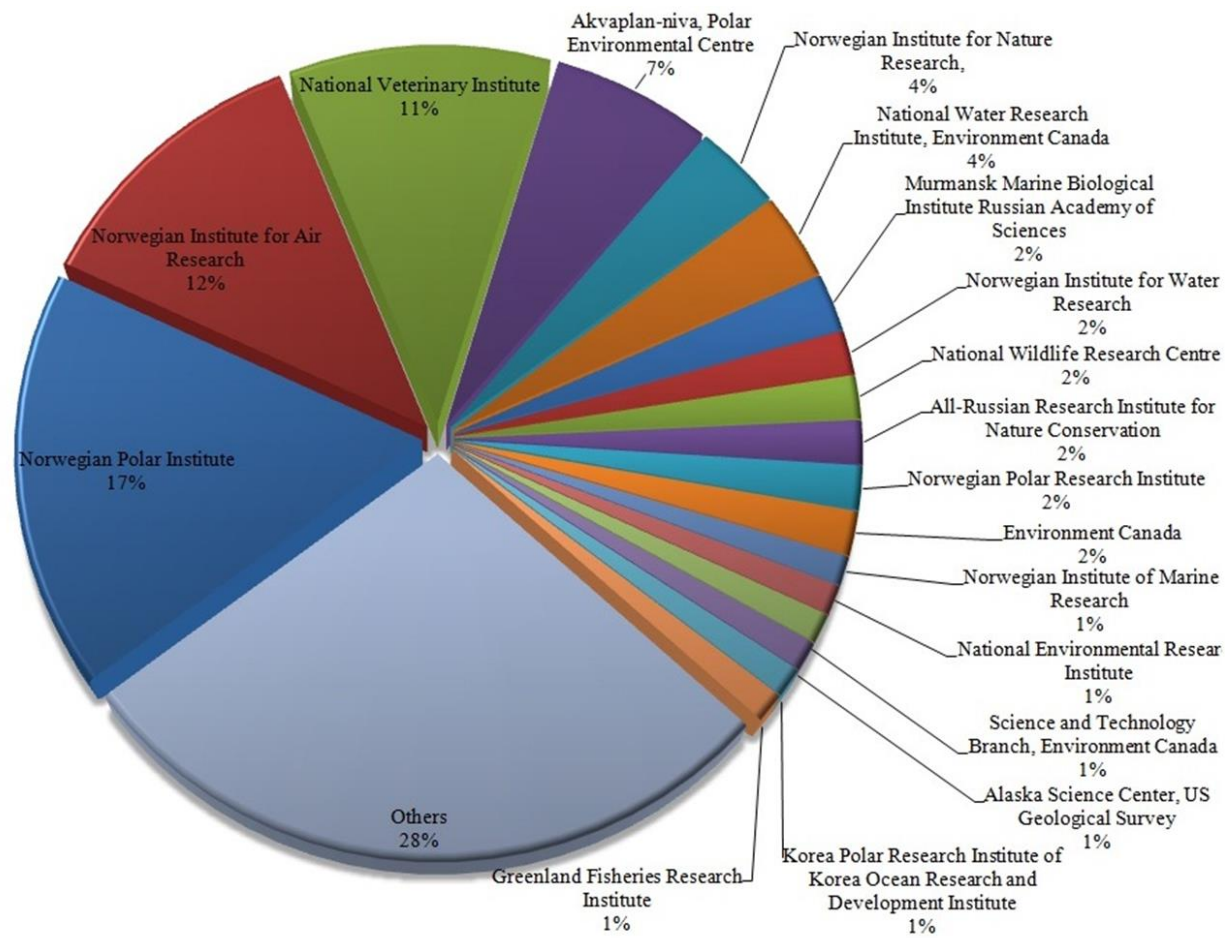
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The great interest in the polar area is evidenced by the number of research units engaged in research in the Arctic, as well as the number of articles published about the region. The need to gain as much information as possible about the area results from its importance for the state of the global environment. That is why every day scientists from all over the world conduct research on: archeology, biology and ecology, geology, geophysics, meteorology, seismology, and chemistry, providing a source of knowledge about the state of the environment of the polar region.

The credibility of the obtained data can be confirmed by preserving the continuity of measurements. Only long-term monitoring of the environment makes it possible to verify environmental changes. Moreover, monitoring the state of the environment, together with studies of sediment and ice cores are the necessary tool for identifying the sources of emission of pollution. The results of the studies of the measurements

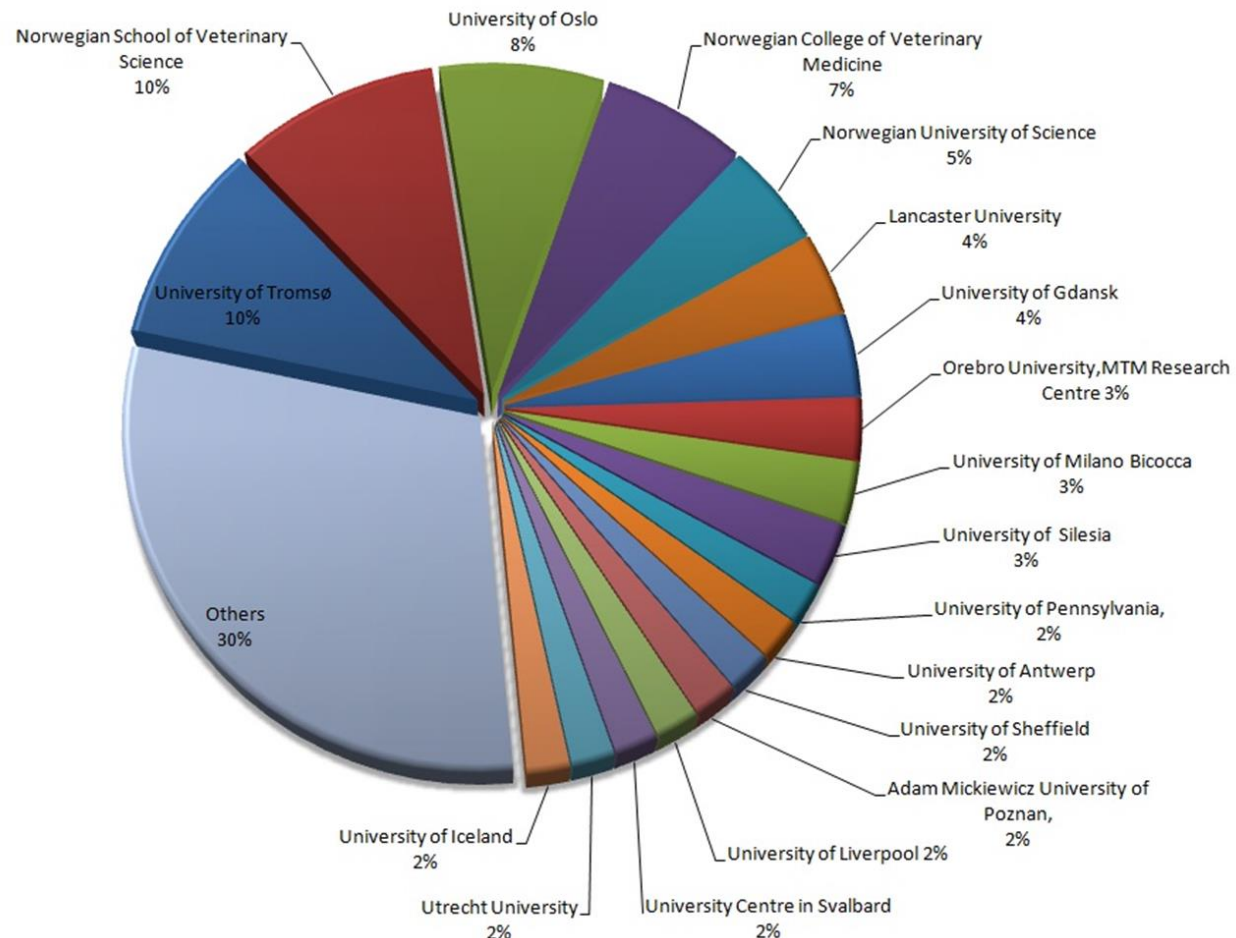
190 of chemical factor concentrations in living animals can form a documented basis for undertaking preventive actions against further expansion of
191 particular pollutants.

192 Research units situated in the Svalbard archipelago are organized and financed by multiple national and international institutions.
193 Studying environmental changes is time-consuming and tedious, and the conclusions from the obtained results can only be drawn after the
194 measurement cycles have been conducted for many years. Cooperation of the institutions is thus crucial. Data obtained in that way enable a
195 thorough analysis and interpretation of the results. The engagement of particular institutions in the development of studies in the polar region has
196 been pictured in Figures 2 to 4. The evaluation was made on the basis of selected scientific publications, directly related to the research
197 conducted in the Svalbard archipelago. The parameter for the evaluation was the number of publications prepared by the given country or
198 institution. The obtained data are of explanatory nature, yet they form the basis for evaluating the engagement of particular countries and research
199 units in the development of research on the polar region. Articles used for the creation of the figures are included in table 7a and b.

