



Ellen Elverland

The Arctic System





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Midnight in Fram Strait, photographed by Rudi Caeyers, NFH/UiT, on an Integrated Arctic Ocean Observing System cruise in 2007

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A typical arctic fjord landscape with glaciers, naked mountains, sea ice and seabirds. The Arctic has long been famous for its enormous tracts of intact country, but man has played an important role in the Arctic for a long time, and still does. In the old days, people visited the region to tap its resources, but recently we have also begun to put pressure on the Arctic without actually being present. Photo: Tor Ivan Karlsen, Norwegian Polar Institute (NPI).

The Arctic System

The Arctic can be described as a contradiction – varied and robust, but yet a region that is vulnerable to climate change and environmental pressures. Because a great deal of energy is transported from the south by the North Atlantic Current, the Gulf Stream, the climate in the Norwegian Arctic differs from that at the same latitude elsewhere.

The Norwegian Arctic is varied, and also complex. There are glaciers, extensive areas of tundra, high mountains, islands, skerries, fjords and enormous expanses of ocean. Changes in one part of the Arctic have an effect on conditions in other areas and give side effects for the entire system. The arctic community is a system in which everything is connected, and many species of animals and plants are specially adapted to life in these harsh surroundings. Indeed, some have become so specialised that they can only exist here.

The Arctic gives us early warning of climate change, and the region plays an important role in the global climate system. As

the climate gradually gets warmer, the ice retreats and more and more islets and skerries become visible. The tundra thaws and the basis for the existence of people and animals shifts.

The ecosystem in Svalbard, the Barents Sea and other parts of the Arctic is not only coming under increasing pressure from climate change that alters nature, but also by human activity such as increasing traffic (cruise tourism, shipping, etc.), growing pressure from fisheries, extraction of natural resources and new pollutants. Norway has a political goal that the exploitation of resources must not result in species being endangered or brought to extinction.

Even though the Arctic is far away, it is nevertheless close. Events elsewhere in the world have consequences here, and changes in the Arctic have the strength and size to directly affect our everyday life. This is really not so surprising either, since the arctic regions comprise around 25 of the 90 lines of latitude. Just the areas of sea in the Arctic are

1.5 times greater than the USA, and in addition there are vast land areas in Greenland, Canada, the USA, Russia and Norway.

A politically important region

The present Norwegian government has made the northern regions its most important strategic area of commitment, because they represent enormous opportunities and also challenges.

The Barents Sea is of strategic importance on several counts, particularly with regard to energy, resource management and the environment. In the fishery protection zone around Svalbard there is international disagreement regarding fishing, and production of oil and gas in the North earns the attention of politicians in many countries. Estimates indicate that the Arctic – principally Russian territory but also the Norwegian Arctic – may have as much as 25 % of the world's remaining petroleum resources. North-western Russia is, moreover, militarily strategically important. Espen Barth Eide, the State Secretary in the Norwegian Ministry of Defence, concluded in 2006 that, in terms of security, conflicts of interest in

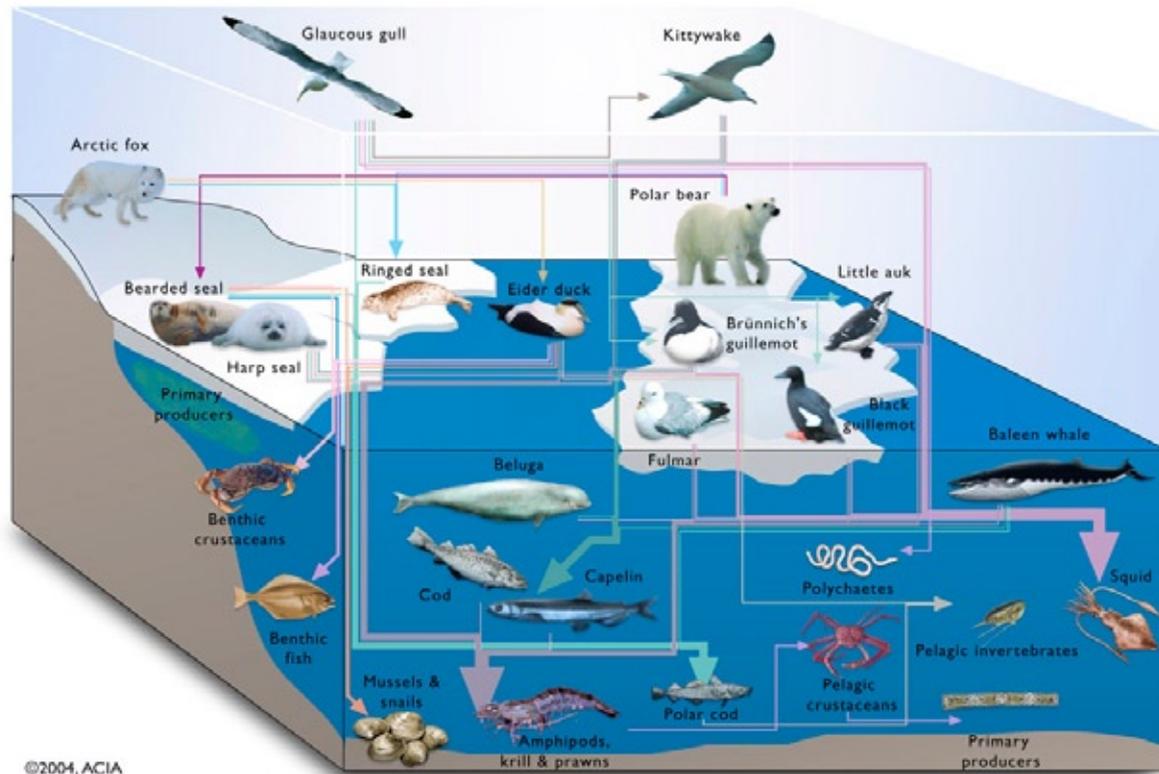
relation to Russia are the greatest challenge facing Norway.

The melting of ice on land in the Arctic helps to raise the sea level globally and may lead to changes in the pattern of ocean currents that are of great importance for the Earth's climate. The region is also an indicator of the state of the environment on the Earth because little pollution is generated here and most pollutants are transported by air and sea from far distant lands. To be able to keep pace with the trend and take any necessary steps, it is important to have good knowledge about the arctic system.

Arctic Ltd

The arctic ecosystem may be compared with a business, a major workplace called Arctic Ltd. This is a well-functioning organisation with long traditions. Everyone knows his or her place in the system and contributes to the organisation in his or her own small way – each species is a small piece in the big jigsaw puzzle that, together, makes up the whole picture.





