DOI: 10.2478/v10216-011-0040-9 ECOL CHEM ENG S. 2012;19(4):571-584

Marek RUMAN[1], Katarzyna KOZAK[2], Sara LEHMANN[2], Krystyna KOZIOŁ[3] and Żaneta POLKOWSKA[2*]

POLLUTANTS PRESENT IN DIFFERENT COMPONENTS OF THE SVALBARD ARCHIPELAGO ENVIRONMENT

ZANIECZYSZCZENIA OBECNE W RÓŻNYCH KOMPONENTACH ŚRODOWISKA ARCHIPELAGU SVALBARD

Abstract: During last years an interest in the processes of transport and fate of pollutants to the polar regions located distantly from industrial centers, has significantly increased. The current analytical techniques enabling conducting studies prove that the Arctic regions (in the past considered as a pollution free area) have become an area of highly intensive anthropopresion. Svalbard archipelago stands out from the other polar regions due to its specific environmental conditions and geographic location, which results in becoming a reservoir of contamination in this area. Systematic environmental monitoring of arctic regions is extremely important due to an unique opportunity of observing a direct impact of pollution on the ongoing processes in the area of interest. In this way measurement data obtained are a valuable source of information, not only on changes occurring in the Arctic ecosystem, but also on estimated global impact of certain xenobiotics present in the environment. Furthermore, qualitative and quantitative studies on particular chemicals deposited in different regions of the Arctic ecosystem may constitute the basis for undertaking actions aimed at preventing negative effects caused by these pollutants.

Keywords: long-range transport of pollutants, persistent organic pollutant

Introduction

Svalbard is an archipelago located between 74°N and 81°N and 10-35°E. Situated entirely northward from the polar circle, it is an isolated group of islands, separated from Greenland and Franz Josef Land by wide straits. The Scandinavian Peninsula, closest part of mainland Europe, is 800 km distant from Svalbard. Thus, the area is far from potential

[1] Faculty of Earth Sciences, University of Silesia, ul. Będzińska 60, Sosnowiec 41-200, Poland, email: marek.ruman@us.edu.pl
[2] Department of Analytical Chemistry, The Chemical Faculty, Gdansk University of Technology, ul. Narutowicza 11/12, 80-233 Gdansk, Poland, phone +48 58 347 21 10, fax +48 58 347 26 94, email: katarzynakozak.gda@o2.pl
[3] Department of Geography, University of Sheffield, Winter Street, Sheffield S10 2TN, UK, email: k.a.koziol@gmail.com
[*]Corresponding author: zanpolko@pg.gda.pl

sources of pollution, besides small local sources. Even so, the Arctic haze phenomenon extends the residence time of pollutants in local environment [1].

There are a few permanent settlements in Svalbard, including the capital - Longyearbyen (others are: Ny Alesund, Sveagruva and Barentsburg). All these were set up as mining localities, however Ny Alesund changed its role fully into a research centre, and the other settlements (particularly Longyearbyen) are partly research and tourism bases. Several research stations are located in other places on Spitsbergen island: the Polish Polar Station in Hornsund and smaller, seasonal research stations, *eg* in Kaffioyra, Bellsund, Petuniabukta [2]. On Bjornoya and Hopen, there are meteorological stations led by the Norwegian Meteorological Institute. There are also both weather and radio stations on Kapp Linne (Isfjord Radio). All the research activities are undertaken in accordance with the Svalbard Treaty, signed on the 9th February 1920 [3].

These settlements and ships are main local contaminant sources. Cruise ships concentrate their activities in the vicinity of Hornsund, Bellsund, Isfjord and north-western coast of Spitsbergen, but they reach also Nordaustlandet and Edgeoya. Not only they burn fuel and pollute the air, but they also allow thousands of tourists visiting coastal parts of these islands (mysteriously, they land most frequently in places occupied by Red Listed plant species) [4]. Even organic air pollution can be of local origin, *eg* in Longyearbyen snowmobile traffic causes in April and May "rush-hour" maxima of aromatic hydrocarbons in the air (up to 10 ppb [5]).

However, the main source for pollution Svalbard is the long-range transport of contaminants, and their persistence due to Arctic haze phenomenon. There is still ongoing debate, whether this transport is happening in the air for all the way or maybe some substances are travelling in the seawater with ocean currents [6]. A deposition and remobilization theory, that includes both transport media, is a possible solution to this question [7]. When the pollutants reach Svalbard, their occurrence is detected in atmospheric monitoring stations (*eg* Ny Alesund).

Transport of pollutants throughout the Svalbard Archipelago

Pollutants can be transported over significant distances. They can cross national borders and even continents. The range of their impact can be distanced from their source of emission by thousands of kilometers, which is why the harmful effects of chemical compounds introduced into the environment was neglected for a long time. The results of research conducted on the quality of air and water in areas considered to be free from the influence of anthropogenic pollution indicate that harmful compounds are deposited on a vast area, including the Svalbard archipelago [8].

Transport of pollutants over long distances includes: transport in surface waters, transport in air, global distribution of pollutants in difference components of the environment (air, water, soil, living organisms) [9].

For the most part, transport over long distances is a consequence of the mass movement of air or water. However, the movement can also occur by diffusion, rapid in the air and somewhat slower in water. The fate of pollutants depends both on the properties of the substances themselves as well as environmental factors. The properties of substances that may affect their transport and distribution in the environment includes: polarity, partition coefficient, vapor pressure, stability. Meanwhile, the environmental factors which have a crucial significance include: temperature, wind speed, air mass circulation, the move of surface waters (currents) [9].

The deposition of pollutants in the Svalbard archipelago is determined by its position (high geographical latitudes) and climatic factors. Low temperatures recorded in this area mean that a condition for survival for many species of animals is the consumption of lipids, which are the main source of energy. Fats, however, are a very good solvent for a large group of pollutants, which contribute to their penetration into the food chain [10].

