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Lake Ellasjøen and the mountain Alfredfjellet, Bjørnøya (Photo: Guttorm N. Christensen)

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Organochlorine contaminants in biota, fog and precipitation from Bjørnøya

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Sammendrag / Summary


Preliminary from two projects that are presently underway on Bjørnøya are summarised in the present report. The aims of the first project: "Bjørnøya: Food-chain studies – The key to designing monitoring programs for arctic islands" are to study biomagnification of POPs in Arctic freshwater and marine food chains from Bjørnøya, and to study the linkages between the marine and the limnic ecosystem, through the deposition of guano. The results obtained so far indicate that guano may be an important transport medium for POPs to lake Ellasjøen. The aim of the second project: "Ellasjøen, Bear Island - A mass balance study of a highly contaminated Arctic area" is to contribute significant new information to the understanding of contaminant pathways in the Arctic hydrosphere and to provide a better understanding of contaminant focusing in a sensitive polar environment. Levels of POPs in air samples seem to be very similar to the levels measured in air samples from the Zeppelin-station near Ny-Ålesund, Svalbard. Levels in fog are relatively high, and the results obtained so far indicate that fog is a very important carrier medium for POPs on Bjørnøya.

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Preface

This report includes preliminary results from two projects that are being carried out at and close to Bjørnøya (Bear Island): 1) “Ellasjøen, Bear Island. – A mass balance study of a highly contaminated arctic area”, and 2) “Bear Island – Food chain studies: The key to designing monitoring programmes for Arctic Islands.” The projects have been managed by Akvaplan-niva, but several institutions have participated in the planning and the actual work. The participating institutions are for sub-project 1:

- the Norwegian Institute for Air Research (NILU),
- the Norwegian Meteorological Institute (DNMI) and
- the Norwegian Polar Institute (NP).

The participating institutions for sub-project 2 are:

- the Norwegian Institute for Air Research (NILU),
- the Norwegian Polar Institute (NP),
- the University of Stockholm and
- the Norwegian Institute for Water Research (NIVA).

In 1999 and 2000 the projects received partial funding from SFT and internal institutional money. For 2000, sub-project 1 also received partial funding from the Norwegian Research Council (NFR). Sub-project 2 has not been directly supported by NFR, but we have received funding from NFR to search for ‘new contaminants’ (i.e. contaminants not included in the SFT-project) in organisms from Bear Island. By coordinating the NFR-project with sub-project 2 we are able to optimise our research budget and effort. The two projects reported here have different objectives and focus on different media, but it is important that the results be integrated and interpreted together. The first part of the report (introduction and area description) are common to both projects, thereafter each of the projects are presented separately in subsequent chapters.

The present report mainly covers the work that has been carried out in 1999 and 2000. It is mainly a data report at this time and extensive treatment of the data (statistical analyses, modelling etc.) has yet to be completed. However, the results from both projects will be processed further, and published in various progress reports as well as in articles in international peer reviewed journals in the coming years.

We acknowledge the Norwegian Coast Guard, the 330-squadron (rescue helicopter) and Norwegian Polar Institute for safe and helpful transport of personnel and equipment to, on and from Bjørnøya. Further we are grateful to the Norwegian Meteorological Institute and their personnel at Bjørnøya Meteorological station for all of their help and accommodation.

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Summary

The preliminary results from two ongoing projects on Bjørnøya are summarised in the present report. The projects are run over several years, so the results presented here are only part of the total “puzzle.” An earlier report (Skotvold *et al.* 1999) gives an introduction to the questions that the projects seek to answer, and also presents data that are to be supplemented with the data reported in this present report. This document is prepared as a technical report, with no extensive data treatments or interpretations. A more extensive report will be prepared when more data is available.

Very high levels of POPs have previously been found in sediment and organisms from lake Ellasjøen on Bjørnøya. Further the nitrogen composition in the organisms from Ellasjøen deviates from the results found in another lake, Øyangen, where the levels of POPs are several times lower. A possible explanation to the differences in nitrogen composition and contamination levels are that seabirds (little auk, kittiwake and glaucous gull), which feed in the marine environment, bring in nutrients (guano) with a nitrogen composition that deviates from the nitrogen composition of other nutrients that enter the freshwater ecosystem through runoff and decomposition processes. Several thousand seabirds use Ellasjøen as a resting area, while there are significantly fewer seabirds resting in Øyangen. Guano can also function as a transport medium for contaminants from the marine environment to the limnic environment in Ellasjøen. However, this hypothesis needs to be tested through analyses of POP-levels, congener-composition and trophic position of organisms from both marine and freshwater food chains, as well as in guano from the three dominating sea-bird species around Ellasjøen (little auk (*Alle alle*), kittiwake (*Rissa tridactyla*) and glaucous gull (*Larus hyperboreus*)). The aims of the project: “Bjørnøya: Food-chain studies – The key to designing monitoring programs for arctic islands” are therefore to study biomagnification of POPs in freshwater and marine food chains from Bjørnøya, and to study the linkages between the marine and the limnic ecosystem, through the deposition of guano.

Samples of zooplankton, chironomids (*Chironomidae* sp.), tadpole schrimp (*Lepidurus arcticus*) and Arctic char (*Salvelinus alpinus*) from three lakes (Ellasjøen, Øyangen and Skutilen) have been analysed for PCBs and selected pesticides. Also these analyses show that levels of POPs are higher in organisms from Ellasjøen than in samples from Øyangen. Only two samples from lake Skutilen, a lake that is located in the same catchment area as Ellasjøen, were analysed. The number of seabirds visiting Skutilen is very low. The results indicate that levels of POPs in organisms from Skutilen are higher than in comparable organisms from Øyangen, but lower than in Ellasjøen. However, more material from Skutilen must be analysed before any conclusions can be drawn.

From the marine ecosystem important food items for seabirds have been analysed for POPs. Muscle from the three seabirds species and their intestinal content (guano) were also analysed. Low levels of POPs were found in marine phytoplankton and zooplankton, while higher levels were found in spider crabs. Analyses of eggs from common guillemot (*Uria aalge*) and Brünnichs guillemots (*Uria lomvia*) showed relatively high POP-levels compared to other food items. Part of the year eggs from these seabirds is an important food source for glaucous gulls. Little auk had the lowest muscle concentrations of POPs while glaucous gulls had the highest concentrations. The average muscle concentration of PCB 7 was more than 160 times higher in glaucous gull than in little auk. Analyses of intestinal content from the same species showed low levels of POPs in samples from little auk, higher levels in samples from kittiwake and very high levels in samples from glaucous gulls.

Based on the results from the present study it seems likely that guano can act as a transport medium for POPs from the marine to the limnic environment, but the role of guano will be further elucidated through a more extensive study that is currently being carried out. Information about the role of guano as a carrier for POPs to terrestrial and limnic environments will be important in the design of future monitoring programmes.

In addition to transport by guano, contaminants are probably transported to Bjørnøya through long-range atmospheric transport. As there are no local sources for POPs at Bjørnøya, also the contaminants taken up by the seabirds must reach the area through long-range transport by water currents or air. There are probably no significant differences in atmospheric transport to the different parts of the island, but the hypothesis that forms the basis for the project "Ellasjøen, Bjørnøya - A mass balance study of a highly contaminated Arctic area" is that the deposition of air-borne compounds is higher around Ellasjøen than around Øyangen. Ellasjøen is situated in the southern mountainous part of Bjørnøya, while Øyangen is situated on the central plains further north. Due to the mountains the precipitation rate and the occurrence of fog are probably higher in the southern part compared with the plains further north. This indicates that the deposition of air-borne contaminants in the catchment area of Ellasjøen is higher than in the catchment area of Øyangen.

Samples of air, fog, rain, snow and meltwater are regularly collected near Ellasjøen and on the northern part of Bjørnøya (The Meteorological Station). A limited number of samples have been analysed so far. Levels of POPs in air samples seem to be very similar to the levels measured in air samples from the Zeppelin-station near Ny-Ålesund, Svalbard. The levels of POPs in snow and rainwater samples are comparable with levels found in other Arctic areas. Levels in fog are relatively high, and the results obtained so far indicate that fog is a very important carrier medium for POPs on Bjørnøya. An unusual PCB-pattern for abiotic samples (air, fog and rain), with a relatively high portion of medium chlorinated PCBs, has been detected in several samples from the island. Abiotic samples are usually dominated by lower chlorinated PCBs. An extensive mapping of atmospheric transport and deposition to Bjørnøya will be carried out during the years 2001 – 2004.

Sammendrag

I denne rapporten presenteres resultater fra to prosjekter som for tiden gjennomføres på Bjørnøya. Prosjektene gjennomføres over flere år, slik at resultatene som presenteres her bare representerer deler av "puslespillet". Bakgrunnen og problemstillingene for de to prosjektene samt deler av de første resultatene frem til 1998 er presentert i en tidligere rapport (Skotvold *et al.* 1999). I denne rapporten presenteres data fra de siste årene, som vil bli ytterligere supplert i tiden fremover. Dette dokumentet er utarbeidet som en teknisk rapport, dvs. at ingen omfattende databehandling eller tolkning er gjennomført. En mer utfyllende rapport, med statistisk databehandling og mer utfyllende tolkninger, vil bli utarbeidet når mer data foreligger.

Det har tidligere blitt funnet svært høye konsentrasjoner av POPer i sediment og organismer fra Ellasjøen på Bjørnøya. Det er også vist at organismene i Ellasjøen har en annen nitrogensammensetning enn organismer fra Øyangen, en annen innsjø på Bjørnøya hvor nivåene av POPer er mye lavere enn i Ellasjøen. En mulig forklaring på de store forskjellene i nitrogensammensetning mellom de to innsjøene, er at sjøfugl transporterer næringsstoffer (via guano) til Ellasjøen. Sjøfugl ernærer seg av organismer fra det marine miljø, som har en annen nitrogensammensetning enn det som tilføres innsjøene via avrenning og nedbrytningsprosesser. Flere tusen sjøfugl benytter Ellasjøen som et hvileområde, mens det er betydelig færre sjøfugl i området rundt Øyangen. Guano kan også fungere som et transportmedium for miljøgifter fra det marine miljø til det limniske miljø i Ellasjøen. Denne hypotesen må imidlertid testes ved å analysere POP-nivåer, kongenersammensetning og trofisk posisjon i organismer fra ferskvanns og marine næringskjeder, men også gjennom analyser av guano fra de tre sjøfuglartene som er dominerende rundt Ellasjøen (alkekonge, krykkje og polarmåke). Målsetningene med prosjektet "Bjørnøya: Food-chain studies – The key to designing monitoring programmes for Arctic islands" er derfor å studere biomagnifikasjon av POPer i ferskvanns- og marine økosystemer, og å studere koblingen mellom disse bl.a. via analyser av guano.

Prøver av dyreplankton, fjærmygglarver, skjoldkreps og røye fra tre innsjøer (Ellasjøen, Øyangen og Skutilen) ble i denne omgang analysert for PCB og utvalgte pestisider. Også disse analysene viste at det var betydelig høyere nivå av POPer i organismer fra Ellasjøen enn i organismer fra de to andre innsjøene. Kun to prøver fra Skutilen er til nå analysert. Denne innsjøen ligger i samme nedbørsfelt som Ellasjøen, men er lite påvirket av sjøfugl. Resultatene antyder at nivåene av POPer i organismer fra Skutilen er høyere enn i tilsvarende organismer fra Øyangen, men lavere enn i Ellasjøen. Flere prøver fra Skutilen må imidlertid analyseres før noen konklusjoner omkring dette kan trekkes.

Fra det marine økosystemet har viktige byttedyr i næringskjedene til sjøfuglartene alkekonge, krykkje og polarmåke blitt analysert for POPer. I tillegg har muskelprøver og prøver av tarminnhold (guano) fra de tre sjøfuglartene blitt analysert. Lave nivåer av POPer ble målt i marint plante- og dyreplankton, mens nivåene i pyntekrabbe, som er et viktig næringsdyr for polarmåke, var høyere. Egg fra lomvi og polarlomvi utgjør i perioder en viktig del av dietten til polarmåke. Analyser av egg fra disse artene viste at de inneholdt høyere konsentrasjoner av POPer enn de andre analyserte næringsemnene. Muskelprøver fra alkekonge hadde lave konsentrasjoner av POPer, mens det ble funnet svært høye nivåer i muskelprøver fra polarmåke. Nivået av PCB 7 var 160 ganger høyere i muskelprøver fra polarmåke enn i muskelprøver fra alkekonge. Analyser av tarminnhold viste samme bilde som analyser av muskelprøver, med lave nivåer i prøver fra alkekonge, høyere i prøver fra krykkje og klart høyest i prøver fra polarmåke. Konsentrasjonen av POPer i tarminnhold fra polarmåke var

flere ganger høyere enn det som ble målt i noen av næringsementene. Disse analysene viser at det ikke er usannsynlig at guano kan fungere som et transportmedium for POPer fra det marine til det limniske miljø. Videre studier vil bidra til å klargjøre guanos rolle i økosystemet på Bjørnøya. Kunnskap om dette vil være viktig når fremtidige overvåkingsprogram for arktiske områder skal designes.

Langtransporterte miljøgifter bidrar trolig også i stor grad til de høye nivåene i Ellasjøen. Innholdet av POPer i luft, nedbør (snø og regn) og tåke er trolig lik på hele Bjørnøya, men hypotesen, som danner grunnlaget for prosjektet "Ellasjøen, Bjørnøya – A mass balance study of a highly contaminated arctic area" er at mengden nedbør og frekvensen av tåke er høyere ved Ellasjøen enn ved Øyangen. Ellasjøen ligger på den sørlige delen av Bjørnøya hvor en finner flere fjellformasjoner, mens Øyangen ligger 6 kilometer lenger nord i et område hvor terrenget er flatt. Fjellformasjonene i nedbørsfeltet til Ellasjøen fører trolig til en høyere nedbørsrate og en hyppigere forekomst av tåke, noe som gjør at dette området mottar en større mengde luftbårne miljøgifter enn de flatere områdene av Bjørnøya.

Prøver av luft, tåke, regn, snø og smeltevann samles regelmessig inn nær Ellasjøen og på den nordlige delen av Bjørnøya (Meteorologisk stasjon). Et begrenset antall prøver har blitt analysert så langt. Konsentrasjonen av POPer i luft fra Bjørnøya synes å være på samme nivå som i luftprøver fra Zeppelinstasjonen, Ny-Ålesund, Svalbard. Konsentrasjonen i snø og regnprøver er sammenlignbare med hva man finner i andre arktiske områder. Konsentrasjonen i tåke er relativt høy, og de foreløpige resultatene indikerer at tåke kan være et viktig depositionsmedium for POPer på Bjørnøya. Et noe uvanlig PCB-mønster for abiotiske prøver (luft, tåke og regn), med en relativt høy andel av de middels klorerte PCBer, har blitt funnet i flere prøver fra Bjørnøya. Det er vanligvis de lavt klorerte PCBer som dominerer i abiotiske prøver. En omfattende kartlegging av atmosfærisk lang-transport og deponisjon til/på Bjørnøya vil bli gjennomført i perioden 2001 – 2004.

1 Introduction

In 1994, Akvaplan-niva carried out an investigation of contaminants in sediments and fish from Lake Ellasjøen on the island of Bjørnøya. This study was based on a very limited number of samples, but some of the highest values of the contaminants PCB and DDT in freshwater sediments and fish ever found in the Arctic were revealed (Skotvold *et al.* 1999). Other studies from the same area showed high PCB-levels in glaucous gull (*Larus hyperboreus*) (Gabrielsen *et al.* 1995, Bustnes 1998). In 1996 a follow-up study was conducted in order to confirm the levels found in the pilot study and to study how the contaminants were transported through the freshwater food-chain. In this study the contamination level in Ellasjøen was compared to Øyangen, another lake on Bjørnøya. Plankton, benthic animals and fish (Arctic char (*Salvelinus alpinus*)) from both lakes were analysed for contaminants and stable isotopes to provide information on contaminant levels and bioaccumulation in the food chain. Biochemical studies were carried out to study the impact of contaminants on the enzyme system of fish. The results from this work have been reported previously (Skotvold *et al.* 1999), but the main results are summarised below.

Concentrations of POPs, and especially PCBs and p,p'-DDE, in surface sediment and in biota from all trophic levels from Ellasjøen were several times higher than those found in corresponding samples from Øyangen, and much higher than in most of the arctic lakes reported to AMAP (AMAP 1998). A large number of analyses confirmed the previously high levels of POPs in fish from Ellasjøen (in particular PCBs and DDE) reported for 1994. The concentrations found in Arctic char are amongst the highest ever reported. The average concentration of ΣPCB in muscle tissue from large fish was 1103.2 ng/g. Concentrations in char from Øyangen, 41.9 ng/g ww, were comparable to the lower levels reported to AMAP (1998). Bioaccumulation factors (BAF), calculated as the OC concentration in fish divided by the concentration in zooplankton, both on lipid basis, were highest for PCB congeners and p,p'-DDE. The BAFs were higher for fish from Ellasjøen than for Øyangen, indicating greater accumulation in the analysed fish from Ellasjøen.