©2004, ACIA

The arctic marine food chain. The chain starts with the smallest, photosynthesising organisms in the sea. Thereafter follow organisms which eat plant material, while the next link consists of carnivores. The food chains in the Arctic are short and have relatively few links from the organisms at the base to the polar bear at the top, but even though they are short, each link may be made up of many millions of individuals of the same species. Figure: ACIA.

The big guns at the top, the polar bear, the seal and the whale, are often the public face of the organisation, but they certainly do not control the firm alone. They are at the mercy of the workers beneath them and must depend upon them for their own existence.

The ecosystem in the Arctic is characterised by short food chains involving few species, i.e. there are few links from the plants lowermost in the chain to the predators at its top. The Arctic is therefore also a vulnerable organisation. Should something go wrong in one chain, there are not many alternative sources of food for those living in the chain above. However, even though the diversity of species is low, it is a large organisation and each species may be represented by several million, perhaps billion, individuals. This especially holds true for species that are far down in the food chain, but the number of individuals per species decreases towards the top.

Arctic Ltd is a conservative, old-fashioned and traditional workplace that has functioned in the same manner for thousands of years. Things take time here and, compared with companies in warmer regions, many processes go much more slowly in Arctic Ltd. Many organisms here grow more slowly, they reach a sexually mature age later and they have fewer offspring than more southerly species. On the other hand, they live for quite a long time, as exemplified well by the fulmar among the birds and the bowhead whale. The fulmar may live for 50 years, while the bowhead whale can reach the ripe old age of nearly 250 years, longer than any other mammal in the entire world. More energy is consumed to maintain heat and to survive in the Arctic than is the case among organisms living in warmer regions, so there is less surplus to be used for reproduction. It may be said that the cold leads to birth control and delays the aging process.

As Arctic Ltd is a slightly old-fashioned organisation, it may respond poorly to change. Changes are generally forced upon it by external constraints, non-biological pressures, which lay the basis for the existence and development of the firm – for better or for worse.

The climate is a factor that lays severe premises for life in the Arctic, and the increasingly warmer climate is now posing great challenges for Arctic Ltd. The ice is retreating and is threatening to literally pull the ground from under the feet of the firm. Together with the ever-rising temperatures, southerly species are moving into the region and threatening to take over the headquarters. New species may also bring viruses and bacteria that have not previously been able to survive in the cold North, and the Arctic

staff may be exposed to diseases against which they lack immune response.

Moreover, as if this were not enough, Arctic is also fighting hazards on several fronts. Together with rapid changes in climate and human activities like fishing, pollutants are the worst menace and are now threatening to destroy the organisation from the inside. They accompany the food chain and are taken up by the very smallest organisms, accumulate upwards and affect the ability for survival and reproduction at the top of the food chain.

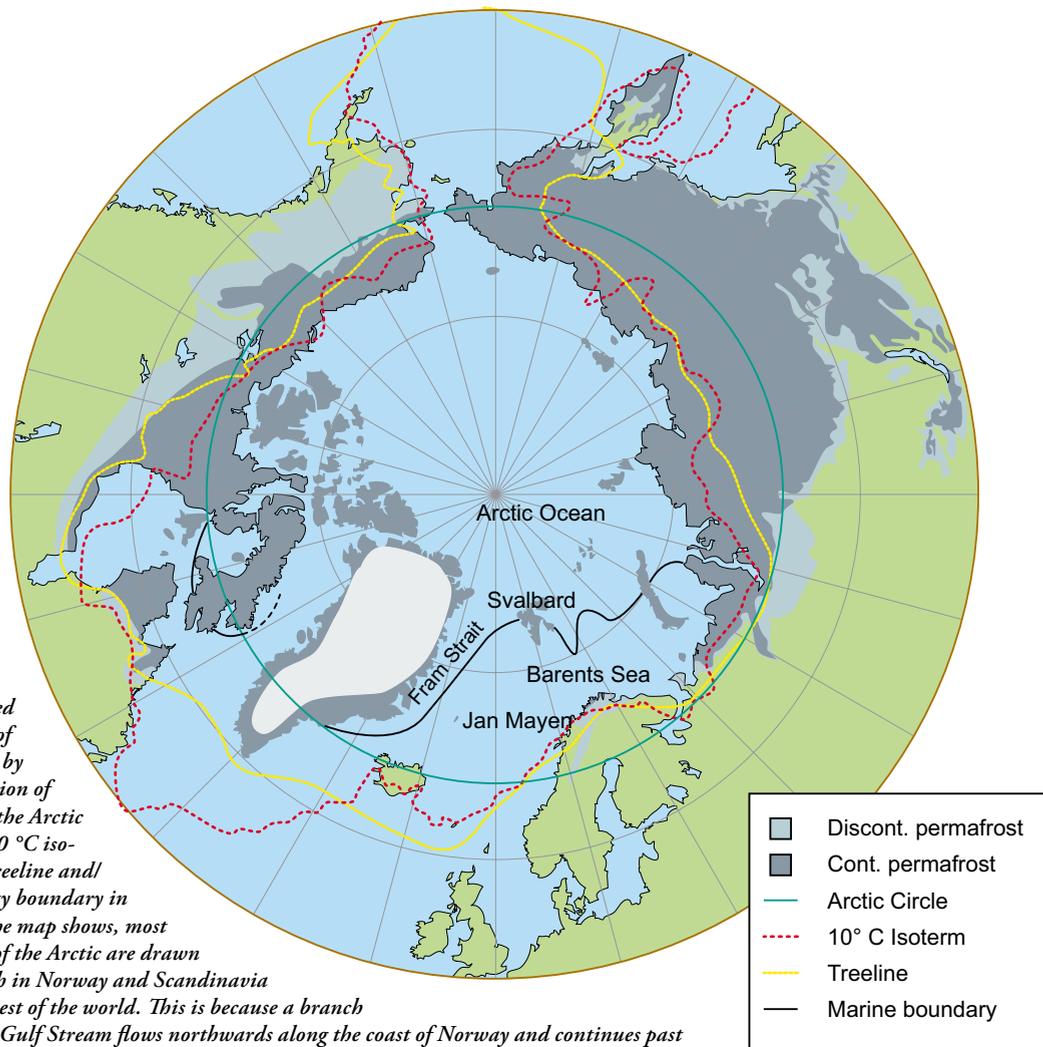
The headquarters

Not surprisingly, the headquarters of Arctic Ltd are in the Arctic. Everyone knows that this lies far to the north, but how it is



The Svalbard reindeer is a subspecies of the reindeer on the mainland. It is only found in Svalbard and has become adapted to the cold, inhospitable climate by evolving short legs and a relatively short, round head. Its summer coat is brown on the back and light-coloured below. In winter, its coat is more light coloured and frequently light grey or yellowish white. Because of their thick coat, even starved animals seem to be fat, and this also makes the reindeer appear extra short-legged. Photo: Ronny Aanes, NPI.

