Effects of increased temperature and bird migrations on zooplankton communities in the high Arctic.

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Abstract

Over the past decades the Arctic has experienced an increase in annual mean temperature. The increase of temperature is higher in the Arctic than it is at lower latitudes and globally. The increase in temperature affects zooplankton communities of Svalbard in several ways. The elongated growing period and less duration of ice cover of lakes and ponds facilitates the colonization of invasive species to Svalbard. As the temperature increase, as does the population of migrating birds, mainly Barnacle geese and Pink-footed geese. This increases the likelihood of dispersal of invasive species as well as it increases the nutrient input to the water bodies and causes euthrophication. Together, these combinations are able to alter the entire ecosystem, changing water bodies that have been considered oligothrophic into euthrophic. This together with increased chance of dispersal of invasive species can alter the zooplankton communities' considerable, making species turnover possible. By comparing 66 locations from Cape Linné and Ny-Ålesund with earlier studies, over the last century, it could be expected to find species which never have been observed at Svalbard earlier.

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1. Introduction

The Arctic has experienced a recent increase in mean temperature. This in addition to less extension of sea ice during winter (Hanssen-Bauer 2003), glaciers rapidly decreasing (figure 1) in net volume mass balance (Dyurgerov and Meier 2000), thawing of permafrost (Shur & Jørgensen 2006), changes in precipitation patterns (Hanssen-Bauer 2007) are all indicators of a changing climate. Polar areas are more susceptible to changes in climate than regions of lower latitudes, and while the global annual surface temperature (figure 2) has increased with 0.6°C ±0.2 (Houghton *et al.* 2001), the surface temperature in Svalbard has increased substantially in comparison (Isaksen & Sollied 2002).

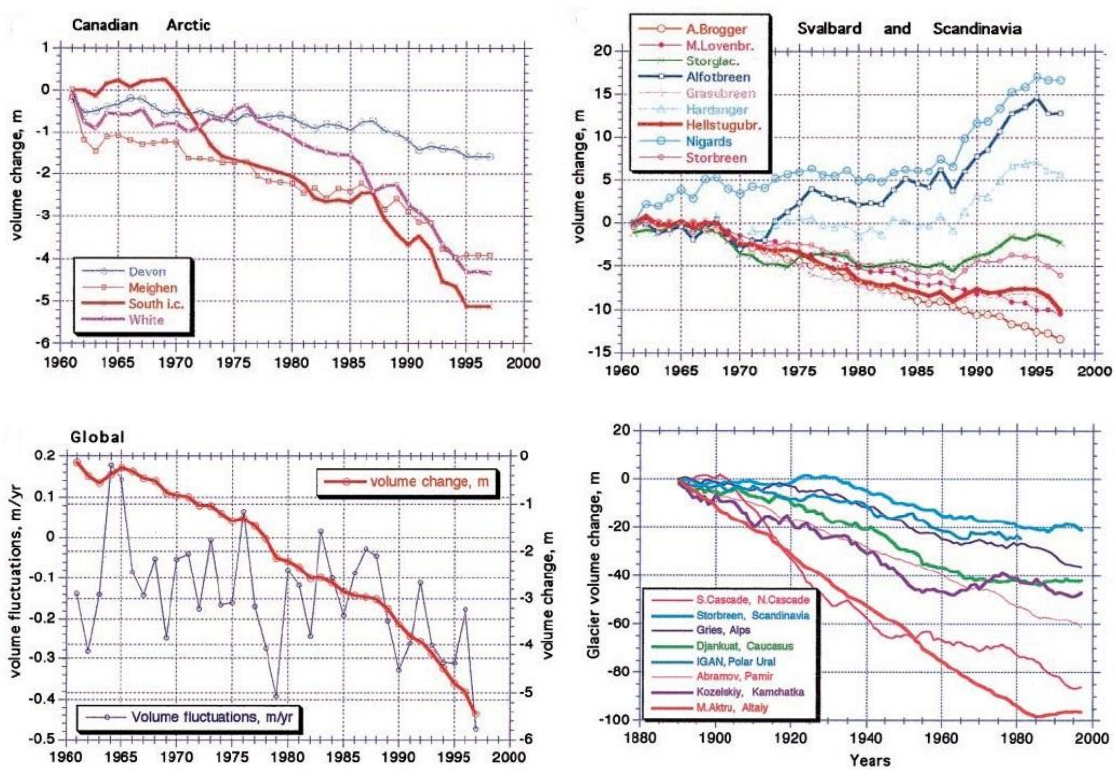


Figure 1: Annually changes in glaciers net volume mass balance in glaciers of different geographical origin. Top, left: changes in net volume mass balance for 4 glaciers of the Canadian Arctic. Top, right: changes in net volume mass balance for 9 glaciers at the opposite side of the Arctic, Svalbard and Scandinavia. Bottom, left: calculated estimates on how the net volume mass balance appears on a global scale. Bottom, right: 8 glaciers from different geographic locations are compared to their net volume mass of 1890 versus today (Dyurgerov and Meier 2000).

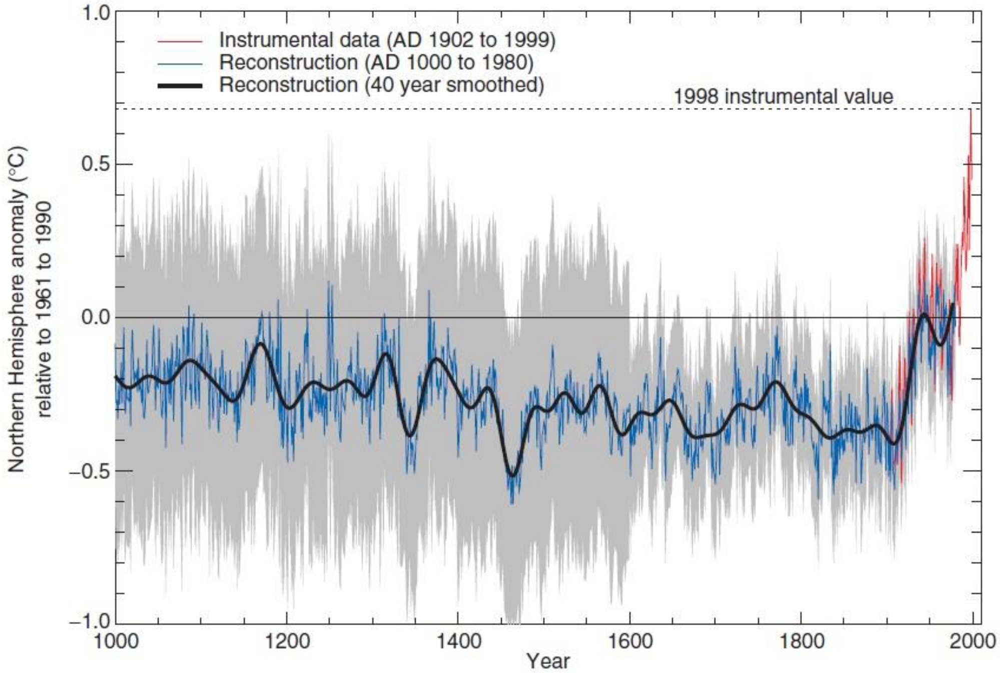


Figure 2: Temperature anomalies in the Northern Hemisphere relative to the 1961-1990 average over the last millennia. The measured values are drawn in red, and reconstruction based on ice cores, tree rings, corals and historical records is shown in blue. The black line is the 40 year average and 2 standard errors are presented in the gray area (Houghton *et al*. 2001).

These areas are also where the largest effect of any changes in climate can be found and where they usually are possible to observe early, again compared to areas of lower latitudes. The Arctic is by definition north of 67°N and extends all the way to 90°N.
In the higher parts of the Arctic, there are mainly ocean, with the exceptions of Greenland, Canada, USA, Russia and Svalbard. The North America and Russian mainland, as well as Greenland extends north to about 83°N and two Russian islands and Svalbard extends to 81°N (Figure 3)..

Spitsbergen is for several reasons an important area for biological studies, and already the pioneering studies on aquatic food webs on Bear Island and Svalbard by

Charles Elton. In the late 1920, Elton (1930) made clear that the simple food-webs of the high Arctic made them particularly suitable for understanding biological processes. Later on, and especially during the last decades, it has also become highly relevant to use arctic ecosystems as early warnings on climate change effects.

