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

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Abstract

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

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

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 spectrometr, negative chemical ionization
GC-MS-NICI	Gas chromatography, mass spectrometr, 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	Heptachlorepoxide
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 spectrometr, 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
∑CHL	Total chlordane levels
∑DDT	Total DDT levels
∑HCH	Total HCH levels

1. Introduction

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

A particular class of pollution is of special concern in the Arctic: the persistent organic pollutants, characterized by durability and resistance to degradation. The residence time of those pollutants is long enough for them to be transported thousands of kilometers by air and ocean water [2,3]. Consequently, the compounds that have not been produced for the past few decades still appear in the environment (including the polar regions). The quantities of those still present there may cause impact negatively the functioning of ecosystems, animal and human 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 been seen very clearly in the area of Svalbard archipelago [1].

Located between 74 - 81° N, and 10-35° E, and separated from Greenland and Franz Josef Land by wide straits, the archipelago of Svalbard is a gateway to the Arctic. In winter the atmospheric circulation concentrates a flux of pollutants from Central Europe, Scandinavia and northwestern Russia into the Arctic. Svalbard, being the first landmass on the way of polluted airmasses, receives a strong contamination "blast" [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 sensitive flora and fauna.. Not surprisingly, specialists from numerous research centers conduct studies in the region, the results of which can be the basis for:

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

2. Svalbard - a vulnerable area of the Arctic

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

- a relatively short distance from continental Europe (800 km north of the Scandinavian Peninsula, from the area where crude oil is extracted in the North Sea, and from the Kola Peninsula and Sweden where minerals (including heavy metals) are mined - all those areas 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 available for shipping and increases tourist traffic there (the existenceof small local sources of pollutants);
- the land relief dominated by mountains: these constitute a natural barrier for the contaminated airmasses coming from Europe and northwestern Asia;
- the location in the gap between the continents surrounding the Arctic Basin which facilitates the exchange of oceanic waters between the moderate and high latitudes, as well as longitudinal circulation of air [1].

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

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

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

- the Icelandic Low in the vicinity of the archipelago which is a typical moving low pressure area of the moderate latitudes of the northern hemisphere – atmospheric activity is the main media spreading the stable pollutants
- the wind speed grows together with the pressure gradient; as a result the pollutants in the air are subject to circulation (advective movement and vertical movement in the atmosphere) and can be transferred across long distances:

  - local winds (along the East-West axis) affect the redistribution of pollutants in the Svalbard region;
  - in the archipelago there often occur katabatic winds caused by radiative cooling of masses of air lingering over the elevated areas, and the cooled air flows down and creates a very strong wind; again, this increases the spreading potential of once deposited contaminants;
- the variable location of the upper tropospheric jet stream:

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

  - the warm West Spitsbergen Current on one side and the cool East Spitsbergen Current on the other cause a significant difference in sea ice formation to the east from the archipelago as compared to the western side (also, this influences the pressure system);
  - undercurrents and surface currents allow more efficient mixing of water transported from a long distance [1,5].

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

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

- extreme climacte conditions: low temperatures, strong winds, a limited amount of solar radiation, and a short growing season (about 2,5 months) contribute to a low biodiversity. Scarcity of water and arid land (together with nutrient limitation) are the main causes of 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 deserts prevail. The processes of regeneration of nature are slow so all anthropogenic changes persistently influence the quality of the environment;
- decreased microbiological activity aggravates the slowing down of the nutrient circulation in nature (about 300 years for 95% of organic matter). A large amount of nutrients is stored in the soil where they are unavailable for organisms. The process of slow degradation leads to a deficit of key nutrients, both on the land surface and beneath the water surface.

Additionally, cold air impedes biological processes. In such difficult conditions the only surviving organisms are those of simple structure, 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 decidedly more slowly than in other climates [7].

In the Svalbard archipelago the green areas consist of low grasses, herbs, mosses, and lichens (vegetation characteristic of tundra). Nearly 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 animals, birds deserve special attention. Many birds migrate to the archipelago in summer. Sea species, such as Glaucous gulls, Kittiwakes and fulmars, preponderate on the islands. The most common birds, though, are Little auks and Guillemots. Colonies of these birds have their 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 land animals are the reindeer (a pasture animal); on bird colonies preys the arctic fox. Another significant group of animals are those living on 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].

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 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 energy for organisms living in polar regions. On the one hand, lipids condition the survival of many species of animals, on the other hand, though, they pose a threat [5]. Stable organic contaminants (occuring both in the water and the land environment in Svalbard) frequently have a tendency to accumulate in adipose tissue. The level of contaminants depends on the processes occurring in organisms: bioaccumulation and biomagnification. As harmful substances move to subsequent trophic levels, the concentration of the toxic substances in organisms on higher levels in the food chain grows. The high content of harmful substances can impact negatively both on an animal and a human organism, despite the low concentrations of those compounds in the environment. Biomagnification causes the spread of contaminants in the entire food chain, endangering the highest-placed organisms the most. Figure no. 1 shows the scheme of the food chain characteristic for the area of the Arctic tundra and of the sea ecosystem of the Svalbard archipelago.

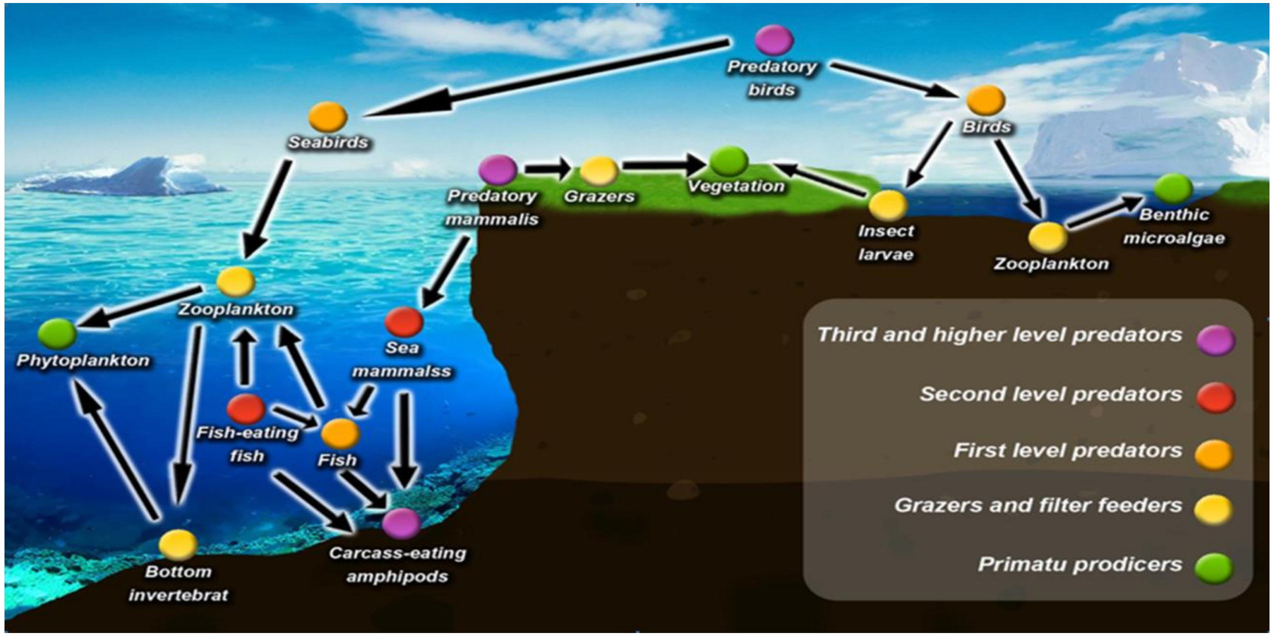


Figure 1. The food chain of the polar ecosystem [7].