The Arctic can be defined in a variety of ways such as by the distribution of permafrost, the Arctic Circle, the 10 °C isotherm, the treeline and/or the salinity boundary in the sea. As the map shows, most boundaries of the Arctic are drawn further north in Norway and Scandinavia than in the rest of the world. This is because a branch of the warm Gulf Stream flows northwards along the coast of Norway and continues past Svalbard into the polar regions. Figure: NPI.



demarcated towards the south is perhaps not so well known. One possibility for drawing a southerly limit for the Arctic is to use a line of latitude, and the one that is most commonly used is the Arctic Circle. It marks the latitude where the sun does not rise above the horizon for at least one day at the winter solstice, about 21 December, and where there is at least one night of midnight sun at the summer solstice, about 20 June.

However, as most organisms in the Arctic do not just depend upon light to exist, climate is a more relevant definition, and the distribution of permafrost or the area north of the 10 °C July isotherm are generally used. The isotherm is the boundary where the average temperature for July is no higher than

10 °C at sea level. It is also possible to use the vegetation and the northern treeline to demarcate the Arctic.

A boundary for the Arctic is not only required on land. In the sea, it is drawn where cold, low-saline water from the north meets warmer, saline water from the Atlantic Ocean. Because the Gulf Stream along the Norwegian coast takes the Atlantic water much further north than it reaches around Canada and Greenland for example, the salinity boundary in the ocean is situated at about 80°N west of Svalbard, whereas it is around 65°N on the east coast of Greenland.

In addition to these purely geographical and climatic delimitations, politics and cul-

ture also play a role, and one could just as well add several lines to illustrate political and cultural definitions of the Arctic.

The Norwegian part of the Arctic is defined as Svalbard, Jan Mayen and the mainland north of the Arctic Circle. For practical reasons, a small area south of the Arctic Circle is also included to take in all the Saltfjellet-Svartisen National Park and the Borough of Rana.

Even though the Norwegian Arctic also includes some of the mainland, our attention here is focussed on Svalbard and the surrounding waters, including part of the Barents Sea. The Svalbard archipelago comprises eight large islands and all the small islands, islets and skerries between 74° and 81° North and 10° and 35° East. The largest island is Spitsbergen.

The Barents Sea

The Barents Sea is an important and large part of the Norwegian Arctic. It stretches from the coast of north Norway in the south to the Arctic Ocean in the north and is bounded by Svalbard in the west and Novaya

Zemlya in the east. The Barents Sea is more than four times the size of Norway and is a productive area because it is comparatively shallow, only 230 metres on average, and because it is here that the cold water from the Arctic Ocean meets the warm Atlantic water that is being carried northwards by the Gulf Stream. Few other maritime areas can boast a corresponding wealth of breeding seabirds. At least 20 million are resident in the Barents Sea in summer. They range over 40 different species and occupy 1600 breeding colonies. This enormous wealth of birds is a result of them finding plenty of food in the form of fish and plankton. Many of the fish that grow up in the Barents Sea have come here as eggs and fry drifting in the ocean currents from spawning grounds further south, and the Barents Sea is totally dependent upon this supply to maintain its productivity.

The primary producers – the men on the shop floor

The primary producers, or the "men on the shop floor", are the real creators of wealth in the Arctic. It is they who transform plain stone into gold – or in this case solar energy into carbohydrates. Without a solid work-



Large parts of the Barents Sea are frozen in winter and only the southernmost part towards the coast of North Norway and Russia remains ice-free throughout the year. As the summer gradually creeps northwards, the Barents Sea ice thaws, and animals and birds follow the ice edge northwards. Photo: Sebastian Gerland, NPI

Did you know that:
 A treaty (a binding agreement between nations), the Svalbard Treaty, was signed in 1920 by Norway, the USA, Denmark, France, Italy, Japan, the Netherlands, Sweden, Great Britain and Ireland, and the British Overseas Dominions. The Svalbard Treaty states that Norway not only has the right, but also an international obligation, to ensure that the natural environment in Svalbard and associated areas is preserved and is not destroyed as a consequence of human pressures.

dependent upon them to survive, grow and reproduce. This is the first step in the arctic food pyramid.

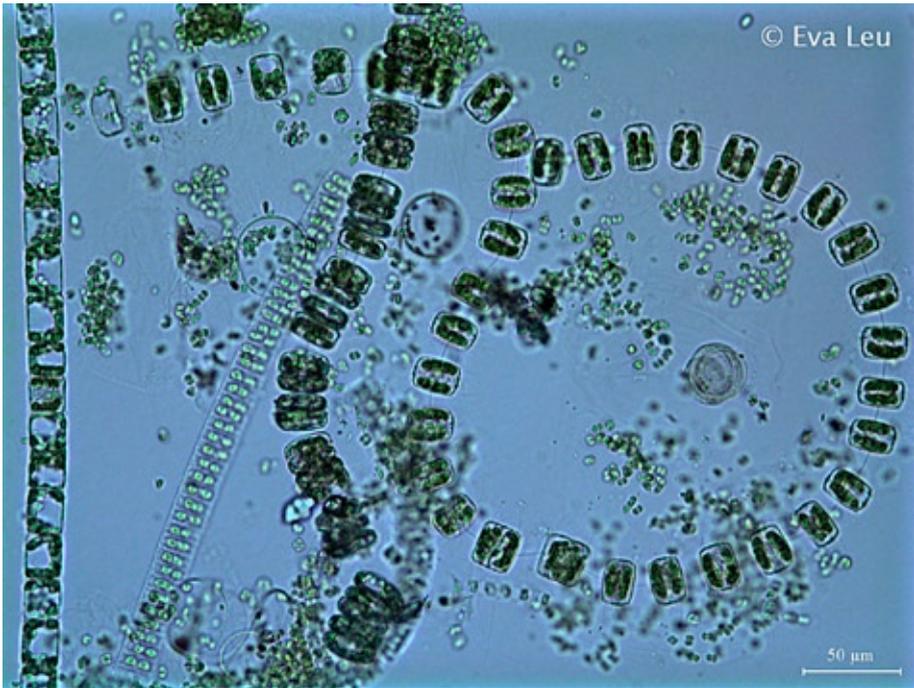
Plant life in the sea

Phytoplankton is a collective name for several species of microscopic algae, all of which have chlorophyll and perform photosynthesis. The most important factors controlling the life of phytoplankton are the availability of food in the water and the light.

force at the base, the organisms higher up in the company would have little to build on.