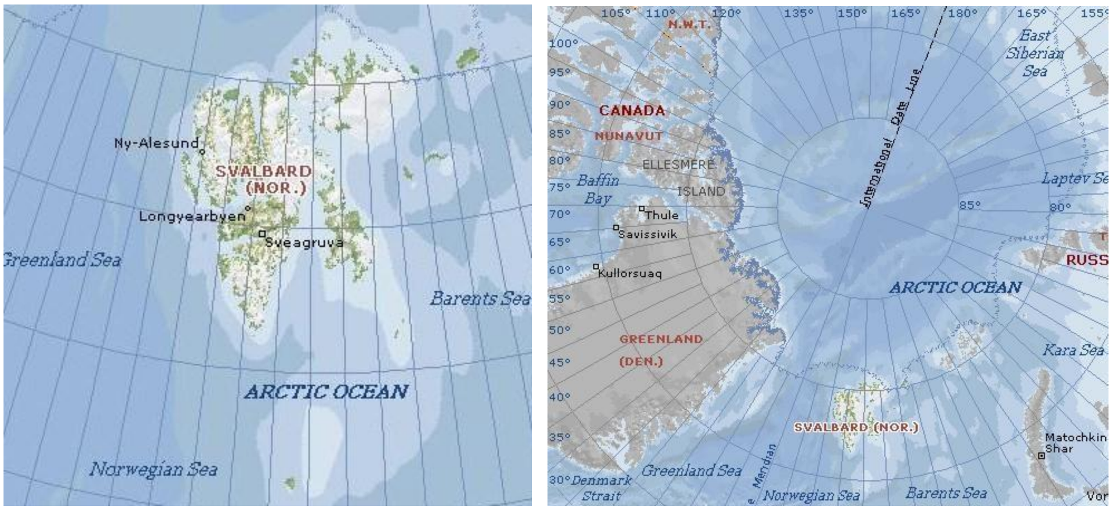


Figure 3: Left (a): Svalbard archipelago and its surrounding oceans. Right (b): The Arctic with the North Pole in centre and Svalbard to the South (http://encarta.msn.com/).

Over the last decades there are several trends indicating that changes in climate are occurring at present and far more quickly than predicted just decades ago (Houghton *et al.* 2001). The effects of a changing climate in the Arctic may have greater consequences than earlier believed (Houghton *et al.* 2001). One already documented biological consequence is an increase in the breeding population of migratory birds, primarily barnacle geese (*Branta leucopsis*) and pink-footed geese (*Anser brachyrhynchus*) over the last decades (Van Geest *et al.* 2007). Migratory birds are recognized as a major contributor in dispersing zooplankton species and together with the increasing populations of birds, the possibility for other than earlier observed species might be found (Green *et al.* 2002; Figureola & Green 2002). The increased breeding populations of bird also contribute to an increased input of nutrients to the water bodies. Due to this, a number of ponds that was previously oligothrohic have become heavily euthrophied. This may create a system shift from benthic to pelagic species (Smol *et al.* 2005). There are two aspects related to the increased geese population, the fist being that the probability for recolonization of invasive species to Svalbard increases substantially. The other is that the increased inputs of nutrients will lead to an increase in primary production. It also makes a contribution to the enrichment of the catchments that release organic matter and nutrients into the water bodies. Several outcomes are of course possible. Existing species could experience more stress due to the increased euthrophication, while others may expand.

A problem which may arise is the fact that the Arctic is exposed to high UV-B radiation partly because the troposphere is about two thirds of what it is around equator (Botkin & Keller 2003), thinner ozone layer in the stratosphere (Botkin & Keller 2003) and twenty-four hours daylight during summer. In addition, at high latitudes the formation of polar stratospheric clouds occurs when the temperature in the stratosphere drops below approximately -80°C. These clouds cause extremely fast depletion of the ozone layer due to heterogeneous chlorine chemistry (Botkin & Keller 2003) Alpine zooplankton species in lakes of southern latitudes i.e. at Finse, Norway, 60°N, 1220 metres above sea level does not inhabit the same property of melanin production to cope with UV-B radiation as arctic species (Hessen 1996). This could make it difficult for alpine species of southern latitudes to establish populations in Svalbard, even though dispersal limitations not are a problem.

Over the recent decades there is reason to suspect that the increased temperature, reduction in permafrost and several other climate related factors has led to a shift in zooplankton communities in the Arctic, as climate driven warming are able to alternate zooplankton communities (Wagner & Benndorf 2007). By investigating zooplankton communities and water chemistry, as well as changes in sediments, it is plausible to find effect in some of these aspects. In summer 2008, a survey was done at two different locations of West-Spitsbergen; Cape Linne (Nordenskioldkysten / Isfjord Radio) and Ny-Ålesund.

Zooplankton is good indicators of changes in the environment due to their sensitivity of changes in abiotic variables. The change in global mean temperature over the last millennia is shown in figure 2. Due to their lack of complexity, Arctic zooplankton communities may yield an early warning about larger impacts on a global scale.

First of all the zooplankton community are fairly well known, due to several studies over nearly a century. The aquatic food webs are simple in arctic ponds and lakes, with zooplankton as the highest trophic level in ponds, while they will be predated by fish in lakes. Svalbard is also isolated, making it an island in the ecological sense. This implies that invasion of other species should be limited and happen over a longer period of time.

The arctic island of Spitsbergen, Svalbard is characterized as arctic tundra with only few larger lakes which are sufficiently deep to avoid freezing to the bottom during winter. These lakes generally contain Arctic charr. In addition to the few larger lakes there are numerous small ponds, characterized as water bodies that freeze entirely to the bottom every winter. As these ponds freeze entirely, fish are excluded, making these ponds predator-free systems for zooplankton. Predation on *Daphnia pulex* by the tadpole shrimp (*Lepidurus arcticus*) is discussed by Christoffersen (2001), but do not seem to have any significant impact on the zooplankton community structure in high Arctic ponds. Some ponds are situated very close to the ocean and have somewhat elevated salinity due to sea spray and saltwater intrusion.

In absence of fish, most of these systems are completely dominated by large-bodied species of asexual *Daphnia* and a number of recent studies has also focussed on the taxonomical difficulties and the number of clones of the *Dapnia spp.* Earlier studies (Olofsson 1918; Summerhayes & Elton 1923; Thomassen 1958, 1961) refers to *Daphnia spp.* observed in Svalbard as *D. pulex*. Amrén (1964a,b) describe *D. tenebrosa* (Sars) in his publications. Halvorsen & Gullestad (1976) describes *D. middendorffiana* (Fisher). They also compare the two species *D. middendorffiana* and *D. pulex* by Brook (1957) and conclude that *D. middendorffiana* is the most likely species, due to the fact that it extends further North than *D. pulex* in North America. More recent studies has revealed that there exist *D. middendorffiana* and both an Arctic and an European subspecies of *D. pulicaria* (Van Geest *et al.* 2007). This finding gives reason to suspect that the taxonomy of Arctic *Daphnia spp.* is far more complex than earlier understandings.

The Arctic zooplankton populations at Svalbard have been subject for studies for many years resulting in reasonable good knowledge about Arctic zooplankton, and thus serving as a good background data for surveys of recent changes in specific compositions that could be accredited direct and indirect effects of climate change and increased bird migration.

This study's aim is to qualitatively describe zooplankton species of Svalbard. By sampling several ponds which has been subject to earlier studies of similar kind, it would be possible to detect changes in the zooplankton communities surveyed. Primarily I was searching for species new to the area that could have become established due to increased growth season or higher temperature. Also the increased population of geese could serve as a vector for immigration of new species (Green *et al.* 2002).

2. Material and methods

Locations for sampling were primarily chosen with background data from the work of Amrén (1964) and Gullestad & Halvorsen (1976). The decision of Cape Linné as an area of investigation was done due to good background data and the conveniences of Isfjord Radio providing lodging and that the amount of ponds subject to sampling is numerous. The area of Ny-Ålesund was chosen because of the proximity to the sampling site of Gullestad & Halvorsen (1976) and that several of the water bodies surrounding Ny-Ålesund has been subject to prior sampling recently. The convenience of Kings Bay providing lodging was also a considerable factor.
In addition this also makes a gradient, since the two areas are separated by mountains and glaciers (see figure 9) which act as a barrier for the dispersal of zooplankton (Hessen *et al.* 2006).