The presence of persistent pollutants from anthropogenic sources in environmental samples collected from polar areas indicate that these compounds can be transported over long distances, far from the places of their release into the environment. The transport of pollutants to polar regions occurs mainly through the atmosphere. During the winter, atmospheric circulation contributes to the creation of a "tunnel", through which pollutants are transported from regions in Central Europe and industrialized areas of Siberia. During the summer, the transport of pollutants from lower latitudes to the north is difficult. The resulting polar front creates a barrier to the polluted air masses [11].

The transport of pollutants over long distances is dependent on circulation and the movement of air masses as well as the physical state of the pollution. They can appear both in a gaseous phase as well as in bound forms, such as droplets and dust particles. Pollutants can be deposited in wet and dry forms [9].

Oceans also play an important role in the circulation and removal of *persistent organic pollution* (POPs). Much of the POPs in water originate from atmospheric deposition. Less volatile and more hydrophobic POPs (such as *polycyclic aromatic hydrocarbons*, PAHs) in marine waters may be subjected to sorption by microorganisms. In this way, a portion of the POPs is removed from surface waters; however, harmful substances do not decompose but are stored in sediments [12].

Pollutants in water appear in various forms. They can be dissolved or adsorbed in suspension. In this form, pollutants can be transported over long distances. The main factor in the spread of pollutants is surface currents. Another important factor influencing the transport of pollutants is water density, whose increase results in water masses being transported to ocean deeps. It is often assumed that oceans, as a result of their size, dilute pollutants and at the same time reduce their concentrations to low levels. However, the distribution of pollutants is not uniform, which can be caused by currents and the falling of suspended matter to the ocean bottom. Also, as a result of the inclusion of POPs in the marine food chain, pollutants can be transported over significant distances and cause the movement of these compounds from one ecosystem to another [9].

Geological-climatic considerations of the Svalbard Archipelago

Geological and geomorphological circumstances

Svalbard is a geologically diversified area, consisting of rocks formed as early as in Precambrian, as well as Tertiary and Quaternary sediments. Western and north-eastern part of the archipelago is built of rocks called *The Basement*, formed before Silurian. These rocks underwent multiple metamorphosis, folding and faulting episodes. The oldest rocks found in the area, dated using zircon minerals, are 3200 million years old [13]. The southern part is generally formed by post-Devonian strata, with Tertiary rocks located in the middle of the area (Central Tertiary Basin, with almost horizontal rock layers [14]). Devonian rocks show only in the middle north of Spitsbergen (the biggest island of the archipelago). Tertiary strata contain coal seams, recently mined in the vicinity of Longyearbyen, Sveagruva and Barentsburg (the latter being rather nominal [15]). Several oil drilling research activities were undertaken, but no significant field was found so far in Svalbard shelf [16, 17].

60% of Svalbard area is glaciated, thus glaciers can be considered the main geomorphological factor in the archipelago. Most of the area is covered by individual ice streams, which join in areas lacking ridges and nunataks. There are some cirque glaciers as well in the area [18]. 90% of glaciers in Svalbard are considered polythermal (subpolar), partly below pressure melting point temperature. Typically, the glaciers move with moderate velocities, not exceeding 1 m per year (in water equivalent) for ice flow and 10 m per year for surface velocity at ELA. However, rapid movement occurs as well, particularly during surge episodes (surge-type glaciers being numerous in Svalbard; [14, 18]). Surges tend to repeat in cycles, which in Svalbard last between several decades and several hundreds of years [19].

Earlier in the Quaternary, the whole Svalbard was covered with an ice sheet. Once it melted, isostatic movements lifted the land, leaving raised beaches next to the shores [14]. Even nowadays the mass balance of Svalbard glaciers is negative, so the percentage covered by ice diminishes. Particularly intensive ablation is experienced by tidewater glaciers, where additional ablation process is calving [19]. Along with glaciers, ice-cored moraines melt and reshape [20].

The non-glaciated area of Svalbard shows an influence of glacial and fluvioglacial shaping, with vast moraines and sandurs, as well as periglacial processes [20, 21]. Coastal zones show influence of former deglaciation [22]. Permafrost in Svalbard is continuous with depths varying between 1 and 500 meters, depending on distance from the sea [14]. The freeze-thaw processes in the active layer cause the formation of patterned grounds in forms of rings and hexagons, or sometimes without that much regularity. In areas with thick debris cover, like scree slopes and talus cones, rock glaciers form by freezing of water between rock fragments. Another periglacial feature often spotted in Svalbard is formations of pingos - some 80 of them were identified in the archipelago [14]. A thorough characterisation of these and other periglacial phenomena in Svalbard was given by Humlum et al [23].

Geological circumstances (limestone, marble, dolomite and gypsum layers) facilitate the occurrence of Karst features in the archipelago as well. On the shores, littoral karstic processes form niches and rounded stacks. In a few locations in Svalbard hydrothermal Karst occurs. The largest area of hydrothermal Karst, located on Sorkappland, is formed around Trolosen springs. Features similar to karstic, *eg* caves, are also found in glaciers [24].

Climatological conditions

Geomorphology of Svalbard, due to its significant proportion of ice-covered area, is prone to change for climatic reasons, particularly with recent warming trends. For example, in the years 1995-2005 the mean surface air temperature in the Arctic has risen for 1°C as compared with 1951-1990 mean, which was followed by retreat of many glaciers in the archipelago [25].

Temperatures in Svalbard are highly influenced by the local branch of Gulf Stream, which makes the area the most favourable place in the Arctic - temperature-wise - for human activities [26]. The warm current increases also the humidity of the area, so that the Norwegian Arctic is one of the most humid part of the northern circumpolar area [27]. Moreover, the warming effect has been increasing over the last decades, as shown by surface sea water temperature changes. Around Svalbard, there were statistically significant warming trends of surface sea water temperature between 1983 and 2004 [28].