Sunlight is the key for the primary producers in the sea and on land (the phytoplankton and the terrestrial plants) because these organisms perform photosynthesis, producing carbohydrates that are used for growth and reproduction, and they are important for the other organisms in the Arctic which do not make their own carbohydrates, but which eat the primary producers and

Phytoplankton thrive in the upper part of the water because that is where they have best access to the light they need for photosynthesis, but most of them are at the mercy of the circulation in the water as they drift passively around. Owing to the vertical mixing of the water masses, whereby nutrient-rich water from the bottom rises to the surface, access to nutrients varies greatly through the year. Some species spend the winter inside the ice or on the sea floor, but when daylight returns



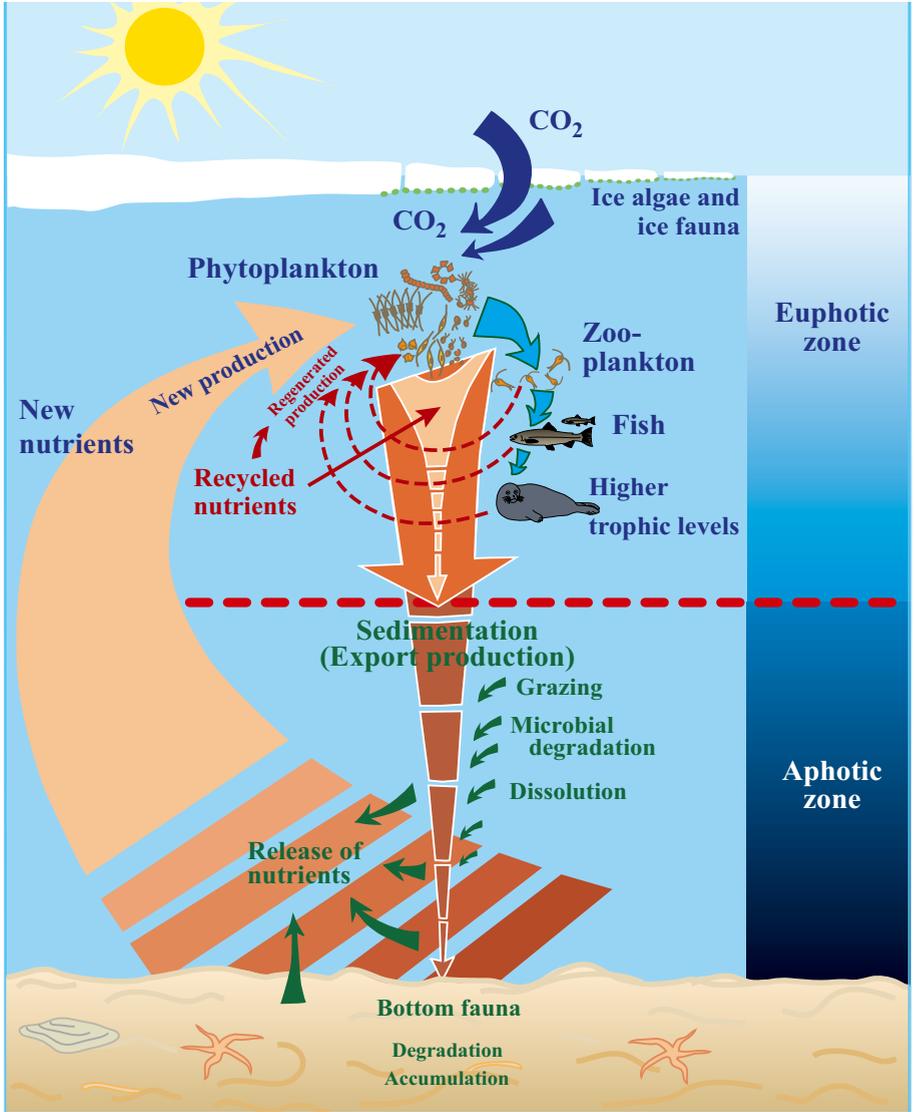
Phytoplankton may look like this through a microscope. The green colour inside the plankton is chlorophyll which the algae use in their photosynthesis. The species of phytoplankton in the photograph, called siliceous algae or diatoms, form long chains. These are single-celled algae. The cell wall is formed of silicic acid and has two shells, making it look like a small box with a lid. Diatom shells are extremely resistant to breakdown. When the diatom dies, its shell is incorporated in the sediment on the sea floor and may be preserved there for many thousands of years. Photo: Eva Leu, NPI.

and the sea gets warmer around April, the production of phytoplankton explodes in the waters in and around the Arctic.

The plankton find good living conditions near the edge of the sea ice owing to the favourable alternation between stable wa-

ter masses and deep vertical mixing where nutrients are brought to the surface. Good production forms the basis for the rich accumulations of fish in the Barents Sea.

Ice algae are microscopic algae that live in or on the lower side of the ice. The algae



The production of planktonic algae begins in earnest when the light returns and conditions uppermost in the water column form a favourable environment for growth. The sun melts the ice and a warmer, less saline, surface layer of water forms above the colder, heavier, underlying layer. The production of phytoplankton can reach the spring peak in this surface layer, and because of the physical stratification of the water masses the biomass (plankton, fish and animals) remains in the euphotic zone (where there is enough light). The plankton production is driven by the availability of nutrients; "new" nutrients which have been released from the demersal (bottom) community during the winter and from the aphotic zone (where it is dark) become mixed upwards through the water column when the water is agitated during the winter. From Wassmann et al. (2006), modified by Froydis Strand, NFH, University of Tromsø (UiT).



Scientists are taking samples of ice algae growing on the lower side of the ice. The layers of algae may be very thick. These algae require little light to start their production and can begin to bloom several weeks before the freely-living algae begin to stir. Because the ice algae are packed with polyunsaturates, they are nutritious for other animals; they are the feed concentrate of the sea. A research project has shown that ice algae can make up 5-25 % of the food for organisms in the next link in the food chain and as much as 50 % early in the season, before the phytoplankton bloom. Photo: Josef Wiktor/ Eva Leu, NPI

that belong to a sea-ice algal community are recruited from various areas around the ice, such as the sea floor or different levels in the water column. If conditions are appropriate, the algal mats beneath the ice may be several tens of centimetres thick and have algal threads up to several metres in length – a feast for creatures that eat algae.