2.1 Sampling

Zooplankton was sampled during the summer of 2008 at two different areas on West-Spitsbergen. The Cape Linné area (Figure 4) was sampled for zooplankton at 48 locations over 4 days (see table 5 for sampling dates, positions and more). The sampling of 18 locations in the Ny-Ålesund area (figure 7) was done by four days of sampling (see table 6 for details). Due to different topography and less accessible water bodies it was not possible to collect samples from as many locations as in the Cape Linné area. However, the amount of samples and positions of locations is satisfactory.

2.2 Study sites and locations

Out of the 66 locations examined, 48 were located at the Cape Linné and the remaining 18 in the surrounding area of Ny-Ålesund. The examined locations in the area of Cape Linné was located just above or below 78°N, while the samples from Ny-Ålesund were all located just below 79°N. The two areas are separated with mountains and glaciers and there should be expected to find different composition of the zooplankton communities in the two areas.

2.2.1 Cape Linné

The Cape Linné area consists of a large costal plain that extends for several kilometres south along the Nordenskiold Coast. This coastal plain is very exposed to harsh weather due to the proximity of the Arctic Ocean (Figure 4) and the elevation is marginal and there is no sheltering topography. To the west, across the Linné River, is the Varderborg plain. On these plains there are numerous ponds, usually not deeper than 2 meters. The ponds also have great transparency making benthic production important. Another effect is that due to the lack of planktivore fish the zooplankton species of cladoceran and copepoda are able to grow large (> 0.5 mm) and because of the shallowness and transparency of the water they evolve melanin pigmentations to cope with ultra violet radiation (Hessen 2007). This makes especially *Daphnia spp.* possible to observe just by looking at the ponds and at dense populations it looks like many small black particles in the water. There were collected samples from 48 locations in this area, where one was from Lake Linné and the reminder from shallow ponds.

Locations 1 to 48 are located in this area and are described below (see table 1 for details). The samplings in this area were done over four days.

Loc. 1

Lake Linné (Figure 5). Sampling were done littoral from shore at the West-side of the lake in the Northern part (Figure 4a). As the elevation was measured to 2 m.a.s.l., this area is sheltered from influence by the sea in both distance and surrounding topography. This is also the only location in this survey which is influenced by a population of fish, Arctic Charr (*Salvelinus alpinus*) [Amrén 1964a], which is recognized as a major intrinsic factor to control zooplankton communities (Hessen *et al.* 2006). Arctic lakes differ substantially from ponds as they do not freeze to the bottom during winter periods and have an additional trophic level in the food web.

Table 1: Locations in the Cape Linné area.

Loc. #:	Description:
1	Lake Linné. East side, northern part of the lake.
2	Moraine and polygonal ground, little or no vegetation
3	As loc. 2. Loc. 3 is a ”twin” pond to loc. 2 with a distance of 75 metres.
4	Moraine around pond. Snow at the eastside.
5	Moss cover around pond. Feathers, goose excrement, gas bubbles.
6	Mosses and grass cover at the west side, gravel and snow at the eastside.
7	Gravel around entire pond, about 20m x 60m, some mosses at outlet
8	Flat terrain, gravel/moraine/polygonal ground. Some mosses at the water edge.
9	Flat terrain, gravel/moraine/polygonal ground, some grasses and mosses.
10	Mosses/grasses at the west side, gravel and snow at the east.
11	Same as for loc. 10. 1m higher, much better water transparency than loc. 10.
12	25m x 50m, gravel and mosses, possible 2 drainages.
13	10m x 30m, vegetation, large numbers of macro zooplankton.
14	50m x 25m, mosses at the west side, gravel/moraine at the east side.
15	50m x 15m, mosses at the west side, gravel/moraine at the east side. About one fifth of the area covered with ice
16	Hollow, about 35 metres in diameter.
17	Pond surrounded with mosses. One third of the area covered with ice.
18	45m x 15m, boggy ground, close to the ocean.
19	Large pond, covered with mosses along the west side.
20	Neighbouring pond to loc. 19. Drains to the sea. Extensive moss cover.
21	Very shallow pond, dominated with rocks and gravel.
22	North of Tunsjøen, much gravel, some mosses.
23	Tunsjøen, north/west side, heavy wind and waves
24	Fyrdammen. Shallow, about 20 cm. Lots of loose sediments.
25	Fyrsjøen, lots of algae, smell of hydrogen sulphide.
26	Close to the ocean, large amount of zooplankton.
27	Even closer to the ocean and even larger amount of zooplankton.
28	Further from the ocean than loc. 26 and 27. Bogs and mosses.
29	South side of the drinking water supply to Isfjord Radio. Some bogs.
30	Southeast of Tunsjøen, gravel and rocks, some sediments.
31	Snow to the east, little vegetation and sediments.
32	Uneven ground, sand and gravel, varying.
33	Bog and mosses. Evidence of numerous birds present.
34	Some mosses and bogs, very shallow, rocky bottom.
35	L-shaped pond, substantial drainage to the ocean. Possible short retention time.
36	Very shallow, lots of rocks and grasses. Firm sediments.
37	Relatively large drainage. Short retention time?
38	Small and shallow, drains to loc. 37, possible short retention time.
39	Larger than loc.36-38, some mosses and bird excrement.
40	Surrounded with grasses and rocks, drains to another pond, possible short retention time.
41	Small shallow pond between Tunsjøen and Fyrsjøen, some grasses and mosses.
42	Pond with drain, mosses and birds. At the shoreline.
43	Small pond, 25m x 25m, extremely much bird facieses, very loose sediments
44	45m x 45m, sandy bottom, at shoreline, lots of zooplankton
45	Large pond, just a few metres from loc. 44. Bogs and mosses.
46	Large pond, close to the ocean, mosses, sandy and rocky bottom, south east of Båtodden
47	Rocks/gravel to the north, mosses/bogs to the south, drains to the sea, relatively small pond.
48	Surrounded by mosses, lots of birds, close to the shoreline.

Locations 2-17

Situated East of the Linné River in an area called the Varderborg Plain (Figure 4a). This area is fairly elevated from sea level, all in the range between 15 and 50 metres above sea level.

Locations 2, 3, 7 and 8 is Borgdammane with an elevation ranging between 30 and 40 metres a.s.l. and are probably more influenced by bird populations inhabiting the mountain to the east than from the sea.