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

- occurs at a critical stage of development (fetal, newborn). The young offspring of polar mammals (the polar bear, the ringed seal) is at 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 many years, so their tissues and organs are highly contaminated.

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

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 (*Salvelinus alpinus*)	- changes in the liver; impact on the immune system; - disturbances of the adaptation to changes in salinity;
OHCs	Ivory gull (*Pagophila eburnea*)	- disturbances of the vitamin metabolism;
PCBs	Arctic fox (*Vulpes lagopus*)	- impairment of reproductive functions; - impact on the vitamin metabolism; - weakening of bones;
PCBs	Arctic Tern (*Sterna paradisaea*)	- decreased reproductive success;
PCBs, PCNs, PBDEs, HBCDs	Glaucous Gull (*Larus hyperboreus*)	- 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 (*Thalarctos maritimus*)	- impairment of reproductive functions; - impact on hormone production and decreased reproductive health; - decreased production of antibodies; - kidney deformations; - weakening of teeth (*periodontosis*);
PCBs, PBDEs HBCD, HCHs	Ringed seal (*Pusa hispida*)	- impairment of reproductive functions;
PBDEs	Beluga whale (*Delphinapterus leucas*)	- increased incidence of digestive system cancers; - decreased immunity.

Large amounts of stable compounds are stored in snow and ice, constituting a potential source of toxic emission into the environment. Chemical substances, including the compounds the production of which has been stopped, are "trapped" in the permafrost, snow, and ice and are gradually released into the environment. As a result, living organisms are continuously exposed to them [14].

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

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

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.	• 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 18^{th} and early 19^{th} centuries was the emission of huge pollutant loads into the environment [15].
The first report about the contamination of the Arctic region (Mitchell) / 1957.	• 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	• The report prooves 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].

Still, the growth of consciousness and knowledge about the presence of anthropopressure in areas far from significant sources of pollution 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 studies of the state and quality of the Arctic environment catalyzed changes in politics and international law. Governmental bodies of many countries as well as groups of experts of numerous organizations and associations have undertaken various actions, including:

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

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

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

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

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

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

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

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	
Hopen	Norwegian Meteorologisk Institutt	
Bjornoya	Herwighamna is a meteorological station	
Longyearbyen	The University Centre in Svalbard	
	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
Kaffioyra	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

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

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

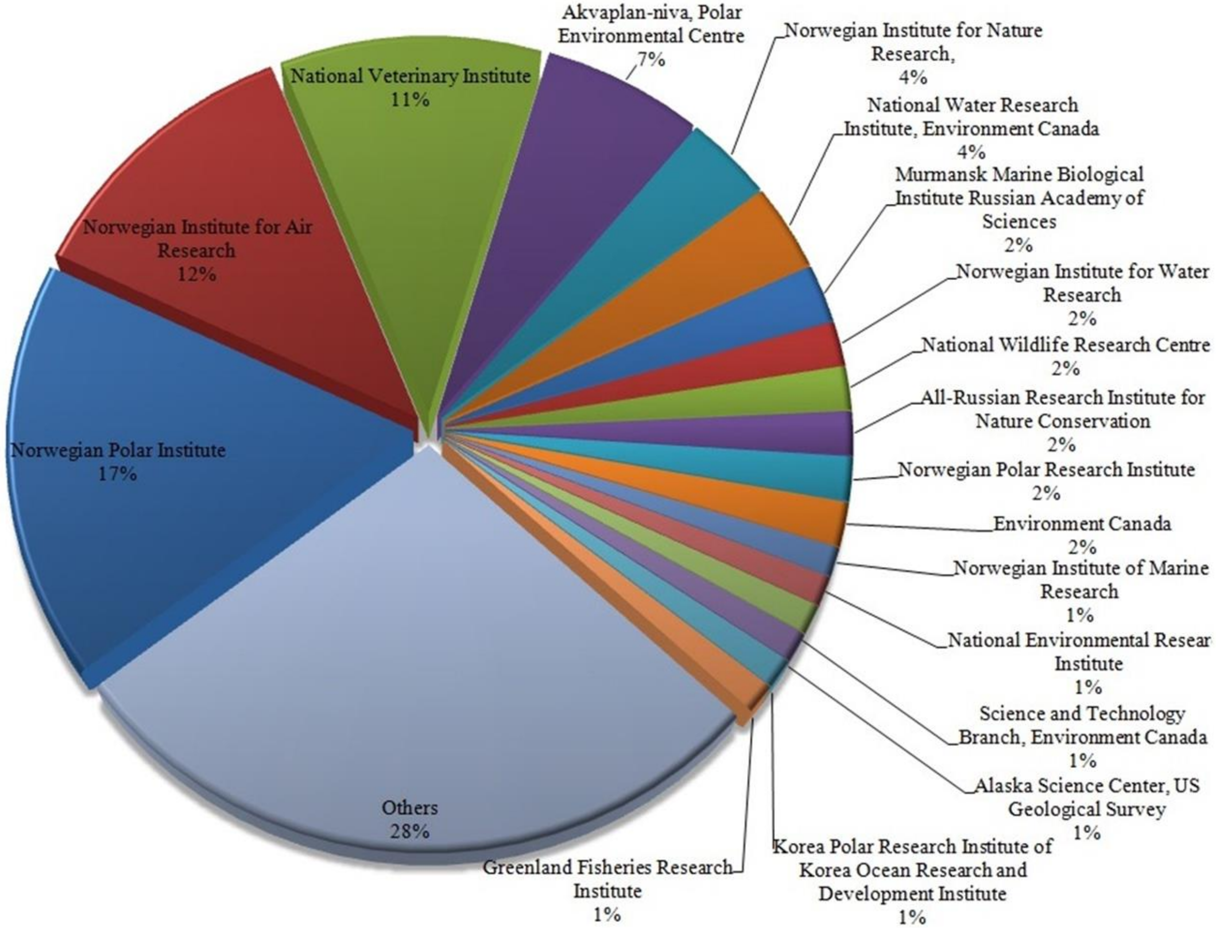
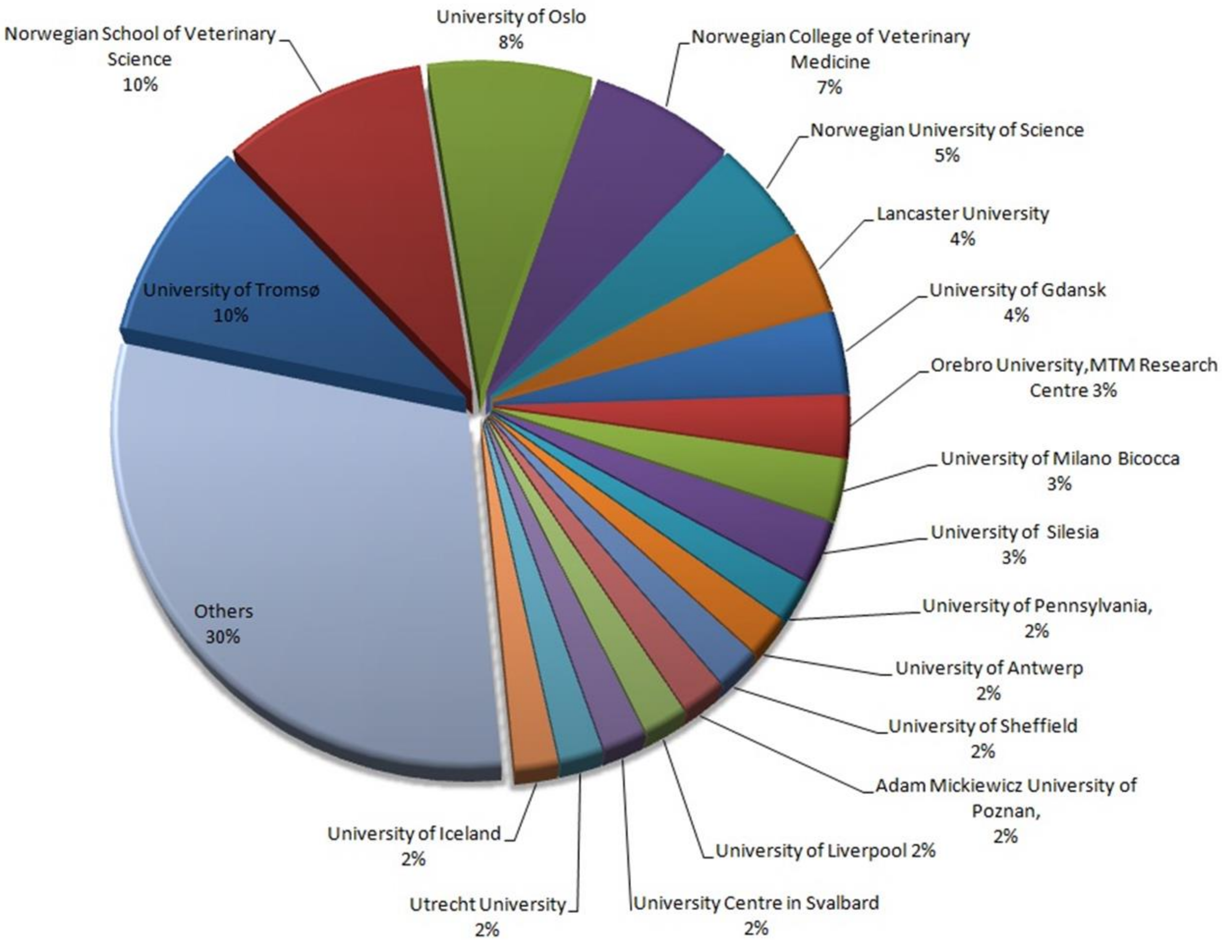