Changes in the relative abundance of the naturally occurring isotopes N and C are often used as a method to characterise food web dynamics and trophic levels (Broman *et al.* 1992; Hobson & Welch 1995). The metabolic processes of animals enrich the heavy isotopes of C and N (¹³C, ¹⁵N) in relation to the lighter (¹²C, ¹⁴N), and these isotopes can therefore be used to characterise the trophic level of an organism. The trophic level can be expressed as a δ value that is given in parts per thousands, as for example δ¹⁵N:

$$\delta^{15}N = \frac{\left(\frac{^{15}N}{^{14}N} \right)_{sample} - \left[\frac{^{15}N}{^{14}N} \right]_{air}}{\left[\frac{^{15}N}{^{14}N} \right]_{air}} \times 1000$$

As δ¹⁵N is known to be more affected by trophic transfer than δ¹³N, this parameter was used in the previous study to describe food chain dynamics. Generally the ¹⁵N/¹⁴N-ratio increases by 3 – 5 ‰ per trophic transfer (Broman *et al.* 1992; Hobson & Welch 1992; Hobson & Welch 1995). There is a good correlation between the levels of PCB and DDT in organisms from Ellasjøen and Øyangen and their trophic levels, measured as δ¹⁵N. However, the values of δ¹⁵N were 6-10‰ higher in organisms from Ellasjøen than in comparable organisms (e.g

zooplankton) from Øyangen. It is believed that the higher $\delta^{15}\text{N}$ -level of Ellasjøen is due to input of guano from the seabirds that are nesting close to the lake (little auk (*Alle alle*) or using the lake as a resting area (kittiwake (*Rissa tridactyla*), glaucous gull (*Larus hyperboreus*)). The hypothesis is that the seabirds, which feed in the marine environment, bring in nutrients (guano) with an isotopic composition that deviates from the isotopic composition of other nutrients that enter the freshwater ecosystem through runoff and decomposition processes. Guano can also function as a transport medium for contaminants from the marine environment to the limnic environment in Ellasjøen. This theory was supported by the fact that there was a similarity between the PCB-99 / PCB-101 ratios in guano samples of seabirds and char from Ellasjøen, but not so in char from Øyangen. However, the data were sparse, and this theory needed to be investigated further.

As there are no local sources for POPs on or near Bjørnøya, it is most likely that the contaminants are transported to the area through long-range atmospheric transport. The congener patterns of PCBs in sediments from both Ellasjøen and Øyangen are similar to patterns found in other lakes that are strongly influenced by atmospheric deposition. Therefore it seems that atmospheric transport and deposition are important mechanisms for the enrichment of POPs in the area. Ellasjøen is situated in the mountainous part of Bjørnøya, while Øyangen is situated on the central plains further north (see section 1.1). The theory is that the precipitation and the occurrence of fog, and thereby the deposition of airborne contaminants, is higher around Ellasjøen than around Øyangen, because of the mountains.

Based on the results from the previous studies we designed two projects with different aims. The objectives of the first project “Ellasjøen, Bear Island – A mass balance study of a high contaminated Arctic area” are to provide comprehensive quantitative information about atmospheric transport and deposition of POPs to and on Bjørnøya. Further, effort will be directed at assessing the relative importance of various source regions of contaminants to the island through an evaluation of contaminant signatures and back trajectories of pollution events. The main goals of the second project “Food-chain studies: The key to designing monitoring programmes for Arctic islands” is to quantify biomagnification processes in marine and freshwater food-chains near and on Bjørnøya, and to elucidate the role of guano as a biological transport medium for POPs.

Both projects involve several institutions both within and outside the Polar Environmental Centre (Akvaplan-niva, the Norwegian Institute for Air Research, the Norwegian Polar Institute, the Norwegian Meteorological Institute, the University of Tromsø and the University of Stockholm). This interdisciplinary co-operation ensures high-quality research within all the different aspects of the projects.

2 Area description

Bjørnøya (74°30' N, 19° E) is situated half way between the mainland of Norway and Svalbard (Figure 1). Bjørnøya has an area of 178 km² and measures 20 km from North to South. The annual average temperature is -3.8°C. Precipitation is low, with an annual normal of 367 mm (DNMI).

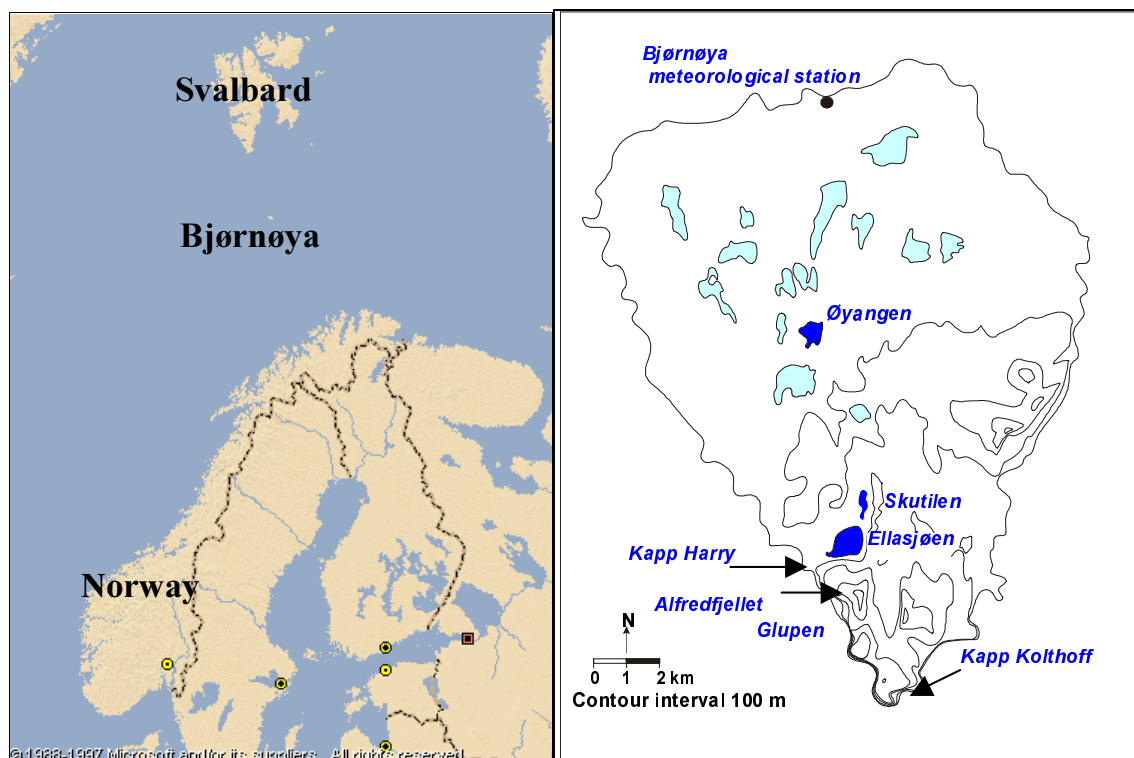


Figure 1. Bjørnøya with Øyangen, Ellasjøen and the meteorological station.

The southern part of the island is mountainous with altitudes up to 536 meters above sea level (masl). Seabirds inhabit the steep cliffs along the south coast. The main species are common guillemot (*Uria aalge*), Brünnich's guillemot (*Uria lomvia*), kittiwake, little auk and glaucous gull. The terrain in the middle and north part of Bjørnøya is flat (30 - 40 masl). The island has about 740 lakes and ponds, which cover 11% of the area. More than 600 of these lakes are found on the central and northern plains. Their depths seldom exceed 5 m. Fewer than ten lakes reach depths of 10 m. These are found in the southern parts of the island. Water temperatures are low, typically below 7°C in summer. There is no summer stratification, but the lakes are cold monomictic (= sub-polar). The upper littoral zone generally comprises a rocky margin, 0.5 - 1 m deep.

2.1 Ellasjøen

Ellasjøen (21 masl), the deepest lake on the island with a maximum depth of 34 m, is situated in the southern, mountainous part of Bjørnøya (Figure 1). The lake has an area of 0.72 km² and its largest measured depth is ≈40 m. The catchment area is 6.1 km² and the lake has an estimated retention time of 6.5 years. In the southern part of the catchment area (Alfredfjellet)

there is a large colony of little auk. Large flocks of kittiwake (hundreds to thousands) can be observed on the lake during the summer period. At the outlet of the lake there is a colony of glaucous gull (approx. 100 pairs). The birds present in the catchment area seem to have a large impact on the lake, indicated by the growth of green algae on the shores directly below the colony. Mosses and lichens occur around the northern and western shore close to the lake although in general the catchment area is devoid of vegetation. The lake has a very well developed profundal and pelagic zone, and is inhabited by stationary Arctic char (Klemetsen *et al.* 1985). The littoral zone in the northern part of the lake is also well developed but in the southern part it is very steep and near the shore the depth is 15 to 20 meters.

2.2 Skutilen

Lake Skutilen is situated in the same catchment area as Ellasjøen. The lake has an area of 0.08 km² and a maximum depth of 2 meters. The primary outlet runs out to Ellasjøen. Birds are seldom seen on Skutilen, and we have not observed Arctic char in this lake. There is hardly any vegetation in the catchment area, except for some mosses. The lake has no pelagic or profundal zone.

2.3 Øyangen

Øyangen (33 m.a.s.l) is situated on the central plains of Bjørnøya (Figure 1). The lake has an area of 0.35 km² and a maximum depth of 5 m. Most of the lake however is less than 1 meter deep. The total catchment area is approximately 2.2 km² and the estimated retention time is 0.9 year. The lake has a population of stationary Arctic char. The lake has no pelagic or profundal zone. The area around Øyangen is very flat and consists mainly of boulders. On Øyangen, flocks of kittiwakes can be observed but the flocks are smaller and not seen as frequently as on Ellasjøen. There is hardly any vegetation in the catchment area, except for some mosses.

3 Bjørnøya - Food chain studies: The key to designing monitoring programmes for Arctic islands

3.1 Introduction

The previous study carried out by Akvaplan-niva on Bjørnøya showed that Ellasjøen was significantly more contaminated by POPs than Øyangen, but also that Ellasjøen had a higher "basic trophic level" (Skotvold *et al.* 1999). Possibly, the higher "basic level" of isotopes is caused by guano-input to the lake. The seabirds feed in the marine environment and may bring in nutrients (through guano) with another isotopic composition than other nutrients that are transported to the lake (runoff from land, decomposed material). It is further possible that guano can be a source for POPs. However, this hypothesis needs to be tested through analyses of POP-levels, congener-composition and trophic position of organisms from both marine and freshwater food chains, as well as in guano from the three dominating sea-bird species around Ellasjøen (little auk, kittiwake and glaucous gull).

The three seabird species that are important around Ellasjøen have different diet, and due to biomagnification processes, it may therefore be expected that both the birds and their guano contain different levels of POPs. Little auk mainly feeds on planktonic organisms (mainly amphipods), kittiwake feeds mainly on plankton and fish (longer food-chain than little auk), while glaucous gull is more or less omnivorous (i.e. eats almost everything, from fish and crabs to garbage and carrion). Some preliminary studies on levels of POPs in organisms from marine food chains near Bjørnøya have indicated that high levels of POPs occur in some marine organisms (Borgå 1997), and it might therefore be expected that elevated levels of POPs can occur in seabird guano. High levels of POPs have also been found in glaucous gulls from Bjørnøya (Gabrielsen *et al.*, 1995; Savinova *et al.* 1995; Borgå 1997). However, no comprehensive studies of marine food chains have been undertaken to date, and it is therefore not known how/from where the seabirds accumulate POPs .

A common situation on Arctic islands is that generally the production on land is very low, except in areas that are enriched by nutrients from seabird guano. Also lakes that are enriched by guano show a higher productivity than lakes lacking this influence. The preliminary studies on Bjørnøya have indicated that there is a strong coupling between the marine environment and the limnic environment on this island. The importance of guano as a carrier for POPs to terrestrial and limnic environments will be important information in the design of future monitoring programmes.

3.2 Objectives

The main objectives of the food-chain study are to:

- Study the biomagnification of POPs in Arctic freshwater and marine food chains from Bjørnøya;
- Investigate bioaccumulation and the role of the food chain structure and lake productivity on contamination levels on Bjørnøya;

- Study the linkages between the marine and the limnic ecosystems, and to quantify to which extent specific congeners of selected compounds are transferred from the marine food chains to the freshwater food chains through the deposition of guano;
- Estimate the contribution of sea-bird guano to the total supply of POPs to Ellasjøen (in co-operation with the project: Ellasjøen, Bjørnøya - A mass balance study of a high-contaminated Arctic area); and,
- Evaluate which organisms play a key-role in the accumulation and identify which species (freshwater and marine) should be used to monitor contamination-levels and effects on Arctic islands.

3.3 Project design 1999 – 2001

Analyses of the samples of sediment and Arctic char that were taken in Ellasjøen and in Øyangen in 1996 showed that the contamination level in Ellasjøen was significantly higher than in Øyangen, but also the $\delta^{15}\text{N}$ -values (indicating trophic level) were higher in Ellasjøen than in Øyangen. However, the number of samples that were analysed, especially from lower trophic levels, was sparse. The sampling campaigns in 1999 and 2000 were designed to increase the database for the freshwater ecosystems, in order to strengthen any conclusions drawn from the previous project. In addition, the aims were to investigate if there is a transfer of contaminants from the marine ecosystem to the freshwater ecosystems through the deposition of guano. Samples of organisms from the marine food-chains ending with the seabirds that are most numerous around Ellasjøen and samples of guano from the same species were therefore obtained, in order to estimate (if possible) which seabird species is most important for the transfer of contaminants. In order to test whether guano or atmospheric transport and deposition is the most important mechanism for enrichment of organic contaminants in lake Ellasjøen, a third lake, Skutilen, was included in the study. Skutilen is situated close to Ellasjøen, and in the same catchment area and it is assumed to receive approximately the same amount of precipitation (per unit area) as rain, snow and fog as Ellasjøen. However, Skutilen is not as frequently used by seabirds as Ellasjøen, and therefore not significantly affected by guano. Thus, if guano is an important transport pathway, low levels of POPs would be expected in Skutilen. However, if atmospheric transport and deposition is most important Skutilen should have comparable contamination levels with Ellasjøen.

To further investigate the hypothesis that guano may be important for the contamination levels in organisms on Bjørnøya, we sampled spider crabs (*Hyas araneus*) from the littoral zone in two different areas. One area is close to the Bjørnøya Meteorological station in the north of the island and one is further south under the seabird cliff at Glupen. In the first area there are few seabirds and very little guano runoff to the sea. The second sampling area is situated directly under the seabird cliffs at Glupen, where large colonies of guillemot were nesting/brooding at the time of the sampling campaign. The littoral zone beneath these bird cliffs is believed to be influenced by guano runoff from the cliffs. The spider crab is a very important component in the diet of glaucous gulls at Bjørnøya, and in a previous study (Borgå 1997) elevated levels of some POPs were detected in spider crabs from Bjørnøya.

3.4 Fieldwork in the lakes

The fieldwork in the lakes was carried out in July 1999 and June 2000 and included the following key activities.

3.4.1 Water

The particulate (phytoplankton) and dissolved phases of water were collected using a stainless steel filtration system. The water was pumped through pre-combusted glass-fibre filters (Whatman GF/F) with a cut off of 0.7-1 μm to retain particles and thereto-associated OCs. The dissolved OCs was trapped from the filtrate on a polyurethan foam (PUF) column. Before the sampling started the water sampler was "calibrated" (run without filter) for at least one hour. The flow rate was approximately 3 litres per minute. The total filtered volume of water for each sample was 400 litres. The PUF adsorbents and the GF/F filters were packed in aluminium foil and frozen at -20 °C after the sampling. Field blanks were collected for each station, directly after the sample had been collected, and by repeating the sample procedure steps.

Water and phytoplankton samples were taken from Ellasjøen, Øyangen, Skutilen and from the marine environment, close to the meteorological station. For more details about the water- and phytoplankton sampling the reader is referred to Christensen (1999).

3.4.2 Zooplankton

In Ellasjøen and Øyangen zooplankton samples, for analyses of POPs, lipid and stable isotopes, were collected by horizontal tows from a boat (net diameter 60 cm, mesh size 90 μm). From each lake, at least 20 grams (wet weight) were collected. Plankton samples were put in glass jars and frozen. As no boat was available in Skutilen, zooplankton was collected in a small landing net by wading in the shallow part of the lake.

3.4.3 Benthos

Benthos for POPs, lipid and stable isotope analyses was collected from fish stomachs from Ellasjøen and Øyangen. The dominant stomach content from fish in Ellasjøen was chironomid larvae and pupae. In Øyangen tadpole shrimp was dominating.

3.4.4 Arctic char

Fish were sampled with multi-gillnets in Ellasjøen and Øyangen. These nets are 40 meter long and consist of eight 5-meter sections with different mesh sizes (10, 12.5, 15, 18.5, 22, 26, 35 and 45 mm). The bottom gillnets used were 1.5 meter in height. Nets were placed individually in the littoral zone. Gillnets were set out for a period of twelve hours during the night. The total catch of Arctic char was 47 in Ellasjøen and 27 in Øyangen.

All collected fish were measured (fork length) to the nearest mm, weighed to the nearest gram and had their sex determined. Gonad maturity was recorded using the Sømmes gonad-index (Sømme 1954). The colour of the flesh was classified as white, pink or reddish. Parasites were determined and counted. Otoliths for age assessment were removed and preserved in 70% ethanol. The stomachs were opened and the contents determined. Where the content of the stomach consisted predominantly of one type of prey it was wrapped in aluminium foil.