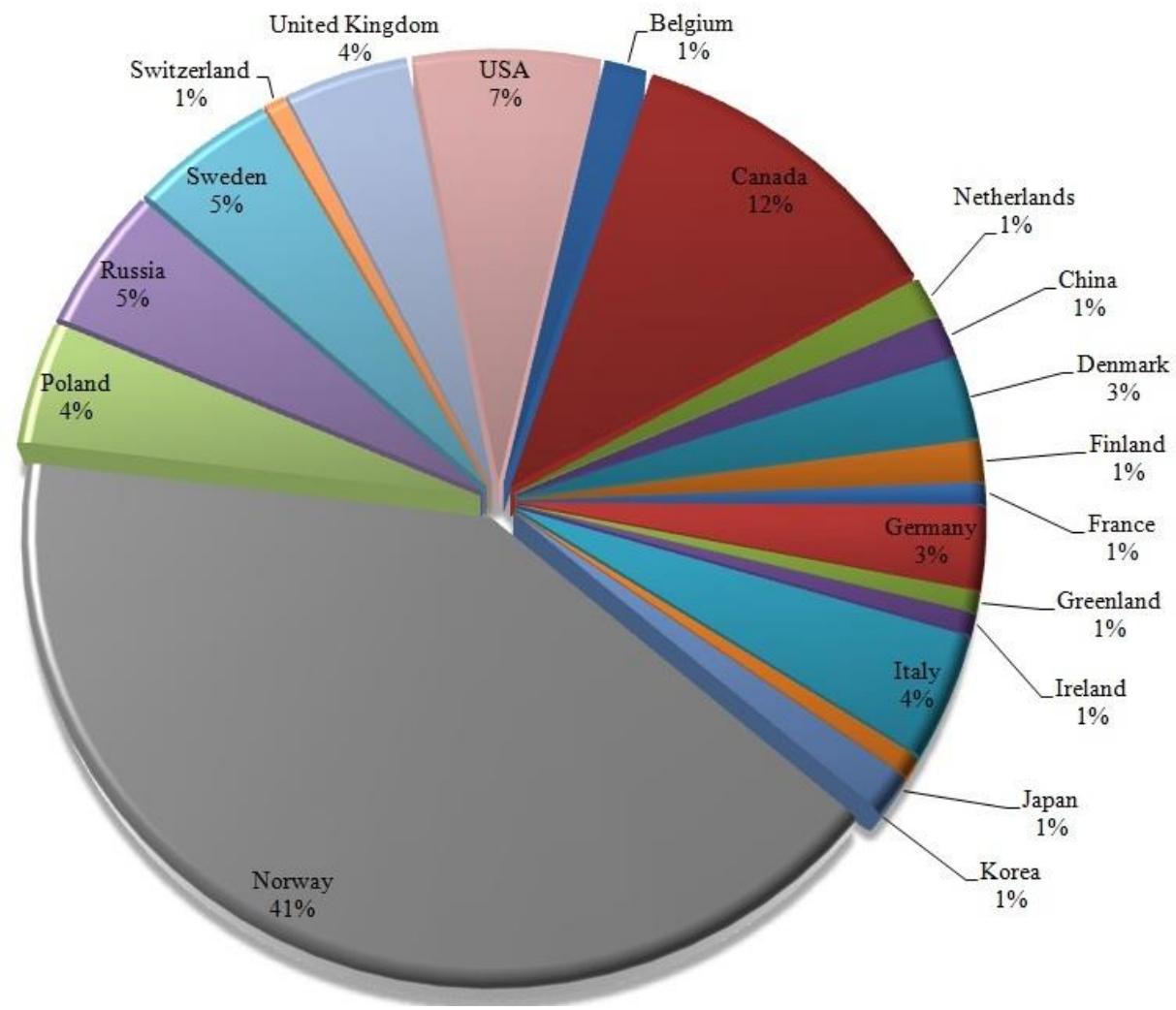


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201 **Figure 2** The participation of higher education institutions in studies on the chemistry of the environmental samples collected in Svalbard.



202
203 **Figure 3.** The participation of research units in studies on the chemistry of the environmental samples collected in Svalbard.



204

205 **Figure 4.** The participation of particular countries in studies on the chemistry of the environmental samples collected in Svalbard (based on the
 206 number of published articles).

207

208 Research groups from the institutions mentioned above have long experience in conducting studies in the Arctic and are recognized
209 internationally. They frequently fulfill the role of consultants on the protection and monitoring of polar ecosystems.

210 Especially remarkable are Poland, Japan, China, and India, which are active participants in the studies in spite of their great geographic
211 distance from the Arctic. The activity of those countries manifests the range of the problem of Arctic region contamination and its importance on
212 a global scale.

213

214 **4. The concentrations of various pollutants present in the environmental samples collected in the Svalbard archipelago**

215

216 Although Svalbard is situated in high latitudes, i.e. far from the potential sources of emission of pollutants, it is still influenced by the
217 human activities. Continental, regional, and also local sources of pollutant emissions threaten the fragile balance of the Arctic ecosystem [1]. For
218 many decades anthropogenic toxic compounds have been penetrating the Svalbard environment. The main manifestations of anthropopressure in
219 the Arctic are: maritime transportation (ship traffic), bituminous coal mining, landfills, storage of dangerous substances, and the extraction of oil
220 and natural gas [2].

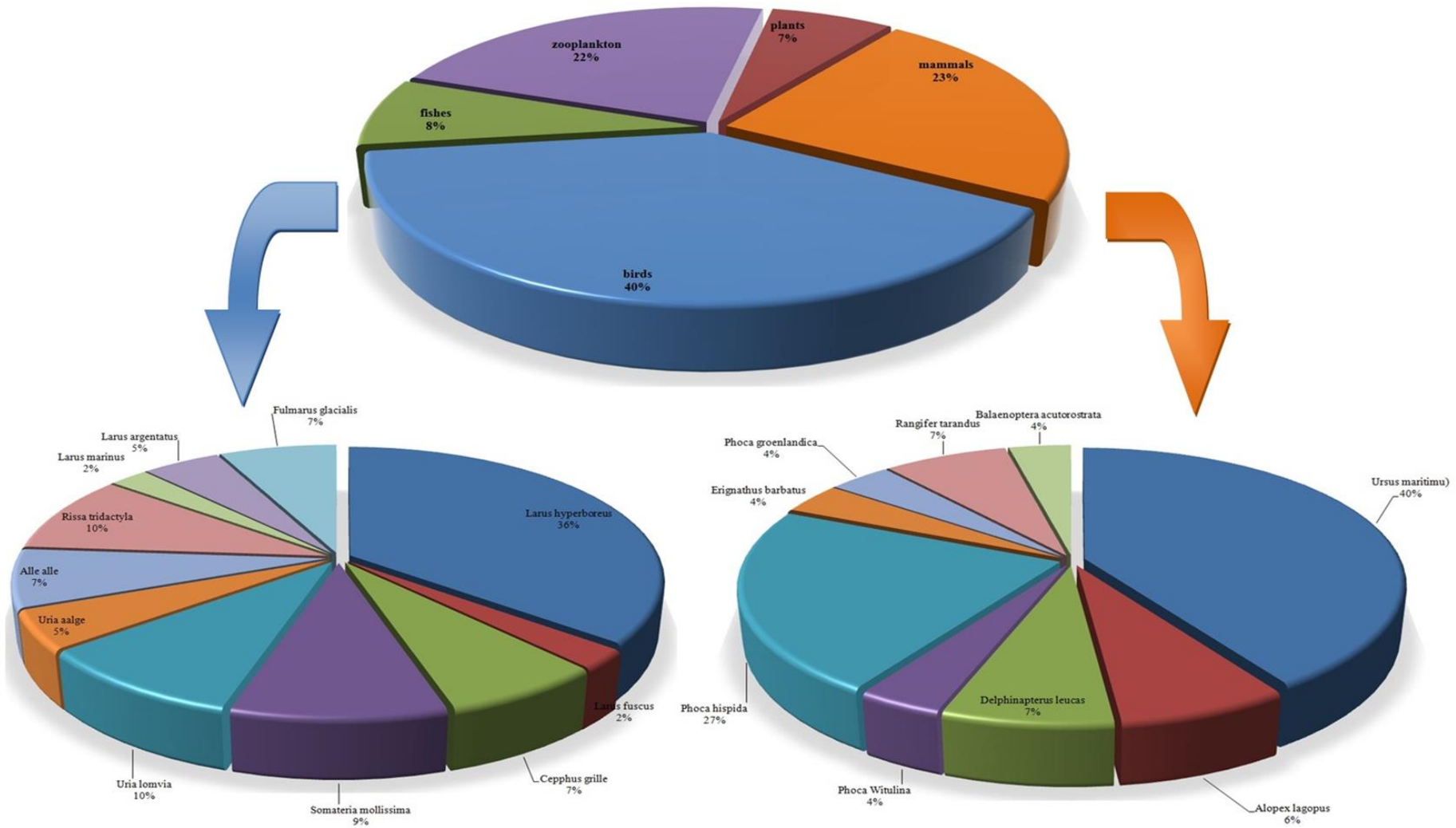
221 As human activity grows so does the threat of pollution of the Arctic environment. The potentially most harmful source of emissions is the
222 production and transportation of crude oil. Another serious danger are pollutants from petrochemical oils used in such industries as tourism or
223 fishing.

224 To be able to evaluate the state of the environment in an area it is necessary to conduct analytical studies of a variety of samples
225 representative of a given ecosystem in which particular pollutants are to be discovered and measured. In that process it is important to mark not
226 only the total amount of a chemical element, e.g. a heavy metal, but also the physical and chemical forms of that element. Such measurements are
227 necessary to appraise the actual threat both to the inanimate environment and biota. Apart from that, the registration of changes in the polar
228 environment not only enables to study dynamics of the ecosystem but can aid forecasting the state of the region.