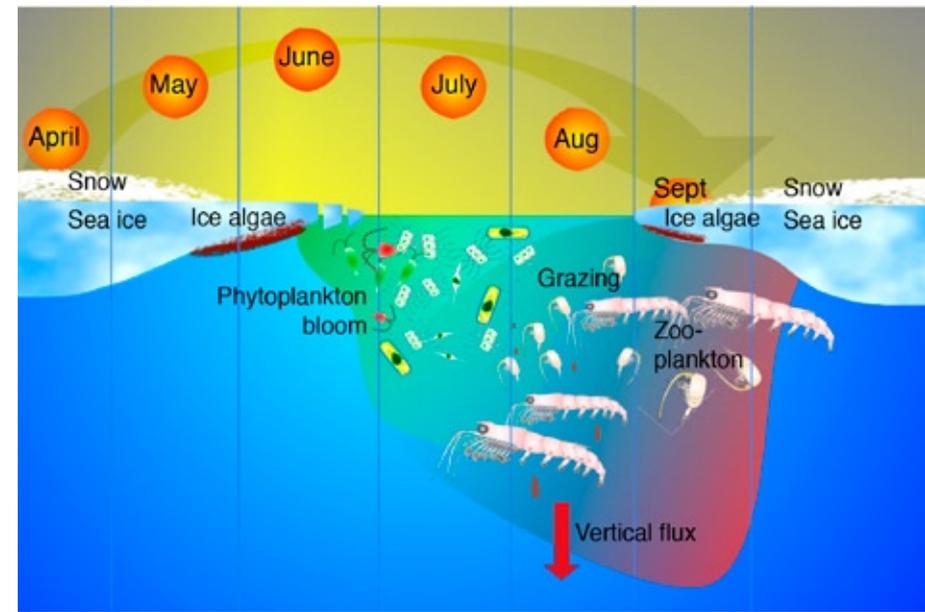
Phytoplankton use carbon that comes from the CO₂ in the air, and thus help to remove large quantities of CO₂ from the atmosphere. Not all the plankton are consumed by other organisms, some die naturally and sink to the bottom where they are buried and thus help to store CO₂ for the unforeseeable fu-

ture. This is one reason why the ocean acts as a gigantic carbon sink (store).

The terrestrial vegetation in Svalbard

The growing season in the Arctic is short and hectic, and the low temperatures mean that no trees can grow here; the largest plants in central parts of Svalbard are dwarf shrubs, and furthest north there are no woody plants. Several species have evolved their own tricks to survive the harsh climate. Most of them are perennials so that they avoid having to start each season as tiny seeds. Moreover, as they grow extremely slowly, they might not have the resources to seed and propagate every year, so many species reproduce by runners or brood buds.

Svalbard is unusual in having the warm ocean currents that also provide support for large bird-nesting colonies. The birds fertilise the ground at the foot of the cliffs, thus providing nutrients for vegetation that can grow there. The bird cliffs in Svalbard are farther north than in many other parts



The sun appears over the horizon in April and supplies light to support the growth of ice algae and phytoplankton. When the sun is at its highest in June, production peaks and the zooplankton thrive on this superabundance of food. The production gradually declines during the season as the phytoplankton use up the nutrients in the water, and when the sun once more sinks below the horizon the plankton hibernate until the next growing season. From Alexander Keck & Paul Wassmann (1993), modified by Froydis Strand, NFH, UiT

of the Arctic and, due to the cold climate, the vegetation is dominated by mosses, in contrast to herbs and grasses farther south. Moss tundra forms, particularly on the cool coast, and these unbroken carpets provide the ground with such good insulation from heat that the permafrost is found at a depth of only 20-30 centimetres, so that it can actually be touched. These factors make the Svalbard moss tundra outstanding in a global context.

Svalbard is divided into three bioclimatic zones on the basis of the temperature conditions, the middle arctic tundra, the northern arctic tundra and the arctic polar desert. Besides the temperature, many other factors are also crucial for the development of vegetation in Svalbard, such as a long or short snow cover, rich or poor bedrock, stable or unstable substrate, and fertilisation by birds or reindeer. The vegetation map shows the main types of vegetation in Svalbard. The 15 predominant ones that are shown here (the variation is much greater on the detailed scale) actually differ in each of the three bioclimatic zones in the archipelago.

The vegetation types vary greatly in Svalbard, from bone-dry steppes in Wijdefjorden, and almost sterile, gravel-dominated polar desert in the coldest areas, to the tundra landscape close to the settlements. All told, there are some 165 species of higher plants in Svalbard, about 370 species of mosses and about 600 species of lichens. These are high figures in relation to the other groups of species in Svalbard, but nevertheless few compared with the mainland.

Primary and secondary consumers – the middle-management level

There are two middle-management levels in Arctic Ltd. The lowest is the primary consumers, which are organisms that live on plants. The level above comprises the secondary consumers, animals which eat animals that eat plants.

The Svalbard reindeer, the Svalbard ptarmigan and the sibling vole are the only terrestrial creatures that remain in Svalbard all winter and are herbivorous, but when the hordes of migrant geese return in spring they sometimes close crop entire areas of wetland

Did you know that:
The length of the day determines when phytoplankton propagate after the dark winter. Laboratory trials show that most species of phytoplankton require at least 12 hours of daylight to propagate. This means that not much plankton growth occurs in the sea until after the spring equinox, 21 March, which is when there is sufficient light.



Moss Campion is a small plant which grows in dense, hemispherical cushions in Svalbard. It has evolved its own means of taking the best advantage of the sunlight; the flowers on the south side (left in the photograph) of the cushion blossom first because the incoming solar radiation is at its maximum there and then. Later in the season, the flowers on the north side bloom. It is also called the compass plant because the compass direction can be determined if you examine the cushion to see which side flowered first. The cushion shape is also an adaptation to retain the heat better. Photo: Arve Elvebakk, Tromsø Museum, UiT

to satisfy their need for plant food. Alongside reindeer grazing, this is the grazing activity that exerts most pressure on the land vegetation in Svalbard.