For analysis of POPs, lipid content and stable isotopes, 20 grams of muscle tissue was taken near the dorsal axial muscle. The smallest fish, being prey items of the largest fish, were preserved as whole fish. All samples for POPs analyses were packed in aluminium foil and frozen.

3.5 Fieldwork, marine food chain

Collection of samples from the marine food chain was carried out in three periods: 1) July 1999 (water and spider crabs north of the island, seabirds near Ellasjøen), 2) early June 2000 (seabird eggs in the bird cliffs in the southern part of the island) and 3) late June 2000 (phytoplankton, zooplankton and spider crabs southwest of the island, on 74°22'N, 18°55'E).

3.5.1 Water

The particulate (phytoplankton) and dissolved phases of seawater were collected by the same methods as for the lakes (see section 3.4.1).

3.5.2 Phytoplankton

Phytoplankton was collected with a phytoplankton net by taking 23 vertical hauls (net diameter 25 cm, mesh size 5 µm) from 20 meters depth to the surface. The samples were filtered through pre-combusted glass-fibre filters (GF/F). After sampling the filters were put into acid-washed and pre-combusted glass jars and frozen. Samples for species identification were preserved with formaldehyde.

3.5.3 Zooplankton

Zooplankton was collected with the zooplankton net "WP3" (net diameter 100 cm, mesh size 1000 µm). The net was lowered down to 30 – 40 meters depth and then the vessel slowly moved forward (1 – 2 knots) for approximately 30 minutes per haul. 4 hauls were taken from respectively 31, 32, 35 and 37 meters. The zooplankton was divided into different size groups by using a steel strainer. Samples for analyses were put into acid-washed and pre-combusted glass jars and frozen. The total amount of zooplankton collected was approximately 300 grams. Zooplankton for species identification was preserved with 96 % ethanol.

3.5.4 Spider crabs

Spider crabs were collected by diving in the littoral zone, near the Meteorological station (July 1999) and near point Glupen in the south-west part of Bjørnøya (late June 2000). All samples were measured with callipers, sorted into size groups, and wrapped in aluminium foil and frozen.

3.5.5 Seabirds

Glaucous gull, kittiwake and little auk were collected close to Ellasjøen. The glaucous gulls were shot near the outlet of Ellasjøen. The kittiwakes were shot close to the shoreline on the northern side of Ellasjøen and the little auks were shot in the nesting cliffs on the southern side of Ellasjøen. A total of 15 of each species were collected and sampled. Each bird was weighed on a Pesola spring balance. Morphological measurements recorded included skull length, bill height, bill depth and the wing length. Samples from brain, liver and muscle were

taken for POPs analyses. From little auk only, tissue from the liver and muscle were taken. Gut and stomach were taken from all birds, and guano was squeezed out from the posterior parts of the colon. Four of the little auk had food (crustaceans) in the gullet. These crustaceans were taken out with a metal spoon. All the samples were taken immediately after the bird had been shot and were wrapped in aluminium foil and frozen.

In addition to samples of intestinal content from all the birds that were shot, samples of guano from little auk and glaucous gulls were taken from the ground in the nesting cliffs for the two species.

3.5.6 Bird eggs

Twenty eggs from glaucous gull, Brünnic's guillemot and common guillemot were collected in the beginning of the brooding season in June 2000. The eggs from Brünnich's guillemot were collected on the south-west part of the bird cliff Fuglefjellet and common guillemot were collected from the lower part of point Kapp Kolthoff. Eggs from glaucous gull were collected from point Kapp Harry, except for 2 eggs that were collected near point Kapp Kolthoff. The eggs were kept cold and transported to Tromsø where they were cracked and the contents put into glass jars and frozen. All the eggs were measured (length and width) to nearest mm and the glaucous gull eggs were also weighed to nearest gram.

3.6 Analyses

Due to limited funding, only a selection of the samples that were collected could be analysed for POPs and stable isotopes. Overviews of the samples that were selected for analyses are given in Table 1 and Table 2.

Table 1. Samples from lakes that have been analysed for POPs. All samples were taken in July 1999.

Sample type	No. Ellasjøen	No. Øyangen	No. Skutilen
Water, particulate	3	2	-
Water, dissolved	3	2	-
Zooplankton	1	1	1
Chironomids (stomach content)	1	-	-
Tadpole shrimps	-	1	1
Arctic char	3 (Pooled from 1-3 individuals)	3 (Pooled from 1-3 individuals)	-

Table 2. Samples from the marine food chains that have been analysed for POPs and stable isotopes.

Sample type	Area	Sampling period	Number of samples
Water, particulate	Met. station, north	July 1999	2
Water, dissolved	Met. station, north	July 1999	2
Phytoplankton	West of Bjørnøya	June 2000	1
Zooplankton < 1 mm	West of Bjørnøya	June 2000	1
Zooplankton > 1 mm	West of Bjørnøya	June 2000	1
Crustaceans	From the gullet of little auk	July 1999	1
Spider crabs < 5 cm	Met. station, north	July 1999	1 (12 ind. pooled)
Spider crabs > 5 cm	Met. station, north	July 1999	1 (11 ind. pooled)
Spider crabs < 5 cm	Glupen	June 2000	1 (16 ind. pooled)
Spider crabs > 5 cm	Glupen	June 2000	1 (12 ind. pooled)
Eggs from common guillemot	Kapp Kolthoff	June 2000	3
Eggs from Brünnichs guillemot	Fuglefjellet	June 2000	3
Little auk, muscle	Ellasjøen	July 1999	3
Kittiwake, muscle	Ellasjøen	July 1999	3
Glaucous gull, muscle	Ellasjøen	July 1999	3
Little auk, intestinal content	Ellasjøen	July 1999	1 (15 ind. pooled)
Kittiwake, intestinal content	Ellasjøen	July 1998	1 (9 ind. pooled)
Glaucous gull, intestinal content	Ellasjøen	July 1999	1 (15 ind. pooled)

Water samples were analysed for PCBs. The samples of organisms from the lakes were analysed for PCB and DDTs (some also for pesticides), as the former analyses had shown that these components were dominating in freshwater biota. The fish samples were analysed for stable isotopes, but due to a mistake at the laboratory, sub-samples for analyses of stable isotopes were not taken from organisms at lower trophic levels. Additional samples for this purpose were taken in July 2001 (not reported here). The samples from the marine food-chains were analysed for PCBs, DDTs, pesticides and stable isotopes.

POP-analyses in biological material were carried out at the Norwegian Institute for Air Research (NILU), while PCB-analyses in water samples and stable isotope analyses were performed at the University of Stockholm. Analytical methods are described in a previous report to SFT (Skotvold *et al.* 1999).

3.7 Results and discussion, freshwater food chain

As the present report mainly is a data report on a study in progress, extensive data treatment and interpretation has not been carried out yet and will therefore not be presented in the following sections. The preliminary assessments presented below are not based on comprehensive inter-compartmental and statistical analyses, but only on preliminary visual data inspections.

3.7.1 Water samples

The water samples consisted of two fractions; a particulate fraction and a dissolved fraction. The contaminant concentrations of the dissolved fraction are expressed here as a volume concentration, while the contaminants in the particulate phase are expressed as ng/g organic carbon in the samples. The PCB-concentration in the particulate matter from Ellasjøen (on a column basis) was approximately 5 times higher than the PCB-concentration in particulate matter from Øyangen. However, the concentration of organic carbon was higher in the

particulate samples from Ellasjøen. Consequently the carbon normalised values showed that PCB-levels in particulate matter was two times higher in Ellasjøen than in Øyangen. In Skutilen, PCB-levels were comparable to level in Ellasjøen. Also in the dissolved phase the PCB-concentrations in Ellasjøen were twice the concentration in Øyangen (Table 3). The distribution of PCBs expressed as a percent of Σ PCB is shown for both lakes and compared for particulate and dissolve fractions in Figure 2. The dominant congeners in the particulate phase were 153 and 138, followed by 123 + 118 and 180 + 193. The lower chlorinated PCBs occurred in lower concentrations. The dominance of PCB 138 and 153 was specially pronounced in samples from Ellasjøen. These two PCB-congeners are also the dominating congeners in guano samples.

In the dissolved phase, the concentrations were several times lower than in the particulate phase (Table 3), but also in those samples the dominant congeners were 153 and 138, followed by 123 + 118. As expected, the relative concentration of the lower chlorinated congeners (essentially up to congener 149 – a hexa-chlorinated PCB) was higher in the dissolved than in the particulate phase. The high occurrence of lower chlorinated PCBs in the dissolved phase was most pronounced in Skutilen, followed by Øyangen. In Ellasjøen PCB 153 and 138 dominated also in the dissolved phase.

Table 3. Average PCB-concentration in dissolved fraction (pg/l) and in particulate matter (ng/g organic carbon) in water samples from Ellasjøe, Skutilen and Øyangen, July 1999. n = number of filters (particulate) or PUFs (dissolved) analysed.

PCB congener	Ellasjøen		Skutilen		Øyangen	
	Particulate (n = 2) ng/g OC	Dissolved (n = 2) pg/l	Particulate (n = 1) ng/g OC	Dissolved (n = 1) pg/l	Particulate (n = 2) ng/g OC	Dissolved (n = 2) pg/l
18	2.2	0.29	4.5	1.32	8.3	0.33
28	14.3	0.85	33.7	1.89	24.1	0.71
52	2.9	0.20	3.4	0.66	11.7	0.26
70	5.5	0.32	11.8	0.48	11.9	0.32
90/101	11.3	0.45	18.0	0.63	16.4	0.36
110	3.3	0.23	7.1	0.42	9.9	0.28
123+118	96.1	1.88	101.9	0.69	30.4	0.70
105	20.8	0.48	16.8	0.20	13.8	0.18
149	6.3	0.14	7.0	0.35	8.6	0.22
153	279.3	4.10	258.7	1.72	108.1	1.29
132	7.9	0.07	1.7	0.10	2.4	0.11
138	295.3	2.96	279.3	1.41	109.6	1.07
158+160	6.6	0.09	12.2	0.06	3.9	0.04
180+193	68.6	0.39	94.1	0.24	37.8	0.21
199	1.0	0.10	0.1	0.04	4.9	0.03
194	6.5	0.16	10.9	0.04	9.4	0.10
Sum (average)	827.9	12.71	861.2	10.25	411.2	6.21

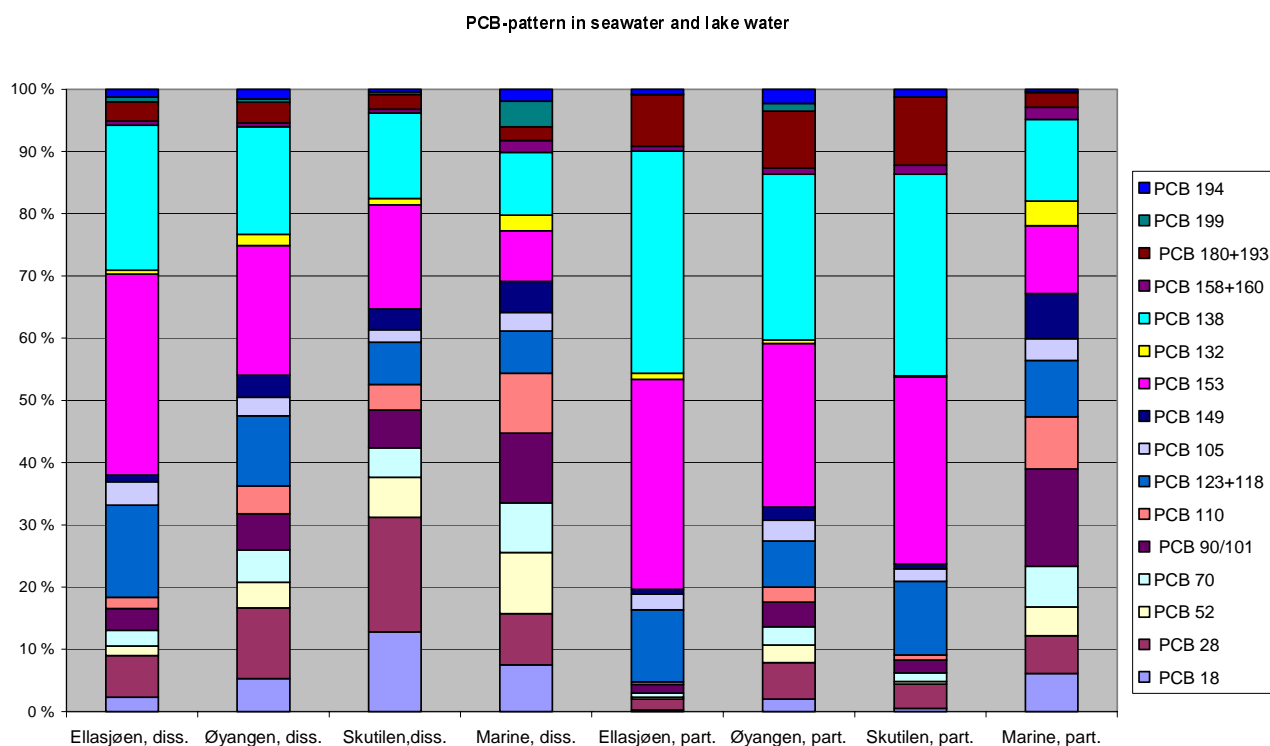


Figure 2. PCB-pattern in freshwater for particulate (carbon normalised data) and dissolved fractions expressed as a percent of total PCB in the respective phases, Bjørnøya July 1999.

3.7.2 Plankton and benthos

The levels of PCB, HCB and DDT in zooplankton and benthic organisms (chironomids and tadpole shrimps) from the three lakes are shown in Table 4. Sampled zooplankton from Ellasjøen had higher concentrations of all the measured contaminants than zooplankton from Skutilen, followed by Øyangen, with the lowest concentrations. Chironomids from Ellasjøen had higher contamination levels than the tadpole shrimp-samples from the two other lakes. Tadpole shrimps from Øyangen had higher levels of contaminants than comparable samples from Skutilen. However, the lipid content was very low in tadpole shrimps from Skutilen, so calculated on a lipid basis, the levels were higher in these organisms from Skutilen than in Øyangen.

Table 4. Selected POPs in zooplankton, chironomids (*Chironomidae* sp.) and tadpole shrimps (*Lepidurus arcticus*) from Øyangen, Ellasjøen and Skutilen, June 1999. All concentrations are given as ng/g ww.

Compound	Øyangen		Ellasjøen		Skutilen	
	Zooplankton	Tadpole shrimps	Zooplankton	Chironomids	Zooplankton	Tadpole shrimps
Lipid (%)	0.62	2.37	1.48	3.68	1.31	0.39
ΣPCB7 (ng/g ww)	1.08	4.03	16.86	44.17	2.55	0.91
ΣPCB (ng/g ww)	2.15	7.09	26.99	73.63	7.18	1.93
HCB (ng/g ww)	0.08	0.62	0.76	1.92	0.16	0.06
ΣDDT* (ng/g ww)	0.16	0.54	1.71	5.42	0.25	0.11

* DDE dominant component

Pesticides were analysed in tadpole shrimps from Øyangen and in zooplankton and tadpole shrimps from Skutilen. The concentrations of most measured pesticides were low in all samples. The highest concentrations of pesticides were found in the tadpole shrimp sample from Øyangen, where the dominant pesticides were DDE followed by γ -HCH.

Based on these very few results it is difficult to conclude anything about the contamination status in Skutilen. More samples from this lake need to be analysed for POPs and stable isotopes in order to clarify the trophic status, as well as the contamination status of the lake.

3.7.3 Arctic char

The Arctic char that were analysed for POPs and stable isotopes supplemented the samples that were analysed in 1998 (see Skotvold *et al.* 1999). Table 5 gives an overview of the fish that were analysed. As can be seen from the table, the fish from Ellasjøen were considerably larger than the fish from Øyangen. The fish from Ellasjøen also had a significantly higher $\delta^{15}\text{N}$ -value than the char from Øyangen. The previous study (Skotvold *et al.* 1999) indicated that the food-chain in Ellasjøen has a higher “basic $\delta^{15}\text{N}$ ” status than Øyangen, and this is probably the main reason for the differences in $\delta^{15}\text{N}$ -values found also in the present study.

Table 5. Data on Arctic char (*Salvelinus alpinus*) that were selected for POP-analyses. The char that were analysed for POPs and stable isotopes were fish that supplement the samples that were analysed in 1998 (see Skotvold *et al.* 1999).

Fish no.	Length (mm)	Weight (g)	Age (years)	$\delta^{15}\text{N}$ (‰)	Average $\delta^{15}\text{N}$
<u>Øyangen</u>					
6	96	7		8.87	
25	98	7		8.28	8.90
26	98	7		9.55	

8	116	13		8.61	
9	117	12		8.85	7.90
23	115	14		6.46	

15	101	8		9.12	
24	93	7		9.00	9.15
27	103	9		9.34	
<u>Ellasjøen</u>					
24	196	64	11	17.68	

25	125	18	5	17.84	16.82
26	109	13	7	15.80	

43	170	52	8	17.75	

Table 6 gives the results from the POP-analyses of the selected fish. As expected the char from Ellasjøen contained the highest concentrations of all the measured contaminants. The results from these analyses confirm the results from the previous study (Skotvold *et al.* 1999) and further strengthen the conclusion that Ellasjøen is more contaminated by POPs than Øyangen.

Table 6. POPs in Arctic char (*Salvelinus alpinus*) from Øyangen and Ellasjøen, June 1999.