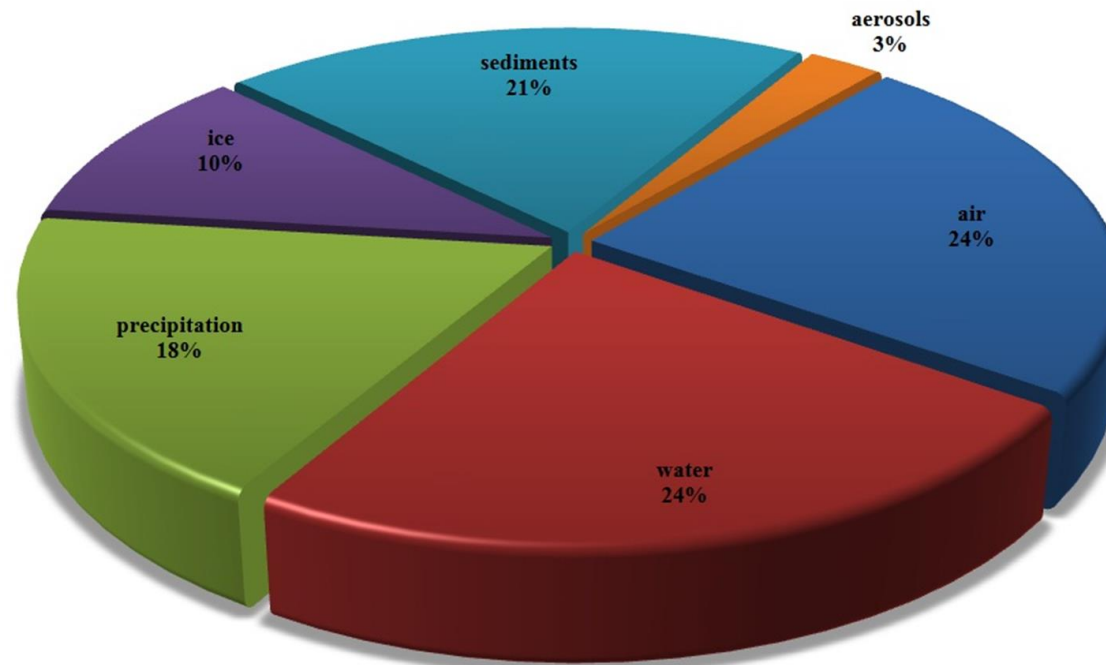
229 On the basis of a literature query on the range and results of the chemical studies of environmental samples collected in Svalbard, a
230 detailed analysis of the pollutant concentrations was made, both in the living organisms and in the inanimate matter. Figures 5 and 6 present the
231 share of particular sample types in the overall research on inanimate environment and biota in the Svalbard region. The evaluation was based on
232 selected scientific articles, which are included in table 7a and b. The most frequent subject of studies is biota samples, where the most frequently
233 analysed sample types were: adipose tissue, eggs, kidneys and livers. A specific element of the inanimate environment from which the samples
234 were taken was water (surface and deep water from the sea, rivers, and lakes). The reason for such a selection of samples was possibly their
235 general availability and simplicity of preparation for an analysis, but foremost they are the crucial supply for living organisms.

236



237

238 **Figure 5.** A schematic breakdown of the types of samples of biological material as a source of information about the state of the environment in
 239 the Svalbard archipelago.



240

241 **Figure 6.** A schematic breakdown of the types of samples of inanimate material as a source of information about the state of the environment in
 242 the Svalbard archipelago

243

244 In tables 6a and 6b there is presented an overview of the techniques used for the final determination of a wide range of analytes studied in
 245 the biotic and abiotic samples collected in the Svalbard Archipelago region. Based on our review, It is possible to state that gas chromatography is
 246 the most often used analytical method. Relatively wide opportunities are given due to application of selective detectors. Application of the ECD
 247 enables determination of even very small amounts of chlorinated organic compounds in the mixture. Hypenation of gas chromatography with
 248 spectroscopic methods is now routinely used to perform quantitative analysis of very complex mixtures. GC is used not only for the separation of
 249 a mixture of compounds but also for the qualitative and quantitative analysis of a wide range of chemical compounds.

250 **Table 6a.** Literature information about the analytical techniques used in the final determination of a wide range of compounds of the samples of
 251 biota collected in the Svalbard archipelago

| Type of biological sample | Determined compounds/compound groups | Analytical Method | Literature |
|---|--|-------------------|--------------------|
| Mammals | | | |
| Polar bears (<i>Ursus maritimus</i>) | PCB, CHL | HRGC-LRMS-ECNI | [1] |
| | | HRGC-ECD | [1],[18],[19],[20] |
| | | GC-MS-EI | [24] |
| | DDT | HRGC-LRMS-ECNI | [1] |
| | | GC-ECD | [26] |
| | | HRGC-ECD | [18],[20] |
| | | GC-MS-EI | [24] |
| | DIEL | GC-MS-EI | [24] |
| | Nonachlor(trans, cis), Oxy | HRGC-LRMS-ECNI | [4] |
| | | GC-ECD | [26] |
| | Hept | HRGC-LRMS-ECNI | [4] |
| | HCH | HRGC-LRMS-ECNI | [4] |
| GC-ECD | | [26] | |
| HRGC-ECD | | [20] | |
| HCB | GC-ECD | [26] | |
| | HRGC-ECD | [18],[20] | |
| PCDD, PCDF | GC-HRMS | [17] | |
| HBCD, PBDE | GC-MS-NCI | [4] | |
| Hg | AAS | [42] | |
| Reindeer (<i>Rangifer tarandus</i>) | Metals (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni, Hg) | AAS | [40] |
| | PAH | GC-MS | [41] |
| Arctic foxes (<i>Alopex lagopus</i>) | PCB | GC-ECD | [24] |
| | | GC-MS-EI | [4] |
| | DDE, Chlordane(trans,cis), Nonachlor(trans,cis), Oxy, CHL, HCB | GC-MS-EI | [4] |
| | | PBDE | GC-MS-NCI |
| PCB | HRGC-ECD | [20],[21],[43] | |
| | HRGC-HRMS-EI | [22] | |



| | | | |
|---|--|-------------------|----------------|
| Ringed seal (<i>Phusa hispida</i>), Harp seal (<i>Phoca groenlandica</i>), Bearded seal (<i>Erignathus barbatus</i>), Harbor seals (<i>Phoca vitulina</i>) | | GC-HRMS-EI | [23] |
| | | GC-LRMS-EI | [23] |
| | | HRGC-MS-EI | [1] |
| | | HRGC-ECD | [20],[21],[43] |
| | DDT | GC-HRMS-EI | [23] |
| | | GC-LRMS-EI | [23] |
| | | GC-LR-MS-ECNI | [23] |
| | | HRGC-MS-EI | [1] |
| | Nonachlor (trans,cis), Oxy, Mirex | HRGC-ECD | [20],[21] |
| | CHL | HRGC-ECD | [20],[21] |
| | GC-HRMS-EI | [23] | |
| | GC-LRMS-EI | [23] | |
| HCH | HRGC-ECD | [20],[21] | |
| | HRGC-MS-EI | [1] | |
| HCB | HRGC-ECD | [20],[21] | |
| | GC-HRMS-EI | [23] | |
| | GC-LRMS-EI | [23] | |
| | HRGC-MS-EI | [1] | |
| HBCD, PBDE | GC-MS-NCI | [4] | |
| White whales (<i>Delphinapterus leucas</i>), Minke whale (<i>Balaenoptera acutorostrata</i>) | PCB, DDT, Chlordane (trans,cis), HCH, Nonachlor (trans,cis), Oxy | GC-MS-NCI | [36] |
| | | HRGC-ECD | [4],[37],[38] |
| | a-Endosulfan | HRGC-ECD | [37] |
| | Mirex | GC-MS-NCI | [36] |
| | | HRGC-ECD | [37] |
| | DIEL, Hept | HRGC-ECD | [4] |
| | CHL, HBCD, PBDE | GC-MS-NCI | [36] |
| HCB | GC-ECD | [36] | |
| | HRGC-ECD | [4],[37] | |
| Birds | | | |
| Glaucous gull (<i>Larus hyperboreus</i>, <i>Larus marinus</i>, <i>Larus argentatus</i>) | | HRGC-ECD | [29],[31],[32] |
| | | GC-ECD | [4],[13].[25] |
| | | GC-MS | [26],[27] |
| | PCB | GC-LRMS-EI | [30] |
| | | GC-LRMS-ECNI | [1] |
| | | GC-HRMS-EI | [1] |
| DDT | GC-ECD | [1] [4],[13].[25] | |
| | HRGC-ECD | [29],[32] | |



| | | | |
|--|---|----------------|-------------------|
| | | GC-LRMS-EI | [30] |
| | DIEL, (α,β)Endosulfan, Endrin, Methoxychlor | GC-ECD | [1],[13] |
| | Toxaphene | GC-ECD | [13] |
| | | GC-LRMS-NCI | [30] |
| | | GC-LRMS-ECNI | [1] |
| | Mirex, Chlordane (trans,cis), Nonachlor (trans,cis), Oxy | GC-LRMS-NCI | [30] |
| | | GC-ECD | [1],[4],[13] |
| | | HRGC-ECD | [32] |
| | Hept | GC-LRMS-NCI | [30] |
| | | GC-ECD | [1] |
| | CHL | HRGC-ECD | [29] |
| | | GC-ECD | [1] |
| | HCH | GC-ECD | [13] |
| | | HRGC-ECD | [28],[29],[32] |
| | HCB | GC-ECD | [1] [4],[13].[25] |
| | | HRGC-ECD | [28],[29],[32] |
| | | GC-LRMS-NCI | [30] |
| | HBCD | GC-MS-NCI | [4] |
| | | HRGC-ECD | [32] |
| | PBDE | GC-MS-NCI | [4] |
| | | GC-LRMS-NCI | [29] |
| | | GC-LRMS-ECNI | [1] |
| | | HRGC-ECD | [32] |
| | Metals (Cu.,Cd,Pb,Hg,Se,Zn,Mn,Fe,Ni,Cr,Co) | AAS | [1] |
| | Hg | AAA | [25] |
| | | HGAAS | [29] |
| | PFAS, PFCA | HPLC-MS/MS-ESI | [4] |
| Fulmar (<i>Fulmarus glacialis</i>) | Hg | AAA | [25] |
| | | AFA | [44] |
| | PCB, DDT, HCB | GC-ECD | [25] |
| | DIEL, MIREX, ENDRIN, Toxaphenes, Oxy, CHL, HCH, PFAS, PCDF, PCDD, Tribromoanisole, HBCD, PBDE | HRGC-LRMS-NICI | [44] |
| Brünnich's guillemot (<i>Uria lomvia</i>), Black guillemots (<i>Cepphus gryle</i>), | Hg | AAA | [25] |
| | | HGAAS | [29] |
| | PCB | GC-ECD | [13], [25] |
| | | GC-MS | [26] |
| | | HRGC-ECD | [29],[31] |