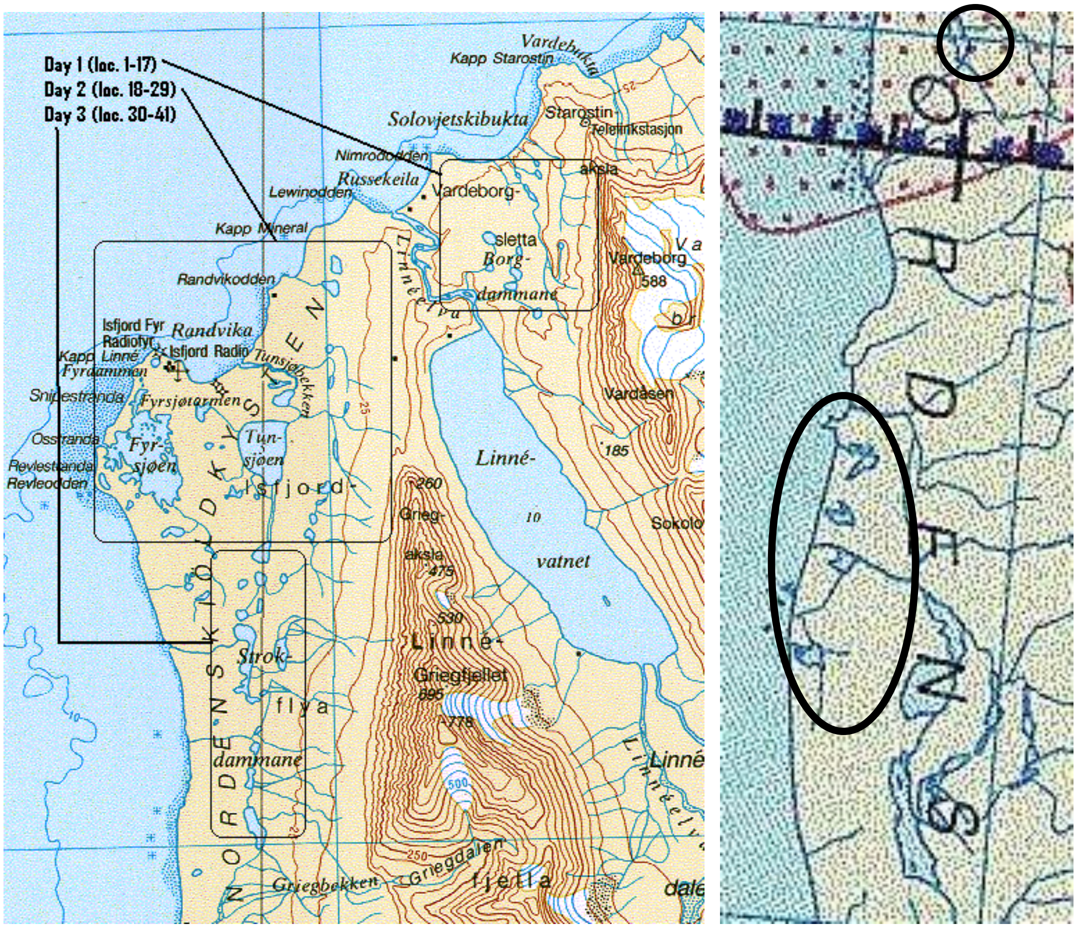


Figure 4: Right (a): Areas of locations (1 to 39 and 41) examined above 78°N at Cape Linné. Left (b): Area of locations 42 to 47 is in the middle of the map. Location 48 is encircled in the North of the map.

Locations 18 to 29 and 41

Situated West of Linné River (see figure 4a) where the elevation of the investigated ponds varied between 0 and 15 m.a.s.l. These ponds will be more exposed to influences by the sea, due to closer proximity to the sea, as well as lower elevation and less topographical sheltering. At the day the samples from these locations were taken, there was significant wind and this might affected the results to some extend. Location 41 was sampled two days later than the rest of locations, due to logistical reasons.

Figure 5: Lake Linné viewed from the north. The outlet is located to the left in the photo.

Locations 30 to 40

South of Isfjord Radio, along Strokflya (see Figure 4a and table 1 for details).

Locations 42 to 48

These locations are located south of 78°N and were all located at or close to the shoreline, hence, subject to substantially influences from the sea. In addition this ponds also had evidence of a large number of birds adjacent, resulting in fertilized soil around several of the ponds (Figure 4b and table 1)


Figure 6: Left (**a**): Location 43. Droppings from Geese and other birds dominated the locations surroundings. Right (**b**): Location 46 seen from North/East clearly shows the shoreline in front and vegetation at the opposite side of the pond.

2.2.2 Ny-Ålesund

Sampling in the surrounding areas of Ny-Ålesund (Figure 7) can mainly be divided into two different areas. The first is in close range to the village, refered to as the Ny-Ålesund area, while the second is located approximately 10 to 12 kilometres North-West of Ny-Ålesund, refered to as the Kvadehuken area. The Ny-Ålesund area is partly sheltered by Kongsfjorden and the surrounding mountains. The second is located at the south-side in the outer part of Kongsfjorden, which is considerable more exposed to wind and sea water influence than the Ny-Ålesund area. Each area is described below.

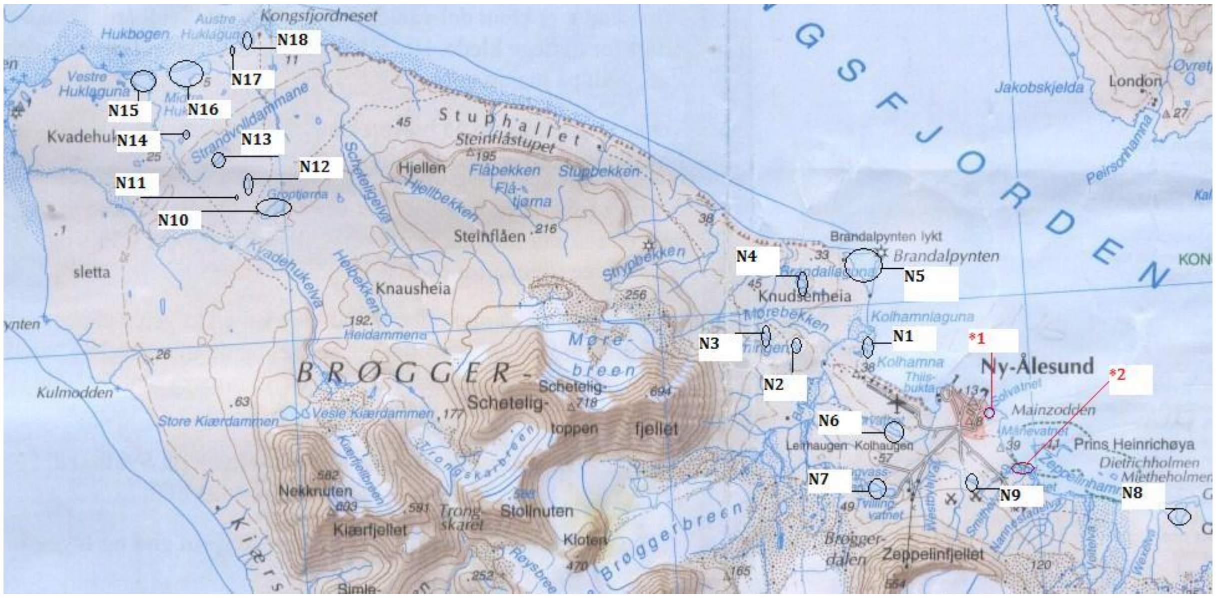


Figure 7: The Ny-Ålesund sampling area. Each sample location is denoted with its location number. In addition “*1” and “*2” is noted in red, and represents Solvatnet (*1) which is a bird sanctuary, and sampling was prohibited. Strandvatnet (*2) where sampling was planned, were completely drained, and do not exist anymore, at least not as a permanent water body as expressed on the map.

Locations investigated in the Ny-Ålesund area are located just around Ny-Ålesund and 10-20 kilometres north of the city. This area does not have as many ponds as for the Cape Linné area, partly because the coastal plain is smaller and partly because of several mountains in the surrounding the area. The investigation were carried out only on the south side of Kongsfjorden, however, some localities across the fjord and in some other protected areas would be of interest, nevertheless, these were not investigated due to logistical reasons.

There were collected 18 samples in the area around Ny-Ålesund, which all were from shallow ponds.

Table 2: Locations in the Ny-Ålesund area.

N1	Small pond at the shoreline, close to the airport. Some mosses, mostly rocks and gravel
N2	20m x 40m, rocky environment, small amounts of mosses, lots of algae.
N3	25m x 60m, rocky environment.
N4	Pond south west of Brandallaguna, some mosses, evidence of birds.
N5	Brandallaguna, mosses, mainly rocky/sandy bottom.
N6	Storvatnet, mosses, mainly rocky/sandy bottom.
N7	Tvillingvatna, deep, rocky environment, some mosses, rocky/sandy bottom
N8	Pond at Gluudneset, at shoreline, mostly rocky with some mosses. Birds present.
N9	Small pond, iron oxides.
N10	Groptjørna, rocky environment, rocky/sandy bottom.
N11	Small, very shallow pond, about 500m west of loc. N10, rocky environment and some mosses.
N12	Pond 4-500m north west of loc. N10, rocky environment, some mosses.
N13	Rocky, shallow pond, about 500m north west of loc. N12.
N14	Small pond, rocky surroundings, rocky/sandy bottom.
N15	Vestre Huklaguna.
N16	Midtre Huklaguna.
N17	Small, highly transparent pond next to Austre Huklaguna.
N18	Austre Huklaguna.

Ny-Ålesund area

In this area the topographical properties varied. There were three locations at sea level, Kolhamnlaguna (N1), Brandallaguna (N5) and Gluudneset (N8). The latter located south and eastward of Ny-Ålesund. The locations at sea level are subject to high conductivity due to close proximity to the sea and zero elevation. These locations are very scarce in vegetation, with exception from N8, where mosses surrounded parts of the pond and nearby area and had a large number of birds present. The "more" inland-character ponds (figure 8) was scarcely vegetated, as well, but not so much influenced by the ocean.