Compound	Øyangen			Ellasjøen		
	Fish no. 6 + 25 + 26	Fish no. 8 + 9 + 23	Fish no. 15 + 24 + 27	Fish no. 24	Fish no. 25 + 26	Fish no. 43
Lipid (%)	1.57	2.97	2.0	2.65	4.03	2.75
$\delta^{15}\text{N}$ (‰)	8.90	7.90	9.15	17.68	16.82	17.75
HCB (ng/g ww)	0.37	0.45	0.92	1.47	2.35	1.59
Σ DDT (ng/g ww)	3.45	1.62	6.46	62.39	40.95	84.66
Σ PCB7 (ng/g ww)	37.33	18.19	55.87	648.00	373.61	906.57
Σ PCB (ng/g ww)	64.67	32.18	97.50	1 191. 81	596. 00	1 629.60

3.8 Results and discussion, marine food chain

3.8.1 Seawater

The concentration of PCB in seawater was lower than in freshwater (Table 7). The relative distribution of individual congeners expressed as a percent of the sum-PCB (particulate or dissolved phase respectively) is illustrated and compared with freshwater in Figure 3. In the seawater samples, the lower chlorinated PCBs dominated in the dissolved phase. In the particulate phase there was a higher occurrence of medium to higher chlorinated PCBs (especially PCB 153 and 138), but to a much lower degree than in the water samples from the lakes.

As Figure 3 shows the dominance of congeners 153 and 138 in the freshwater is clear, as is the much reduced influence of the higher chlorinated PCBs in the seawater. The differences between the seawater and freshwater concentrations and overall PCB distribution warrant further consideration to understand these differences.

Table 7. Average PCB-concentrations in dissolved phase (pg/l) and in particulate matter (ng/g organic carbon) of seawater. Meteorological station, July 1999.

PCB congener	Seawater	
	Particulate (n = 2) ng/g OC	Dissolved (n= 2) pg/l
18	3.5	0.30
28	3.5	0.33
52	2.6	0.39
70	3.7	0.32
90/101	9.0	0.45
110	4.8	0.38
123+118	5.2	0.27
105	2.0	0.12
149	4.2	0.2
153	6.3	0.32
132	2.3	0.10
138	7.5	0.40
158+160	1.2	0.08
180+193	1.3	0.09
199	0.1	0.16
194	0.2	0.08
Sum (average)	57.4	3.98

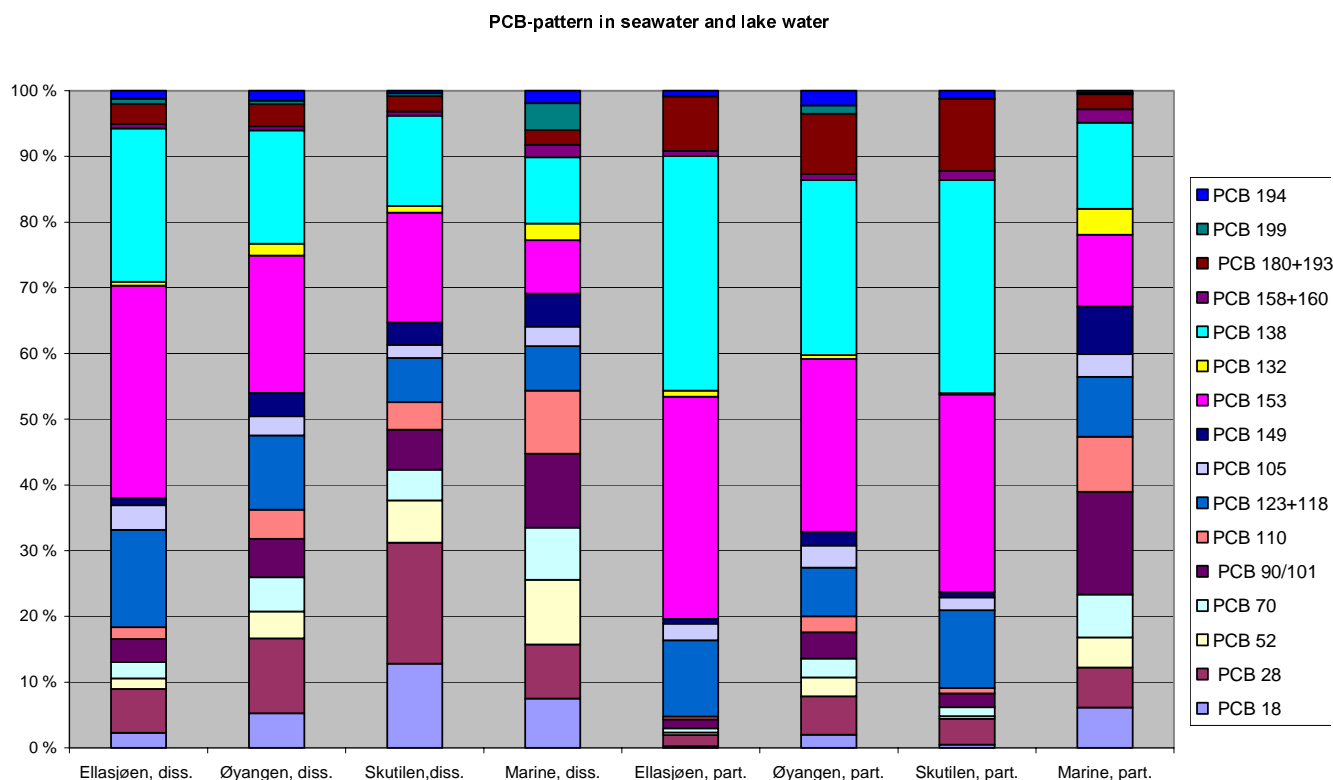


Figure 3. Comparison of PCB-pattern in particulate (carbon normalised data) and dissolved phase of seawater and freshwater, Bjørnøya July 1999.

3.8.2 Plankton

Low concentrations of PCBs and pesticides (mostly below detection limit for pesticides) were found in the marine phytoplankton sample taken west of Bjørnøya (Table 8). The concentrations in zooplankton were higher and seemed to increase from small zooplankton (mainly copepods) to larger zooplankton (mainly comb jellies, arrow worms and medusa) to larger crustaceans (except PCB, which were highest in the zooplankton > 1 mm).

Table 8. PCBs and pesticides in phytoplankton and zooplankton sampled near Bjørnøya, July 2000. Unless otherwise stated, all concentrations are given as ng/g ww.

Compound	Phytoplankton	Zooplankton < 1 mm	Zooplankton > 1 mm	Zooplankton from gullet*
Lipid (%)	n.a.	3.26	4.08	7.03
$\delta^{15}\text{N}$ (‰)	-	6.7	8.0	7.6
ΣPCB7	0.34	1.43	7.40	2.11
ΣPCB	0.65	2.50	11.5	4.69
HCB	0.03	0.17	0.33	0.94
α -HCH	<0.1	0.36	0.32	1.23
β -HCH	<0.2	<0.3	0.11	0.90
γ -HCH	<0.1	0.04	0.14	0.56
Chlordene	<0.1	<0.1	<0.1	<0.1
Heptachlor	<0.1	<0.1	<0.1	<0.6
Heptachlorepoxide	<0.1	0.11	0.18	0.78
Heptachlorendoepoxide	<0.1	<0.1	0.12	<0.6
oxy-Chlordane	<0.1	0.17	0.39	0.48
trans-Chlordane	<0.1	0.03	0.03	0.12
cis-Chlordane	<0.1	0.08	0.13	0.49
trans-Nonachlor	<0.1	0.08	0.14	0.70
cis-Nonachlor	<0.1	0.01	0.03	0.26
Dieldrin	<0.1	0.38	0.64	3.28
Aldrin	<0.1	<0.1	<0.6	<2.5
Endrin	<0.1	0.12	0.42	1.33
Isodrine	<0.1	<0.2	<0.2	<0.9
Trifluralin	<0.1	0.01	0.01	<0.1
a-Endosulfan	<0.1	0.01	0.01	0.06
ΣDDT (ng/g ww)	0.09	0.53	0.98	1.52
Sum tox (26+50 +62)	0.3	0.29	0.67	2.16

* from little auk, mainly large crustaceans (>2 mm)

3.8.3 Spider crabs

Spider crabs had slightly higher PCB and pesticide concentrations than zooplankton (Table 9). There were no obvious differences between the two size groups or between the two areas.

Table 9. POPs in spider crabs (*Hyas araneus*) from the littoral zone near Bjørnøya Meteorological station and Glupen. All concentrations are given as ng/g ww.

Compound	Spider crabs, Bj. Met.		Spider crabs, Glupen	
	< 5 cm	> 5 cm	<5 cm	> 5 cm
Lipid (%)	6.76	9.0	9.47	9.79
$\delta^{15}\text{N}$ (‰)	7.6	7.2	12.0	10.0
ΣPCB7	8.55	15.8	12.0	10.0
ΣPCB	13.5	26.4	19.1	16.5
HCB	1.21	2.32	1.70	2.03
α -HCH	1.75	2.22	1.57	1.53
β -HCH	<0.6	<0.4	<0.4	<1.1
γ -HCH	0.41	0.59	0.40	0.38
Chlordene	<0.1	<0.1	<0.1	<0.1
Heptachlore	<0.4	<0.7	<0.7	<0.7
Heptachlorepoxyde	0.52	0.65	0.54	0.31
Heptachloreendoepoxyde	<0.4	<0.6	<0.6	<0.6
Oxychlordane	0.91	1.09	1.27	0.42
trans-Chlordane	<0.1	<0.1	<0.1	<0.1
cis-Chlordane	0.15	0.18	0.11	0.13
trans-Nonachlor	0.61	0.88	0.55	0.57
cis-Nonachlor	0.19	0.25	0.16	0.17
Dieldrin	1.55	1.98	1.19	1.11
Aldrin	<1.4	<2.7	<2.5	<2.6
Endrin	0.90	1.24	0.74	0.72
Isodrine	<0.5	<0.9	<0.9	<0.9
Trifluralin	<0.1	<0.1	<0.1	<0.1
a-Endosulfan	<0.1	<0.1	<0.1	<0.1
ΣDDT (ng/g ww)	3.77	6.84	4.55	4.24
Sum tox (26+50 +62)	1.54	2.15	1.3	1.46

3.8.4 Seabirds

Eggs

Eggs from Common guillemot and Brünnichs guillemot, which are important food items for glaucous gulls, had several fold higher concentrations of PCBs and some pesticides than the spider crab samples (Table 10).

Table 10. POPs in eggs from common guillemot (*Uria aalge*) and Brünnichs guillemot (*Uria lomvia*), Bjørnøya June 2000. Unless otherwise stated, all concentrations are given as ng/g ww

Compound	Eggs from Brünnichs guillemot			Eggs from common guillemot		
	1	2	3	1	2	3
Sample no.						
Lipid (%)	11.9	11.8	13.7	12.3	11.1	12.8
$\delta^{15}\text{N}$ (‰)	10.7	11.1	10.4	13.2	12.9	12.8
Σ PCB 7	87.4	133	55.7	105	142	196
Σ PCB	185	274	123	242	290	221
HCB	51.3	58.9	43.9	37.9	33.7	42.8
α -HCH	0.76	0.60	0.57	0.31	0.31	0.38
β -HCH	3.61	5.79	1.66	1.44	1.09	1.65
γ -HCH	0.30	0.27	0.20	0.11	0.11	0.13
Chlordene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Heptachlor	<0.1	<0.2	<0.2	<0.1	<0.1	<0.1
Heptachlorepoxide	6.43	9.48	2.05	4.91	3.54	2.79
Heptachlorendoepoxide	<0.1	<0.2	<0.2	<0.1	<0.1	<0.1
Oxychlordane	11.9	13.6	5.59	10.3	10.6	10.5
trans-Chlordane	0.04	0.05	0.02	0.03	0.04	0.03
cis-Chlordane	0.32	0.29	0.07	0.11	0.11	0.11
trans-Nonachlor	0.30	0.41	0.09	0.21	0.14	0.28
cis-Nonachlor	3.19	3.36	0.91	0.20	0.36	0.69
Dieldrin	14.2	13.3	4.29	7.23	4.35	3.59
Aldrin	0.43	0.70	<1.2	<0.9	<0.7	<0.8
Endrin	20.5	25.7	7.96	2.72	4.41	6.93
Isodrine	<0.3	<0.3	<0.4	<0.3	<0.2	<0.3
Trifluralin	0.02	0.02	0.01	0.01	0.01	0.01
a-Endosulfan	<0.1	0.01	0.01	0.01	0.01	0.01
Σ DDT (ng/g ww)	125	166	116	143	125	144
Sum tox (26+50 +62)	36.7	40.8	17.8	13	14.9	16.3

Muscle

Muscle samples from three individuals (males) of the selected bird species little auk, kittiwake and glaucous gull were analysed for PCB and pesticides. The samples from the plankton-feeder little auk had, as expected, the lowest levels of contaminants, followed by kittiwake (pelagic food-chain) and glaucous gulls (benthic/omnivorous food-chain) (Table 11). The concentrations of POPs varied considerably between individuals of the same species. Notably, one glaucous gull showed very high concentrations (up to an order of magnitude greater) of most of the analysed contaminants (Table 11).

Table 11. PCBs and pesticides in muscle samples from seabird from Bjørnøya, June 1999. Unless otherwise stated, all concentrations are given as ng/g ww.

Compound Sample no.	Little auk			Kittiwake			Glaucous gull		
	1	2	3	1	2	3	1	2	3
Lipid (%)	2.43	2.24	2.26	5.54	7.64	9.24	11	6.64	8.53
$\delta^{15}\text{N}$ (‰)	10.3	10.7	10.8	12.4	11.4	12.0	13.0	12.6	12.9
Sum PCB 7	80.5	55.0	42.4	188	659	672	22 150	2 576	3 935
HCB	5.57	3.10	2.01	6.83	11.0	17.4	159	43.8	94.4
α -HCH	0.27	0.43	0.29	0.20	0.36	0.29	0.52	0.26	0.36
β -HCH	1.71	1.26	0.82	1.32	1.58	2.95	13.5	3.50	18.1
γ -HCH	0.35	0.28	0.29	0.08	0.16	0.16	0.11	<0.1	0.09
Chlordene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1
Heptachlor	<0.1	<0.1	<0.1	<0.2	<0.5	<0.6	<1.5	<0.6	<0.8
Heptachlorepoxyde	4.36	5.88	3.60	7.54	14.8	19.3	327	28.1	76.7
Heptachloendoepoxyde	<0.1	<0.1	<0.1	<0.2	<0.5	<0.6	<1.4	<0.5	<0.7
Oxychlordane	6.50	4.98	3.35	15.0	40.4	39.8	831	97.1	214
trans-Chlordane	0.02	0.02	0.01	0.05	0.11	0.11	3.53	0.28	0.60
cis-Chlordane	0.10	0.24	0.11	0.27	0.30	0.40	1.52	0.40	0.45
trans-Nonachlor	12.7	14.9	6.62	2.62	1.50	1.83	14.5	8.89	13.8
cis-Nonachlor	2.66	6.61	3.18	1.24	0.96	2.29	4.16	4.90	6.86
Dieldrin	4.21	22.3	5.89	8.08	8.80	14.1	253	11.5	23.4
Aldrin	0.33	<0.4	<0.3	0.34	< 2	<2.3	2.48	1.42	2.75
Endrin	3.30	7.29	1.96	5.67	5.70	8.29	154	16.3	42
Isodrine	<0.2	<0.2	<0.1	<0.3	<0.7	<0.8	<2	<0.7	< 1
Trifluralin	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
a-Endosulfan	0.42	<0.1	<0.1	<0.1	<0.1	<0.1	0.13	<0.1	<0.1
Σ DDT (ng/g ww)	42.6	46.9	27.4	68.4	25.1	27.1	2 655	819	1 352
Sum tox (26+50 +62)	6.58	12.4	5.38	18.5	17.2	19.8	346	51.2	128

Figure 4 shows levels of PCB7 in the marine organisms that were included in the present study.