| | | | |
|---|-----------------------------|--------------------|--------------------|
| | DDT, HCB | GC-ECD HRGC-ECD | [13], [25] [29] |
| | DIEL, CHL, Oxy | GC-ECD | [13] |
| | HCH | GC-ECD HRGC-ECD | [13] [29] |
| Little auk (<i>Alle alle</i>) | PCB | GC-ECD HRGC-ECD | [25] [31] |
| | DDE, HCB | GC-ECD | [25] |
| | Hg | AAA | [25] |
| Eider (<i>Somateria mollissima</i>) | Hg | AAA HGAAS | [25] [29] |
| | PCB | GC-ECD | [25] |
| | | GC-MS | [27] |
| | | HRGC-ECD | [28],[29] |
| | DDT, HCB | GC-ECD HRGC-ECD | [25] [28],[29] |
| CHL, HCH | HRGC-ECD | [28],[29] | |
| Kittiwake (<i>Rissa tridactyla</i>) | Hg | HGAAS | [29] |
| | PCB, DDT, CHL, HCH, HCB | HRGC-ECD | [28],[29] |
| Fisches | | | |
| Polar cod (<i>Boreogadus saida</i>); Arctic charr (<i>Salvelinus alpinus</i>), Cod (<i>Gadus morhua</i>, <i>Boreogadus saida</i>), Capelin (<i>Mallotus villosus</i>) Long rough dab (<i>Hippoglossoides platessoides</i>), Herring (<i>Clupea harengus</i>) | PCB | HRGC-HRMS-NICI | [33] |
| | | GC-LRMS-NICI | [33] |
| | | GC-MS | [34] |
| | DDT | HRGC-HRMS-NICI | [33] |
| | | GC-LRMS-NICI | [33] |
| | | GC-MS-ENCI | [35] |
| | a-endosulfan, Oxy, CHL, HCH | HRGC-HRMS-NICI | [33] |
| | Hept | HRGC-HRMS-NICI | [33] |
| | | GC-MS | [34] |
| | CHB | GC-LRMS-NICI | [33] |
| | | GC-MS | [34] |
| HCB | GC-MS | [34] | |
| HBCD | GC-MS-NCI | [4] | |
| PBDE | GC-MS-NCI | [4] | |
| | GC-LRMS-NICI | [33] | |



| | | | |
|---|--|----------------|------|
| | PCN | GC-LRMS-NICI | [33] |
| Arthropod, Mollusca | | | |
| Tadpole shrimps (<i>Lepidurus arcticus</i>), Bivalve (<i>Mya truncata, Serripes groenlandicus, Hiatella arctica, Chlamys islandica</i>) | PCB | GC-LRMS-NICI | [33] |
| | | GC-MS-NICI | [39] |
| | DDT, CHB | GC-LRMS-NICI | [33] |
| | Chlordane(trans,cis), Nonachlor(trans,cis), Oxy, Hept, CHL, HCH, HCB | GC-MS-NICI | [39] |
| Echinodermata | | | |
| Sea urchins (<i>Strongylocentrotus droebachiensis, Strongylocentrotus pallidus</i>) | Metals (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni,As) | ICP-MS | [38] |
| Zooplankton | | | |
| Calanoid copepods, <i>Thysanoessa inermis, Themisto libellula, Gammarus wilkitzkii, Cyclops abyssorum, Daphnia umblae, Calanus finmarchicus, Calanus glacialis, Calanus hyperboreus, Krill, Themisto abyssorum, Themisto libellula, Chaetognatha</i> | PCB, DDT | GC-LRMS-NICI | [33] |
| | | HRGC-HRMS-NICI | [33] |
| | | GC-MS-ENCI | [34] |
| | DIEL, a-endosulfan | HRGC-HRMS-NICI | [33] |
| | Chlordane(trans,cis), HCH, HCB | GC-MS-ENCI | [34] |
| | Nonachlor(trans,cis), Oxy | HRGC-HRMS-NICI | [33] |
| | | GC-MS-ENCI | [34] |
| | CHB | GC-LRMS-NICI | [33] |
| | PBDE | GC-MS-NICI | [4] |
| Insect | | | |
| Chironomid larvae (<i>Chironomidae</i>) | PCB, DDT, PBDE, PCN | GC-LRMS-NICI | [33] |
| Plants | | | |
| Laminarian kelps (<i>Laminaria saccharina, L. digitata, Alaria esculenta</i>), Filamentous algae (<i>Conjugatophyceae - Zygnema sp.</i>), Lichen (<i>Cetraria nioalis</i>), Moss (<i>Tamenfhyppnum nitens, Rhacomifriurn lanuginosum</i>), Vascular plant (<i>Cassiope tetragona</i>), | Metals (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni,As, Hg) | AAS | [40] |
| | PAH | GC-MS | [41] |



253 **Table 6b.** Literature information about the analytical techniques used in the final determination of a wide range of compounds of the inanimate
 254 material collected in the Svalbard archipelago

| Type of biological sample | Determined compounds/compound groups | Analytical Method | Literature |
|---------------------------|--------------------------------------|-------------------|------------|
| Air | PAHs | HRGC-MS | [1] |
| | | GC-MS-EI | [33] |
| | PCB | HRGC-MS | [1] |
| | | HRGC-HRMS-EI | [1] |
| | Heptachlor, Oxy, CHL | GC-HRMS | [55],[57] |
| | | GC-MRMS | [57] |
| | Chlordane(trans,cis) | GC-MS-EI | [33] |
| | | HRGC-MS | [1] |
| | | HRGC-LRMS-NICI | [1] |
| | Nonachlor(trans,cis) | GC-HRMS | [57] |
| | | HRGC-MS | [1] |
| | DDT, HCH | HRGC-LRMS-NICI | [1] |
| | | GC-HRMS | [57] |
| | | GC-MS-EI | [33],[60] |
| GC-MS-NICI | | [60] | |
| HCB | HRGC-MS | [1], [56] | |
| | HRGC-HRMS-EI | [1] | |
| | GC-HRMS | [57] | |
| | GC-MS-EI | [33],[60] | |
| Metals (Ni,Hg,Pb,Cd,Cu) | GC-MS-NICI | [60] | |
| | HRGC-MS | [1] | |
| | GC-HRMS | [57] | |
| n-Alkanes (17-29) | ICP-MS | [60] | |
| n-Alkanoic acids (14-28) | HRGC-FID | [1] | |
| PCN | HRGC-MS | [1] | |
| PAHs, n-Alkanes | HRGC-LRMS | [33] | |
| | GC-MS | [1] | |



| | | | |
|--|---|--|-----------------------------|
| Rainfall | Anions (Cl^- , NO_3^- , SO_4^{2-} , HCO_3^-), Cations (Ca^{2+} , K^+ , Mg^{2+} , Na^+ , NH_4^+) | IC | [1],[61] |
| Snow | PCB | GC-HRMS-EI GC-MS | [49] [59] |
| | DDT, HCH, HCB, PAHs, DDT, Chlordane(trans,cis), Nonachlor(trans,cis), HCH, HCB, PAH | GC-MS | [1],[41],[59],[62] |
| | Anions (Cl^- , NO_3^- , SO_4^{2-}), Cations (Ca^{2+} , K^+ , Mg^{2+} , Na^+) | IC | [53], [58] |
| | Hg | CVAFS | [52] |
| | PCN | HRGC-LRMS | [33] |
| Seawater, groundwater, surface water (streams, river, lake, spring) | PCB | GC-HRMS-EI GC-MS | [49] [1] |
| | Metals (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni) | ICP-MS AAS | [38] [40] |
| | Anions (SO_4^{2-} , HCO_3^- , PO_4^{2-}), Cations (Ca^{2+} , K^+ , Mg^{2+} , Na^+) | IC AAS | [53] [1] |
| | PCB | GC-MS-EI GC-HRMS-EI | [33] [49] |
| Glacier ice, ice core, ice | DDT, Endrin-ketone, Endosulfan sulfate | GC-ECD GC-MS-ECNI | [54] [54] |
| | HCH | GC-MS-EI GC-LRMS-EI GC-ECD GC-MS-ECNI | [33] [1] [54] [54] |
| | HCB | GC-MS-EI | [33] |
| | chlordane (cis, trans) | GC-MS-EI GC-ECD GC-MS-ECNI | [33] [54] [54] |
| | Aldrin, Dieldrin, α -Endosulfan(α,β), Endrin-aldehyde, Heptachlor, Heptachlor-epoxide, Chlorpyrifos, Dacthal, Diazinon, Dimethoate, Disulfoton, Imidan, Terbufos, Alachlor, Desethyl-atrazine, Pendimethalin, Methoxychlor, Ethion, Fenitrothion, Fonofos, Guthion, Methyl-Parathion, Hexazinone, Metolachlor, Flutriafol | GC-LRMS-EI GC-ECD GC-MS-ECNI | [1] [54] [54] |
| | Trifluralin | GC-ECD GC-MS-ECNI | [54] [54] |
| | Metals (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni) | AAS | [40] |
| | Anions (SO_4^{2-} , HCO_3^- , PO_4^{2-} , NO_3^-), Cations (Ca^{2+} , K^+ , Mg^{2+} , Na^+ , Ni^+) | IC | [53] |



| | | | |
|-----------------|---|----------------------------|---|
| Sediment | PCB | GC-MS GC-ECD GC-HRMS | [1],[48],[62] [47],[51] [51],[63] |
| | DDT, HCH, PBDE | GC-MS | [1],[41] |
| | HBCD | GC-TOF-ESI | [1] |
| | PAH | GC-ECD GC-MS | [47] [48],[50],[62] |
| | Metals (Cd,Zn,Cu,Pb,Cr,Co,Ni,As,Hg,Sb,Sc,Ti,V) | ICP-AES ICP-QMS | [1],[53] [1] |
| | Anions (SO ₄ ²⁻ ,HCO ₃ ⁻ ,PO ₄ ²⁻), Cations (Ca ²⁺ ,K ⁺ ,Mg ²⁺ ,Na ⁺) | IC | [53] |