Not only oceanic, but also atmospheric circulation shapes major climatological conditions in Svalbard. Typical atmospheric circulation for Svalbard is dominated by low pressure, eastern and northern directions of air influx, especially between October and March [29]. However, the circulation patterns in Svalbard have changed significantly since 1950. The frequency of southern and western circulation increased, and also, the activity of low pressure systems increased [30]. These changes influenced also the frequency of extreme precipitation events (with high totals). Because of that, two years in the last decade of 20th century in Hornsund were characterised by precipitation totals above 600 mm [31]. The highest daily total in Hornsund was reached in 1994, and it equalled to 58.3 mm [32].

Precipitation is significantly influenced by the orographic effect, *eg* winter accumulation snow on Hans glacier (in water equivalent) can be even 10 times the precipitation in Polish Polar Station in Hornsund, close to the sea shore, during the same period [33]. Also the topoclimate of glaciers influences precipitation and temperatures locally [34]. Typical annual precipitation totals in the stations located close to the sea shore vary between 190 and 525 mm [35].

Radiation in Svalbard is heavily influenced by annual cycle of polar day and night, with transitional periods in spring and autumn. The month with highest total radiation is June, *eg* in Hornsund in 2008 the total radiation amounted to 545 MJm^{-2}. The radiation balance for Hornsund for one year (V 2008 - IV 2009) was equal to 105 MJm^{-2} which portrays the harsh conditions in the area [36]. Thus, the vegetation starts to bloom in lower temperatures than in temperate latitudes: 0°C is the beginning of vegetation period in Svalbard and 2.5°C is enough for flowers to blossom and produce seeds [37].

The plant cover interacts with local climate conditions both ways. Albedo values on tundra differ between a few and 90% in autumn, when the snow cover is not stable; on the opposite, spring values are characterised by very small changes. In the summer (July-August), only 14÷17% of incident radiation is reflected from the plant-covered surface, which enables the ground to gain warmth at that time. The ground devoid of plant cover conducts heat downwards while plants conserve favourable conditions for life in the thin layer around the ground surface [38, 39].

Hydrological features

The main sources of liquid water in Svalbard are melting of the glaciers, snow and permafrost plus rain. In glaciated catchments 90% of overall discharge comes from glacier melt [40]. The characteristics of a proglacial river outflow were described by Sobota et al [41] using Waldemar River in Svalbard as an example. Peak discharges occurred in connection to high temperatures and foehn effects. Also daily discharge dynamics links to temperature cycle (with a small time lag), with minima in the morning and maxima between 4 and 6 p.m. Typical for proglacial rivers is high suspended sediment load, for Waldemar River on average 0.38÷0.41 g/dm^3. Other characteristics of proglacial discharge in Svalbard can be found *eg* in Hodson et al [42, 43], Krawczyk & Bartoszewski [44] and Hodgkins et al [45].

While precipitation water in Svalbard is usually characterised by dominant sodium and chloride ions, riverine waters tend to take up magnesium, calcium and carbonate ions from rock sources, sometimes supplemented by sulphate ion [43, 46, 47]. Hodson et al [43] mention three factors that shape chemical composition of riverine waters in Svalbard: release of solute from snow, rapid reactions with mineral material and slow dissolution of silicate minerals. Proglacial waters in Bellsund region [46] showed mineralisation values between 50 and 100 mg/dm^3 TDS (Total Dissolved Solids), while waters of non-glacierised catchments reached TDS concentration of 200 mg/dm^3. Yet another example of comparison between glacial catchment and an ice-free one, is provided in two articles by Krawczyk [48, 49]. For a hydrological year with relatively low discharge denudation rates in glacial catchment (Bayelva) were almost twice as high as in the karst catchment devoid of glaciers (Londonelva).

Flora and fauna in the Svalbard Archipelago

The area with plant cover on Spitsbergen (largest island in the archipelago) is estimated for 10% [2]. Svalbard contains three bioclimatic zones: polar desert, northern Arctic tundra and middle Arctic tundra. Due to this extent of diversity, plant communities can cover less than 5% and up to 50% of land in different locations. The areas richest in vegetation are those around inner fiords, which is exemplified by rich collections in herbaria from Bellsund area [4, 50].

About 5800 floral and faunal species live in the vicinity of Svalbard, of which approximately 4000 are terrestrial [4]. 165 species are native vascular plants, the local flora being richer than elsewhere at the same latitude with similarities to floras of Novaya Zemlya and Franz Josef Land [51, 52]. Floral composition is dominated by lichens (at least 600 species [53], and mosses on land, with addition of flowering plants, including dwarf trees (polar willow *Salix polaris*, net-leaved willow *Salix reticulate* and dwarf birch *Betula nana* [54]).

Plants and animals in the Arctic have developed several strategies to survive freezing temperatures and other adverse environmental conditions. Appropriate strategies include freeze avoidance, freeze tolerance and protective dehydration [55]. To propagate despite the short vegetation season, plants use vegetative reproduction frequently [4].

The areas of most abundant vegetation are those fertilised by excrements, while sparse is plant cover of the disturbed places. Bird cliff meadows and lush moss tundra occur below slopes inhabited by bird colonies, due to fertilising effect; reindeer and other grazing species may be important providers of fertilising nutrients as well [4, 56]. These prove to be important seed banks for the surrounding areas [51]. On the other hand, areas freshly deglaciated and disturbed by river erosion and deposition are those devoid of plant cover. Other areas do not seem to have changed the vegetation cover extent significantly over decades [57]. People in the Arctic also cause disturbances to plant cover, particularly by leaving vehicle tracks and pedestrian trampling. In extreme cases, these can lead to a complete change of environment, *eg* by draining wetland through a single track [58]. Some of these disturbed places need several decades to recover, *eg* vehicle tracks left after building the Polish Polar Station in Hornsund remain unchanged after more than 50 years.

Important to mention are also marine ecosystems, diversified in deep fjords according to the proportion of freshwater coming from rivers and melting glaciers, as well as saline oceanic water, the influx of which can be blocked by sea floor topography. An example of thorough fiord ecosystem investigation can be found in Hop et al [59].