In the sea, zooplankton consume the phytoplankton. They reproduce in spring, at the same time as the phytoplankton blooms are

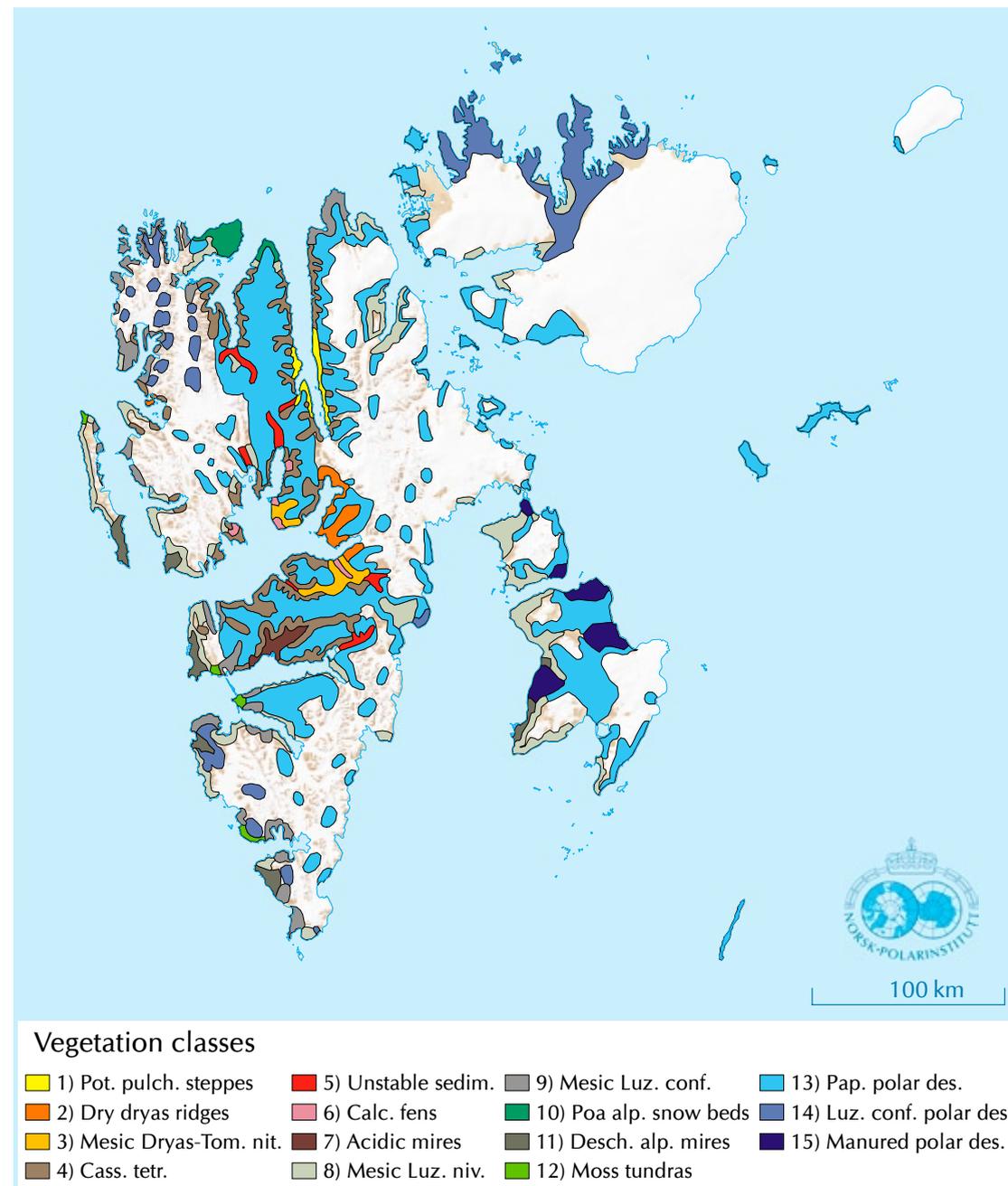
at their peak making the maximum amount of food available. Since the edge of the sea ice is a productive zone for the phytoplankton, the same applies to the zooplankton, and as the ice gradually retreats northwards through the summer, the zooplankton production follows it.

Many other species exploit this enormous supply of food and the ice edge in summer abounds in animal and bird life. The zooplankton are voraciously devoured by numerous larger species, mainly other zooplankton, fish and shrimps, but also some birds. For instance, the main food of the polar cod is zooplankton and other small fish, but it is itself eaten by larger fish and seabirds, and, along with the capelin, it is the



Did you know that:

In botany, a hotspot denotes an area where the species diversity is higher than in the surrounding area. This is because the microclimate and/or the bedrock are better just there than in the area around. Such a hotspot is found in Colesdalen, a valley in Isfjorden, where polar bilberry, cloudberry, arctic harebell and dwarf birch grow. These species are not found anywhere else in Svalbard.



The main types of vegetation in Svalbard. Those with yellowish to reddish-brown shades belong in the warmest, middle arctic tundra zone in the fjord districts, those with grey and green shades belong in the northern arctic tundra zone along the coasts and the blue and violet shades belong in the polar desert zone furthest north and east. 1) High-arctic steppes dominated by Tufted Cinquefoil. 2) Dry ridges dominated by Mountain Avenas. 3) Mesic (semi-moist) areas dominated by Mountain Avenas and Golden Autumn Moss. 4) Areas dominated by White Arctic Bell-heather. 5) Unstable sediments. 6) Calcareous fens. 7) Acidic and nutrient-poor mires. 8) Mesic (semi-moist) areas dominated by Arctic Wood Rush. 9) Mesic (semi-moist) areas dominated by Northern Wood Rush. 10) Snow patches dominated by Alpine Meadow-grass. 11) Mires dominated by Alpine Hair-grass. 12) Moss tundras. 13) Polar desert dominated by Svalbard Poppy. 14) Polar desert dominated by Northern Wood Rush. 15) Bird-fertilised polar desert. Figure by Arve Elvebakk, Tromsø Museum, UiT, modified by NPI.



The beautiful Boreal Jacob's-ladder grows on nutrient-rich soil on the west side of Svalbard, as here on Tempelfjellet. It is quite rare in Svalbard and is found in only one place on the Norwegian mainland. The Norwegian Red List rates it as critically endangered and it is protected in Norway. Photo: Odd Harald Hansen, NPI

main item on the diet of larger species of fish, seabirds, whales and seals.

As most creatures find their food at different levels in the food pyramid, it is difficult to rank them in order in chains, and we therefore speak of a food web. For instance, the Arctic fox and the glaucous gull find their food at many different levels in the food pyramid. They are generalists and eat practically everything they come across, even rubbish.