Figure 2 The participation of higher education institutions in studies on the chemistry of the environmental samples collected in Svalbard.



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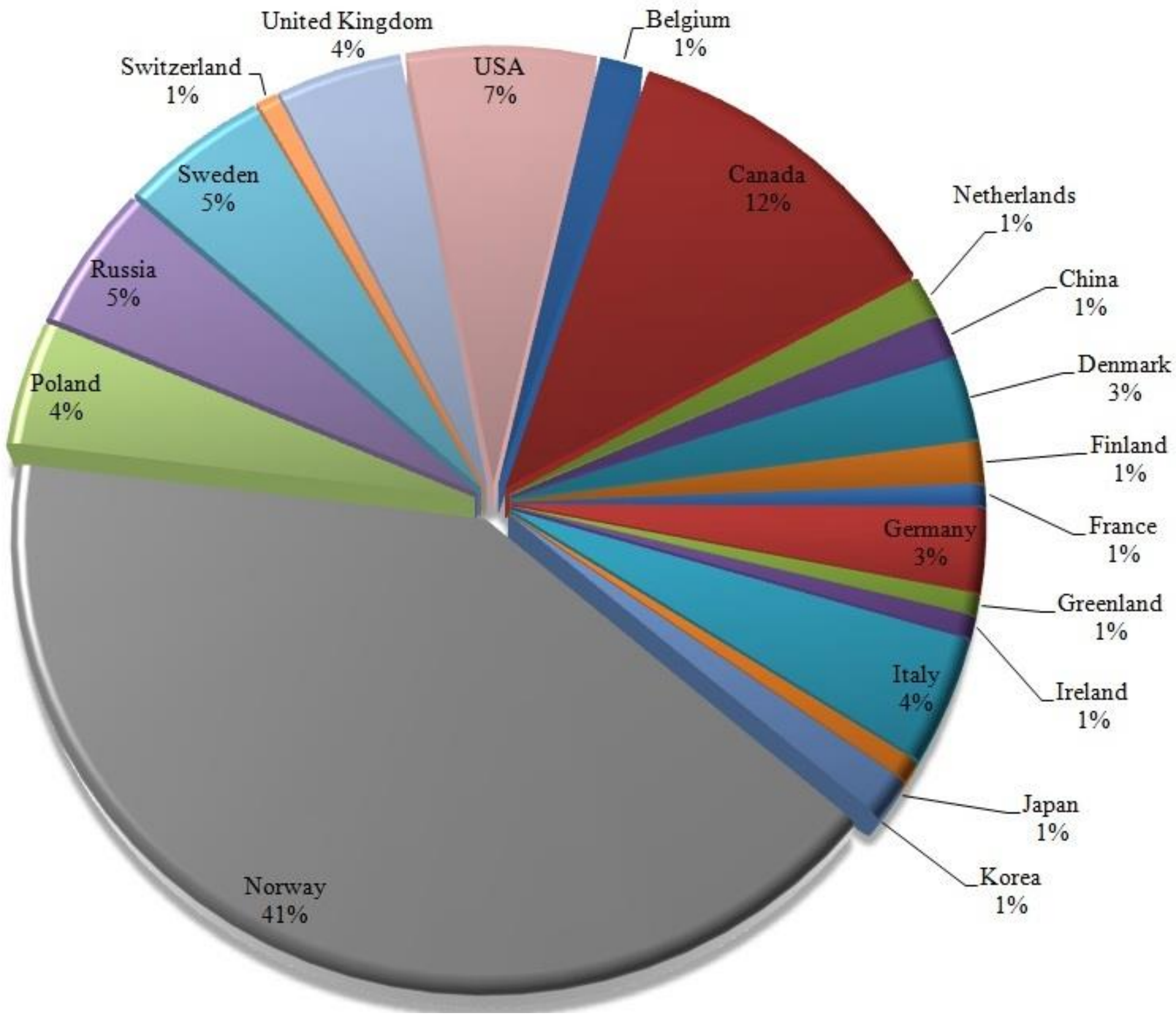
203 **Figure 3.** The participation of research units in studies on the chemistry of the environmental samples collected in Svalbard.



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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).

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

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

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

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

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

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 representative of a given ecosystem in which particular pollutants are to be discovered and measured. In that process it is important to mark not 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 necessary to appraise the actual threat both to the inanimate environment and biota. Apart from that, the registration of changes in the polar environment not only enables to study dynamics of the ecosystem but can aid forecasting the state of the region.