Human activity and pollution

In the Svalbard air, many pollutants were detected, both inorganic and organic. Organic pollution includes *n*-alkanes, PAHs (polycyclic aromatic hydrocarbons) and *n*-alkanoic acids [60], polybrominated diphenyl ethers [61], hexachlorocyclohexane and hexachlorobenzene [62] and organic acids (*eg* oxalic, succinic, malonic [63]). Zeppelin station in Ny Alesund is also one of the monitoring stations in the Arctic that is most affected by airborne *polychlorinated biphenyl* (PCBs), due to its proximity to mainland Europe, which altogether with northern Russia is the most frequent source of the contaminated air inflow to the Arctic [64, 65]. In Austfonna ice cores, even organophosphorus and other pesticides were found [66].

Airborne contaminants are scavenged by snow and rainfall, reaching the ground; also riming and fog can deposit pollutants from the atmosphere [67]. In the composition of snow from Svalbard additional sulphate is occurring, most probably due to local coal combustion sources. However, Svalbard experiences much less inorganic contaminants than the Russian Arctic [68]. Acid precipitation events from the industrial era can be found in ice cores taken in Svalbard [11]. Also organic pollution occurs in precipitation water - PAHs (naphthalene, phenanthrene, fluorene, acenaphthene, fluoranthene and pyrene) were detected in rainwater in Hornsund [69].

The pollution impacts upon rare species in Svalbard, and this influence is dominated by long-lasting organic pollutants. These affect - at most - the species on top of food chain, particularly because these pollutants concentrate in fat, which is a dietary demand in the Arctic for energy reasons [70]. Svalbard and East Greenland polar bears and Svalbard glaucous gull are known to be the animals most affected by organohalogen compounds in the whole Arctic [71, 72]. Also polar foxes and, of marine mammals, ringed and harbour seals are on the list of species endangered with high POPs (persistent organic pollutants) intake [70, 73, 74]. These pollutants can cause several adverse effects upon the immune system, behaviour and reproduction of mammals, birds and fish in the Arctic. The intake of gull eggs, which happens in some northern communities, is even risky for people, because of the level of toxic substances within them [75].

Research on polar bears shows that the amount of Persistent Organic Polutions (chlorinated hydrocarbon compounds) in their tissue follows an increasing trend from west to east of the Arctic [76-78]. However, the particular types of organochlorine pesticides reveal different patterns and strength of the trend [71] *eg* showing a local maximum of chlordane concentration in Western Russian Arctic [79]. Temporal trends of the concentration of chlordanes, hexachlorocyclohexanes, chlorobenxenes, dieldrin and DDT metabolites over the last decade of 20th century were decreasing, which gives optimistic views for the future of POPs concentration in polar bears [80]. However, not all the legacy contaminants become less abundant over time [78]. Thus, it is very important to monitor those contaminants closely in the pristine Svalbard environment (Table 1).

Table 1

Literature information of the results of studies conducted in Polar areas

Location/date of sample collection	**Sample type**	**Determined compounds**	**Range of values/scope**		**Final determination technique**	**Litera-ture**
Ny-Alesund, Svalbard/ 07-08 2005	Surface lake sediments	PAH, PCB, DDT, HCH, PBDE	PAH: 11÷1100 ng g^{-1} d.w. PCB: 0.08÷4.9 ng g^{-1} d.w. DDT: 0.07÷4.2 ng g^{-1} d.w. HCH: 0.21÷6.9 ng g^{-1} d.w. PBDE: 0.024÷0.19 ng g^{-1} d.w.		GC-MS GC-MS/MS	[81]
Ny-Allesund Svalbard/ 07-08 2007	Moss (m) Reindeer droppings (r) Soil (s)	∑ PAH	∑PAH m: 158÷244 ng g^{-1} d.w. ∑PAH r: 49÷340 ng g^{-1} d.w. ∑PAH s: 37÷324 ng g^{-1} d.w.		GC-MS	[82]
Barentsburg, Spitsbergen / 08 2001	Fragments of the liver, kidneys and gastro-intestinal tract of adult gulls	∑PCB, ∑PBDE, ∑DDT, ∑CB, ∑CHL, ∑Toksafen, Hg	∑PCB: 367÷2347 ng g^{-1} w.w. ∑CB: 8÷58 ng g^{-1} w.w. ∑CHL: 13÷48 ng g^{-1} w.w. ∑PBDE: 4÷33 ng g^{-1} w.w. ∑DDT: 122÷408 ng g^{-1} w.w. ∑Toksafen: 7÷421 ng g^{-1} w.w. Hg: 0.1÷0.5 µg g^{-1} w.w.		GC–MS GC-ECNI/MS AAS	[83]
Lakes Ellasjøen, Oyangen-Bjornoya (Norway)/ 07 1996	Sediments Plankton Fauna bottom	HCB, HCH, ∑PCB, ∑DDT	Ellasjøen: ∑DDT: 6.9 ng g^{-1} d.w. HCH: <0.2 ng g^{-1} d.w. ∑PCB: 60 ng g^{-1} d.w.	Øyangen: ∑DDT: 0.8 ng g^{-1} d.w. HCH: <0.4 ng g^{-1} d.w. ∑PCB: 4.4 ng g^{-1} d.w.	HRGC/ HRMS	[84]
Bjornoya, the Barents Sea (Norway)/ 2003-2005	Fragments: liver (w) and brain (m) of adult gulls	HCB BDE PCB Chloro-organic pesticides Hg	w [µg/g w.w.] HCB: 2.6÷206.4 *p,p′*-DDE: 17.2–732.3 ΣPCB_{24}: 84.1÷4 274.0 ΣBDE_{11}: 1.8÷102.8	m [µg/g w.w.] HCB: 0.8÷27.0 *p,p′*-DDE: 4.4÷232.0 ΣPCB_{24}: 16.7÷711.5 ΣBDE_{11}: 0.2÷10.9	GC-MS GC-ECD LC-MS-MS AAS	[85]
Lake Ellasjoen, -Bjornoya, (Norway)/ 04 2001	Sediments	Persistent Organic Pollutants As Cd Co Cr Cu Hg Ni Pb V Zn	∑DDT: 1.6 ng/g d.w. ∑PCB: 46.4 ng/g d.w. ∑PBDE: 0.73 ng/g d.w. 6.98 mg/kg d.w. 2.20 mg/kg d.w. 42.3 mg/kg d.w. 14.4 mg/kg d.w. 34.4 mg/kg d.w. 0.155 mg/kg d.w. 52.5 mg/kg d.w. 86.6 mg/kg d.w. 18.1 mg/kg d.w. 373 mg/kg d.w.		GCMS ICP-AES ICP-QMS	[86]