Kvadehuksletta area

This area is very exposed to wind and influence from the sea. The elevation varied between 45 m.a.s.l. for location N10, Groptjørna, along a gradient towards 0 m.a.s.l. at Vestre Huklaguna (Figure 7), noted location 15. Locations 15 to 18 were at sea level and are subject to massive influences from the sea.

Figure 8: Sampling data at location N3. Vegetation is scarce.

2.3 Zooplankton

For each location there were done 4 successive hawls, with a few exceptions where the ponds were too shallow, partly covered with snow or ice or just very small, i.e. >10 m^2, with 90µm mesh. Two were pelagic and two littoral and/or benthic, this to be sure to get as many different species as possible.

Figure 9: Western part of Spitsbergen with the two areas of sampling. The Cape Linné area is situated at 78°N and the Ny-Ålesund area is situated at 79°N.

2.4 Total phosphorous

Samples were kept in 20 mL scintillation vials, which had been rinsed by 1% (~0.12 mol/L) hydrochloric acid solution for more than 24 hours to avoid contamination. Unfortunately, due to several more sampled locations at Cape Linné than anticipated, additional vials had to be brought to Svalbard before departing to Ny-Ålesund. Of logistical reasons there were not possible to acid wash vials used sampling in Ny-Ålesund. However, risk of contamination was considered marginal in this scenario and the sampling in Ny-Ålesund continued in the same manner as for Cape Linné. The water samples for total phosphorous (as a proxy of impact from geese feces) were collected in accordance to (Van Geest *et al.* 2007), approximately 10 centimetres below the water surface. To avoid contamination as well as possible biological alternation of the samples every sample was filter thru a 90 µm mesh to avoid macro zooplankton. For several localities at both Cape Linné and Ny-Ålesund it already exist known background data on nutrient levels from several recent limnological surveys. Samples collected at Cape Linné were kept at UNIS during the fieldwork in Ny-Ålesund.

2.5 Preservation

For qualitative analysis of zooplankton Lugol-solution (potassium iodide and iodine-solution) were used ($KI_{(aq)} + I_{2\,(aq)}$). Preservation of *Daphnia spp.* for DNA analysis was made with ethanol (C_2H_5OH). The purpose of DNA analysis of *Daphnia spp.* is that there has recently been discovered that there exists both European as well as Arctic subspecies of *D.pulicaria* at Svalbard (Van Geest *et al.* 2007), and analysis of DNA with known primers may reveal new species, subspecies or hybrids. During transport from UNIS, Longyearbyen to the University of Oslo, the ethanol used for preserving the samples was diluted to 70%-solution (ethanol/water), and added as close to 100% ethanol when arriving at the laboratory in Oslo.

2.6 Laborararatory analysis

All laboratory analysis was done at the University of Oslo after returning from Svalbard.

2.6.1 Determination of species

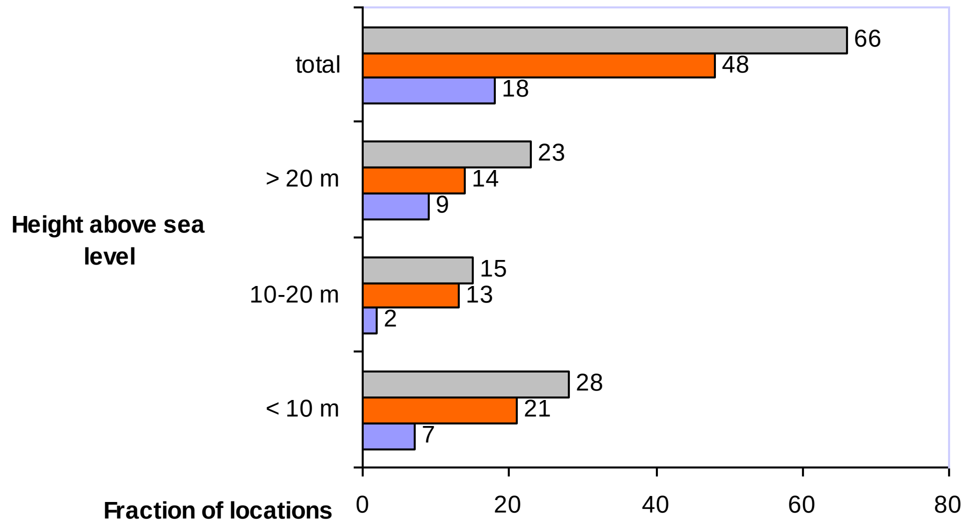
Species of both cladoceran and copepoda were determined under a dissenting microscope, according to Enckell (1998) and the NINA database. Bjørn Walseng (NINA) was also consulted to confirm different findings of species.

2.6.2 Total phosphorous

Samples from 62 locations were analyzed for relative content of total phosphorous. Total phosphorous (TP) was measured spectrophotometrically by Berit Kaasa at the Department of Biology, University of Oslo.

2.7 Elevation

For all 66 locations (Figure 10), 28 were situated less than 10 metres above sea level. This indicates a strong influence from seawater in these ponds. Except from Lake Linné (Figure 7**)**, which is shielded from the sea by a distance > 1 kilometre and topographically barriers. Several of the ponds with an elevation measured less than 10 m.a.s.l., may not be considered as lagoon-type since they are shielded from the sea by rocky cliffs and considerable distance from the shore. Altogether 13 ponds, 6 in the Cape Linné area and 7 in the Ny-Ålesund area, measured elevation to be at sea surface level (figure 10). This is notable because nearly 20 per cent of all water bodies surveyed and almost 40 per cent of the locations in the Ny-Ålesund area have an elevation equal to 0 metres above sea level. There were 15 ponds with elevations between 10 and 20 m.a.s.l., where only two were located in the Ny-Ålesund area and the reminder at the Cape Linné area. These ponds are probably not affected as much by seawater influence as those with elevation less than 10 metres above sea surface. 50 percent of the ponds investigated in Ny-Ålesund were located above 20 metres above the sea surface, as well as 14 ponds in the Cape Linné area, which constitutes 29.2 per cent relative to the Cape Linné area and 21.2 per cent of all locations. These ponds are even more sheltered from seawater influence and more influenced by organic material, mainly from bird excrements.



	< 10 m	10-20 m	> 20 m	total
Both areas together	28	15	23	66
Cape Linné	21	13	14	48
Ny-Ålesund	7	2	9	18

Figure 10: Distribution of three different levels of elevation for locations of both study areas and for all locations combined. The numbers at the end of each bar represents the number of locations.

3 Results

Out of 66 locations, whereas one is considered a lake, there were dense populations of large zooplankton, with few exceptions, in all ponds. The species composition and density of zooplankton varied with distance to the sea and the influence of this, as well as other factors like nutrient input and retention time.

3.1 Zooplankton

Cladocera and copepods seem to be present in almost every water body, with a few exceptions. For most ponds, however, large cladoceran i.e. *Daphnia spp.* seemed to dominate. Smaller cladoceran i.e. *Macrotroix hirsuticornis, Chydorus spaericus* and *A. harpae* are not that numerous, especially in ponds with dense populations, but may be substantial in ponds with lesser dense populations. For the *Eutythemora raboti* in the Ny-Ålesund area, it seemingly occurs in water bodies with close proximity to the sea. At the Cape Linné area they seem to appear almost everywhere. Due to sub sampling of several locations of the Cape Linné area, some species might be missing.

3.1.1 Cape Linné

Five species of cladocerans were detected in the Cape Linné area. Out of the 48 locations, two of the locations are missing data, making the real number of locations 46. *Daphnia pulicaria* was found in 36 of these, while *D. tenebrosa* was detected at 26. *Macrotrix hirsuticornis* was found at 12 locations, *Chydorus spaericus* at 9 locations and *Acroperus harpae* was detected at 3 locations (see table 3). Three species of copepods were detected at the same locations. *Eurythonema raboti* was found at 19, while *Diacyclops crassicaudis* or *Cyclops abyssorum* was found at 7 of the 46 locations (see table 3). In addition different development stages of undetermined species of copepods were detected in 5 locations.