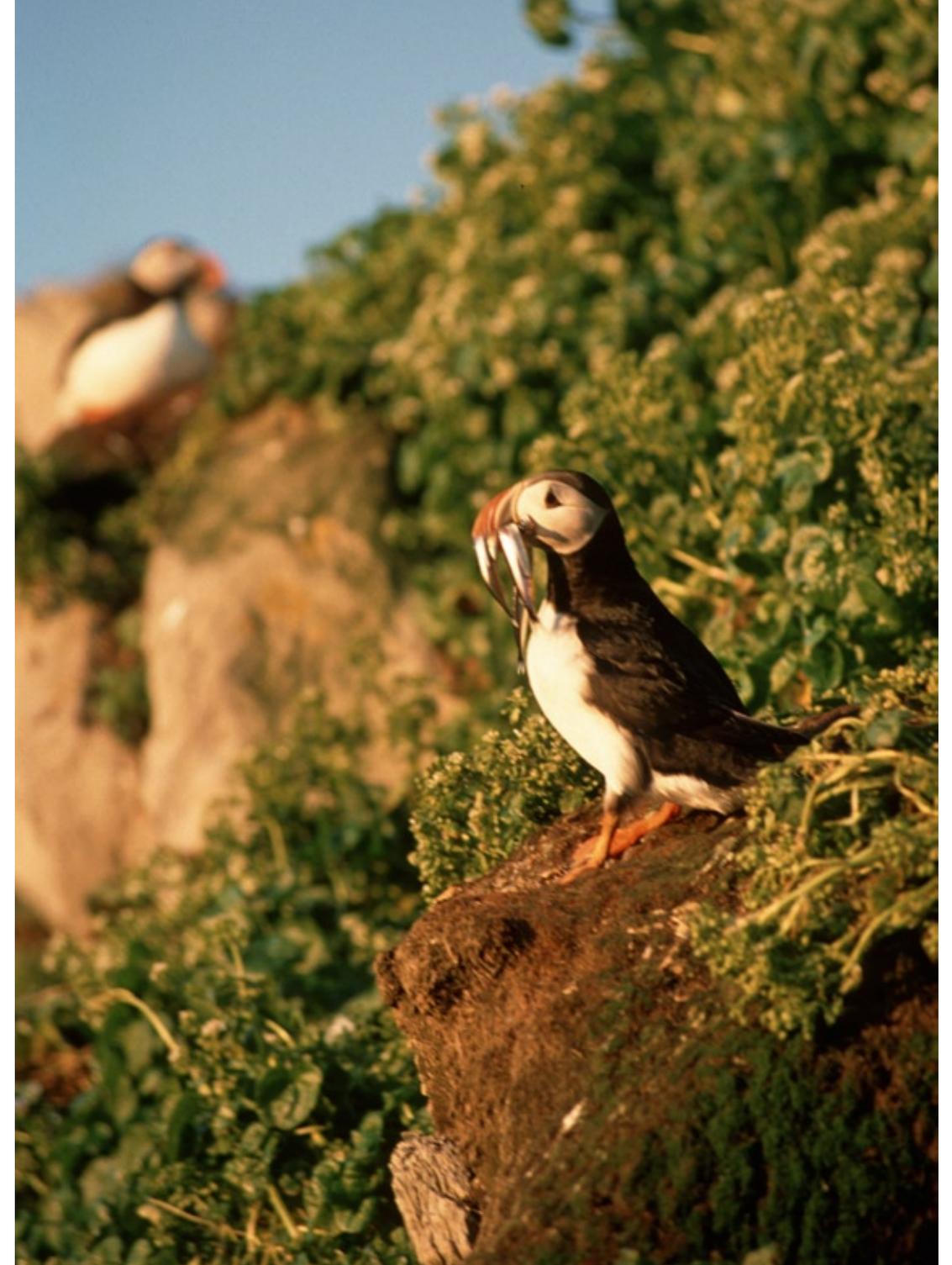
Animals that have specialised on just one species as their food are called specialists, but because particular food may be periodically very difficult to come by in the Arctic, it is good to have alternative sources to turn to. Consequently, there are not many spe-

cialists. However, a few species on the middle-management level can almost be called specialists because they very much prefer one particular item of food where it is available.

As all forms of life are closely tied to one another through the food chain, a collapse in one link may have a strong impact on the links above. The common guillemot colonies on Bjørnøya (Bear Island) collapsed in 1986-87 as a direct consequence of the collapse of the capelin stock the same year. Common guillemots on Bjørnøya have become specialised on capelin and live almost exclusively on them. The breeding population was reduced by nearly 90 % and thousands of emaciated, dead guillemots were washed ashore on the coast of Finnmark.



The sea angel, *Clione limacina*, on the left, is a favourite dish for whales. It feeds on smaller species of plankton, and moves up and down the water column in search of prey. On the right is *Calanus finmarchicus*, a copepod which lives mainly in arctic waters. *Calanus finmarchicus* is highly nutritious for seabirds. It feeds on phytoplankton and converts this food into energy-rich oil which it stores in an internal oil sack. This oil is a veritable food concentrate for other creatures. Photo: Tor Ivan Karlsen, NPI (*Clione limacina*) and Eva Leu, NPI (*Calanus finmarchicus*).



A puffin near its nest in eastern Finnmark, with its beak full of small fish. The nutrients that make the slopes below the bird cliffs exceptionally green originate in the sea. The birds take food from the sea to their nests. Their excrements are excellent fertiliser for plants in the Arctic, which otherwise grow on particularly poor soils. The puffin is a typical colonial breeder which excavates its nest in grass-covered earth on islands and islets. Where earth is absent, it nests in fissures and cavities in cliffs, or among stones. Most of the Svalbard colonies consist of more or less scattered pairs on steep cliffs where they nest along with fulmars, kittiwakes and Brünnich's guillemots. Puffins mostly eat small, shoaling fish. Outside the breeding season, they live almost exclusively on the open sea and obtain all their food there. Photo: Geir Wing Gabrielsen, NPI.



The common guillemot population has now recovered, but has still not reached the same level as it was in 1986. Its close relative, the Brünnich's guillemot, is, however, not so specialised and it survived the capelin crash comparatively well. Its population grew in the years following the common guillemot crash due to decreased competition for food – one man's poison is another man's meat.

Predators and top predators – the bosses and the managing director

The marine mammals, whales and seals, reign supreme in the Arctic Ltd management, along with Arctic foxes, skuas and glaucous gulls on land. These species find most of

their food at the middle-management level, but may well eat one another when times are hard. The top predators have no natural enemies in their own setting.