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

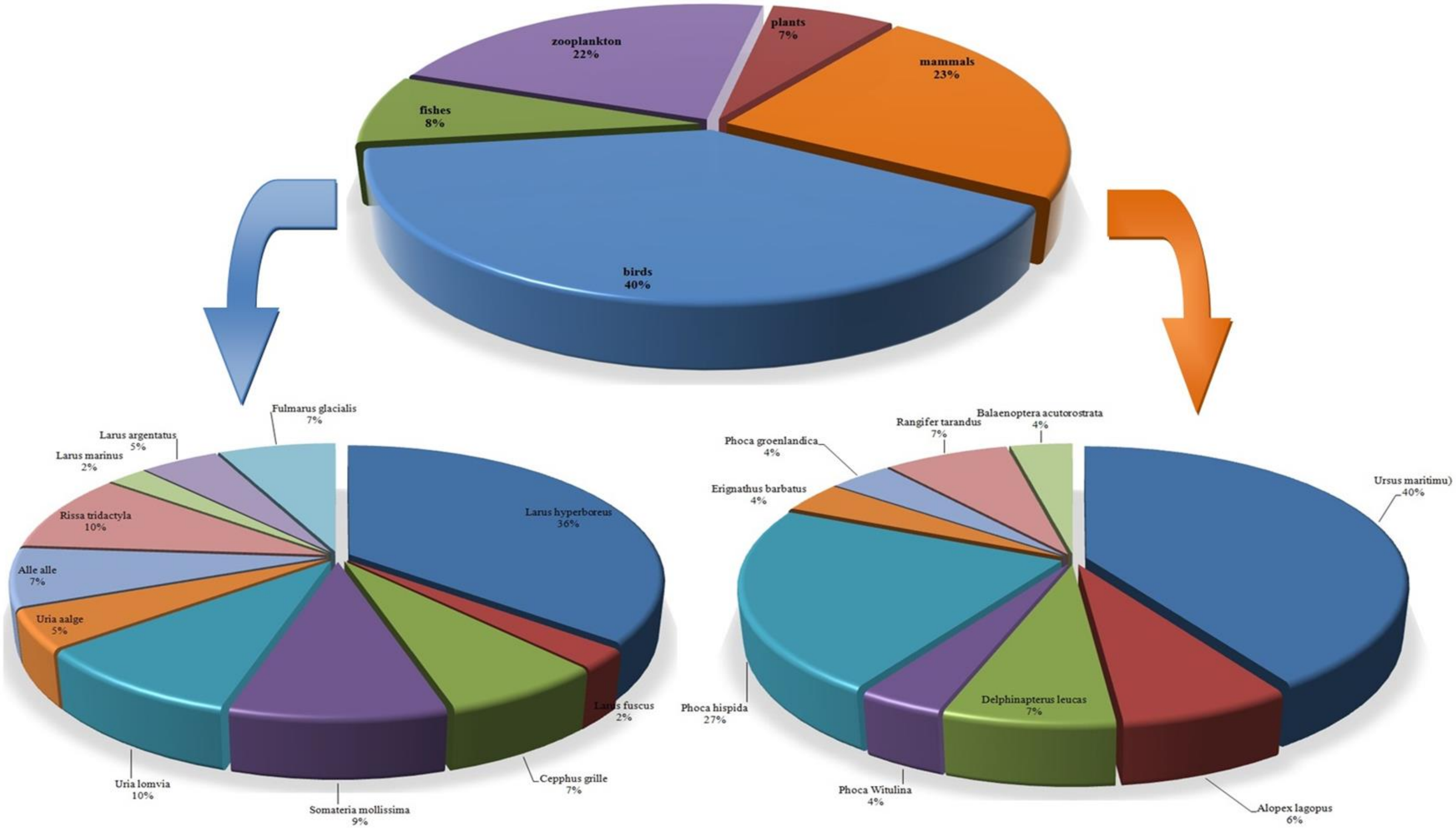

Figure 5. A schematic breakdown of the types of samples of biological material as a source of information about the state of the environment in the Svalbard archipelago.

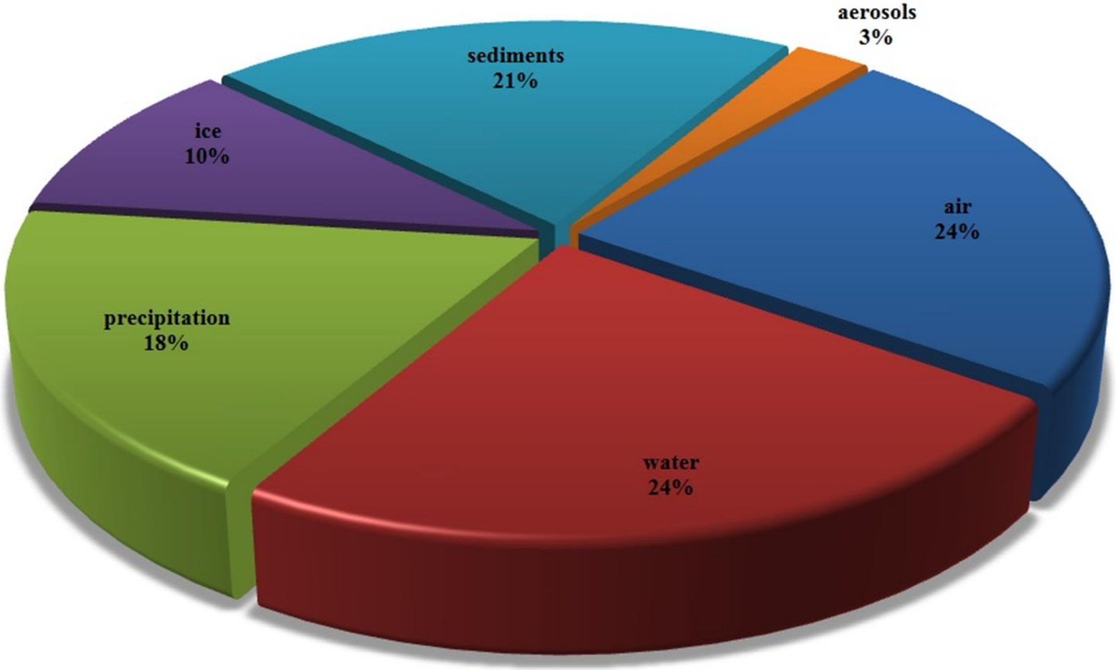

Figure 6. A schematic breakdown of the types of samples of inanimate material as a source of information about the state of the environment in the Svalbard archipelago

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 the biotic and abiotic samples collected in the Svalbard Archipelago region. Based on our review, It is posible to state that gas chromatography is the most often used analytical method. Relatively wide opportunities are given due to application of selective detectors. Application of the ECD enables determination of even very small amounts of chlorinated organic compounds in the mixture. Hypenation of gas chromatography with spectroscopic methods is now routinely used to perform quantitative analysis of very complex mixtures. GC is used not only for the separation of a mixture of compounds but also for the qualitative and quantitative analysis of a wide range of chemical compounds.

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

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

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

		GC-LRMS-EI	[30]
	DIEL, (α,β)Endosulfan, Endrin, Methoxychlor	GC-ECD	[1],[13]
	Toxaphene	GC-ECD GC-LRMS-NCI GC-LRMS-ECNI	[13] [30] [1]
	Mirex, Chlordane (trans,cis), Nonachlor (trans,cis), Oxy	GC-LRMS-NCI GC-ECD HRGC-ECD	[30] [1],[4],[13] [32]
	Hept	GC-LRMS-NCI GC-ECD	[30] [1]
	CHL	HRGC-ECD GC-ECD	[29] [1]
	HCH	GC-ECD HRGC-ECD	[13] [28],[29],[32]
	HCB	GC-ECD HRGC-ECD GC-LRMS-NCI	[1] [4],[13].[25] [28],[29],[32] [30]
	HBCD	GC-MS-NCI HRGC-ECD	[4] [32]
	PBDE	GC-MS-NCI GC-LRMS-NCI GC-LRMS-ECNI HRGC-ECD	[4] [29] [1] [32]
	Metals (Cu,,Cd,Pb,Hg,Se,Zn,Mn,Fe,Ni,Cr,Co)	AAS	[1]
	Hg	AAA HGAAS	[25] [29]
	PFAS, PFCA	HPLC-MS/MS-ESI	[4]
Fulmar (*Fulmarus glacialis*)	Hg	AAA AFA	[25] [44]
	PCB, DDT, HCB	GC-ECD	[25]
	DIEL, MIREX, ENDRIN, Toxaphenes, Oxy, CHL, HCH, PFAS, PCDF, PCDD, Tribromoanisole, HBCD, PBDE	HRGC-LRMS-NICI	[44]
Brűnnich's guillemot (*Uria lomvia*), Black guillemots (*Cepphus gryle*),	Hg	AAA HGAAS	[25] [29]
	PCB	GC-ECD GC-MS HRGC-ECD	[13], [25] [26] [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 (*Alle alle*)	PCB	GC-ECD HRGC-ECD	[25] [31]
	DDE, HCB	GC-ECD	[25]
	Hg	AAA	[25]
Eider (*Somateria mollissima*)	Hg	AAA HGAAS	[25] [29]
	PCB	GC-ECD GC-MS HRGC-ECD	[25] [27] [28],[29]
	DDT, HCB	GC-ECD HRGC-ECD	[25] [28],[29]
	CHL, HCH	HRGC-ECD	[28],[29]
Kittiwake (*Rissa tridactyla*)	Hg	HGAAS	[29]
	PCB, DDT, CHL, HCH, HCB	HRGC-ECD	[28],[29]
Fisches			
Polar cod (*Boreogadus saida*); Arctic charr (*Salvelinus alpinus*), Cod (*Gadus morhua, Boreogadus saida*), Capelin (*Mallotus villosus*) Long rough dab (*Hippoglossoides platessoides*), Herring (*Clupea harengus*)	PCB	HRGC-HRMS-NICI GC-LRMS-NICI GC-MS	[33] [33] [34]
	DDT	HRGC-HRMS-NICI GC-LRMS-NICI GC-MS-ENCI	[33] [33] [35]
	a-endosulfan, Oxy, CHL, HCH	HRGC-HRMS-NICI	[33]
	Hept	HRGC-HRMS-NICI GC-MS	[33] [34]
	CHB	GC-LRMS-NICI GC-MS	[33] [34]
	HCB	GC-MS	[34]
	HBCD	GC-MS-NCI	[4]
	PBDE	GC-MS-NCI GC-LRMS-NICI	[4] [33]