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Table 7a and 7b collates literature information about the results of the studies of environmental samples collected in the Svalbard archipelago. In the samples of biota the concentrations of particular xenobiotics are set at different levels although one can notice tendency of elevated concentration levels in predators at higher trophic levels (glaucous gull fulmar, polar bears, arctic foxes, ringed seal, harp seal, bearded seal, harbor seals). The observed tendency may be combined with bioaccumulation and biomagnification of pollutants that take place in organisms inhabiting the Arctic ecosystems. On the other hand while analyzing content of xenobiotics in the samples taken from abiotic parts of the Arctic ecosystem the highest levels were noted in the samples of ice (glacier ice, ice core) and water. High concentration level of pollutants in the water and ice samples may result from wet and dry deposition at the ice surface (ice is kind of sink for pollutants) and the ablation process. In the short period of time (the ablation process) large loads of pollutants are released directly to the ecosystems exposed to their action (systems of water bodies of permanent or ephemerid character), it is combined with rising of the strong environmental stress. The most often determined xenobiotics were chemicals belonging to the POPs

Table 7a. Literature information about the results of the studies of the samples of biota collected in the Svalbard archipelago

| Type of biological sample | Determined compounds/compound groups | Identified content/ scope | Literature |
|---------------------------|--------------------------------------|---------------------------|------------|
| Mammals | | | |

| | | ng/g lipid weight | ng/g wet weight | |
|---|---|-------------------|-----------------|-------------------------|
| Polar bears (<i>Ursus maritimus</i>) | PCB 28 -209 | 1-27900 | 0.1-13.5 | [4],[18],[19],[20] |
| | $\Sigma(6-16)$ PCB | 2154-80300 | 17.6-67.7 | [4],[18],[20] |
| | DDT(p,p'), DDE(p,p'), DDD(p,p') | 2-1820 | 0.1-1.7 | [4],[18],[20],[24],[26] |
| | $\Sigma(2-6)$ DDT | 58-1490 | 2.2-2.8 | [4],[20] |
| | DIEL | 119-601 | - | [24] |
| | Nonachlor(trans) | 31-188 | 0.2-0.4 | [4],[26] |
| | Oxy | 298-3952 | 1.3-4.6 | [4],[26] |
| | Hept | - | 0.1 | [4] |
| | $\Sigma(6-11)$ CHL | 1.713-8310 | 1.8-5.2 | [4],[18],[20],[24] |
| | HCH(α,γ,β) | 17-514 | 0.1-2.0 | [4],[26] |
| | Σ HCH | 212-1150 | 1.3-2.9 | [4],[20] |
| | HCB | 30-947 | - | [18],[20],[26] |
| | PCDD | 1.1-42 | - | [17] |
| | PCDF | 0.15-1.6 | - | [17] |
| | BDE 28-209 | 0.02-0.31.73 | 0.01-8.79 | [4] |
| | HBCD | 5.31-16.51 | 0.03-0.85 | [4] |
| | $\Sigma(8)$ PBDE | 20.74-44.55 | 2.65-9.72 | [4] |
| Hg | 1.02-14.19 [$\mu\text{g/g d. w.}$] | - | [42] | |
| <hr/> | | | | |
| Reindeer (<i>Rangifer tarandus</i>) | | ng/g dry weight | ng/g wet weight | |
| | Metal (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni) | - | 240-641000 | [40] |
| | Hg | - | 302 | [40] |
| | PAH(Nap,Pyr,BaP,Ace,Acp,Fl,Phe,An,Flu,BaA,Chr,BbF,BkF,BghiP,,DbA,InP) | 0.1-148 | - | [41] |
| $\Sigma(16)$ PAH | 49-340 | - | [41] | |
| <hr/> | | | | |
| Arctic foxes (<i>Alopex lagopus</i>) | | ng/g lipid weight | - | |
| | PCB 85-209 | 0.1-120670.5 | - | [4],[24] |
| | $\Sigma(7-33)$ PCB | 400-36048.5 | - | [4],[24] |





| | | | | |
|--|---------------------------------|-------------------|-------------------|---------------------|
| | p,p-DDE | 0.9-1445.4 | - | [4] |
| | Chlordane(trans,cis) | 1.9-63.7 | - | [4] |
| | Nonachlor(trans,cis) | 0,3-1693.1 | - | [4] |
| | Oxy | 246.1-14520.1 | - | [4] |
| | ∑(7)CHL | 400.0-22479.6 | - | [4] |
| | HCB | 29.3-338.0 | - | [4] |
| | BDE 47-154 | 0.1-207.2 | - | [4] |
| | ∑(5)PBDE | 1.6-231.6 | - | [4] |
| | | | | |
| | | ng/g lipid weight | ng/g wet weight | |
| Ringed seal (<i>Phusa hispida</i>), Harp seal (<i>Phoca groenlandica</i>), Bearded seal (<i>Erignathus barbatus</i>), Harbor seals (<i>Phoca vitulina</i>) | PCB 28-209 | 1-8790 | 0.86-139.24 | [1],[20],[21],[22] |
| | ∑(6-28)PCB | 450-20382 | 159.14-624.81 | [20],[21],[43] |
| | DDT(p,p'), DDE(p,p'), DDD(p,p') | 62-10004 | 1.36-569.7 | [20],[21],[23],[43] |
| | ∑(2-3)DDT | 547-10381 | 164.95-621.01 | [20],[21] |
| | Nonachlor(trans,cis) | 162-6883 | 8.49-45.95 | [20],[21] |
| | Oxy | 98-2403 | 15.26-109.16 | [20],[21] |
| | Mirex | - | 11.34-11.52 | [21] |
| | ∑(3-10)CHL | 354-8890 | 0.76-186.96 | [20],[21],[23] |
| | HCH(α,γ,β) | 3-86 | 2.27-44.55 | [20],[21] |
| | ∑HCH | 42-177 | 42.32-79.29 | [20],[21] |
| | HCB | 11-956 | 0.05-17.01 | [20],[21],[23] |
| | BDE(28-154) | 0.38-73.83 | - | [4] |
| | HBCD | 14.6-34.5 | - | [4] |
| | ∑(8)PBDE | 42.04-94.23 | - | [4] |
| | | | | |
| | | ng/g lipid weight | ng/g lipid weight | |
| White whales (<i>Delphinapterus leucas</i>), Minke whale (<i>Balaenoptera acutorostrata</i>) | ∑(27-102)PCB | - | 631-10075 | [4],[36],[37] |
| | DDT(p,p') DDE(p,p') DDD(p,p') | - | 64.8-5149 | [4],[36] |
| | ∑(3)DDT | - | 308-6770 | [4],[36],[37] |



| | | | | | |
|--|------------------------------|-------------------------------|-------------------|-----------------|--|
| | a-Endosulfan | - | 2.63-22.6 | [37] | |
| | MIREX | - | 4.27-28.7 | [36],[37] | |
| | DIEL | - | 222-2657 | [4],[37] | |
| | Chlordane(trans,cis) | - | 9.75-880 | [4],[36] | |
| | Nonachlor(trans,cis) | - | 97.0-1860 | [4],[36] | |
| | Oxy | - | 59.4-2037 | [4],[36] | |
| | Hept | - | 152-633 | [4] | |
| | $\Sigma(5-7)$ CHL | - | 115-6143 | [4],[36],[37] | |
| | HCH(α,γ,β) | - | 8.31-210 | [36],[4] | |
| | Σ HCH | - | 15.1-510 | [4],[36],[37] | |
| | HCB | - | 2.50-1423 | [4],[36],[37] | |
| | HBCD | - | 5.48-237 | [36] | |
| | $\Sigma(3)$ CHB | - | 210-12760 | [36] | |
| | CHB 26-62 | - | 2.44-6950 | [36] | |
| | BDE 28-183 | - | 0.111-86.5 | [36] | |
| | HBCD | - | 5.48-237 | [36] | |
| | $\Sigma(7)$ PBDE | - | 22.7-137 | [36] | |
| Birds | | | | | |
| Glaucous gull (<i>Larus hyperboreus</i>, <i>Larus marinus</i>, <i>Larus argentatus</i>) | | | ng/g lipid weight | ng/g wet weight | |
| | | $\Sigma(6-32)$ PCB | 1-4274000 | 0.1-292439 | [1],[4],[13],[25],[26],[27],[28],[29],[30],[31],[32] |
| | | DDT(p,p',o,p') DDE(p,p',o,p') | 5-732300 | 0.1-84736 | [1],[4],[13],[22],[25],[29],[32] |
| | | DDD(p,p',o,p') | 267-7419 | 5.1-8072.1 | [1],[13],[26],[29] |
| | | $\Sigma(3-5)$ DDT | 2-173 | | [13] |
| | | Toxaphene | - | 4.6-421 | [1],[30] |
| | | Mirex | 14-11300 | 3.9- 4335 | [1],[4],[30],[32] |
| | | (α,β)Endosulfan | - | 0.1-8.8 | [1] |
| | | Endrin | - | 0.7-2.0 | [1] |
| | | Methoxychlor | - | 1.0-3.6 | [1] |