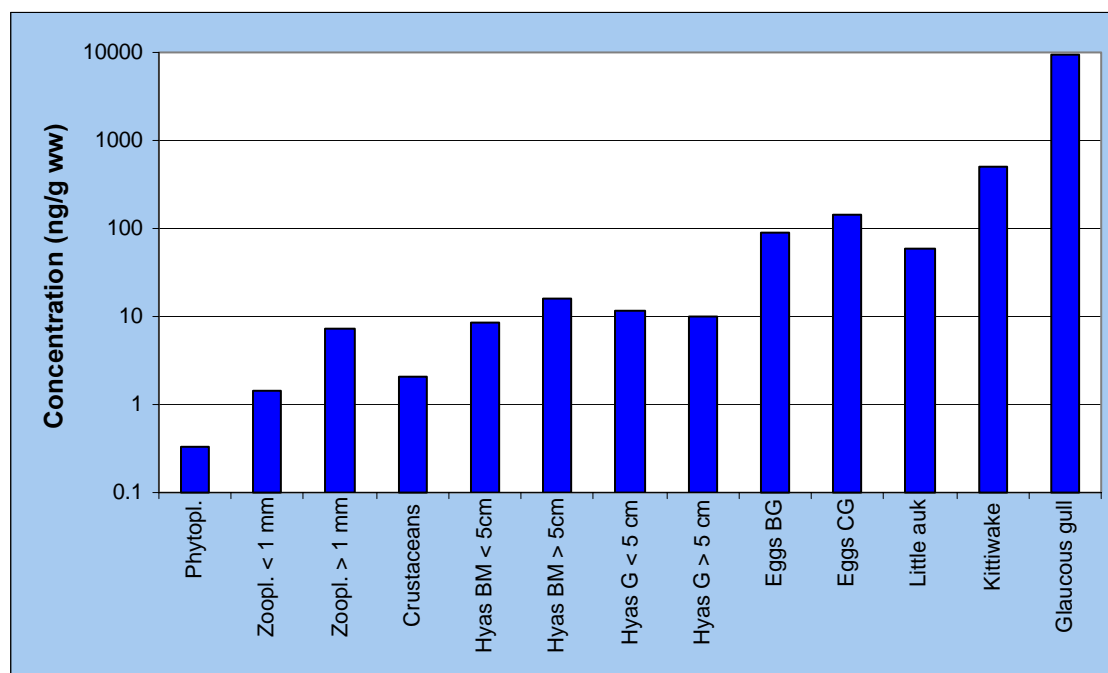


Figure 4. Sum PCB7 (ng/g ww) in samples from the marine food-chain near Bjørnøya, July 2000. Note log-scale. Hyas BM = spider crabs (*Hyas araneus*) Bjørnøya meteorological station (BM), HyasG = *Hyas Glupen*, BG = *Brünnichs guillemot (Uria lomvia)*, CG = *Common guillemot(Uria aalge)*. The samples shown as little auk (*Alle alle*), kittiwake(*Rissa tridactyla*) and glaucous gull(*Larus hyperboreus*) represent muscle samples from the respective species.

Intestinal content and guano

In order to clarify the importance of guano as a carrier of POPs to the limnic system on Bjørnøya, samples of guano taken from the ground in colonies of little auk and glaucous gull, as well as intestinal content (posterior part of colon) from little auk, kittiwake and glaucous gull were analysed for POPs (Table 12 and Table 13). The lipid-level and the concentration of POPs in the ground-sampled guano were relatively low compared to the levels found in intestinal content from the same species. The “age” of the guano samples taken from the ground is not known, and concentrations may have been reduced due to volatilization and wash-out processes. On the other hand concentrations in the intestinal content may be further reduced before the guano is dropped from the birds, even though most of the absorption processes occur in the small intestine.

However, there was a tremendous difference between the three species investigated. Little auk had the lowest concentrations of POPs both in guano and in the intestinal content. Kittiwake had levels that were in between little auk and glaucous gull, while the glaucous gull had very high levels of PCB and some pesticides in the intestinal content (Table 13). A comparison of PCB7 in intestinal content from the three species is given in Figure 5, and the PCB-pattern in intestinal content from glaucous gull is shown in Figure 6. The role of guano will be further investigated in 2001 through additional sampling and analyses of guano.

Table 12. POPs in guano samples from little auk (*Alle alle*) and glaucous gull (*Larus hyperboreus*). These guano samples were taken from the ground, and the "age" of the samples is therefore not known. Unless otherwise stated, all concentrations are given as ng/g ww.

Compound	Little auk	Glaucous gull
Lipid (%)	0.43	0.11
∑PCB7	3.09	51.9
∑PCB	6.42	85.30
HCB	0.54	2.91
α-HCH	0.11	0.06
γ-HCH	0.10	0.04
Chlordene	<0.01	<0.01
Heptachlor	<0.01	<0.01
Heptachlorepoxyde	0.63	2.96
Heptachlorendoepoxyde	0.58	6.65
Oxychlordane	0.01	0.01
trans-Chlordane	0.04	0.08
cis-Chlordane	0.53	0.37
trans-Nonachlor	0.22	0.19
cis-Nonachlor	1.10	1.77
Dieldrin	<0.04	<0.04
Aldrin	<0.01	0.01
Endrin	0.04	0.01
Isodrine	n.a.	n.a.
Trifluralin	0.66	3.36

Table 13. POPs in intestinal content (posterior part of colon) from little auk (*Alle alle*), kittiwake (*Rissa tridactyla*) and glaucous gull (*Larus hyperboreus*) sampled near Ellasjøen, Bjørnøya 1999. Intestinal content from 10 (kittiwake) or 15 (little auk and glaucous gull) individuals was pooled before analyses (ng/g ww).

Compound	Little auk	Kittiwake	Glaucous gull
Lipid (%)	2.21	2.87	5.94
∑PCB7	29.1	107.4	3 371.4
∑PCB	60.6	178	5 709
HCB	5.98	5.59	94.6
α-HCH	0.25	0.14	0.31
γ-HCH	0.18	0.08	<0.3
chlordan	<0.08	<0.01	<0.07
Heptachlor	<0.15	<0.01	<0.15
Heptachlorepoxyde	2.48	5.01	25.1
Oxychlordane	2.68	9.39	153
trans-chlordane	0.01	0.02	0.18
cis-chlordane	0.01	0.08	0.26
trans-Nonachlor	3.14	0.46	2.93
cis-Nonachlor	1.66	0.22	2.14
Dieldrin	3.51	4.57	35.1
Aldrin	<0.29	<0.13	<3.5
Trifluralin	0.05	<0.01	<0.20
a-Endosulfan	<0.09	0.01	0.05
∑DDT (ng/g ww)	15.6	n.a.	764
Sum tox (26+50)	4.47	4.19	53.1

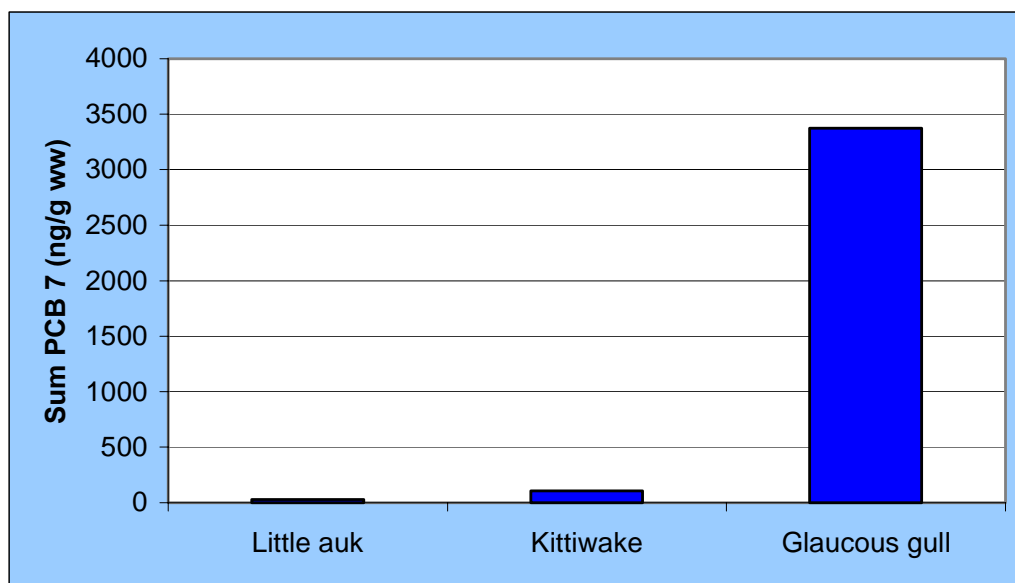


Figure 5. Sum PCB7 in intestinal content from little auk (*Alle alle*), kittiwake (*Rissa tridactyla*) and glaucous gull (*Larus hyperboreus*) from Bjørnøya, June 1999.

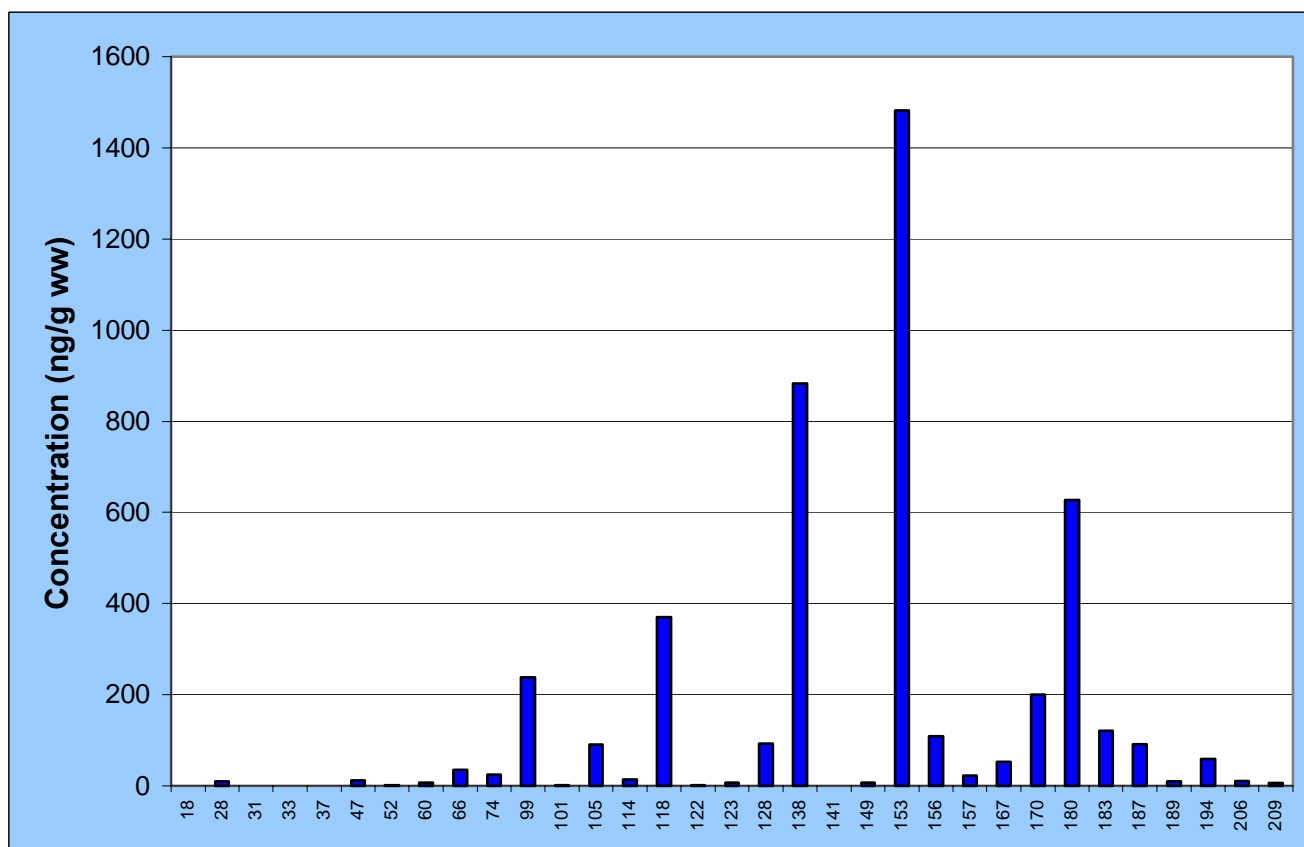


Figure 6. PCB-pattern in intestinal guano from glaucous gull (*Larus hyperboreus*), Bjørnøya June 1999.

The dominant PCB-congeners in the intestinal content of glaucous gull were 153, followed by 138, 180 and 118. The same pattern has been observed in fish from Ellasjøen (Skotvold *et al.* 1999). This PCB-profile, which is highly unusual for abiotic samples, has been observed in air and precipitation samples from Bjørnøya (see chapter 4.6). This may indicate that the whole area is affected by the numerous bird colonies that populate the island during the summer time. However, this hypothesis needs to be investigated further through comparisons of PCB-patterns in biotic and abiotic samples taken at different times throughout the year.

4 Ellasjøen, Bjørnøya – A mass balance study of a highly contaminated Arctic area

4.1 Introduction

The POP-patterns found in biota from Lake Ellasjøen on Bjørnøya deviate considerably from the typical patterns expected for local contamination, i.e. no local source can be assumed to be responsible for the high POP values found. Thus, as there is no local source to explain these contaminants, the questions that need to be addressed include the source of these contaminants, the transport pathways that deliver these contaminants to this site, total deposition and finally contaminant fate including biological uptake, sinks and effects.

As outlined in the AMAP report (1998), atmospheric long-range transport is very important for a selected number of semi-volatile compounds, including the above mentioned chemicals. Previous investigations, from the early 1980's on high volume air samples, carried out at Bjørnøya revealed several long-range transport episodes from Eastern Europe. Thus, there are strong indications that Bjørnøya as well as Svalbard belongs to the main atmospheric deposition sites in the Norwegian Arctic and can be considered as 'hot spot' areas for the deposition of airborne pollutants as defined by AMAP (1998).

4.2 Objectives

The overall objective of this project is to contribute with significant new information to the understanding of contaminant pathways in the Arctic hydrosphere and to provide a better understanding of contaminant focusing in a sensitive polar environment. This will be accomplished through a comprehensive mass balance study of the atmospheric loadings of PCBs and other contaminants to the Lake Ellasjøen watershed to determine the seasonal importance of atmospheric deposition on a remote Arctic island. Further, effort will be directed at assessing the relative importance of various source regions of contaminants to the island through an evaluation of contaminant signatures and back trajectories of pollution events. This will be accomplished through a series of research and monitoring goals, specifically:

- Seasonal measurements of atmospheric concentrations of POPs over two years. Back trajectories will be determined for specific pollution events.
- Seasonal measurements of the deposition of POPs by precipitation (rain and snow) to the watershed.
- Quantitative determination of the hydrologic and contaminant budget of the lake watershed with emphasis on i) snowpack melting and subsequent influx of contaminants to and from the lake and ii) the loadings of summer rainfall events.
- Investigation of the snowpack/air exchange of contaminants during the melt season to assess the roles of volatilization and runoff in determining the fate and timing of contaminant releases from the snowpack either to runoff, air or soil.
- Evaluation of the relative importance of fog to the water and contaminant budgets of the system for the first time in an Arctic system.
- Quantification of the fate of contaminants within the lake using a contaminant transfer model developed for Canadian Arctic lakes specifically including an assessment of

sedimentation and biological uptake, estimates of direct loadings of contaminants by the bird populations and contaminant export from the lake.

A further objective of this project is to provide an assessment of procedures that can be used most effectively to detect these contaminants and their effects in other similar, remote environments. In other words, we want to utilize this knowledge base to refine monitoring approaches for other regions by identifying key ecological niches and/or techniques that are transferable and that can efficiently characterize ecological conditions in remote northern systems. Such an approach will assist other researchers and monitoring agencies in standardizing approaches thereby providing an improved “tool kit” to national and international decision makers.

4.3 Project design 1999 - 2001

In 1999 we installed scientific equipment at two different sites on Bjørnøya. One set of equipment was installed in the catchment area of Ellasjøen and one set of equipment close to the Bjørnøya Meteorological station. The equipment measures meteorological conditions and collects samples for POPs analysis. The main goals for the first field season were to install the equipment and collect some preliminary samples of surface snow, rainwater, fogwater and ambient air.

In 2000 we collected ambient air, rainwater, surface snow, snow, meltwater, fog-water and recorded different weather parameters during three field periods. Snow and rainwater were sampled from both sites. A high volume air sampler at the meteorological station collected air samples. An automatic weather station at Ellasjøen continually records weather data.

4.4 Methods – scientific equipment

The methods and the scientific equipment used in this project are described in detail in the field reports from 1999 and 2000 (Christensen 1999, Christensen and Evenset 2000).

4.4.1 Weather station

To be able to monitor rainfall and humidity throughout the year, a weather station was installed on the cabin near Ellasjøen. This is an automatic weather station (type 2700) by Aanderaa instruments with a relative humidity sensor (type 3445) and a rainfall sensor (type 3064). The weather data are logged every hour throughout the year. The data are stored in a data storage unit (type 2990). The power source for the weather station is a 12-volt 220-amp battery that is charged by a wind generator (type Ampair 100). In May 2000, a visibility sensor was connected to the automatic weather station. This sensor measures the visibility from 0 – 3000 meters and gives information about frequency and density of fog. A rainfall sensor (type 3864) was installed to one of the fog collectors to get quantitative data on the amount of fog water collected during the “summer-period” (June - September). The data from this sensor are stored in the same storage unit as the rest of the weather data.

4.4.2 Air

Ambient air

To measure the levels of airborne pollutants on Bjørnøya, a high volume air sampler was installed in a small hut close to the meteorological station. Due to the power requirements of this sampler it had to be installed close to the power source at the meteorological station. The sampler consists of a filter holder unit that contains one filter and two polyurethane foam (PUF) adsorbent plugs, a rotameter (air-flow indicator), a bleed air valve and a high volume vacuum pump.

One air sample was taken with this high volume air sampler every week (46 – 50 hour sampling period) from July 1999 until May 2000. From the end of May 2000, the sampling period was increased to one week (164 – 190 hours), with exception of one sample that was run for 408 hours. The flow-rate was in the interval 18.0 - 22.6 m³ per hour. The 48-hour samples consisted of a total volume of 855 – 2 026 m³ while the weekly samples consisted of a total volume of 3 041 – 7 711 m³. A sample “blank” was taken every month. On a blank sample the filter and the two PUF's are installed for 10-12 hours without the vacuum pump running. The filter and the PUF's were wrapped in aluminum foil and frozen until they were analysed. The employees at the meteorological station were responsible for running the air sampler.