Table 3: The occurrence of zooplankton for each location at Cape Linné. *Cyclops abyssorum* is not differenced from *Diacyclops crassicaudis* and both species may be described as *Diacyclops crasscaudis*. *) Copepodite or nauplii, not determined to species.

Location	*Daphina tenebrosa*	*Daphnia pulicaria*	*Macrothrix hirsuticornis*	*Chydorus sphaericus*	*Acroperus harpae*	*Eutythemora raboti*	*Diacyclops crassicaudis*
1						*	
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	X	X					X
5	X	X				X	
6	X	X				X	X
7		X					
8		X	X			*	
9	X	X					
10		X				*	
11							
12		X				X	X
13**	X	X				*	
14	X	X				X	
15		X				*	
16		X				*	
17		X					
18	X	X				X	
19	X	X					
20	X	X	X				
21		X	X	X		X	
22	X	X	X	X		X	X
23	X			X		X	X
24	X	X				X	
25**						*	
26	X	X				X	
27	X	X				X	
28	X	X	X	X			
29		X	X			*	
30							
31		X		X		X	X
32	X	X	X	X	X		X
33	X	X				*	
34	X	X	X	X		*	
35				X			
36	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-
38			X				
39	X	X	X		X		
40							
41	X	X				*	
42	X	X				X	
43	X	X		X		X	
44	X	X				X	
45	X	X				X	
46	X	X				X	
47		X	X		X		
48	X	X	X			X	

3.1.2 Ny-Ålesund

There were also detected 5 different species of cladocerans in the Ny-Ålesund area. Of the 18 locations *D. tenebrosa* and *D. pulicaria* was found at 11. *M. hirsuticornis* was detected at 4 locations, *C. spaericus* was found at 5 and *A. harpae* at 2 (table 4).
Three species of copepods was also detected. *E. raboti* was found at 7 locations, while *D. crassicaudis* or *C. abyssorum* appeared at 3 locations (table 4). In addition development stages of undetermined species of copepods were detected in one additional location.

Table 4: The occurrence of zooplankton for each location in Ny-Ålesund. *Cyclops abyssorum* is not differenced from *Diacyclops crassicaudis* and both species may be described as *Diacyclops crasscaudis*. *) Copepodite or nauplii, not determined to species.

Location	*Daphina tenebrosa.*	*Daphnia pulicaria.*	*Macrothrix hirsuticornis*	*Chydorus sphaericus*	*Acroperus harpae*	*Eutythemora raboti*	*Diacyclops crassicaudis*
N1	X	X				X	
N2	X	X					
N3	X	X	X			X*	
N4	X	X	X				
N5	X	X	X				
N6	X	X				*	*
N7	X	X					
N8						X*	X*
N9							
N10	X	X	X	X			X*
N11				X	X		
N12	X	X		X	X		
N13				X			
N14	X	X		X			
N15	X	X				X	
N16						X	X
N17						X	
N18						X	

3.1.3 Species in both areas

The same species were found in both areas, although the composition may differ in several ways. *D. tenebrosa* (also described as *D. middendorfiana* and *D. pulex*) and *D. pulicaria* are the largest of the cladocerans in the two areas investigated. *M. hirsuticornis*, *C. spaericus* and *A. harpae* is the three smaller species. Hence, 5 different species of cladocerans were detected during the survey. *E. raboti* was the copepod detected at most locations, in addition to *D. crassicaudis* and *C. abyssorum*.

Altogether, there were detected 5 species of cladocerans and 3 species of copepods during the entire survey.

3.1.4 Unexpected findings

The finding of *A. harpae* was not expected. Whether or not this species is new to Svalbard is not absolute certain. Summerhayes & Elton (1923) described the species, however, neither Amrén (1964b) nor Gullestad & Halvorsen (1976) detected the species, and Gullestad & Halvorsen (1976) concluded that the species probably did not exist at Svalbard. Another observation made at Cape Linné was that *Daphnia spp.* seems to be patchy distributed even in small ponds. This observation was made at location 41, where dense amounts of zooplankton occurred during sampling, while two days later only a few individuals were collected per hawl.

It may be considered unexpected to find *M. hirsuticornis* and *C. spaericus*, as well. These species are described by Gulllestad & Halvorsen (1976) and Jørgensen & Eie (1993), but not mentioned by Amrén (1964a;b).

3.1.5 Cape Linné versus Ny-Ålesund

The correlation between the number of species found at a location and the measured content of phosphorous is higher for the Ny-Ålesund area than for Cape Linné (figure 11 and 12). There seem to be no correlation between the number of species and elevation (figure 11 and 12) for either areas.

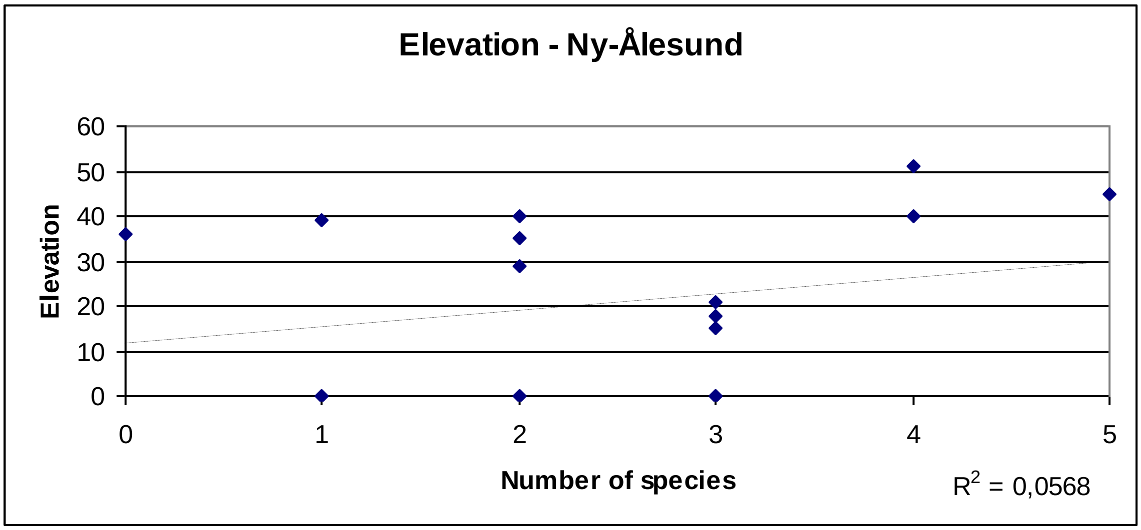


Figure 11: The number of species found at each location related to elevation in the Ny-Ålesund area.

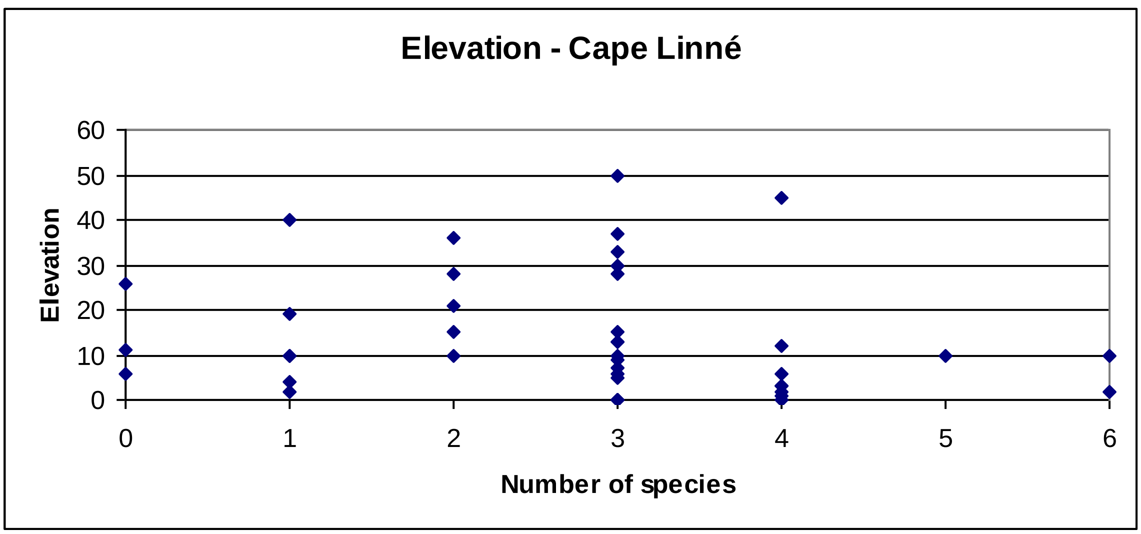


Figure 12: The number of species found at each location related to elevation in the Cape Linné area.