| | | | | |
|---|--|-------------------|-----------------|--|
| | Chlordane(trans,cis) | 30-1100 | 0.2-18.2 | [1],[30],[32] |
| | Nonachlor(trans,cis) | 30-1500 | 0.2-16.1 | [4],[30],[32] |
| | Oxy | 9-103900 | 9.99-25438 | [1],[4],[13],[22],[30],[32] |
| | Hept | - | 1.4-128.1 | [1],[30] |
| | $\Sigma(3-5)CHL$ | - | 0.9-1565.6 | [1],[28],[29] |
| | ΣCB | - | 8-58 | [1] |
| | HCH(α,γ,β) | 2-900 | 0.02-8800 | [1],[29],[32] |
| | ΣHCH | 1-137 | 0.1-173.7 | [13],[28] |
| | HCB | 14-10400 | 0.9-6235 | [1],[4],[13],[22],[25],[28],[29],[30],[32] |
| | BDE 17-209 | 0.4-56800 | 0.02-18.5 | [1],[4],[30],[32] |
| | HBCD | 5-15000 | 0.07-1.24 | [4],[32] |
| | $\Sigma(8-10)PBDE$ | - | 6-2655 | [1],[4] |
| | Metal(Cu,Cd,Pb,Hg,Se,Zn,Mn,Fe,Ni,Cr,Co) | - | 100-601000 | [1],[25],[40] |
| | Total Hg | - | 150-2000 | [45] |
| | MeHg | - | 340-1300 | [45] |
| | ΣTEQ | - | 0.0655 | [1] |
| | PFAS(PFH _x S, PFOS, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTriA, PFTA, PFPA) | - | 0.7-349 | [4] |
| | $\Sigma PFCA$ | - | 14.7-262 | [4] |
| | | | | |
| | | ng/g lipid weight | ng/g wet weight | |
| Fulmar (<i>Fulmarus glacialis</i>) | Total Hg | - | 130-3360 | [45] |
| | MeHg | - | 450-1600 | [45] |
| | Hg | - | 1200-12200 | [25],[44] |
| | PCB 77-169 | 0.1-111.1 | - | [44] |
| | $\Sigma(23-79)PCB$ | 4827-18 187 | 1600-59000 | [25],[44] |
| | DDT(p,p';o,p'), DDE(p,p';o,p'), DDD(p,p';o,p') | 0.3-2781 | 630-22000 | [25],[44] |



| | | | | |
|--|---------------------------------------|-------------------|-----------------|-------------------------------|
| | $\Sigma(6)$ DDT | 867-2881 | - | [44] |
| | DIEL | 162-1218 | - | [44] |
| | MIREX | 67.0-235 | - | [44] |
| | ENDRIN | 20.7-79.6 | - | [44] |
| | $\Sigma(4)$ Toxaphenes | 167-688 | - | [44] |
| | Oxy | 658-4164 | - | [44] |
| | $\Sigma(9)$ CHL | 615-5047 | - | [44] |
| | β -HCH | 15.7-23.0 | - | [44] |
| | $\Sigma(3)$ HCH | 12.9-23.0 | - | [44] |
| | HCB | 293-1754 | - | [44] |
| | PFAS(PFH _x S, PFOS, PFOSA) | 0.5-8.3 | - | [44] |
| | $\Sigma(9)$ PCDF | 1.2-57.4 | - | [44] |
| | $\Sigma(7)$ PCDD | 0.7-27.5 | - | [44] |
| | $\Sigma(4)$ TEQ | 2.3-37.6 | - | [44] |
| | Tribromoanisole | 0.4-0.8 | - | [44] |
| | $\Sigma(3)$ HBCD | 3.8-61.6 | - | [44] |
| | $\Sigma(2-16)$ PBDE | 4.2-5255 | - | [44] |
| | | ng/g lipid weight | ng/g wet weight | |
| Brünnich's guillemot (<i>Uria lomvia</i>), Black guillemots (<i>Cepphus gryle</i>), | Hg | - | 200-630 | [25],[29] |
| | Total Hg | 600-620 | - | [45] |
| | MeHg | 200-900 | - | [45] |
| | PCB 114-189 | - | 0.3-0.69 | [26] |
| | $\Sigma(7-30)$ PCB | 712.7-3595.2 | 40-500 | [13],[25],[26],[27],[29],[31] |
| | DDT(p,p') DDE(o,p';p,p') | - | 2-480 | [13],[25],[29] |
| | $\Sigma(4-5)$ DDT | - | 136-480 | [13],[29] |
| | DIEL | - | 1-3 | [13] |
| | Oxy | - | 23-47 | [13] |
| | $\Sigma(5)$ CHL | - | 40 | [29] |
| | β -HCH | - | 5820 | [29] |



| | | | | | |
|--|-----------------|---------------------|-------------------|-----------------|----------------|
| | γ -HCH | - | 230 | [29] | |
| | Σ HCH | - | 1-6 | [13] | |
| | HCB | - | 28-122 | [13],[25],[29] | |
| | Σ TEQ | - | 0.001-0.005 | [31] | |
| Little auk (<i>Alle alle</i>) | | | ng/g lipid weight | ng/g wet weight | |
| | | Σ (7-30)PCB | 1631.7-6787.6 | 200-7100 | [25],[31] |
| | | DDE(o,p') | - | 67-2100 | [25] |
| | | HCB | - | 14-400 | [25] |
| | | Hg | - | 490 | [25] |
| | | Total Hg | - | 10-510 | [45] |
| | | Me Hg | - | 23-380 | [45] |
| | | Σ TEQ | - | 0.003-0.01 | [31] |
| Eider (<i>Somateria mollissima</i>) | | | ng/g lipid weight | ng/g wet weight | |
| | | Hg | - | 1030 | [25] |
| | | Σ (7-19)PCB | - | 0.8-1788.1 | [25],[27],[28] |
| | | DDE(o,p') | - | 11-680 | [25] |
| | | Σ (6)DDT | - | 0.5-513.6 | [28] |
| | | Σ (3)CHL | - | 0.1-88.6 | [28] |
| | | Σ (3)HCH | - | 0.2-139.7 | [28] |
| | | HCB | - | 0.3 -130 | [25],[28] |
| Kittiwake (<i>Rissa tridactyla</i>) | | | ng/g lipid weight | ng/g wet weight | |
| | | Hg | - | 130 | [29] |
| | | Σ (14-16)PCB | - | 7.5-16125.6 | [28],[29] |
| | | DDE(p,p') | - | 240 | [29] |
| | | Σ (5-6)DDT | - | 0.1-1269.0 | [28],[29] |
| | | Σ (3-5)CHL | - | 0.1-920.1 | [28],[29] |
| | | β -HCH | - | 3890 | [29] |
| | | γ -HCH | - | 50 | [29] |
| | Σ (3)HCH | - | 0.1-36 | [28] | |

| | | | | |
|---|----------------------|-------------------|-----------------|-----------|
| | HCB | - | 0.5-452.5 | [28],[29] |
| | Σ TEQ | - | 0.005-0.01 | [31] |
| Fisches | | | | |
| | | ng/g lipid weight | ng/g wet weight | |
| Polar cod (<i>Boreogadus saida</i>); Arctic charr (<i>Salvelinus alpinus</i>), Cod (<i>Gadus morhua</i>, <i>Boreogadus saida</i>), Capelin (<i>Mallotus villosus</i>) Long rough dab (<i>Hippoglossoides platessoides</i>), Herring (<i>Clupea harengus</i>) | Σ (7-33)PCB | - | 7-5175 | [33],[35] |
| | Σ (3-6)DDT | - | 2-423 | [33],[35] |
| | a-endosulfan | - | 0.01-0.1 | [33] |
| | Oxy | - | 0.11 | [33] |
| | Hept | - | 1.7 | [33] |
| | Σ (4)CHL | - | 3-207 | [35] |
| | α -HCH | - | 0.01-0.7 | [33] |
| | γ -HCH | - | 0.05-0.4 | [33] |
| | Σ (3)HCH | - | 1-17 | [35] |
| | CHB 26-50 | - | 0.74-28 | [33] |
| | HCB | - | 1-44 | [35] |
| | BDE 28-209 | 0.02-1.78 | 0.1-22.89 | [4],[33] |
| | HBCD | 1.38-2.87 | - | [4] |
| | Σ (8)PBDE | 0.49-3.59 | - | [4] |
| CN 42-67 | - | 0.5-30.2(pg/g ww) | [33] | |
| Arthropod, Mollusca | | | | |
| | | ng/g lipid weight | ng/g wet weight | |
| Tadpole shrimps (<i>Lepidurus arcticus</i>), Bivalve (<i>Mya truncata</i>, <i>Serripes groenlandicus</i>, <i>Hiatella arctica</i>, <i>Chlamys islandica</i>) | PCB 101-194 | 0.1-40.51 | - | [39] |
| | Σ (16-33)PCB | 25.57-171.61 | 5.58 | [33],[39] |
| | Σ (6)DDT | - | 0.53 | [33] |
| | Chlordane(trans,cis) | 0.32-5.21 | - | [39] |
| | Nonachlor(trans,cis) | 1.10-27.09 | - | [39] |
| | Oxy | 1.12-14.25 | - | [39] |
| | Hept | 2.40-3.46 | - | [39] |