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

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

Type of biological sample	Determined compounds/compound groups	Analyitical Metod	Literature
Air	PAHs	HRGC-MS GC-MS-EI	[1] [33]
	PCB	HRGC-MS HRGC-HRMS-EI GC-HRMS	[1] [1] [55],[57]
	Heptachlor, Oxy, CHL	GC-MRMS	[57]
	Chlordane(trans,cis)	GC-MS-EI HRGC-MS HRGC-LRMS-NICI GC-HRMS	[33] [1] [1] [57]
	Nonachlor(trans,cis)	HRGC-MS HRGC-LRMS-NICI GC-HRMS	[1] [1] [57]
	DDT, HCH	GC-MS-EI GC-MS-NICI HRGC-MS HRGC-HRMS-EI GC-HRMS	[33],[60] [60] [1], [56] [1] [57]
	HCB	GC-MS-EI GC-MS-NICI HRGC-MS GC-HRMS	[33],[60] [60] [1] [57]
	Metals (Ni,Hg,Pb,Cd,Cu)	ICP-MS	[60]
	n-Alkanes (17-29)	HRGC-FID	[1]
	n-Alkanoic acids (14-28)	HRGC-MS	[1]
	PCN	HRGC-LRMS	[33]
	PAHs, n-Alkanes	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]
Glacier ice, ice core, ice	PCB	GC-MS-EI GC-HRMS-EI	[33] [49]
	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,	GC-LRMS-EI GC-ECD GC-MS-ECNI	[1] [54] [54]
	Methoxychlor, Ethion, Fenitrothion, Fonofos, Guthion, Methyl-Parathion, Hexazinone, Metolachlor, Flutriafol	GC-LRMS-EI	[1]
	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]

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 (*Ursus maritimus*)	PCB 28 -209	1-27900	0.1-13.5	[4],[18],[19],[20]
	∑(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]
	∑(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]
	∑(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]
	∑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]
	∑(8)PBDE	20.74-44.55	2.65-9.72	[4]
	Hg	1.02-14.19 [μg/g d. w.]	-	[42]
Reindeer (*Rangifer tarandus*)		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]
	∑(16)PAH	49-340	-	[41]
Arctic foxes (*Alopex lagopus*)		ng/g lipid weight	-	
	PCB 85-209	0.1-120670.5	-	[4],[24]
	∑(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]
Ringed seal (*Phusa hispida*), Harp seal (*Phoca groenlandica*), Bearded seal (*Erignathus barbatus*), Harbor seals (*Phoca vitulina*)		ng/g lipid weight	ng/g wet weight	
	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]
White whales (*Delphinapterus leucas*), Minke whale (*Balaenoptera acutorostrata*)		ng/g lipid weight	ng/g lipid weight	
	∑(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]
	∑(5-7)CHL	-	115-6143	[4],[36],[37]
	HCH(α,γ,β)	-	8.31-210	[36],[4]
	∑HCH	-	15.1-510	[4],[36],[37]
	HCB	-	2.50-1423	[4],[36],[37]
	HBCD	-	5.48-237	[36]
	∑(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]
	∑(7)PBDE	-	22.7-137	[36]
Birds				
		ng/g lipid weight	ng/g wet weight	
Glaucous gull (*Larus hyperboreus, Larus marinus, Larus argentatus*)	∑(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′) DDD(p,p′,o,p′)	5-732300	0.1-84736	[1],[4],[13],[22],[25],[29],[32]
	∑(3-5)DDT	267-7419	5.1-8072.1	[1],[13],[26],[29]
	DIEL	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]
	∑(3-5)CHL	-	0.9-1565.6	[1],[28],[29]
	∑CB	-	8–58	[1]
	HCH(α,γ,β)	2-900	0.02-8800	[1],[29],[32]
	∑HCH	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]
	∑(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]
	∑TEQ	-	0.0655	[1]
	PFAS(PFHxS, PFOS, PFOA , PFNA, PFDA, PFUnA, PFDoA, PFTriA, PFTA, PFPA)	-	0.7-349	[4]
	∑PFCA	-	14.7-262	[4]
Fulmar (*Fulmarus glacialis*)		ng/g lipid weight	ng/g wet weight	
	Total Hg	-	130-3360	[45]
	MeHg	-	450-1600	[45]
	Hg	-	1200-12200	[25],[44]
	PCB 77-169	0.1-111.1	-	[44]
	∑(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]

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

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

	HCB	-	0.5-452.5	[28],[29]
	∑TEQ	-	0.005-0.01	[31]
Fisches				
		ng/g lipid weight	ng/g wet weight	
Polar cod (*Boreogadus saida*); Arctic charr (*Salvelinus alpinus*), Cod (*Gadus morhua, Boreogadus saida*), Capelin (*Mallotus villosus*) Long rough dab (*Hippoglossoides platessoides*), Herring (*Clupea harengus*)	∑(7-33)PCB	-	7-5175	[33],[35]
	∑(3-6)DDT	-	2-423	[33],[35]
	a-endosulfan	-	0.01-0.1	[33]
	Oxy	-	0.11	[33]
	Hept	-	1.7	[33]
	∑(4)CHL	-	3-207	[35]
	α-HCH	-	0.01-0.7	[33]
	γ-HCH	-	0.05-0.4	[33]
	∑(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]
	∑(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 (*Lepidurus arcticus*), Bivalve (*Mya truncata, Serripes groenlandicus, Hiatella arctica, Chlamys islandica*)	PCB 101-194	0.1-40.51	-	[39]
	∑(16-33)PCB	25.57-171.61	5.58	[33],[39]
	∑(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]