Passive air sampler - semipermeable membrane device (SPMD)

To measure the pollution in the air close to Ellasjøen two semipermeable membrane devices (SPMDs) were installed in a ventilated wooden box that was mounted on a pole 2 meters above the ground. The SPMD is a passive air sampler that consists of a semipermeable membrane filled with lipids.

4.4.3 Rainwater

Wet – only sampler

A wet-only sampler was installed at the station to measure the pollutants in rainwater. This sampler has a rainfall sensor that activates the sampler when rainfall exceeds the evaporative ability of the heated sensors. When it stops raining the heated sensor dries, terminates the contact and the sampler closes. The sampler was not activated by moderate fog. The rainwater was collected into a 5-litre “Duran” bottle that was stored inside the sampler. Due to fairly high power requirements also this sampler had to be located at the meteorological station. The personnel at the station were responsible for looking after the Wet-only sampler and to change the bottle when it was filled.

Melt water / rainwater collector

One meltwater collector was installed on each site. These collectors consist of a one square meter horizontal stainless steel plate that is mounted one meter above the ground. These collectors are supposed to be covered with snow during the winter and when the snow is melting the water will run into the steel barrel.

This collector gives the opportunity to measure the amount of pollutants in meltwater. However the design of the collector and the strong wind at Bjørnøya resulted in little accumulation of snow on the collector and therefore an inadequately small amount of meltwater was collected.

These collectors have also been used during the summer period (June – September) to collect rainwater.

Rain gauge (Ombrometer)

There is considerable variation in precipitation within the watershed, and in order to verify and assess the spatial differences in precipitation (rainfall) during the summer period (May – September), 15 rain gauges were set up in the catchment area of Ellasjøen. These rain gauges are of Norwegian standard (NILU) design. The rain gauges were assembled in June and disassembled in September. To prevent them from exceeding their reservoir capacity ($\cong 3$ L) they were supposed to be emptied every month. Due to bad weather, the employees at the station were not always able to empty the bottles as planned, consequently they overflowed in some periods. In 2001, additional rain gauges were set up at in the vicinity of the meteorological station in order to assist in the calibration of these rain gauges against the standard meteorological station precipitation gauge.

4.4.4 Snow

Surface snow

Surface snow (fresh) was collected in different periods of the year. The snow was collected with a shovel covered with aluminium foil. The upper 3 cm of the snow layer were collected into a 50-litre steel barrel.

In July 1999 surface snow was collected at two different sites in the catchment area of Ellasjøen. One site was located south of Ellasjøen, close to the little auk breeding colony and the other site was south of Lake Skutilen. These samples consist of aged or weathered snow.

In April 2000 two surface snow samples were collected 2 km south of the meteorological station. These samples were collected after a snowfall and therefore are considered fresh snow.

Snow collector

To be able to collect fresh snow through the whole winter, two snow collectors were made. These snow collectors were constructed of aluminium and consisted of a 3-meter high funnel with an opening at the top (0.4 m² surface area). The snow is collected into a 50-litre steel barrel attached to the bottom of the funnel. Initially, one snow collector was installed at the meteorological station and one at Ellasjøen.

Fog collector

Fog collectors were constructed as described by Schemenauer and Cerceda (1994). These fog collectors can produce measurements of the deposition of fog water to a vertical surface. The fog collectors consist of an aluminium frame that measures 1.0 m x 1.0 m on the inside. The frame is supported with 3-meter long posts. A polypropylene mesh, manufactured by Tildenet Ltd. in the United Kingdom, is wrapped in a double layer round the frame. The fog water was collected into a 50-litre steel barrel.

Initially, one fog collector was installed in the catchment area of Ellasjøen and one near the meteorological station. In May 2000 two additional fog collectors were installed at Ellasjøen. The fog collectors at both sites are facing the dominant wind directions during fog events, which are Southwest or Northeast. To quantify the potential for fog water precipitation, we measured the volume of water collected from the fog sampler into a 5-litre plastic can. During

4.6 Results and discussion

4.6.1 Precipitation and fog

Weather station

In May 2000 a visibility sensor was mounted to the weather station at Ellasjøen. For working purposes, the presence of fog has been defined as “days with visibility less than 1000 meters”. In the period from late June until the middle of September the data confirm a higher number of days with fog in the Ellasjøen area compared to the station (Figure 7). The number of days with fog (visibility <1000 meter) during the summer time on Bjørnøya is high compared to other areas in the arctic. Ny-Ålesund, Svalbard has less than 2 days with fog per month in the summer period. The frequency of fog at Bjørnøya indicates that deposition of fog-water likely plays a very important role, especially during the summer months.

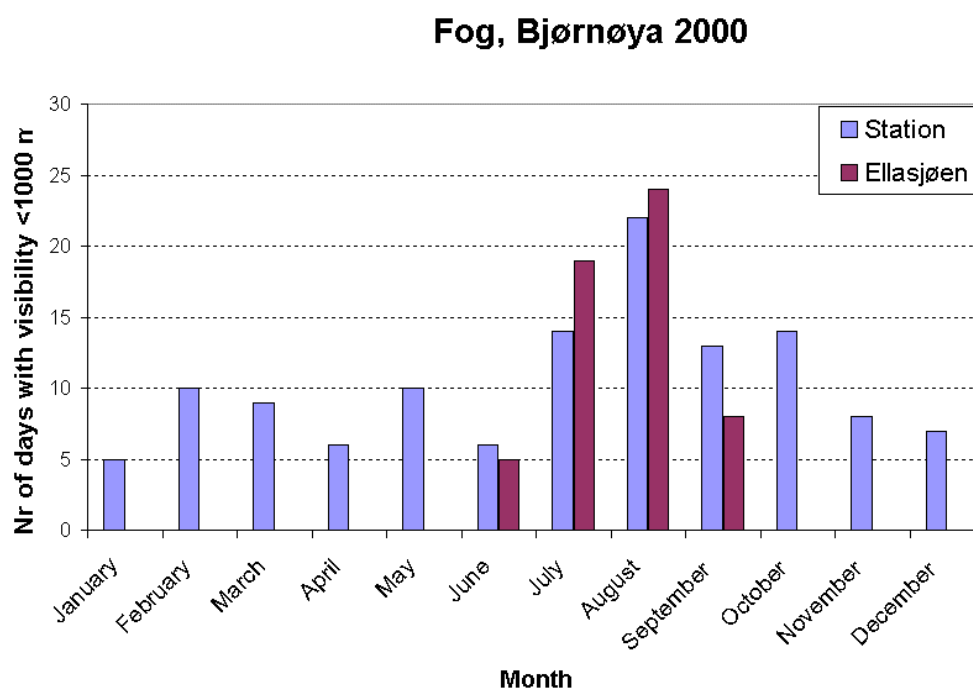


Figure 7. Number of days with visibility less than 1000 meter measured at the station and Ellasjøen. The measurements at Ellasjøen are carried out from middle of June until middle of September.

Rain-gauges

The data collected with the rain gauges indicate that there are large, local, spatial differences in the measured amount of precipitation in the catchment area of Ellasjøen. Over a couple of hundred meters, a 6 times difference in the amount of rainfall was observed. This means that it is difficult to compare the amount of rainfall at the station with the amount of rainfall at Ellasjøen by using only one rainfall sampler. Therefore we installed 15 rain gauges in the catchment area of Ellasjøen and 5 in the area close to the station to investigate if there are any differences in the amount of rainfall between the two sites and if local spatial rainfall differences occur in the vicinity of the station, as has been observed at Ellasjøen. The results

indicates that there are 3 – 4 times more rainfall in the catchment area of Ellasjøen compared to the station area on the northern part of the island (Figure 8).

Rainfall, Bjørnøya 2001

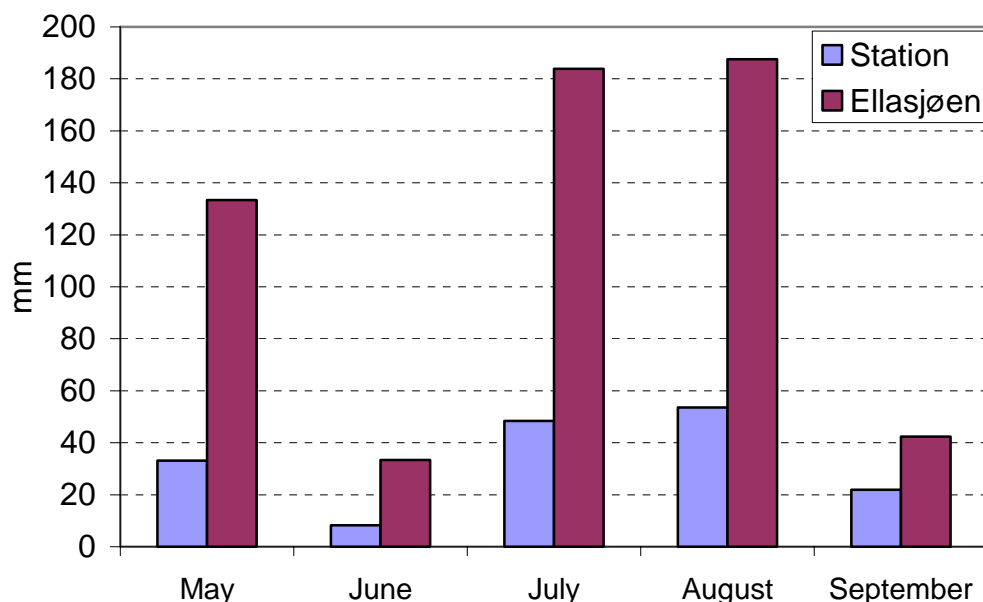


Figure 8. Amount of rainfall per month (May – September), measured with Rain-gauges in the catchment area of Ellasjøen and at the Bjørnøya meteorological station, Bjørnøya 2001.

4.6.2 Air

First measurements in air showed that HCB dominated in the two air samples from Bjørnøya collected in 1999 (Figure 9). The concentration values and the distribution pattern of the analysed chlorinated pesticides were relatively similar to the results available from the Zeppelin Mountain research station in Ny-Ålesund, Svalbard. The content of Σ PCB (101, 105, 118, 138, 153, 156, 180) in air in July 1999 and September 1999 was 92.4 pg/m^3 and 24.5 pg/m^3 , respectively. These PCB levels were considerably higher than concentrations found in air samples taken at the Zeppelin Mountain research station (Ny-Ålesund, Svalbard). Usually, the low chlorinated congeners are dominating air samples. However, the middle chlorinated PCB congeners were predominant in these two Bjørnøya air samples.

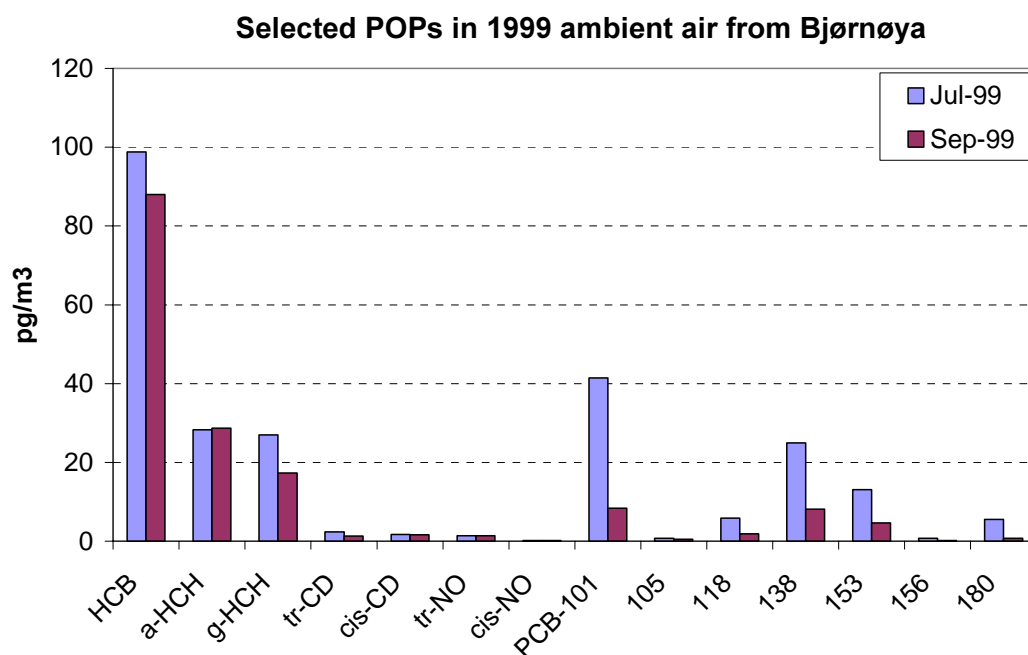


Figure 9. PCB and pesticides in air from Bjørnøya in July and September 1999.

In 2000 and 2001, a year around sampling campaign for the determination of POP compounds in ambient air took place at Bjørnøya. The high volume air sampler collected samples every, or every second week. Similar sample equipment and methods for sample preparation and POP quantification were employed as used for ambient air samples from the Zeppelin mountain research station on Svalbard (Norway) and comparable with other standard methods used for ambient air sampling for POP analysis at other Arctic atmospheric research stations. The compounds selected for the year-round POP measuring campaign are listed in Table 15.

Table 15. POP compounds selected for analysis in Bjørnøya ambient air.

Pesticides	PCB
α-HCH, β-HCH, γ-HCH, chlordene, heptachlor, heptachlor-exoepoxide, heptachlor-endoepoxide, oxy-chlordane, trans-chlordane, cis-chlordane, trans-nonachlor, cis-nonachlor, α-endosulfan, o,p'-DDE, p,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT, p,p'-DDT	PCB-18, PCB-28, PCB-31, PCB-33, PCB-37, PCB-47, PCB-52, PCB-60, PCB-66, PCB-74, PCB-99, PCB-101, PCB-105, PCB-114, PCB-118, PCB-122, PCB-123, PCB-128, PCB-138, PCB-141, PCB-149, PCB-153, PCB-156, PCB-157, PCB-167, PCB-170, PCB-180, PCB-183, PCB-187, PCB-189, PCB-194, PCB-206, PCB-209

The SUM PCB concentrations (SUM 33 PCB, see table 15) determined in the Bjørnøya ambient air samples are higher than the levels measured in air from Zeppelin in Ny-Ålesund, Svalbard (Kallenborn *et al.* 2001, Kallenborn *et al.* 2002). Indications for higher levels during the winter season 1999/2000 are obvious (Figure 10). Due to the favourable meteorological (e.g., extended polar front) and physico-chemical conditions (e.g., elevated half-life time, reduced photochemical transformation) during winter, the probability for long range transport during this season is elevated, and higher concentration values may be the consequence. Similar features were also found for the distribution of PCB in air from other stations. However, the levels from the winter season 2001 were considerably lower than the levels measured in air samples collected during the winter season 2000. One of the reasons for this

might be difference in the weather conditions between the two years. This will be investigated further.

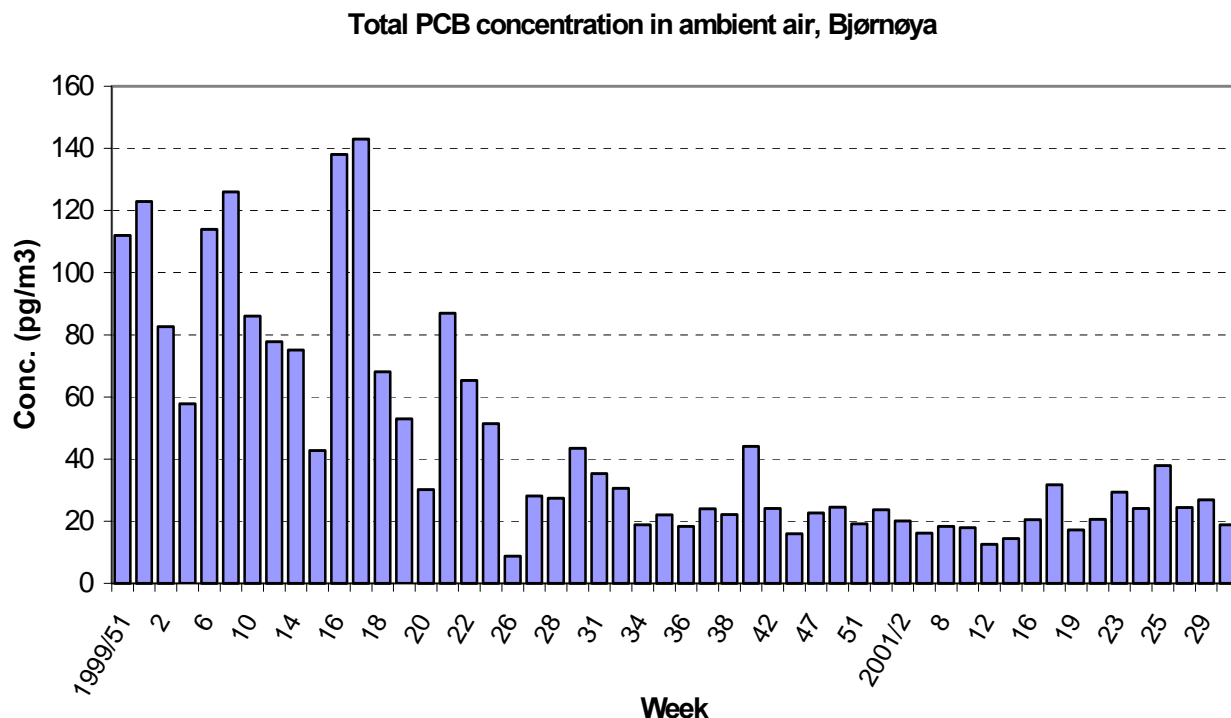


Figure 10. SUM PCB distribution in ambient air samples from Bjørnøya in the period from December 1999 – August 2001.