| | | | | |
|---|---------------------------------------|-------------------|-----------------|-----------|
| | $\Sigma(6)$ CHL | 6.14-39.19 | - | [39] |
| | α -HCH | 1.93-20.73 | - | [39] |
| | HCB | 51.10-79.00 | - | [39] |
| | CHB 26 | - | 0.62 | [33] |
| Echinodermata | | | | |
| | | ng/g lipid weight | ng/g dry weight | |
| Sea urchins (<i>Strongylocentrotus droebachiensis</i>, <i>Strongylocentrotus pallidus</i>) | Metal (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni,As) | - | 30-582000 | [38] |
| Zooplankton | | | | |
| | | ng/g lipid weight | ng/g wet weight | |
| <i>Calanoid copepods, Thysanoessa inermis, Themisto libellula, Gammarus wilkitzkii, Cyclops abyssorum, Daphnia umblae, Calanus finmarchicus, Calanus glacialis, Calanus hyperboreus, Krill, Themisto abyssorum, Themisto libellula, Chaetognatha</i> | PCB 28 -153 | 0.1-12.1 | - | [34] |
| | PCB 153 | 0.3-7.6 | - | [34] |
| | $\Sigma(7-33)$ PCB | - | 0.16-60 | [33] |
| | DDE(p,p') | 1-26.8 | - | [34] |
| | $\Sigma(6)$ DDT | 1.7-31.1 | 0.16-3.5 | [33] |
| | DIEL | - | 1.0 | [33] |
| | a-endosulfan | - | 0.04-0.06 | [33] |
| | Chlordane(trans,cis) | 0.7-9.4 | | [34] |
| | Nonachlor(trans,cis) | 0.4-7.7 | 0.2 | [33],[34] |
| | Oxy | 0.7-4 | 0.7 | [33],[34] |
| | HCH(α,γ) | 0.8-7.2 | - | [34] |
| | $\Sigma(3)$ HCH | 1.1-4 | - | [34] |
| | HCB | 0.4-52.8 | - | [34] |
| | CHB 26-50 | - | 0.25-1.84 | [33] |
| | BDE 47-209 | 0.05-7.22 | 0.05-0.14 | [4],[33] |
| $\Sigma(8)$ PBDE | 0.16-14.67 | - | [4] | |
| Insect | | | | |
| | | ng/g dry weight | ng/g wet weight | |
| Chironomid larvae (<i>Chironomidae</i>) | $\Sigma(33)$ PCB | - | 60.0 | [33] |
| | $\Sigma(6)$ DDT | - | 5.42 | [33] |



| | | | | |
|--|---|-----------------|---------------------|-----------|
| | BDE 47-99 | - | 0.22-1.40 | [33] |
| | CN 42-67 | - | 0.28-2.20 (pg/g ww) | [33] |
| Plants | | | | |
| Laminarian kelps (<i>Laminaria saccharina</i>, <i>L. digitata</i>, <i>Alaria esculenta</i>), Filamentous algae (<i>Conjugatophyceae - Zygnema sp.</i>), Lichen (<i>Cetraria nivalis</i>), Moss (<i>Tamenfhyppnum nitens</i>, <i>Rhacomifriurn lanuginosum</i>), Vascular plant (<i>Cassiope tetragona</i>), | | ng/g dry weight | ng/g wet weight | |
| | Metal (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni,As) | 6-2654000 | - | [38],[40] |
| | Hg | 60-1950 | - | [40] |
| | PHA(Nap,Pyr,BaP,Ace,Acp,Fl,Phe,An,Flu,BaA,Chr,BbF,BkF,BghiP,,DbA,InP) | 0.3-81 | - | [41] |
| | $\Sigma(16)$ PAH | 158-244 | - | [41] |

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Table 7b. Literature information about the results of the studies of the samples of the inanimate material collected in the Svalbard archipelago

| Non-living material samples | Determined compounds/compound groups | Identified content/scope | Literature |
|-----------------------------|--|--------------------------|-------------------------|
| Air | | pg/m ³ | |
| | PCB 10-209 | 0.01-330 | [1],[33],[55],[57] |
| | $\Sigma(31-206)$ PCB | 3.37-207.02 | [55],[57] |
| | Heptachlor | 0.02-4.55 | [57] |
| | Oxy | 0.025-1.95 | [57] |
| | Chlordane(trans,cis) | 0.01-4.47 | [1],[33],[57] |
| | Nonachlor(trans,cis) | 0.01-3.48 | [1],[57] |
| | DDT(p,p',o,p'), DDE(p,p',o,p'), DDD(p,p',o,p') | 0.01-112.44 | [1],[33],[57] |
| | $\Sigma(4-6)$ DDT | 1-17.54 | [57],[60] |
| | Σ CHL | 1.86-17.49 | [57] |
| | HCH(α,γ,β) | 0.02-203.0 | [1],[33],[56],[57],[60] |
| | Σ HCH | 12.56-42.76 | [57] |
| HCB | 0.18-760 | [1],[33],[57],[60] | |



| | | | |
|-----------------|--|------------------|-----------|
| | ΣTEQ (fg · m-3) | 0.02-0.09 | [55] |
| | Metal(Ni,Hg,Pb,Cd,Cu) | 10-1790 | [60] |
| | n-Alkanes(17-29) | 30-6000 | [1] |
| | n-Alkanoic acids(14-28) | 20-3310 | [1] |
| | PCN 15-75 | 0.02-12.0 | [33] |
| | ΣPCN | 8.7-48.0 | [33] |
| | | | |
| | | mg/l | |
| Rainfall | pH | 4.70-5.45 | [1],[61] |
| | SpC | 8.9- 121 [μS/cm] | [61] |
| | Anions(Cl ⁻ ,NO ₃ ⁻ ,SO ₄ ²⁻ ,HCO ₃ ⁻) | 1-28218 | [1],[61] |
| | Cations(Ca ²⁺ ,K ⁺ ,Mg ²⁺ ,Na ⁺ ,NH ₄ ⁺) | 1-16070 | [1],[61] |
| | | | |
| | | ng/l | |
| Snow | PCB 28-194 | 0.000001-0.0161 | [49] |
| | Σ(7-15)PCB | 0.001-2.0 | [49],[59] |
| | Σ(6)DDT | 0.000391-0.0595 | [59] |
| | γ-HCH | 0.186-3.09 | [59] |
| | HCB | 0.0031-0.0351 | [59] |
| | PAH(Nap,Ace,Acp,Fl,Phe,An,Flu,Pyr, BaA,Chr,BbF,BkF,BaP,DbA,InP,BghiP) | 0.100-133000 | [41] |
| | Σ(16)PAH | 37000-324000 | [41] |
| | pH | 5.23-6.04 | [58] |
| | SpC | 6.1-80.4 [μS/cm] | [58] |
| | Anions(Cl ⁻ ,NO ₃ ⁻ ,SO ₄ ²⁻) | 71-20700 | [53],[58] |
| | Cations(Ca ²⁺ ,K ⁺ ,Mg ²⁺ ,Na ⁺) | 86-9760 | [53],[58] |
| | S | 170-880 | [58] |
| | Hg(total) | 2.2-40.6 | [52] |
| | Hg(reactive) | 6.6-59.9 | [52] |
| | PCN 15-75 | 0.13-470.0 | [33] |
| ΣPCN | 59.0-1100 | [33] | |





| | | ng/l | |
|--|--|-------------------|--|
| Seawater, groundwater, surface water (streams, river, lake, spring) | PCB (18-209) | 0.00001-308 | [1],[49],[63] |
| | Σ(7-15)PCB | 0.00054-406 | [1],[9] |
| | DDD(p,p') | 0.0001-0.0004 | [62] |
| | Chlordane(trans,cis) | 0.0012-0.0013 | [62] |
| | Nonachlor(trans,cis) | 0.0002-0.0006 | [62] |
| | HCH(α,γ) | 0.0022-0.021 | [62] |
| | HCB | 0.022-0.0078 | [62] |
| | Metal(Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni) | 0.5-457.5 | [38],[40] |
| | Anions(SO ₄ ²⁻ ,HCO ₃ ⁻ ,PO ₄ ²⁻) | 0.8-332428 [mg/l] | [1],[53] |
| | Cations(Ca ²⁺ ,K ⁺ ,Mg ²⁺ ,Na ⁺) | 0.6-54108 [mg/l] | [1],[53] |
| | N-NH ₄ | 0.61-19.40 [mg/l] | [1] |
| | N-NO ₂ | 4.90-1.1 [mg/l] | [1] |
| | N-NO ₃ | 00.4-50.70 [mg/l] | [1] |
| | PAH(Nap,Ace,Acp,Fl,Phe,An,Flu,Pyr,Chr,BbF,BkF,BaP) | 0.025-310 | [1] |
| | Σ(12)PAH | 3.3-603 | [1] |
| | SiO ₂ | 0.12-3.3 [mg/l] | [53] |
| | pH | 6.84-7.03 | [53] |
| | | | |
| | | pg/l | pg*cm ⁻² *rok ⁻¹ |
| Glacier ice, ice core, ice | PCB 18 -199 | 0.004-6.44 | - [49] |
| | Σ(9-15)PCB | 2-2000 | - [33],[49] |
| | DDE (p,p') | - | 1.14 [54] |
| | DDT (p,p'-o,p') | - | 2.93-11.5 [54] |
| | ΣDDT | 0.391-59.5 | - [54] |
| | HCH(α,γ) | 1.1 -3090 | 295-369 [1],[33],[54] |
| | HCB | 3.10-35.3 | - [33] |
| | chlordane (γ-α) | - | 13.4-18.3 [54] |



| | | | |
|--|--|---------|----------|
| Aldrin | 69 | 30000 | [1],[54] |
| Dieldrin | 7.5 | 54.7 | [1],[54] |
| α -Endosulfan(α,β) | 10.7-19.7 | 2.8-6.8 | [1],[54] |
| Endrin-aldehyde | 13.6 | 16.3 | [1],[54] |
| Endrin-ketone | - | 13.6 | [54] |
| Heptachlor | 6.5 | 470 | [1],[54] |
| Heptachlor-epoxide | 32.8 | 1580 | [1],[54] |
| Methoxychlor | 4.7 | - | [1] |
| Chlorpyrifos | 16.2 | 809 | [1],[54] |
| Dacthal | 0.3 | 12.7 | [1],[54] |
| Diazinon | 20.5 | 1410 | [1],[54] |
| Dimethoate | 87 | 598 | [1],[54] |
| Disulfoton | 6.5 | 447 | [1],[54] |
| Endosulfan sulfate | - | 2.81 | [54] |
| Ethion | 3.1 | - | [1] |
| Fenitrothion | 32.9 | - | [1] |
| Fonofos | 4.6 | - | [1] |
| Guthion | 21.6 | - | [1] |
| Imidan | 44.1 | 3030 | [1],[54] |
| Methyl-Parathion | 7.4 | 357 | [1] |
| Terbufos | 11.1 | 530 | [1],[54] |
| Alachlor | 1.2 | 57 | [1],[54] |
| Desethyl-atrazine | 2.1 | 144 | [1],[54] |
| Hexazinone | 1.5 | - | [1] |
| Metolachlor | 9.3 | - | [1] |
| Pendimethalin | 18.6 | 890 | [1],[54] |
| Trifluralin | - | 2.32 | [54] |
| Flutriafol | 9.8 | - | [1] |
| Metal(Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni) | 1.5-2552.5 [$\mu\text{g}/\text{kg}$] | - | [40] |