	∑(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 (*Strongylocentrotus droebachiensis, Strongylocentrotus pallidus*)	Metal (Cd,Zn,Cu,Pb,Cr,Mn,Fe,Co,Ni,As)	-	30-582000	[38]
Zooplankton				
Calanoid copepods, Thysanoessa inermis, Themisto libellula, Gammarus wilkitzkii, Cyclops abyssorum, Daphnia umblae, Calanus finmarchicus, Calanus glacialis, Calanus hyperboreus, Krill, Themisto abyssorum, Themisto libellula, Chaetognatha		ng/g lipid weight	ng/g wet weight	
	PCB 28 -153	0.1-12.1	-	[34]
	PCB 153	0.3-7.6	-	[34]
	∑(7-33)PCB	-	0.16-60	[33]
	DDE(p,p')	1-26.8	-	[34]
	∑(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]
	∑(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]
	∑(8)PBDE	0.16-14.67	-	[4]
Insect				
Chironomid larvae (*Chironomidae*)		ng/g dry weight	ng/g wet weight	
	∑(33)PCB	-	60.0	[33]
	∑(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 (*Laminaria saccharina, L. digitata, Alaria esculenta*), Filamentous algae (*Conjugatophyceae - Zygnema sp.*), Lichen (*Cetraria nioalis*), Moss (*Tamenfhypnum nitens, Rhacomifriurn lanuginosum*), Vascular plant (*Cassiope tetragona*),		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]
	∑(16)PAH	158-244	-	[41]

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/m3	
	PCB 10-209	0.01-330	[1],[33],[55],[57]
	Σ(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]
	Σ(4-6)DDT	1-17.54	[57],[60]
	ΣCHL	1.86-17.49	[57]
	HCH(α,γ,β)	0.02-203.0	[1],[33],[56],[57],[60]
	ΣHCH	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]
Rainfall		mg/l	
	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]
Snow		ng/l	
	PCB 28-194	0.000001-0.0161	[49]
	∑(7-15)PCB	0.001-2.0	[49],[59]
	∑(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]
	∑(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]

Seawater, groundwater, surface water (streams, river, lake, spring)		ng/l		
	PCB (18-209)	0.00001-308		[1],[49],[63]
	∑(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]
	∑(12)PAH	3.3-603		[1]
	SiO_2	0.12-3.3 [mg/l]		[53]
	pH	6.84-7.03		[53]
Glacier ice, ice core, ice		pg/l	pg*cm^{-2}*rok^{-1}	
	PCB 18 -199	0.004-6.44	-	[49]
	∑(9-15)PCB	2-2000	-	[33],[49]
	DDE (p,p')	-	1.14	[54]
	DDT (p,p'-o,p')	-	2.93-11.5	[54]
	∑DDT	0.391-59.5	-	[54]
	HCH(α,γ)	1.1 -3090	295-369	[1],[33],[54]
	HCB	3.10-35.3	-	[33]
	chlordane (ɣ-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 [μg/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]
Sediment		ng/g dry weight		
	PCB 28 -209	0.1 -12.9		[47],[51],[62],
	∑(7-18)PCB	0.06-60		[1],[47],[48],[51],[62]
	∑DDT	0.07-6.9		[48]
	DIEL	0.5-1.6		[1]
	∑HCH	0.42–7.0		[48]
	BDE(3-209)	0.007-0.46		[48]
	∑(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]
	∑(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]
Soil		ng/g dry weight		
	PAH((Nap,Ace,Acp,Fl,Phe,An,Flu,Pyr, BaA,Chr,BbF,BkF,BaP,DbA,InP,BghiP)	0.3-324		[41]
	∑(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]

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5. Methods of remediation of the Svalbard archipelago

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

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

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

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 In Situ Treatment of Sediment Shorelines (ITOSS)	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 • sediment washing; • sediment mixing; • bioremediation; • bioremediation combined with sediment mixing.	Sveagruva	[64]
				Ex-situ remediation method • 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 • 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 • 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 • 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) • technical methods - pouring - irrigation	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		Creating a method for limiting the chemical activity of coal heaps	Ny- Ålesund	[70]

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

6. Conclusions and remarks

The Arctic region, situated far from the main sources of emission of pollutants, is considered to be predictive of changes in the global environment. It is the source of information which allows early warning against the threats posed by the use of toxic chemical substances. The 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 undertaking of proper actions aimed at prevention of the negative impact of contaminants.

The Svalbard archipelago in the Arctic region had been, until recently, considered to be a pristine area isolated from the influence of anthropogenic degradation present in other geographic regions. However, the results of the studies published in the last few decades prove that pollutants from distant sources are increasingly dangerous for that region which is rich in rare, fragile species of flora and fauna. The environmental conditions and geographic location make the Svalbard archipelago a reservoir of pollution, from hardly volatile to very volatile chemical compounds, which makes the area focus of advanced scientific investigations.

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

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

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

References:

[1] M. Ruman, K. Kozak, S. Lehmann, K. Kozioł, Ż. Polkowska, Pollutants present in different components of the Svalbard archipelago environment, Ecol. Chem. Eng. S. 19 (2012) 571–584.

[2] K.C. Jones, P. de Voogt, Persistent organic pollutants (POPs): state of the science, Environ. Pollut. 100 (1999) 209-221.

[3] C.J. Halsall, A.J. Sweetman, L.A. Barrie, K.C. Jones, Modelling the behaviour of PAHs during atmospheric transport from the UK to the Arctic, Atmos. Environ. 35 (2001) 255-267.

[4] R.J. Letcher, J.O. Bustnes, R. Dietz, B.M. Jenssen, E.H. Jørgensen, C. Sonne, J. Verreault, M.M. Vijayan, G.W. Gabrielsen, Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish, Sci. Total Environ. 408 (2010) 2995-3043.

[5] P. Fernández, J.O. Grimalt, On Global Distribution of Persistent Organic Pollutants, Chimia 57 (2003) 514-527.

[6] Ö. Gustafsson, T.P. Andersson, J. Axelman, T.D. Bucheli, P. Kömp, M.S. McLachlan, A. Sobek , J.O. Thörngren, Observations of the PCB distribution within and in-between ice, snow, ice-rafted debris, ice-interstitial water, and seawater in the Barents Sea marginal ice zone and the North Pole area, Sci. Total Environ. 342 (2005) 261-279..

[7] AMAP, Arctic Pollution Issues: A State of the Arctic Environment Report. Arctic Monitoring and Assessment Programme (AMAP), Oslo, 1997.

[8] T. Koivurova, Environmental Protection in the Arctic and the Antarctic: Can the Polar Regimes Learn from Each Other, International Journal of Legal Information. 33 (2005) 204-218.

[9] A. Umbreit, Spitsbergen: Svalbard, Franz Josef Land & Jan Mayen, fourth ed., Bradt Publications, UK, 2009.

[10] S. Rognerud, J.O. Grimalt, B.O. Rosseland, P. Fernandez, R. Hofer, R. Lackner, B. Lauritzen, L. Lien, J.C. Massabuau, A. Ribes, Mercury and organochlorine contamination in brown trout (Salmo trutta) and Arctic charr (Salvelinus alpinus) from high mountain lakes in Europe and the Svalbard archipelago, Water, Air, and Soil Pollution: Focus 2 (2001) 209-232.

[11] D.J. Hoffman, C.P. Rice, T.J. Kubiak, PCBs and dioxins in birds, in: W.N. Beyer, G.H. Heinz, A.W. Redmon-Norwood (Eds.), Environmental Contaminants in Wildlife-Interpreting Tissue Concentrations (Special Publications Series), CRC Press, Boca Raton, FL, 1996, pp. 165-207.

[12] J.A. Bogan, W.R.P. Bourne, Organochlorine levels in Atlantic seabirds, Nature 240 (1972) 358.

[13] G.W. Gabrielsen, J.U. Skaare, A. Polder, V. Bakken, Chlorinated hydrocarbons in glaucous gulls (Larus hyperboreus) in the southern part of Svalbard, Sci. Total Environ. 160 (1995) 337-346.