The PCB distribution reflected a typical pattern for ambient air samples from a pristine and uncontaminated region (Figure 11). In general, the tri- and tetra PCBs counted for more than 80% of the PCB burden. However, the proportion of the tri- and tetra PCBs in ambient air from Bjørnøya are lower than in comparable air samples the Zeppelin station.

Relative PCB concentration in ambient air, Bjørnøya

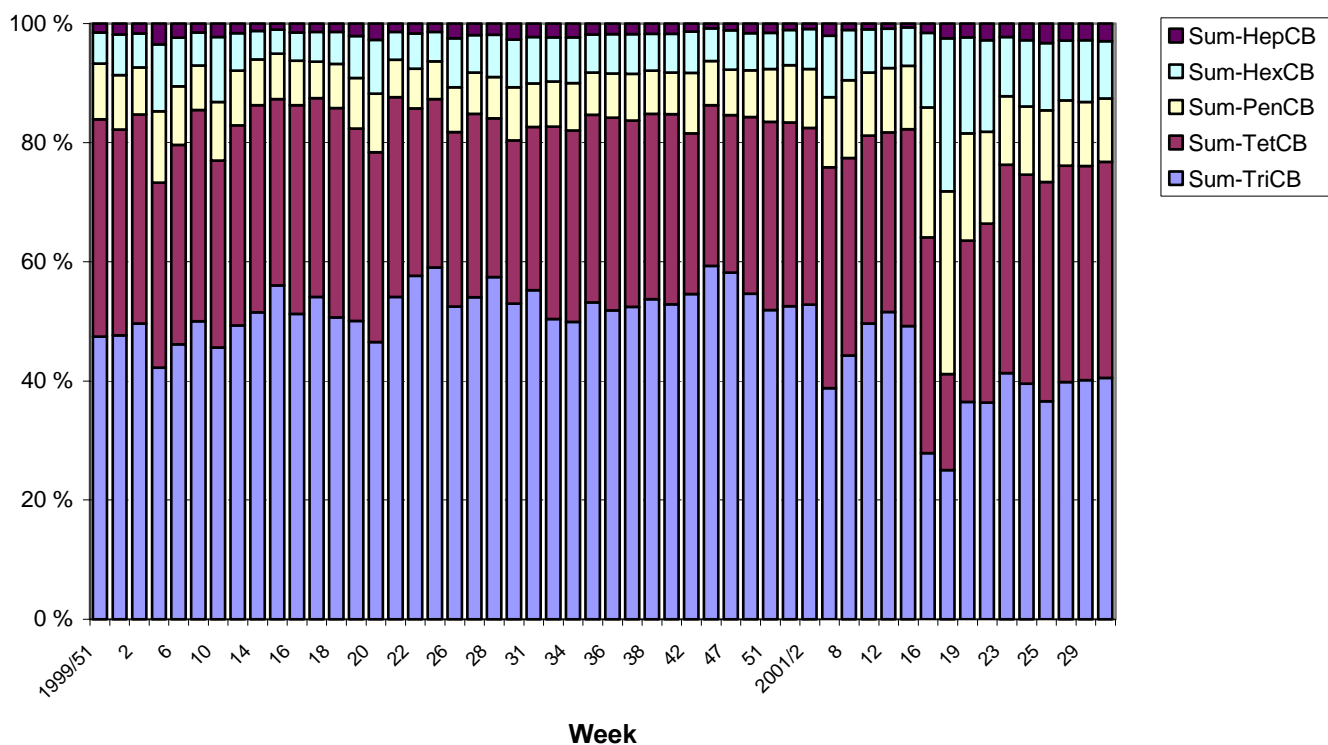


Figure 11. Percentage distribution of Sum PCB in Bjørnøya air separated according to the degree of chlorination in the period from December 1999–August 2001.

The PCB-congener pattern from Bjørnøya reflects a typical pattern for ambient air with the lower chlorinated congeners dominating (Figure 12). However the portion of the middle chlorinated congeners (138, 149 and 153) are relatively high compared to the results from the Zeppelin station. The differences in the proportion of the tri- and tetra PCB contribution and the PCB-congener pattern indicate unlike sources for the two sites. This will be studied further in a back trajectory study.

PCB-congener pattern in ambient air, Bjørnøya

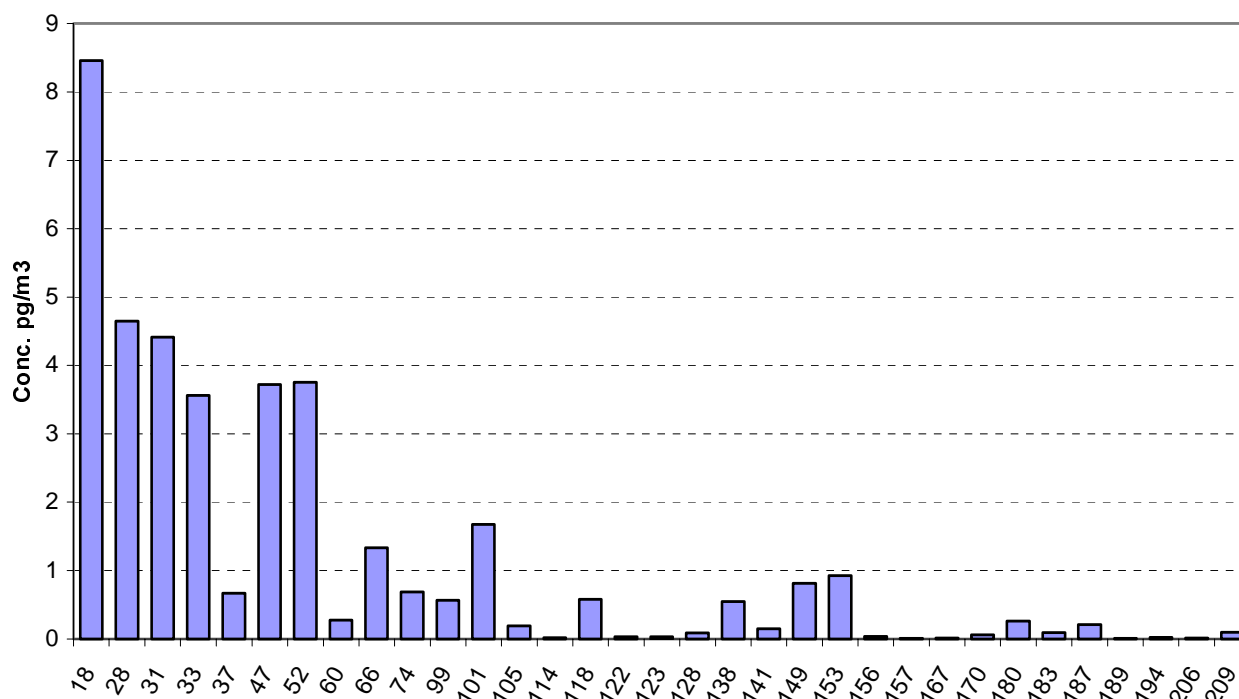


Figure 12. Average PCB-congener pattern in ambient air from Bjørnøya in the period from December 1999 - November 2000.

In addition to PCBs, a selected number of chlorinated pesticides were analysed in Bjørnøya ambient air. α -HCH (a-HCH) was the predominant pesticide in all samples (Figure 12), counting for more than 50 % of the total chlorinated pesticide burden. γ -HCH was the second highest contaminant in all samples. The sum concentrations of both hexachlorocyclohexane (HCH) isomers in all samples represented between 60 and 85% of the total chloropesticide burden in all Bjørnøya ambient air samples. A relatively even distribution for *trans*-, *cis*-chlordane and *trans*-Nonachlor was determined for all Bjørnøya air samples. The sum of chloropesticide concentration values was found to be in the same concentration range as determined for PCBs.

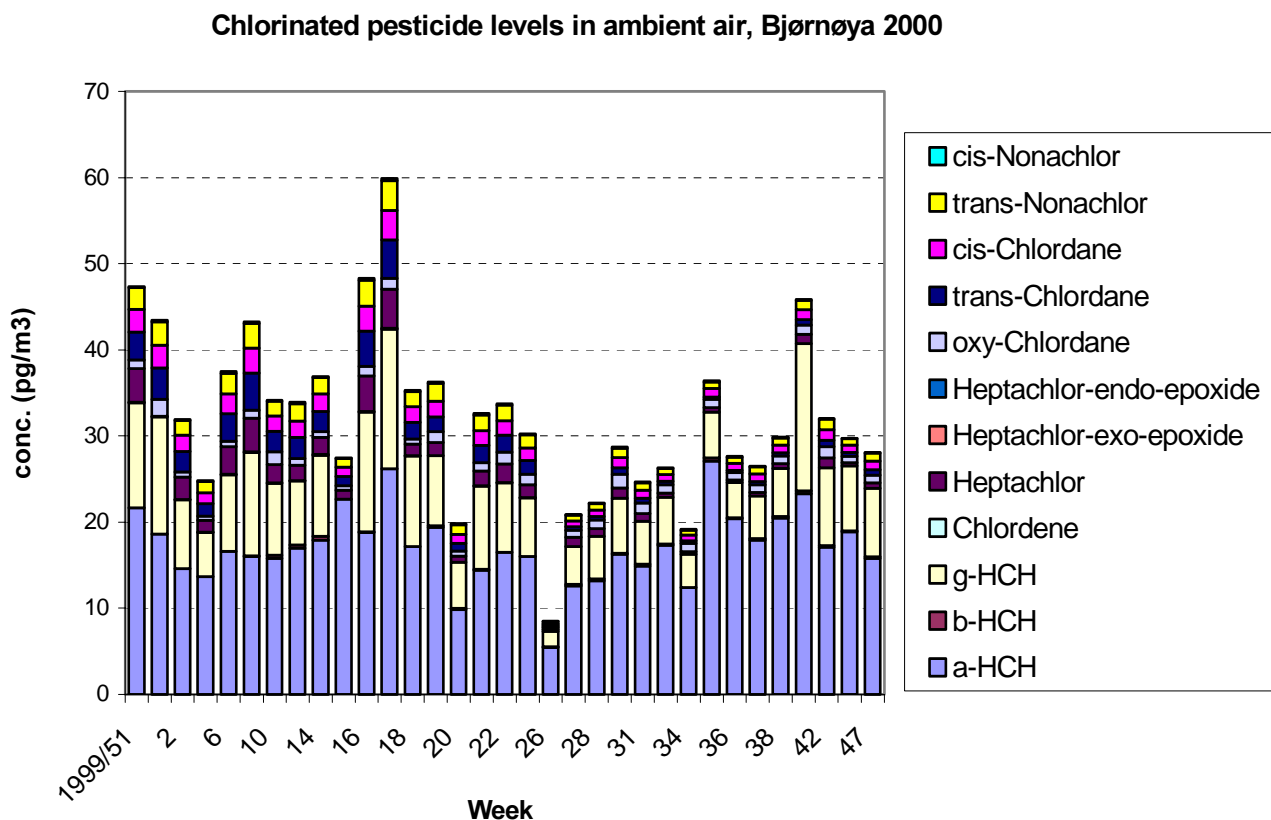


Figure 13. The levels of selected chlorinated pesticides in Bjørnøya ambient air samples in the period from December 1999 – November 2000.

The ratio of the two hexachlorocyclohexane isomers α - and γ -HCH is often used as indicator for possible atmospheric long range transport events. An elevated input of the γ -HCH (Lindane), a still used insecticide in middle latitude regions, indicates atmospheric transport from source regions. In Arctic ambient air usually α -HCH is the predominant HCH isomer, whereas γ -HCH levels are considerably lower. This pattern is mainly due to the earlier extensive use of the technical mixture as pesticides in the first half of the 20th century in the northern hemisphere. The α -HCH accounts for more than 60% in the original technical mixtures. Thus, the high values still found in the environment are due to evaporation from sediments (former sinks) in the Northern regions. A ratio (α -/ γ -HCH) of 3 to 8 represents the normal background situation in ambient air unaffected from long-range transport events. A significant reduction under the threshold of "1" is a clear indication for an atmospheric long-range transport event. In all samples analysed, all α -/ γ -HCH ratios are above the mentioned threshold (Figure 14). Thus, no indications for a typical atmospheric long-range transport event can be seen in the data available. However, in general the α -/ γ -HCH values determined in Bjørnøya air are lower than the values calculated for air samples from the Zeppelin mountain research station (α -/ γ -HCH = between 4 and 7). This indicates that there are different sources for HCHs for Bjørnøya and the Zeppelin station.

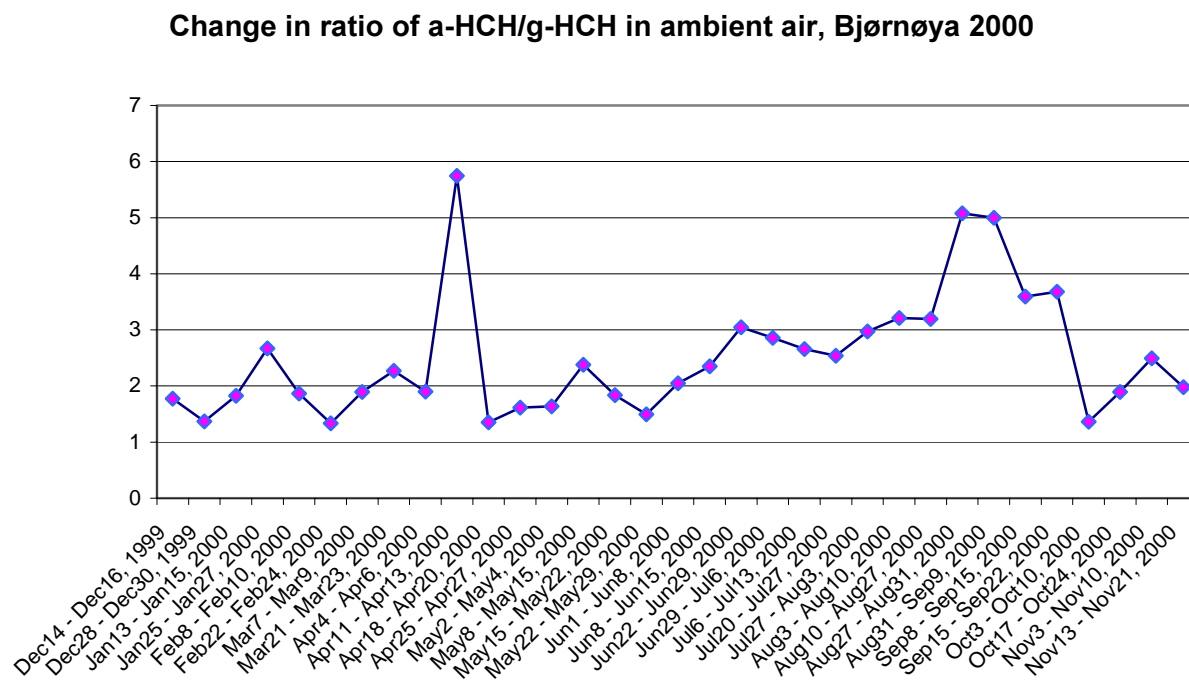


Figure 14. α - γ -HCH ratios in ambient air from Bjørnøya in the period from December 1999 – November 2000.

The DDT mixture (*o,p'*- and *p,p'*-DDT) was the most used pesticide in agricultural application during the first half of the last century. Although banned for open use in agricultural applications in middle latitude countries since the early 1970s, substantial amounts of DDT and its degradation products are still present in the environment. This is mainly due to the unregulated use of this chemical in tropical and developing countries and remobilisation as well as long-range transport processes.

In Bjørnøya air, the *p,p'*-DDE was the most abundant DDT-related contaminant with up to 60% of the DDT related burden in ambient air. This dominance is also found in air samples from the Zeppelin mountain research station and from the Canadian Arctic monitoring stations.

In ambient air samples from other Arctic research stations (e.g., Zeppelin mountain, Alert, Dunai), average sum DDT concentrations up to 8 - 9 pg/m^3 are found. The maximum levels for Bjørnøya exceeded these average values twice (Figure 15). Thus, the relatively high values in the period from December 1999 to June 2000 indicate local sources (e.g., biological input - guano), especially since the *p,p'*-DDE values are elevated. However, seasonal changes in the input of *p,p'*-DDE are reported also in ambient air samples from other Arctic research stations and support the feature found in Bjørnøya, where high DDT values are found in the winter season. However, the SUM DDT concentration determined in Bjørnøya air belongs to the highest DDT concentration measured in Arctic air.