Ellasjoen and Oyangen Lakes-Bjornoya (Norway)/ 07 1999	Zooplankton (z) Chironomid larvae (l) fish (Arctic char) (f)	CHB BDE PBDE PCN	Ellasjøen : ΣCHB : 2.2 ng/g w.w.(z) ΣPCN: 3.2 pg/g w.w.(z) ΣPCN: 21.8 pg/g w.w.(f) ΣPBDE: 0.78 ng/g w.w.(z) PBB153: 0.23÷1.6 ng/g w.w.(l)	Øyangen: ΣCHB : 4.53 ng/g w.w.(f) ΣPCN: 4.58÷9.8 pg/g w.w.(f) ΣPBDE: 1.6 ng/g w.w.(f) ΣPBDE: 1.3 ng/g w.w.(l)		GC/LRMS-NICI GC-MS	[87]
South-Western part of the Barents Sea/ 07 2006	Sediment cores (0-1 cm; 14-15 cm)	PAH	Station Fjord areas (0-1 cm) ΣPAH: 209÷326 ng/g w.w. (14-15 cm) ΣPAH: 68.3÷363 ng/g w.w.	Tromsø-flaket (0-1 cm) ΣPAH: 58.8÷97.2 ng/g w.w. (14-15 cm) ΣPAH: 20÷143 ng/g w.w.	Ingøydjupet (0-1 cm) ΣPAH: 208÷217 ng/g w.w. (14-15 cm) ΣPAH: 20÷363 ng/g w.w.	GC-MS	[88]
Ny-Alesund, Svalbard/ 07 1998 04-05 1999	Air	PAH Alkanoic acids n-Alkanes	Σ C_{17-29} : 19÷97 ng/m^3 Σ A_{14-28}: 6 ng/m^3 Σ PAH: 0.6÷2.0 ng/m^3 Average value 23-28. 07. 1998 [ng/m^3] n-C_{17}: 0.65 n-C_{18}: 2.84 n-C_{19}: 1.22 n-C_{20}: 6.05 n-C_{21}: 3.48 n-C_{22}: 1.36 n-C_{23}:1.34 n-C_{24}: 0.81 n-C_{25}: 0.51 n-C_{26}: 0.26 n-C_{27}: 0.13 n-C_{28}: 0.07 n-C_{29}: 0.04	Average value 07. 1998 [ng/m^3] A_{14}: 0.22 A_{15}: 0.17 A_{16}: 2.65 A_{17}: 0.13 A_{18}: 0.91 A_{19}: 0.03 A_{20}: 0.17 A_{21}: 0.09 A_{22}: 0.67 A_{23}: 0.13 A_{24}: 0.23 A_{25}: 0.05 A_{26}: 0.10 A_{27}: 0.02 A_{28}: 0.17		HR GC-FID HR GC-MS	[89]
Kapp Wijk, Austfjordnes-Svalbard/ 01.11.1998-15.03.1999	Hypodermic and abdominal fat tissue from arctic foxes	PBDE PCB HCB Chloro-organic pesticides	[ng/g w. lipids] Average value aryt. ΣPCB ΣPBDE Σ chloro-organic pesticides HCB DDE	Hyp. fat tissue 9875.1 40.0 6296.6 135.3 154.9	Abd. fat tissue 12 363.6 37.5 6020.9 129.6 156.6	GC-MS-NCI	[90]

			Three selected areas from which samples were collected; (ng/g w. lipids)				
			Alaska	Greenland	Svalbard		
Area including east from Alaska to Svalbard/ 2005-2008	Fat tissue from polar bears	ΣPBDE ΣPCB ΣDDT β-HCH α-HCH	3.4÷6.3 1115÷3043 56.0÷106 267÷504 12.8÷24.8	37.5÷49.8 8751÷ 12687 155÷273 58.1÷96.8 9.7÷14.0	32.5÷60.6 2854÷9246 75.0÷187 45.8÷93.6 6.8÷10.6	GC-MS	[78]
			(ng/g w. lipids) Adult males	(ng/g w. lipids) Adult females	(ng/g w. lipids) Young		
Svalbard/ 07. 1996- 10. 2001	Hypodermic layer of fat from a white whale	HCB α-HCH β-HCH γ-HCH ΣHCH ΣDDT ΣCHB ΣPCB ΣPBDE	358÷476 16.9÷40.0 32.5÷ 97.0 19.7÷41.7 70.5÷145 2370÷5810 551÷12760 3380÷6210 77.6÷116	322 140 34.6 16.0 64.6 2650 690 3730 120	66.8÷498 11.5÷25.6 8.31÷39.3 9.43÷33.3 39.9÷93.0 308÷4600 210÷664 631÷4990 22.7÷137	GC-ECD/MS GC-MS-NCI	[91]

Conclusions

The Arctic is one of the last wild areas in the world which has for the most part remained unchanged. Difficult climatic conditions make regeneration processes a slow process, so the changes caused by anthropogenic activities have a significant impact on the quality of the environment. The introduction of degradation factors such as persistent organic compounds and heavy metals contribute to the breach of homeostatic mechanisms, which in consequence can lead to the collapse of ecological balance.