[14] J. Ma, H. Hung, Ch. Tian, R. Kallenborn, Revolatilization of persistent organic pollutants in the Arctic induced by climate change, Nature Climate Change 1 (2011) 255-260.

[15] T.J. Garrett, L.L. Verzella, An evolving history of Arctic aerosols, Bull. Am. Met. Soc. 89 (2008) 299-302.

[16] A. Rozwadowska, T. Petelski, T. Zieliński, Pomiary aerozolowe w Hornsundzie w trakcie XXIX wyprawy polarnej PAN, Prob. Klim. Pol. 18 (2008) 161-170.

[17] M. Oehme , A. Biseth , M. Schlabach, Ø. Wiig, Concentrations of polychlorinated dibenzo-p-dioxins, dibenzofurans and non-ortho substituted biphenyls in polar bear milk from Svalbard (Norway), Environ. Pollut., 90 (1995) 401-407.

[18] A. Bernhoft, Ø. Wiig, J.U. Skaare, Organochlorines in Polar Bears (Ursus maritimus) at Svalbard, Environ. Pollut. 95 (1997) 159-175.

[19] E.O. Henriksen , Ø. Wiig , J.U. Skaare , G.W. Gabrielsen , A.E. Derocher, Monitoring PCBs in polar bears: lessons learned from Svalbard, J. Environ. Monit. 3 (2001) 493-498.

[20] L. Kleivane , T. Severinsen , J.U. Skaare, Biological transport and mammal to mammal transfer of organochlorines in Arctic fauna, Mar. Environ. Res., 49 (2000) 343-357.

[21] K. Bang, B.M. Jenssen, C. Lydersen, J.U. Skaare, Organochlorine burdens in blood of ringed and bearded seals from north-western Svalbard, Chemosphere, 44 (2001) 193-203.

[22] J. Wolkers, I.C. Burkow, C. Lydersen, S. Dahle, M. Monshouwer, R.F. Witkamp, Congener specific PCB and polychlorinated camphene toxaphene. levels in Svalbard ringed seals Phoca hispida in relation to sex, age, condition and cytochrome P450 enzyme activity, Sci. Total Environ. 216 (1998) 1-11.

[23] H. Routti, B. van Bavel, R.J. Letcher, A. Arukwe, S. Chu, G.W. Gabrielsen, Concentrations, patterns and metabolites of organochlorine pesticides in relation to xenobiotic phase I and II enzyme activities in ringed seals (Phoca hispida) from Svalbard and the Baltic Sea, Environ. Pollut. 157 (2009) 2428-2434.

[24] G. Wang-Andersen, J.U. Skaare, P. Prestrud, E. Steinnes, Level and congener pattern of PCBs in artic fox, Alopex lagopus, in Svalbard, Environ. Pollut. 82 (1993) 269-275.

[25] G. Norheim, B. Kjos-Hanssen, Persistent Chlorinated Hydrocarbons and Mercury in Birds Caught Off the West Coast of Spitsbergen, Environ. Pollut. 33 (1984) 143-152.

[26] F.F. Daelemans, F. Mehlum, P. J. C. Schepens, Polychlorinated Biphenyls in Two Species of Arctic Seabirds from the Svalbard Area, B. Environ. Contam. Tox. 48 (1992) 828-834.

[27] F. Mehlum, F. F. Daelemans, PCBs in Arctic seabirds from the Svalbard region, Sci. Total Environ. 160 (1995) 441-446.

[28] T.N. Savinova, A. Polder, G.W. Gabrielsen, J.U. Skaare, Chlorinated hydrocarbon in seabirds from the Barents Sea area, Sci. Total. Environ. 160 (1995) 497-504.

[29] R.T. Barrett, , J.U. Skaare, G.W. Gabrielsen, Recent changes in levels of persistent organochlorines and mercury in eggs of seabirds from the Barents Sea, Environ. Pollut. 92 (1996) 13-18.

[30] D. Herzke, G.W. Gabrielsen, A. Evenset, I.C. Burkow, Polychlorinated camphenes (toxaphenes), polybrominated diphenylethers and other halogenated organic pollutants in glaucous gull (Larus hyperboreus) from Svalbard and Bjørnøya (Bear Island), Environ. Pollut. 121 (2003) 293-300.

[31] K. Borgå, H. Wolkers, J.U. Skaare, H. Hop, D.C.G. Muir, G.W. Gabrielsen, Bioaccumulation of PCBs in Arctic seabirds: influence of dietary exposure and congener biotransformation, Environ. Pollut. 134 (2005) 397-409.

[32] K. Sagerup, L.B. Helgason, A. Polder, H. Strøm, T.D. Josefsen, J.U. Skåre, G.W. Gabrielsen, Persistent organic pollutants and mercury in dead and dying glaucous gulls (Larus hyperboreus) at Bjørnøya (Svalbard), Sci. of the Total Environ. 407 (2009) 6009-6016.

[33] T.F. Bidleman, P.A. Helm, B.M. Braune, G.W. Gabrielsen, Polychlorinated naphthalenes in polar environments - A review, Sci. Total Environ. 408 (2010) 2919-2935.

[34] I.G. Hallanger, A. Ruus, N.A. Warner, D. Herzke, A. Evenset, M. Schøyen, G.W. Gabrielsen, K. Borgå, Differences between Arctic and Atlantic fjord systems on bioaccumulation of persistent organic pollutants in zooplankton from Svalbard, Sci. Total Environ. 409 (2011) 2783-2795.

[35] K. Stange, J. Klungsøyr, Organochlorine contaminants in fish and polycyclic aromatic hydrocarbons in sediments from the Barents Sea, J. Mar. Sci. 54 (1997) 318-332.

[36] G.D. Villanger, C. Lydersen, K.M. Kovacs, E. Lie, J.U. Skaare, B.M. Jenssen, Disruptive effects of persistent organohalogen contaminants on thyroid function in white whales (Delphinapterus leucas) from Svalbard, Sci. Total Environ. 409 (2011) 2511-2524.

[37] K.E. Hobbs , D.C.G. Muir, E.W. Born, R. Dietz, T. Haug, T. Metcalfe, C. Metcalfe, N. Øien, Levels and patterns of persistent organochlorines in minke whale (Balaenoptera acutorostrata) stocks from the North Atlantic and European Arctic, Environ. Pollut. 121 (2003) 239-252.

[38] I.Y. Ahn, J. Ji, H. Park, Metal accumulation in sea urchins and their kelp diet in an Arctic fjord (Kongsfjorden, Svalbard), Mar. Pollut. B. 58 (2009) 1571-1577.

[39] I. Vieweg, H. Hop, T. Brey, S. Huber, W.G. Ambrose Jr., W.L. Locke 5th, G.W. Gabrielsen, Persistent organic pollutants in four bivalve species from Svalbard waters, Environ. Pollut. 161 (2012) 134-142.

[40] K. Drbal, J. Elster, J. Komárek, Heavy metals in water, ice and biological material from Spitsbergen, Svalbard, Polar Res. 2 (1992) 99-101.

[41] Z. Wang, X. Ma, G. Na, Z. Lin, Q. Ding, Z. Yao, Correlations between physicochemical properties of PAHs and their distribution in soil, moss and reindeer dung at Ny-Ålesund of the Arctic, Environ. Pollut. 157 (2009) 3132-3136.

[42] E.W. Born, A. Renzoni, R. Diez, Total mercury in hair of polar bears (Ursus maritimus) from Greenland and Svalbard, Polar Res. 9 (1991) 113-120.

[43] T. Severinsen, J.U. Skaare, C. Lydersen, Spatial distribution of persistent organochlorines in ringed seal (Phoca hispida) blubber, Mar. Environ. Res. 49 (2000) 291-302.