| | | | | |
|-----------------|---|-------------------|---|--------------------------|
| | SiO ₂ | 0-0.038 [mg/l] | - | [53] |
| | pH | 6.37 | - | [53] |
| | Anions(SO ₄ ²⁻ , HCO ₃ ⁻ , PO ₄ ²⁻ , NO ₃ ⁻) | 8.9-3899.5 [mg/l] | - | [53] |
| | Cations(Ca ²⁺ , K ⁺ , Mg ²⁺ , Na ⁺ , Ni ⁺) | 58.6-2069 [mg/l] | - | [53] |
| | | ng/g dry weight | | |
| Sediment | PCB 28 -209 | 0.1 -12.9 | | [47],[51],[62], |
| | Σ(7-18)PCB | 0.06-60 | | [1],[47],[48],[51],[62] |
| | ΣDDT | 0.07-6.9 | | [48] |
| | DIEL | 0.5-1.6 | | [1] |
| | ΣHCH | 0.42-7.0 | | [48] |
| | BDE(3-209) | 0.007-0.46 | | [48] |
| | Σ(11-14)PBDE | 0.024-0.97 | | [1],[48] |
| | Organic Carbon % TOC | 0.1-6.3 [%] | | [51],[62] |
| | PAH((Nap,Ace,Acp,Fl,Phe,An,Flu,Pyr, BaA,Chr,BbF,BkF,BaP,DbA,InP,BghiP) | 0.14-2500 | | [62],[47],[48],[50],[62] |
| | Σ(12-16)PAH | 1-640 | | [47],[48],[50],[62] |
| | Metal(Cd,Zn,Cu,Pb,Cr,Co,Ni,As,Hg,Sb,Sc,Ti, V) | 31-411000 | | [1],[53] |
| | | ng/g dry weight | | |
| Soil | PAH((Nap,Ace,Acp,Fl,Phe,An,Flu,Pyr, BaA,Chr,BbF,BkF,BaP,DbA,InP,BghiP) | 0.3-324 | | [41] |
| | Σ(16)PAH | 37-324 | | [41] |
| | SiO ₂ | 0.63 [mg/l] | | [53] |
| | Anions(SO ₄ ²⁻ , HCO ₃ ⁻ , PO ₄ ²⁻) | 93-70539 [mg/l] | | [53] |
| | Cations(Ca ²⁺ , K ⁺ , Mg ²⁺ , Na ⁺) | 508-11022 [mg/l] | | [53] |

271 **5. Methods of remediation of the Svalbard archipelago**

272 Anthropopressure led to the degradation of vast areas of the Svalbard archipelago (beaches, sea bottom, tundra soils). The organisms
273 dwelling in the sea, on the shore, and on the islands have also been continuously exposed to various xenobiotics. The harsh climate and
274 environmental conditions contribute to the slowing down of normal remediation process of nature [64-70]. In particular limiting factors are:

- 275 • limited access to water (for most of the year water is frozen, unless in pressurized or salinated conditions);
- 276 • a deficit of nutrients (the circulation of biogenic chemical elements: nitrogen and phosphorus is slowed down in polar environments);
- 277 • and very low temperatures (as the temperature falls, microbiological activity decreases, moreover, some physical and chemical properties
278 of pollutants change under the influence of temperature).

279 The introduction of contaminants (such as: persistent organic pollutants, heavy metals, crude oil hydrocarbons) into the environment disturbs
280 the homeostatic mechanisms of the ecosystem, which, in turn, can lead to a collapse of ecological balance. In recent years there was an increase
281 in the number of projects and programs aimed at remediating the contaminated area of the Svalbard archipelago. The ecological restoration of the
282 archipelago is a tedious and slow process. The cleaning of the Arctic requires the use of new technologies and the creation of proper
283 methodologies of action. Table 8 collates the basic information about remediation programs realized in the Svalbard region.

284 **Table 8.** The main remedial programs conducted in the Svalbard region



| Compounds/ Harmful substances | Program/project | Institutions | Threat | Remediation methods | Areas of activity | Literature |
|---|---|---|--|---|-----------------------------|------------|
| Crude oil hydrocarbons (PAHs) | Experimental Program | The program was sponsored by an international partnership of spill response and research agencies, composed of: Canadian Coast Guard; Environment Canada; Exxon Research and Engineering Co. (USA); Fisheries and Oceans Canada; Imperial Oil Resources (Canada); Marine Pollution Control Unit (UK); Minerals Management Service (USA); Norwegian Pollution Control Authority; Swedish Rescue Service Agency; and the Texas General Land Office | Contamination, with crude oil hydrocarbons - crude oil and petrochemical oil spills - of shores and beaches | In-situ remediation methods <ul style="list-style-type: none"> • sediment washing; • sediment mixing; • bioremediation; • bioremediation combined with sediment mixing. | Sveagruva | [64] |
| | In Situ Treatment of Sediment Shorelines (ITOSS) | | | Ex-situ remediation method <ul style="list-style-type: none"> • biodegradation - bioreactors | The shores of the island | [65] |
| | Experimental Program | The study was funded by grants from Total E&P Norway AS and the Norwegian College of Fishery Science at the University of Tromsø. The study was also supported financially by the Roald Amundsen Centre for Arctic Research and the Kellfrid and Helge Jacobsen Foundation of the University of Tromsø, University Centre in Svalbard, CECA SA, France | | In-situ remediation methods <ul style="list-style-type: none"> • bioremediation | Kapp Wijk - Isfjorden fjord | [66] |
| | Experimental Project | This project is funded by the Norwegian Research Council and the Norwegian Geotechnical Institute | Contamination of soils with crude oil hydrocarbons - crude oil and petrochemical oil spills | Ex-situ remediation methods <ul style="list-style-type: none"> • biostimulation • bioaugmentation | Longyearbyen | [67] |
| Total petroleum hydrocarbons (TPH), aliphatic hydrocarbons, and aromatic hydrocarbons | The impact of oil contamination and bioremediation treatments on the composition and degradation efficiency of polar bacterial sea-ice communities. | Those studies were funded by the European Union within the scope of the ARCOP-project (Arctic-Operational Platform, www.arcop.fi) and the Alfred-Wegener Foundation for Polar –and Marine Research. | Contamination of soils with crude oil hydrocarbons, a decrease of the number and diversity of species - crude oil and petrochemical oil spills | In-situ remediation methods <ul style="list-style-type: none"> • biostimulation | Van Mijenfjorden | [68] |



| | | | | | | |
|----------------------------|---|---|--|--|--------------------|------|
| Metals Sulfur compounds | The project “Snow and temperature control of biogeochemical oxidation processes in natural and managed High Arctic”. | The study was funded by the Danish Natural Science Research Council. The funding is continued by the Danish ministry of Science (VTU), DGE, and UNIS. | Contamination of tundra soils, surface and deep waters - leachates from heaps (gangues) of bituminous coal the burning of contaminants in coal heaps | In-situ remediation method (stabilization of bituminous coal heaps) | Valley Bjørndalen, | [69] |
| | Environmental controls of subsurface processes in coal waste rock dumps in Svalbard: Processes, scales, and remediation actions | Department of Geography & Geology, University of Copenhagen | | <ul style="list-style-type: none"> • technical methods - pouring - irrigation | | |
| | | | | Creating a method for limiting the chemical activity of coal heaps | Ny- Ålesund | [70] |

285

286 More and more information has been available about the use of various remediation technologies. That has an important impact on the
 287 lowering of xenobiotic concentrations and of the intensity of anthropopressure. The programs in question complement the prevention system
 288 against the harmful effects of pollutants in the Arctic.

289

290 **6. Conclusions and remarks**

291

292 The Arctic region, situated far from the main sources of emission of pollutants, is considered to be predictive of changes in the global
 293 environment. It is the source of information which allows early warning against the threats posed by the use of toxic chemical substances. The
 294 studies on the concentrations of pollutants in the Arctic are a key element in the monitoring of the quality of the environment and enable the
 295 undertaking of proper actions aimed at prevention of the negative impact of contaminants.

296 The Svalbard archipelago in the Arctic region had been, until recently, considered to be a pristine area isolated from the influence of
 297 anthropogenic degradation present in other geographic regions. However, the results of the studies published in the last few decades prove that

298 pollutants from distant sources are increasingly dangerous for that region which is rich in rare, fragile species of flora and fauna. The
299 environmental conditions and geographic location make the Svalbard archipelago a reservoir of pollution, from hardly volatile to very volatile
300 chemical compounds, which makes the area focus of advanced scientific investigations.

301 The activity of many countries in the research and international actions on behalf of the protection of polar areas, as well as highlighting
302 the range of the problem, have contributed to a decrease in the concentration of some toxic chemicals (e.g.: PCBs, DDTs) in the Arctic
303 environment. However, the regulations concerning the use of toxic substances in that area are still insufficient. There is also little information
304 about the secondary sources of persistent organic pollutants and the dynamics of release from those.

305 The concentration of many specific contaminants (from the groups: PBDEs, PFOAs, PFOSs) has not been evaluated yet. It is therefore
306 necessary to conduct detailed studies concerning:

- 307 • the determination of the sources of emissions;
- 308 • the ways of transportation of pollutants in the environment;
- 309 • the ability of the pollutants to accumulate in various elements of an ecosystem;
- 310 • the release of those from already deposited supplies.

311



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