Climatic factors, high and low pressure, contribute to the transport of air masses. The transportation of pollutants over long distances causes that compounds emitted from industrial plants in Europe, Russia, Canada, Asia and North America are deposited over a large area of the Arctic. In winter and spring, the transport is surprisingly fast, as the emission of pollutants from areas in Europe to Arctic areas is a matter of days. Marine transport of pollutants is significantly slower. It is believed that it takes several decades for pollution to reach Arctic areas [81].

Pollution originating from distant sources is an increasing threat to Arctic areas. Environmental conditions and geographical location make this area a reservoir of medium volatile organic pollutants. The issue of transport and the fate of persistent pollutants in distant areas has gained increased attention in the last decade. The Arctic, which in the past was considered a pristine area in terms of the influence of anthropogenic pollution, has become an area of their high concentration. Pollution detected in the Arctic shows how important the further of detailed studies are of emission sources, transport routes of pollutants in the environment as well as the possibility of their accumulation in different elements of the ecosystem [8].

Acknowledgements

The authors wish to thank: M.Sc., Eng. Katarzyna Cichała-Kamrowska for her assistance in collecting data for the preparation of the article, and Assoc. Prof. Piotr Głowacki, Polish Academy of Sciences (PAN) - head of the Department of Polar Research Institute of Geophysics, for his hospitality during stay at the Polish Polar Station (Hornsund, Norway), and giving the inspiration to write this article. The authors express their gratitude for the financial support to the Foundation for Polish Science, the Master Programme.

List of Acronyms

d.w.: dry weight; w.w.: wet weight; AAS: Atomic Absorption Spectrometry; CHB: Chlorobornanes; CHL: Chlordane; DDE: dichlorodifenylodichloroetylen; DDT: dichlorodifenylotrichloroethane; GC-MS: Gass Chromatography-Mass Spectrometry; GC/LRMS-NICI: Gas Chromatography-Low-Resolution Mass Spectrometry in the Negative Ion Chemical Ionization mode; GC-ECD: Gas Chromatography - Electron Capture Detector; GC-MS/MS: Gas Chromatography-Tandem Mass Spectrometry; GC-MS-NCI: Gas Chromatography-Mass Spectrometry-Negative Chemical Ionization; HCB: Hexachlorobenzene; HCH: Hexachlorocyclohexane; HRGC/HRMS: High Resolution Gas Chromatography/High Resolution Mass Spectrometry; HRGC-FID: High Resolution Gas Chromatography-Flame Ionization Detector; HRGC-MS: High Resolution Gas Chromatography-Mass Spectrometry; ICP-AES: Inductively Coupled Plasma Atomic Emission Spectrometry; ICP-QMS: Inductively Coupled Plasma Quadrupole Mass Spectrometry; LC-MS/MS: Liquid Chromatography-Tandem Mass Spectrometry; PBDE: Polybrominated diphenyl ethers; PCB:Polychlorinated biphenyls; PCN: Polychlorinated naphthalenes; PAH: Polycyclic aromatic hydrocarbons.

References

[l] Shaw G. Arctic haze. In: Encyclopedia of Atmospheric Sciences. Elsevier Science. 2003;155-159.
[2] Borysiak J, Ratyńska H, The state of floral research on Spitsbergen with emphasis on Bellsund, Hornsund and Kaffiøyra [in Polish]. In: Glaciological Workshop 2004. Polish Geomorphologists Association, Sosnowiec-Poznań-Longyearbyen 2004, VI-248-VI-260.
[3] Machowski J. Polish Polar Res. 1995;16:13-35.
[4] Lydersen C, Steen H, Alsos IG. Svalbard. In: Environmental conditions and impacts for Red List species. Norwegian Biodiversity Information Centre. 2010;119-134.
[5] Reimann S, Kallenborn R, Schmidbauer N. Environ Sci Technol. 2008;43:4791-4795.
[6] Butt CM, Berger U, Bossi R, Tomy GT. Sci Total Environ. 2010;408:2936-2965.
[7] Burkov IC, Kallenborn R. Toxicol Lett. 2000;112-113:87-92.
[8] Jiao L, Zheng GJ, Minh TB, Richardson B, Chen L, Zhang Y, Yeung LW, et al. Environ Pollut. 2009;157:1342-1351.
[9] Walker CH, Hopkin SP, Sibly RM, Peakall DB. Podstawy ekotoksykologii. Warszawa: WN PWN; 2002.
[10] Brunström B, Halldin K. Toxicol Lett. 2000;112-113:111-118.
[11] Simoões JC, Zagorodnov V S. Atmos Environ. 2001;35:403-413.
[12] Palm A, Cousins I, Gustafsson Ö, Axelman J, Grunder K, Broman D, et al. Environ Pollut. 2004;128:85-97.
[13] Ingólffson O. no date: https://notendur.hi.is/oi/svalbard_geology.htm.
[14] Fookes PG. Geology Today. 2008;24:146-152.
[15] Schildberg U. Coal in the ice-mining in Spitsbergen [Kohle im Eis - Bergbau auf Spitzbergen], Gluckauf: Die Fachzeitschrift fur Rohstoff, Bergbau und Energie. 2007;143:352-355.
[16] Yoon JR, Kim Y. Ocean and Polar Res. 2001;23:51-62.