DDT and transformation products in ambient air, Bjørnøya 2000

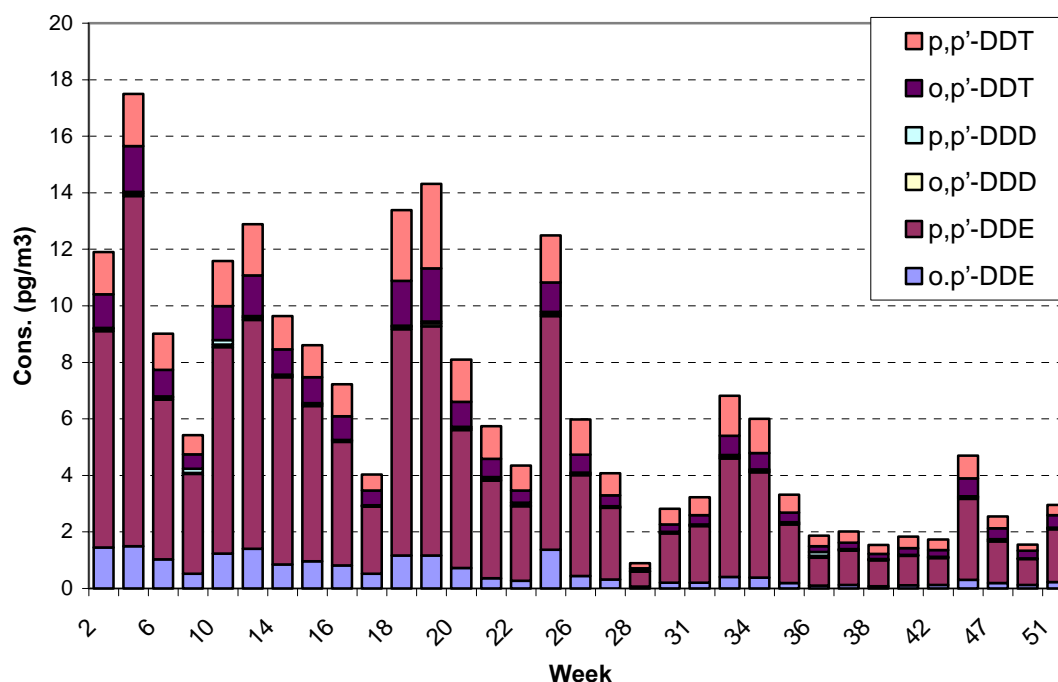


Figure 15. Levels and patterns of p,p'-/o,p'-DDT and its transformation products in Bjørnøya ambient air in the period from December 1999 – November 2000.

4.6.3 Rainwater

Wet-only and rain collector

The Σ PCB concentrations in the rainwater samples from Bjørnøya varied from 391 pg/l to 3 732 pg/l). These values are comparable to values found in rainwater from other Arctic areas. The highest concentrations occurred in rainwater collected from the station in July – October 2000 (Table 16, Figure 16). The middle-chlorinated PCB congeners were dominant in all the samples. It was not possible to detect pesticides other than HCB, α -HCH and β - and γ -HCH in these samples.

Table 16. PCBs and pesticides in rainwater, sampled in the catchment area of Lake Ellasjøen and at the meteorological station on Bjørnøya. All concentrations are given as pg/l.

Compound	Wet-only, Station 11.07.99 – 15.08.99	Rainwater, Lake Ellasjøen 04.06.00 – 05.09.00	Rainwater, Station (1) 12.07.99 – 01.10.99	Rainwater, Station (2) 26.07.00 – 19.09.00	Rainwater, Station (3) 19.09.00 – 24.11.00
∑PCB7 (pg/l)		300	2697	733	593
∑PCB (pg/l)	1427	391	3732	1178	845
HCB (pg/l)	not analysed	14.4<LOQ	14.4<LOQ	14.3<LOQ	11.1<LOQ
α-HCH	not analysed	513.3	422.9	274.3	676.1
β- and γ-HCH	not analysed	407.3	317.6	216.3	1122.6
Heptaklor (HC)	not analysed	<LOD	<LOD	<LOD	<LOD
Heptakloreposid (HCE)	not analysed	<LOD	<LOD	<LOD	<LOD
Oksyklordan (oxy-CD)	not analysed	<LOD	<LOD	<LOD	<LOD
Trans-Klordan (t-CD)	not analysed	<LOD	<LOD	<LOD	<LOD
Cis-Klordan (c-CD)	not analysed	<LOD	76	<LOD	<LOD
Trans-Nonaklor (t-NC)	not analysed	<LOD	836	<LOD	<LOD
Cis-Nonaklor (c-NC)	not analysed	<LOD	<LOD	<LOD	<LOD
Dieldrin	not analysed	<LOD	<LOD	<LOD	<LOD
Mirex	not analysed	<LOD	<LOD	<LOD	<LOD
∑DDT (ng/g ww)	not analysed	327	<LOD	269	<LOD
Sum toks (26, 32, 38, 40, 44, 50, 51, 58, 62, 69)	not analysed	<LOD	<LOD	36.3	<LOD

Rainwater, Bjørnøya

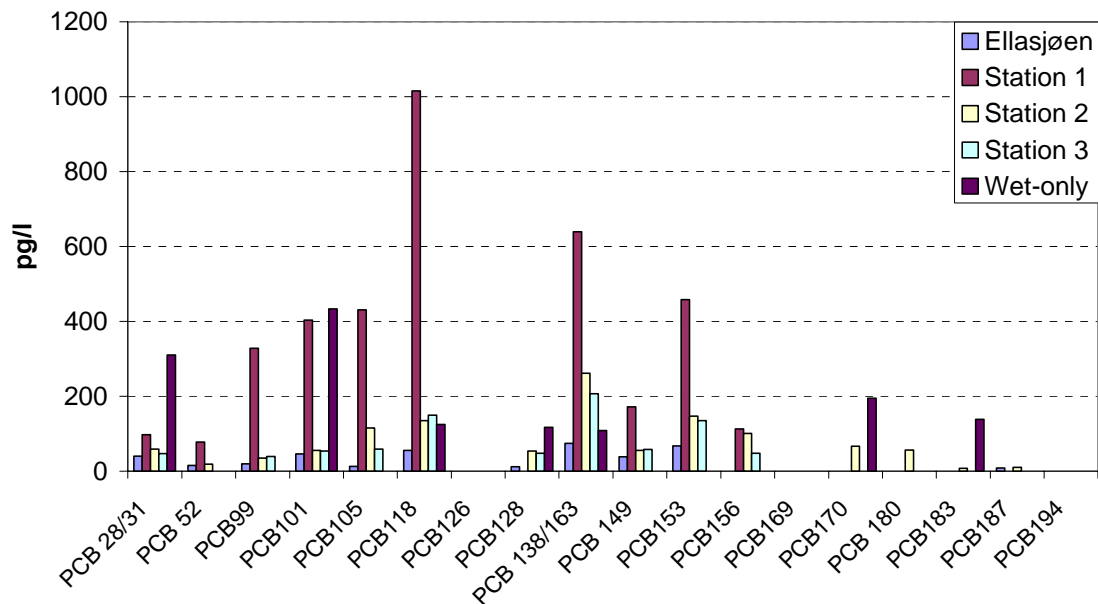


Figure 16. PCB found in rainwater from Bjørnøya.

Meltwater

The meltwater collectors are supposed to collect snow and further let the snow melt into steel barrels. However, these collectors are not functioning satisfactorily due to strong wind and the small surface area of the collector (0.4 m²), resulting in little accumulation of snow in the collectors. The amount of water collected by these collectors was therefore not enough for analysis. The methods for snow- and melt-water sampling were therefore changed before the 2001 sampling campaign.

The snow accumulates in some areas near Ellasjøen to a depth of 2 - 4 meters. We will use steel tubes (3-meter long, 20 cm diameter) to sample representative profiles of this snow. In the first instance, the tubes will be sealed and brought back to the station where the snow will be melted under artificial conditions to assess total contaminant burden of the annual snowpack. Subsequently, the tubes will be re-filled at the same location, returned to station and allowed to melt under natural conditions (i.e. outside). Under the natural melting conditions, the sampling tubes will be open at the top so that natural evaporation of contaminants can occur and simultaneously, additional loadings from rainwater and snow will be collected into the tube. By undertaking this comparative melting in triplicate, we can compare the content of contaminants in the two types of set-up. The artificial melting setup gives us an idea of the total contaminant content in the snow at the time of sampling while the second experiment assesses what contaminants are retained in the melting water and later released to the catchment area. The sampling of the snow will be done at the end of April before the melting season starts.

4.6.4 Snow and surface snow

In all snow samples, PCB levels were dominant (Table 17). The Σ PCB concentrations varied between 3 200 pg/l and 24 891 pg/l. The highest values were found in the sample consisting of old snow, collected south of Ellasjøen in July 1999. HCHs were the main contributors for the chlorinated pesticides whereas HCB was a minor contaminant in the 1999-snow samples from Bjørnøya. Due to high volatility, HCB probably revolatilized to the atmosphere. It was not possible to detect pesticides other than HCB, α -HCH and β - and γ -HCH in these samples.

The higher chlorinated PCB congeners were almost non-existent in both old surface snow and snow collected in snow collectors (Figure 17). This distribution of congeners is typical for long-range transport and deposition. The fresh snow sample from Ellasjøen sampled in July 1999 was different from a surface snow sample from Skutilen, suggesting perhaps that the Skutilen sample was aged surface snow while the Ellasjøen sample was fresh snow. Gregor *et al.* (1996) noted large differences in PCB concentrations between fresh snow and aged snow in the Canadian Arctic. The concentrations in snow from Bjørnøya were generally higher than levels found in snow in Canada (Barrie *et al.*, 1997) and in Northern Norway (Dividalen).

Table 17. PCBs and pesticides in snow, sampled in the catchment area of Lake Ellasjøen and at the meteorological station on Bjørnøya. All concentrations are given as pg/l.

	Snow, Lake Ellasjøen	Snow, Met. station	Surface snow, Lake Ellasjøen	Surface snow, Lake Skutilen
Compound	01.10.99 – 04.04.00	01.12.99 – 30.05.00	21.07.99	21.07.99
ΣPCB7 (pg/l)	2392	5977	19708	560
ΣPCB (pg/l)	3200	7220	24891	1099
HCB (pg/l)	1.1	2	4.9	not analysed
α-HCH	17.1	20	86.4	not analysed
β- and γ-HCH	15.4	57.9	193.7	not analysed
Heptaklor (HC)	<LOD	<LOD	<LOD	not analysed
Heptakloreposid (HCE)	<LOD	<LOD	<LOD	not analysed
Oksyklordan (oxy-CD)	<LOD	<LOD	<LOD	not analysed
Trans-Klordan (t-CD)	<LOD	<LOD	<LOD	not analysed
cis-Klordan (c-CD)	125.2	<LOD	<LOD	not analysed
Trans-Nonaklor (t-NC)	<LOD	<LOD	<LOD	not analysed
cis-Nonaklor (c-NC)	<LOD	<LOD	<LOD	not analysed
Dieldrin	<LOD	<LOD	<LOD	not analysed
Mirex	<LOD	<LOD	<LOD	not analysed
ΣDDT (ng/g ww)	not analysed	<LOD	not analysed	not analysed
Sum toks (26, 32, 38, 40, 44, 50, 51, 58, 62, 69)	<LOD	<LOD	<LOD	not analysed

Snow, Bjørnøya

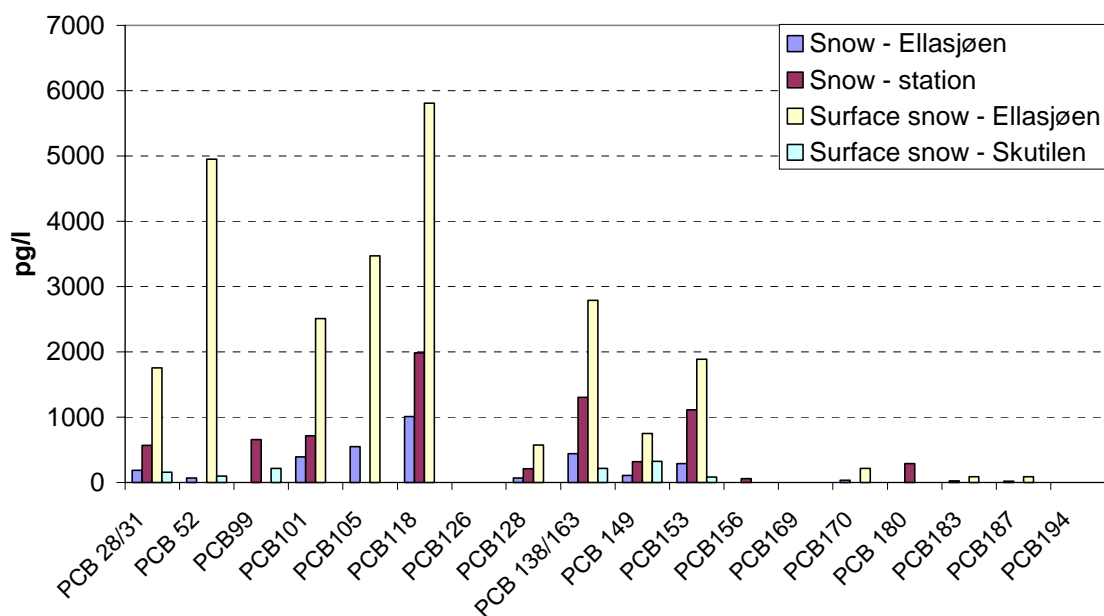


Figure 17. PCB pattern found in snow from Bjørnøya.

4.6.5 Fog

The Σ PCB concentrations found in the fog were between 1 605 pg/l and 13 105 pg/l (Table 18). The highest and lowest values were found at Ellasjøen. Fog water collected on Bjørnøya was dominated by medium chlorinated PCB congeners (Figure 18). The reason for this could be a strong influence of local biological sources (e.g., seabird guano). It was not possible to detect other pesticides than HCB, α -HCH and β - and γ -HCH in these samples. Some of the fog samples had high amounts of particulate material. The reason for this is not known.

Table 18. PCBs and pesticides in fog sampled in the catchment area of Lake Ellasjøen and at the meteorological station on Bjørnøya. All concentrations are given as pg/l.

Compound	Lake Ellasjøen	Lake Ellasjøen	Met. station	Met. station	Met. station
	20.07.99 – 15.09.99	04.06.00 – 05.09.00	27.07.99 – 15.09.99	31.05.00 – 26.07.00	26.07.00 – 19.09.00
Σ PCB7 (pg/l)	8 108	1 106	2 694	7 618	2 422
Σ PCB (pg/l)	13 105	1 605	2 931	10 908	3 511
HCB (pg/l)	10.5	24.8 <LOQ	56.4	10.6	14.4 <LOQ
α -HCH	<LOD	663.5	1374.8	<LOD	408.3
β - and γ -HCH	<LOD	340.7	718	<LOD	254
Heptaklor (HC)	<LOD	<LOD	<LOD	<LOD	<LOD
Heptakloreposid (HCE)	<LOD	<LOD	<LOD	<LOD	<LOD
Oksyklordan (oxy-CD)	<LOD	<LOD	<LOD	<LOD	<LOD
trans-Klordan (t-CD)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-Klordan (c-CD)	125.2	<LOD	<LOD	<LOD	<LOD
trans-Nonaklor (t-NC)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-Nonaklor (c-NC)	<LOD	<LOD	<LOD	<LOD	124
Dieldrin	<LOD	<LOD	<LOD	<LOD	1889.4
Mirex	<LOD	<LOD	<LOD	<LOD	<LOD
Σ DDT (ng/g ww)	not analysed	100.4	not analysed	not analysed	93
Sum tox (26, 32, 38, 40, 44, 50, 51, 58, 62, 69)	<LOD	<LOD	<LOD	20	<LOD

Fog, Bjørnøya

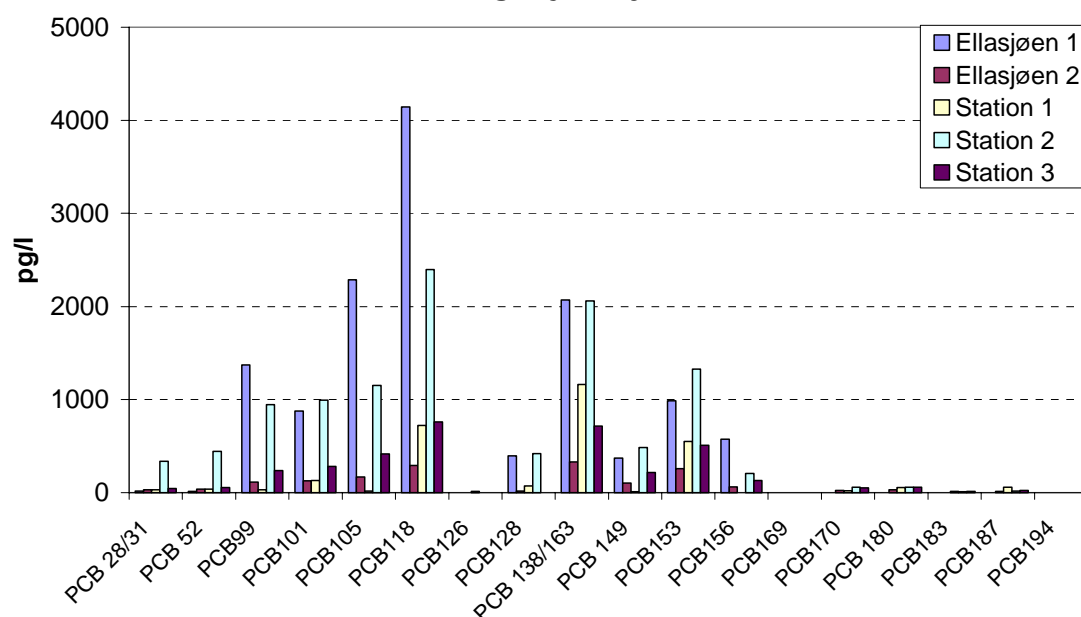


Figure 18. PCB pattern found in fog-water from Bjørnøya.

5 References

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