3.2 Total phosphorous

The relative content of total phosphorous (TP) was measured for 18 locations in Ny-Ålesund area (table 6) and 44 locations in the Cape Linné area (table 5).

Table 5: Position, elevation, sampling date/time and measured total phosphorous for locations at Cape Linné.

Loc. #:	Latitude:	Longitude:	Accuracy: (GPS)	Sample date:	Time:	Elevation: (m.a.s.l)	Phosphourous: (TP) µg P / L
1	78°03.356N	013°45.453E	9m	Jul. 25th 08	10:35	2	-
2	78°04.297N	013°47.616E	5m	Jul. 25th 08	12:20	35	4
3	78°04.336N	013°47.961E	9m	Jul. 25th 08	12:55	30	-
4	78°04.114N	013°48.358E	25m	Jul. 25th 08	13:00	37	2
5	78°04.511N	013°49.224E	10m	Jul. 25th 08	14:15	50	3
6	78°04.446N	013°48.775E	11m	Jul. 25th 08	14:50	*	-
7	78°04.493N	013°47.843E	10m	Jul. 25th 08	15:20	40	-
8	78°04.367N	013°47.033E	6m	Jul. 25th 08	15:45	30	1
9	78°04.554N	013°46.984E	5m	Jul. 25th 08	16:25	28	2
10	78°04.820N	013°48.398E	6m	Jul. 25th 08	17:05	21	1
11	78°04.884N	013°48.114E	4m	Jul. 25th 08	17:30	26	1
12	78°04.969N	013°47.872E	5m	Jul. 25th 08	17:50	28	1
13	78°04.954N	013°48.291E	4m	Jul. 25th 08	18:05	30	1
14	78°05.003N	013°48.445E	4m	Jul. 25th 08	18:30	33	1
15	78°05.048N	013°48.490E	7m	Jul. 25th 08	18:50	36	4
16	78°04.879N	013°47.605E	9m	Jul. 25th 08	19:10	15	2
17	78°04.962N	013°47.489E	6m	Jul. 25th 08	19:30	19	2
18	78°04.668N	013°43.227E	4m	Jul. 26th 08	10:25	15	2
19	78°04.419N	013°41.993E	6m	Jul. 26th 08	11:00	10	2
20	78°04.253N	013°41.895E	3m	Jul. 26th 08	11:30	*	3
21	78°03.589N	013°40.317E	5m	Jul. 26th 08	12:30	0	18
22	78°03.479N	013°40.265E	4m	Jul. 26th 08	12:50	2	9
23	78°03.334N	013°39.185E	8m	Jul. 26th 08	13:15	3	11
24	78°03.732N	013°36.385E	6m	Jul. 26th 08	14:50	6	14
25	78°03.732N	013°35.779E	7m	Jul. 26th 08	15:30	10	14
26	78°02.975N	013°34.791E	9m	Jul. 26th 08	16:20	5	14
27	78°02.810N	013°35.525E	6m	Jul. 26th 08	17:05	0	3
28	78°02.810N	013°36.725E	5m	Jul. 26th 08	17:45	2	5
29	78°03.369N	013°37.825E	6m	Jul. 26th 08	18:30	7	3
30	78°02.864N	013°38.912E	3m	Jul. 27th 08	10:10	6	5
31	78°02.460N	013°39.848E	5m	Jul. 27th 08	10:55	6	7
32	78°02.349N	013°39.588E	6m	Jul. 27th 08	11:15	10	4
33	78°02.318N	013°39.258E	4m	Jul. 27th 08	11:45	13	4
34	78°02.095N	013°38.981E	5m	Jul. 27th 08	12:20	10	3
35	78°01.890N	013°39.429E	5m	Jul. 27th 08	12:55	10	5
36	78°01.339N	013°39.620E	7m	Jul. 27th 08	13:40	8	18
37	78°01.238N	013°39.504E	8m	Jul. 27th 08	14:05	4	7
38	78°00.981N	013°39.314E	5m	Jul. 27th 08	14:30	4	5
39	78°00.830N	013°39.261E	10m	Jul. 27th 08	15:00	12	6
40	78°01.916N	013°40.204E	4m	Jul. 27th 08	16:15	11	8
41	78°03.916N	013°37.992E	5m	Jul. 27th 08	17:25	13	6
42	77°56.922N	013°37.346E	5m	Jul. 28th 08	13:50	0	8
43	77°57.282N	013°36.995E	4m	Jul. 28th 08	14:30	1	517
44	77°57.375N	013°36.985E	5m	Jul. 28th 08	14:50	0	60
45	77°57.522N	013°37.331E	6m	Jul. 28th 08	15:20	0	8
46	77°58.032N	013°37.972E	6m	Jul. 28th 08	16:10	0	10
47	77°58.825N	013°38.323E	4m	Jul. 28th 08	16:50	9	9
48	77°59.594N	013°38.697E	5m	Jul. 28th 08	17:30	3	13

Table 6: Position, elevation, sampling date/time and measured total phosphorous for locations in Ny-Ålesund.

N1	78°55.971N	011°51.556E	6m	Aug. 1st 08	14:35	0	9
N2	78°56.083N	011°49.015E	5m	Aug. 1st 08	15:40	35	7
N3	78°56.157N	011°47.893E	10m	Aug. 2nd 08	12:50	51	8
N4	78°56.490N	011°49.149E	4m	Aug. 2nd 08	13:30	21	8
N5	78°56.691N	011°51.141E	7m	Aug. 2nd 08	14:00	0	6
N6	78°55.422N	011°52.512E	4m	Aug. 2nd 08	15:25	18	8
N7	78°55.041N	011°52.068E	4m	Aug. 2nd 08	16:10	29	6
N8	78°54.824N	012°03.507E	7m	Aug. 3rd 08	13:30	0	8
N9	78°55.056N	011°55.661E	6m	Aug. 3rd 08	14:50	36	6
N10	78°55.111N	011°29.071E	4m	Aug. 5th 08	11:40	45	17
N11	78°57.105N	011°27.543E	6m	Aug. 5th 08	12:05	40	9
N12	78°57.248N	011°28.042E	11m	Aug. 5th 08	12:25	40	9
N13	78°57.459N	011°27.153E	19m	Aug. 5th 08	12:45	39	8
N14	78°57.647N	011°25.948E	7m	Aug. 5th 08	13:10	15	9
N15	78°58.006N	011°24.732E	5m	Aug. 5th 08	13:40	0	7
N16	78°58.084N	011°25.443E	5m	Aug. 5th 08	14:05	0	9
N17	78°58.254N	011°27.691E	4m	Aug. 5th 08	14:30	0	10
N18	78°58.285N	011°28.011E	6m	Aug. 5th 08	14:50	0	9

The average for all 62 locations was 15.8 µg P/L. There are, however, two locations with extremely high TP values, location 43 (Figure 6a) and 44. If these two are excluded, the average drops to 6.7 µg P/L. The range over all locations spends from 1 to 517 µg P/L. For the Ny-Ålesund area, the minimum value is 6 µg P/L, the maximum at 17 µg P/L and the average is 8.5 µg P/L, with a standard deviation of 2.4. The Cape Linné area has an average value of 18.8 µg P/L, minimum of 1 µg P/L and a maximum at 517 µg P/L (Figure 6a), with a standard deviation of 77.4.

For the Ny-Ålesund area, there is a week correlation between the phosphorous content and the number of species at a given location (figure 14), R^2= 0,54. For Cape Linné there seem to be no correlation between these to variables (figure 13), R^2=0,07.