[17] Spencer AM, Briskeby PI., Christensen LD, Foyn R, Kjølleberg M, Kvadsheim E, et al. Episodes. 2008;31:115-124.
[18] Hagen JO, Kohler J, Melvold K, Winther JG. Polar Res. 2003;22:145-159.
[19] Jania J, Głowacki P, Bukowska-Jania E, Kolondra L, Perski Z, Pulina M, et al. The glaciers in the vicinity of Hornsund fiord [in Polish]. In: Glaciological Workshop 2004, Polish Geomorphologists Association, Sosnowiec-Poznań-Longyearbyen 2004, VI-48-VI-97.
[20] Lønne I., Lyså A. Geomorphology. 2005;72:300-319.
[21] Hanáček M, Flašar J, Nývlt D. Czech Polar Reports. 2011;1:11-33.
[22] Zagórski P. The influence of glaciers on transformation of the coast of NW part of Wedel Jarlsberg Land (Spitsbergen) in late Pleistocene and Holocene [in Polish]. Słupskie Prace Geograf; 2007.
[23] Humlum O, Instanes A, Sollid JL. Polar Res. 2003;22:191-215.
[24] Pulina M. Karstic phenomena of south Spitsbergen [in Polish]. In: Glaciological Workshop 2004. Polish Geomorphologists Association, Sosnowiec-Poznań-Longyearbyen 2004, VI-124-VI-147.
[25] Przybylak R. Annals of Glaciology. 2007;46:316-324.
[26] Araźny A. Bulletin of Geography - physical geography series. 2010;3:47-64.
[27] Araźny A. Problemy Klimatologii Polarnej. 2003;13:107-115.
[28] Kruszewski G. Problemy Klimatologii Polarnej [in Polish]. 2004;14:79-86.
[29] Niedźwiedź T. Problemy Klimatologii Polarnej [in Polish]. 1992;2:77-84.
[30] Niedźwiedź T. Problemy Klimatologii Polarnej [in Polish]. 2006;16:91-105.
[31] Niedźwiedź T. Problemy Klimatologii Polarnej [in Polish]. 2003;13:79-92.
[32] Niedźwiedź T. Problemy Klimatologii Polarnej [in Polish]. 2002;12:65-75.
[33] Leszkiewicz J, Głowacki P. Problemy Klimatologii Polarnej [in Polish]. 2001;11:41-54.
[34] Kejna M. Problemy Klimatologii Polarnej [in Polish]. 2001;11:55-65.
[35] Førland EJ, Hanssen-Bauer I, Nordli PØ. DNMI Rapport, Oslo: Norwegian Meteorological Institute; 1997;1-72.
[36] Budzik T, Sikora S, Araźny A. Problemy Klimatologii Polarnej [in Polish]. 2009;19:233-246.
[37] Kwaśniewska E, Pereyma J. Problemy Klimatologii Polarnej [in Polish]. 2004;14:157-169.
[38] Angiel M. Problemy Klimatologii Polarnej [in Polish]. 1992;2:121-129.
[39] Coulson S, Hodgkinson ID, Strathdee A, Bale JS, Block W, Worland MR, et al. Polar Biol. 1993;13:67-70.
[40] Bartoszewski S, Gluza A, Pękala K, Repelewska-Pękalowa J, Siwek K, Zagórski P. The natural environment of Bellsund [in Polish]. In: Bellsund. Elements of natural environment. Field guide. Polish Geomorphologists Association, Spitsbergen: Glaciological Workshop; 2004:1-10.
[41] Sobota I, Ćmielewski M, Nowak M. Problemy Klimatologii Polarnej [in Polish]. 2010;20:161-170.
[42] Hodson A, Gurnell A, Tranter M, Bogen J, Hagen JO, Clark M. Hydrol Process. 1998;12:73-86.
[43] Hodson A, Tranter M, Gurnell A, Clark M, Hagen JO. J Hydrol. 2002;257:91-114.
[44] Krawczyk WE, Bartoszewski SA. J Hydrol. 2008;362:206-219.
[45] Hodgkins R, Cooper R, Wadham J, Tranter M. J Hydrol. 2009;378:150-160.
[46] Chmiel S, Bartoszewski S, Gluza A, Siwek K, Zagórski P. Landform Analys. 2007;5:13-15.
[47] Dragon K, Marciniak M. J Hydrol. 2010;386:160-172.
[48] Krawczyk WE, Lefauconnier B, Pettersson LE. Phys Chem Earth. 2003;28:1257-1271.
[49] Krawczyk WE, Pettersson LE. Permafrost Periglac. 2007;18:337350.
[50] Święs F. Aktualny stan badań geobotanicznych na południowo-zachodnim wybrzeżu Bellsundu (Ziemia Wedela Jarlsberga, Spitsbergen) [in Polish: Current state of geobotanical research on south-western Bellsund coast (Wedel Jarlsberg Land, Spitsbergen)]. XX lat badań polarnych Instytutu Nauk o Ziemi UMCS na Spitsbergenie. 2006;85-89.
[51] Cooper E, Alsos IG, Hagen D, Smith FM, Coulson SJ, Hodgkinson ID. J Veg Sci. 2004;15:115-224.
[52] Yurtsev BA. J Veg Sci. 1994;5:765-776.
[53] Konoreva L. The study of Lichens of Spitsbergen. In: Study of flora, vegetation and productivity of Arctic plant communities in Spitsbergen, The Polar-Alpine Botanical Garden-Institute KSC RAS, Apatity; 2010.
[54] Engelskjøn T, Lund L, Alsos IG. Polar Res. 2003;22:317-339
[55] Ávila-Jiménez ML, Coulson SJ, Solhøy T, Sjöblom A. Polar Res. 2010;29:127-137.
[56] Vanderpuye AW, Elvebakk A, Nilsen L. J Veg Sci. 2002;13:875-884.
[57] Prach K, Košnar J, Klimešová J, Hais M. Polar Biol. 2010;33: 635-639.
[58] Forbes BC, Ebersole JJ, Strandberg B. Conserv Biol. 2001;15:954-969.
[59] Hop H, Pearson T, Hegseth EN, Kovacs KM, Wiencke C, Kwasniewski S, et al. Polar Research. 2002;21:67-208.
[60] Cecinato A, Mabilia R, Marino F. Atmos Envion. 2000;34:5061-5066.