[44] L.B. Knudsen, K. Borgå, E.H. Jørgensen, B. van Bavel, M. Schlabach, J. Verreault, G.W. Gabrielsen, Halogenated organic contaminants and mercury in northern fulmars (Fulmarus glacialis): levels, relationships to dietary descriptors and blood to liver comparison, Environ. Pollution 146 (2007) 25-33.

[45] I. Jæger, H. Hop, G.W. Gabrielsen, Biomagnification of mercury in selected species from an Arctic marine food web in Svalbard, Sci. Total Environ. 407 (2009) 4744-4751.

[46] A. Hodson, M. Tranter, A. Gurnell, M. Clark, J.O. Hagen, The hydrochemistry of Bayelva, a high Arctic proglacial stream in Svalbard, J. Hydrol. 257 (2002) 91-114.

[47] G. Sapota, B. Wojtasik, D. Burska, K. Nowiński, Persistent Organic Pollutants (POPs) and Polycyclic Aromatic Hydrocarbons (PAHs) in surface sediments from selected fjords, tidal plains and lakes of the North Spitsbergen, Polar Res. 30 (2009) 59-76.

[48] L. Jiao, G.J. Zheng, T.B. Minh, B. Richardson, L. Chen, Y. Zhang, L.W. Yeung, J.C.W. Lam, X. Yang, P.K.S. Lam, M.H. Wong, Persistent toxic substances in remote lake and coastal sediments from Svalbard, Norwegian Arctic: Levels, sources and fluxes, Environ. Pollut. 157 (2009) 1342-1351.

[49] Ö. Gustafsson, T.P. Andersson, J. Axelman, T.D. Bucheli, P. Kömp, M.S. McLachlan, A. Sobek, J.O. Thörngren, Observations of the PCB distribution within and in-between ice, snow, ice-rafted debris, ice-interstitial water, and seawater in the Barents Sea marginal ice zone and the North Pole area, Sci. Total Environ. 342 (2005) 261-279.

[50] S. Boitsov, H.K. Jensen, J. Klungsøyr, Natural background and anthropogenic inputs of polycyclic aromatic hydrocarbons (PAH) in sediments of South-Western Barents Sea, Mar. Environ. Res. 68 (2009) 236-245.

[51] T. Skotvold, V. Savinov, Regional distribution of PCBs and presence of technical PCB mixtures in sediments from Norwegian and Russian Arctic Lakes, Sci. Total Environ. 306 (2003) 85-97.

[52] C.P. Ferrari, C. Padova, X. Faïn, P-A. Gauchard, A. Dommergue, K. Aspmo, T. Berg, W. Cairns, C. Barbante, P. Cescon, L. Kaleschke, A. Richter, F. Wittrock, C. Boutron, Atmospheric mercury depletion event study in Ny-Alesund (Svalbard) in spring 2005. Deposition and transformation of Hg in surface snow during springtime, Sci. Total Environ. 397 (2008) 167-177.

[53] F R. Siegel, J.L. Galasso, J.H. Kravitz, W.D. Basinger, The Svalbard western coast: site of baseline geochemistry and incipient contamination, Environ. Geol. 39 (2000) 816-822.

[54] R.M. Ruggirello, M.H. Hermanson, E. Isaksson, C. Teixeira, S. Forsström, D.C.G. Muir, V. Pohjola, R. van de Wal, H.A.J. Meijer, Current use and legacy pesticide deposition to ice caps on Svalbard, J. Geophys. Res. 115 (2010) D18308, doi:10.1029/2010JD014005.

[55] Choi S.D., Baek S.Y., Chang Y.S., Wania F., Ikonomou M.G., Yoon Y.J., Park B.K., Hong S., Passive Air Sampling of Polychlorinated Biphenyls and Organochlorine Pesticides at the Korean Arctic and Antarctic Research Stations: Implications for Long-Range Transport and Local Pollution, Environ. Sci. Technol. 42 (2008) 7125-7131.

[56] S. Becker, C.J. Halsall, W. Tych, R. Kallenborn, Y.S.H. Hung, Long-term trends in atmospheric concentrations alpha- and gamma-HCH in the Arctic provide insight into the effects of legislation and climatic fluctuations on contaminant levels, Atmos. Environ. 42 (2008) 8225-8233.

[57] R. Kallenborn, G. Christensen, A. Evenset, M. Schlabach, A. Stohl, Atmospheric transport of persistent organic pollutants (POPs) to Bjørnøya (Bear island), J. Environ. Monitor. 9 (2007) 1082-1091.

[58] P. de Caritat, G. Hall, S. Gìslason, W. Belsey, M. Braun, N.I. Goloubeva, H.K. Olsen, J.O. Scheie, J.E. Vaive, Chemical composition of arctic snow: concentration levels and regional distribution of major elements, Sci. Total Environ. 336 (2005) 183-199.

[59] B.M.J. Herbert, S. Villa, C.J. Halsall, Chemical interactions with snow: Understanding the behavior and fate of semi-volatile organic compounds in snow, Ecotox. Environ. Safe. 63 (2006) 3-16.

[60] T. Berg, R. Kallenborn, M. Stein, Temporal Trends in Atmospheric Heavy Metal and Organochlorine Concentrations at Zeppelin, Svalbard, Arct. Antarct. Alp. Res. 36 (2004) 284-291.

[61] W.E. Krawczyk, S.A. Bartoszewski, K. Siwek, Rain water chemistry at Calypsobyen, Svalbard, Pol. Polar Res. 29 (2008) 149-162.

[62] N.L. Rose, C.L. Rose, J.F. Boyle, P.G. Appleby, Lake-sediment evidence for local and remote sources of atmospherically deposited pollutants on Svalbard, J. Paleolimnol. 31 (2004) 499-513.

[63] A. Sobek, Ö. Gustafsson, Latitudinal Fractionation of Polychlorinated Biphenyls in Surface Seawater along a 62° N 89° N Transect from the Southern Norwegian Sea to the North Pole Area, Environ. Sci. Technol. 38 (2004) 2746-2751.

[64] E. H. Owens, G.A. Sergy, C.C. Guénette, R.C. Prince, K. Lee, The Reduction of Stranded Oil by In Situ Shoreline Treatment Options, Spill Sci. Technol. B. 8 (2003) 257-272.

[65] R.M. Garrett, S.J. Rothenburger, R.C. Prince, Biodegradation of Fuel Oil Under Laboratory and Arctic Marine Conditions, Spill Sci. Technol. B. 8 (2003) 297-302.

[66] S. Røberg, J.I. Østerhus, B. Landfald, Dynamics of bacterial community exposed to hydrocarbons and oleophilic fertilizer in high-Arctic intertidal beach, Polar Biol. 34 (2011) 1455-1465.

[67] M. Børresen, G.D. Breedveld, A.G. Rike, Assessment of the biodegradation potential of hydrocarbons in contaminated soil from a permafrost site, Cold Reg. Sci. Technol. 37 (2003) 137-149.

[68] B. Gerdes, R. Brinkmeyer, G. Dieckmann, E. Helmke, Influence of crude oil on changes of bacterial communities in Arctic sea-ice, FEMS Microbiol. Ecol. 53 (2005) 129-139.

[69] J. Hollesen , B. Elberling , B.U. Hansen, Modelling subsurface temperatures in a heat producing coal waste rock pile, Svalbard (78°N), Cold Reg. Sci. Technol. 58 (2009) 68-76.

[70] ARCFAC PROJECT REPORT, V. (EC contract No. ARCFAC 026129), Norwegian Polar Institutte Svalbard, Longyearbyen, 2007, http://arcfac.npolar.no/pdf/Project_Reports/ID12_Murray_Rprt.pdf.