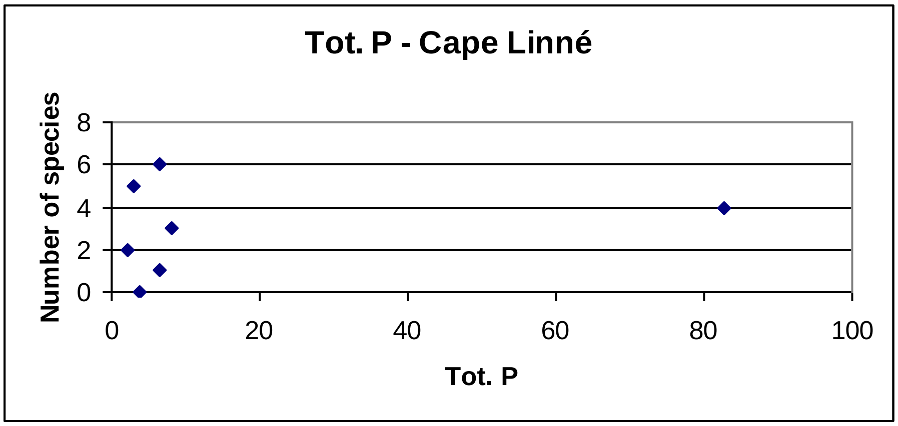


Figure 13: The number of species related to the mean content of phosphorous for locations at Cape Linné.

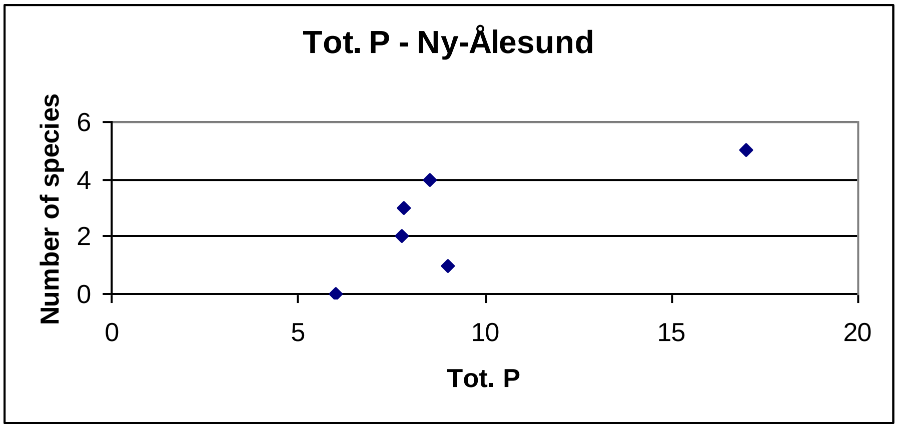


Figure 14: The number of species related to the mean content of phosphorous for locations in Ny-Ålesund.

4 Discussion

Gullestad & Halvorsen (1976) surveyed a large number of localities especially just north of Ny-Ålesund. They questioned some of the earlier findings in regards to zooplankton on Svalbard. Olofsson (1918) and Summerhayes & Elton (1923) describe *Daphnia spp.* as *D.pulex*, while Amrén (1964) describes *Daphnia spp.* as *D.tenebrosa* = *D.middendorfiana*. Gullestad & Halvorsen (1976) compare the two species *D.pulex* and *D.middendorfiana* with the two distinct forms they found and based on the distinct brown coloration together with the far northern range of *D.middendorfiana* in Northern America. They conclude that *Daphnia spp.* of Svalbard is *D.middendorfiana* and that the smaller form probably is a new generation of the same species. Amrén (1964a,b) conducted a massive survey in the Cape Linné area and describes *Daphnia spp.* as *D. tenebrosa*. Jørgensen & Eie (1993) describe *Daphnia spp.* as *D.pulex* in an investigation on the Mossel-peninsula. More recent surveys, i.e. Van Geest *et al.* (2007), reveal that there not only exist two species of *Daphnia* at Svalbard, but in addition to *D.tenebrosa*, as described by Amrén (1964b), there is both a polar and a European subspecies of *D. pulicaria*. During the summer of 1977, altogether 20 locations at the Mossel peninsula located at the north side of Spitsbergen were surveyed by Jørgensen and Eie (1993). Out of the 20 locations, there were 9 lakes, 8 ponds and 3 rivers/streams. They discovered three species not observed at Svalbard earlier; *Limnocalanus macrurus, Bosmina longirostris* and *Sida crystalline*. In addition they also found *D. middendorffiana*, *Chydorus spaericus, Macrotrix hirsuticornis, Alona guttata, Cyclops abyssorum* and *Diacyclops spp*.

The increase in population of migratory birds affects other areas than the Arctic. Since a larger population needs a larger amount of resources, the area of over wintering gets affected as well the breeding area. For geese using Vårsolbukta as a pre-breeding area, there are several advantages of using an Arctic area for this purpose. First, the nesting date is usually varying with snowmelt and by being closer to the breeding area the birds will receive signals concerning snowmelt. Secondly, there is 24 hours daylight at Vårsolbukta, making it possible to forage more than it will on lower latitudes (Hubner

2006). As these birds forage on mosses, they also contribute to increased fertilization and higher productivity, for terrestrial systems as well as aquatic.

In accordance to Green *et al.* (2002) and Figureola & Green (2002) it would be expected to find more species at Cape Linné, than in Ny-Ålesund. The reason for this is that the chance of dispersal is higher in an area of more water bodies, than with fewer ponds per area. The fact that coastal plain around and south of Cape Linné have a very dense population of ponds compared to Ny-Ålesund should suggest that dispersal of new species are more likely to occurs at Cape Linné, than the Ny-Ålesund area.

Considering the relative content of total P, it seems like a fraction of the ponds at Cape Linné is undergoing eutrophication, while Ny-Ålesund is less affected. While Ny-Ålesund has a standard deviation of 2.4 in total P, Cape Linné has a standard deviation of 77.4, yet admittedly mainly due to two extremely enriched localities that were heavily affected by geese grazing and droppings. There were also a number of more modestly affected localities in this area. If larger parts of the Nordenskiold Coast become a pre-breeding area for geese, as Vårsolbukta in the south is (Hubner 2006), it will increase the probability both for bird-induced dispersal of zooplankton species as well as community shifts due to eutrophication.

The ponds around Ny-Ålesund were less enriched in P and also had more even zooplankton community compositions. The copepod *E. raboti* was detected in ponds near the shoreline and not in ponds located distant from the sea at higher elevation. This is consistent to Olofsson (1918), that the copepod needs longer development time and are able to live in conditions with up to 50% seawater. That the more elevated ponds in further distance from the sea should have a shorter growth period and longer ice cover seems plausible. However, this is not entirely consistent with the location N3, which is not in near proximity to sea and has an elevation approximately 50 m.a.s.l. Location N8 is the pond located at Gluudneset, which entirely consisted of copepods, *E. raboti*, and different development stages of undetermined species. No cladocerans was detected here, however, this could be an effect of seasonal variation or sampling strategy. About location N9, this was a small pond heavily influenced by iron oxides, and contained no zooplankton. This was more or less expected as the pond seemed to be used as a waste area for old machinery.

Not all species inhabiting a water body is necessary sampled by a single sample and that cumulative sampling may neither gives a “true” measure, since visiting species may be sampled (cf. Hessen *et al.* 2007). However, the relatively low biodiversity of Svalbard makes it plausible that most species are sampled by a single sample method. However, the seasonal change in the zooplankton communities may be of a more important factor. As shown by Amrén (1964b) the entire zooplankton community in a pond could be inhabited only by copepods at one time, while it earlier in the same season only consisted of *Daphnia spp*. Also, the patchy distribution of zooplankton, as observed at Cape Linné, may influence the number of species collected in a sample. In ponds of fairly size, for instance Tunsjøen and Fyrsjøen at Cape Linné and Brandallaguna and the lagoons of Kvadehuken, wind conditions may also have influenced the sampling method. Subsampling of several locations from the Cape Linné area may have given an inaccurate result, as species may have been left out.

5 Conclusion

Over the last decades there has been climate induced changes in the zooplankton communities at Svalbard. These changes are apparent at Cape Linné, where the distribution of zooplankton has changed substantially since early 1960’s (Amrén 1964b). For Ny-Ålesund the changes are not as apparent as for Cape Linné, mainly since because of the lack of earlier comparable surveys. The increase in the population of migratory birds as well as the recent increase in temperature seems likely to be an effect of these changes. However, since the composition of zooplankton communities changes during the season, some species may not show in this sampling method. To be sure to have sampled all existing species, samples has to be made over an entire season. More surveys are also needed to investigate further what is happening with eutrophication as well as the warming of the climate and the effects from birds.

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