[61] De Wit CA, Alaee M, Muir DCG. Chemosphere. 2005;64:209-233.
[62] Su Y, Hung H, Blanchard P, Patton GW, Kallenborn R, Konoplev A, et al. Environ Sci Technol. 2006;40:6601-6607.
[63] Kawamura K, Imai Y, Barrie LA. Atmos Environ. 2005;39:599-614.
[64] Hung H, Kallenborn R, Breivik K, Su Y, Brorström-Lundén E, Olafsdottir K, Thorlacius JM, et al. Sci Total Environ. 2010;408:2854-2873.
[65] Choi SD, Baek SY, Chang YS, Wania F, Ikonomou MG, Yoon YJ, et al. Environ Sci Technol. 2008;42:7125-7131.
[66] Hermanson M, Isaksson E, Teixeira C, Muir DCG, Compher KM, Li YF, et al. Environ Sci Technol. 2005;9:163-8169.
[67] Bryś T. Problemy Klimatologii Polarnej [in Polish]. 2002;12:89-106.
[68] De Caritat P, Hall G, Gìslason S, Belsey W, Braun M, Goloubeva NI, et al. Sci Total Environ. 2005;336:183-199.
[69] Krawczyk WE, Skręt U. Polish Polar Res. 2005;26:65-76.
[70] Brunström B, Halldin K. Toxicol Lett. 2000;112-113:111-118.
[71] Verreault J, Muir DCG, Norstrom RJ, Stirling I, Fisk AT, Gabrielsen GW, et al. Sci Total Environ. 2005;351-352:369-390.
[72] Muir DCG, de Wit CA. Sci Total Environ. 2010;408:3044-3051.
[73] Daelemans FF, Mehlum F, Lydersen C, Schepens PJC. Chemosphere. 1993:27:429-437.
[74] Wolkers H, Lydersen C, Kovacs KM. Sci Total Environ. 2004;319:137-146.
[75] Pusch K, Schlabach M, Prinzinger R, Gabrielsen GW. J Environ Monit. 2005;7:635-639.
[76] Norstrom RJ, Belikov SE, Born EW, Garner GW, Malone B, Olpinski S, et al. Arch Environ Contam Toxicol. 1998;35:354-367.
[77] Muir DCG, Norstrom RJ. Toxicol Lett. 2000;112-113:93-101.
[78] McKinney MA, Letcher RJ, Aars J, Born EW, Branigan M, Dietz R, et al. Environ Int. 2011;37:365-374.
[79] Lie E, Bernhofta A, Rigetb F, Belikovc SE, Boltunovc AN, Derocherd AE, et al. Sci Total Environ. 2003;306;159-170.
[80] Dietz R, Riget FF, Sonne C, Letcher R, Born EW, Muir DCG. Sci Total Environ. 2004;331:107-124.
[81] Polkowska Ż, Cichała-Kamrowska K, Ruman M, Kozioł K, Krawczyk WE, Namieśnik J. Sensors. 2011;11:8910-8929.
[82] Wang Z, Ma X, Na G, Lin Z, Ding Q, Yao Z. Environ Pollut. 2009;157:3132-3136.
[83] Sagerup K, Savinov V, Savinova T, Kuklin V, Muir DCG, Gabrielsen GW. Environ Pollut. 2009;157:2282-2290.
[84] Evenset A, Christensen GN, Skotvold T, Fjeld E, Schlabach M, Wartena E, et al. Sci Total Environ. 2004;318:125-141.
[85] Sagerup K, Helgason LB, Polder A, Strømb H, Josefsen TD, Skåre JU, et al. Sci Total Environ. 2009;407:6009-6016.
[86] Evenset A, Christensen GN, Carroll J, Zaborska A, Berger U, Herzke D, et al. Environ Pollut. 2007;146:196-205.
[87] Evenset A, Christensena GN, Kallenbornb R. Environ Pollut. 2005;136:419-430.
[88] Boitsov S, Jensen HKB, Klungsøyr J. Mar Environ Res. 2009;68:236-245.
[89] Cecinato A, Mabilia R, Marino F. Atmos Environ. 2000;34:506-5066.
[90] Fuglei E, Bustnes JO, Hop H, Mørk T, Bjornfoth H, Van Bavel B. Environ Pollut. 2007;146:128-138.
[91] Villanger GD, Lydersen C, Kovacs KM, LieE, Skaare JU, Jenssen BM. Sci Total Environ. 2011;409:2511-2524.

ZANIECZYSZCZENIA OBECNE W RÓŻNYCH KOMPONENTACH ŚRODOWISKA ARCHIPELAGU SVALBARD

[1]Katedra Chemii Analitycznej, Wydział Chemiczny, Politechnika Gdańska
[2]Katedra Geografii Fizycznej, Wydział Nauk o Ziemi, Uniwersytet Śląski
[3]Katedra Geografii, Uniwersytet w Sheffield

Abstrakt: Na przestrzeni ostatnich lat znacząco wzrosło zainteresowanie procesami transportu i losem trwałych zanieczyszczeń w miejscach odległych od centrów przemysłowych, takich jak obszary polarne. Nowoczesne techniki analityczne pozwoliły na przeprowadzenie badań, które dowiodły, że również Arktyka, która w przeszłości była uważana za teren pozbawiony zanieczyszczeń, stała się obszarem o dużej intensywności antropopresji. Archipelag Svalbard wyróżnia się na tle innych rejonów polarnych ze względu na specyficzne warunki środowiskowe oraz położenie geograficzne, które czynią ten obszar rezerwuarem zanieczyszczeń. Monitorowanie stanu środowiska rejonów arktycznych jest niezwykle ważne ze względu na unikatową możliwość obserwacji bezpośredniego wpływu zanieczyszczeń na procesy zachodzące w badanym obszarze. Uzyskane w ten sposób dane pomiarowe stanowią cenne źródło informacji nie tylko o zmianach zachodzących w ekosystemie Arktyki, ale również pozwalają na oszacowanie wpływu określonych ksenobiotyków na środowisko w skali globalnej. Ponadto badania rodzaju i ilości substancji chemicznych zdeponowanych w różnych elementach ekosystemu stanowią podstawę do podejmowania działań, które mają na celu zapobieganie negatywnym oddziaływaniom zanieczyszczeń.

Słowa kluczowe: transport zanieczyszczeń na duże odległości, trwałe zanieczyszczenia organiczne