Whereas preconditions for life in the sea are largely determined by the availability of light, the temperature in the ocean currents, the ice edge and the availability of food, creatures living on land also have other external constraints to take into account. For instance, they are greatly influenced by precipitation, they need a suitable place to give birth to their offspring and they are dependent upon ice-free areas to find their food.

The managing director of Arctic Ltd is the polar bear. It has no natural enemies and reigns supreme at the very top of the food pyramid. Its favourite dish is seal, but when it is hungry it eats almost anything, birds' eggs, reindeer and carcasses.

The polar bear is a marine mammal because it spends large parts of its life hunting seals in the sea and on the sea ice. Most polar bears follow the ice edge northwards in summer, but some remain on land and live on whatever they can find while they wait for the ice to return. Such bears often get very hungry before the summer is over. In other words, the polar bear is very dependent upon the sea ice, where it can live and hunt.



Did you know that:

There are between 20 000 and 25 000 polar bears in the entire Arctic. Following an airborne count, the Norwegian Polar Institute has estimated that there are nearly 3000 polar bears in the Norwegian Arctic, and satellite transmitter tracking has revealed that Norway and Russia share a common population (in Svalbard and Franz Joseph Land).



Walrus were once extremely common in Svalbard, but 350 years of intensive hunting almost made the population extinct. They were protected in the archipelago in 1952, when only a couple of hundred walrus were left. The numbers are still low after more than 50 years of protection, and the walrus figures on the Norwegian Red List of endangered species. The numbers have risen in recent years, and former resting places on land have begun to be used again after many decades. Photo: Tor Iwan Karlsen, NPI

The surrounding world - external constraints and working conditions

Large organisations like Arctic Ltd are controlled by external constraints, which they must take into account. These are the abiotic factors, pressures that are not biological but which nevertheless help to determine the way of life of the animals and plants in the region and the basis for their existence. In the Arctic, the external, natural constraints are the climate, ocean currents, light, sea ice, glaciers and bedrock, and the climate exerts great influence on how the other constraints function.

Climate

The Arctic is so vast that clear definitions of precise temperature and precipitation intervals are impossible to give. However, because some of the boundaries of the region are actually drawn on the basis of the climate (an area where the average temperature in July is lower than +10 °C, an area having such low temperatures that trees do not grow there, or an area with permafrost in the ground), some criteria do exist for what an arctic climate is.

As the variations in temperature and precipitation in the Arctic are large, it is most practical to relate to average values, but extremes can occur in both directions. To be able to speak about climate in a meaningful manner, the various weather observations must be measured and standardised. These are called normals. A normal value is the average value of a weather measurement (e.g. temperature or precipitation) over a given period. In Norway, and elsewhere in the world, the average of the weather in the years 1961-1990 is designated as the last and valid normal period.

As the Arctic has few inhabitants, there are no precise weather measurements for the whole region, but Svalbard is one of the areas where weather observations have been made over a long period. They show that Svalbard Airport has an average annual precipitation of 190 millimetres and an average annual temperature of -6.7 °C.



These photographs show a guillemot colony on Feitnakken on Bjørnøya. The one on the left shows the colony before the capelin crash in 1986. The whole area is covered by nesting guillemots sitting close together on the ledges. The photograph on the right shows the colony after the capelin crash in 1987, when only a small part of the cliff was occupied. The large areas of ground lacking vegetation testify to the high age of the guillemot colony. Photos: Vidar Bakken (1986) and Olof Olsson (1987)



A replete polar bear rests after a good meal of seal while an ivory gull finishes off the remains. Polar bears prefer the blubber, the most nutritious part of the seal. If food is plentiful in the area, a polar bear often leaves a seal carcass without eating all the meat – definitely to the great delight of birds and other scavengers who are patiently awaiting their turn. Photo: Magnus Andersen, NPI

Did you know that:
 The lowest temperature measured at Svalbard Airport is -46.3 °C, measured in March 1986; the average for March is -15.7 °C. For comparison, the lowest temperature in March in Tromsø is -14.3 °C measured in 1978 (average -2.3 °C), Trondheim -12.0 °C measured in 1981 (average +0.1 °C), Bergen -7.0 °C measured in 1965 (average +2.3 °C) and Oslo -15.2 °C measured in 1987 (average -0.2 °C).

Ten quickies about climate change

These ten facts about climate and climate change have been written by Jan Gunnar Winther, the Director of the Norwegian Polar Institute and a climate researcher.

1 Weather versus climate. Weather is variations over short periods, whereas climate is changes in the weather situation over many years. The climate can be said to be the average weather over a long period. Consequently, it is impossible to link isolated episodes of outstanding weather situations, like a cold, snowy day in Tromsø in May or record high temperatures in Svalbard, directly to climate change.

2 The climate has always varied. Yes, the climate varies naturally on both long time scales (ice ages versus interglacials) because of the position of the earth relative to the sun, and over short periods due to the dynamics in the ocean and the atmosphere which causes storms, extreme precipitation and floods. However, the changes in climate we are now experiencing are very rapid compared with those which have occurred in historic time, and the pattern suggests that our emission of greenhouse gases goes a long way towards explaining this.

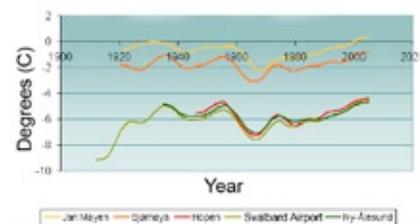
3 The CO₂ content in the atmosphere and the temperature have been higher previously. Yes, there have been periods with higher temperatures if we go millions of years back in time, but the astrophysical and climatic conditions were entirely different then. For instance, the continents were in completely different positions. Scientists have reliable data which show that the atmosphere now has 30 % more CO₂ than it has had during the interglacials in the past 700 000 years.

Water vapour is a more important greenhouse gas than CO₂. Yes, water vapour contributes about three times more to the greenhouse gas effect than CO₂. However, the most important difference is that whereas water vapour occurs naturally in the atmosphere, human-induced CO₂ emissions give a greenhouse effect in addition to that which is natural.

Human-induced CO₂ emissions account for only 1-2 % of the annual, natural CO₂ cycle. That is correct, but because of its slow breakdown, CO₂ accumulates in the atmosphere so that the atmosphere now contains 30 % more CO₂ than it did before the Industrial Revolution. In addition, the oceans gradually lose their ability to absorb CO₂ as the water becomes warmer, a so-called positive feedback loop that intensifies the warming.

The sun controls the earth's climate. The sun naturally has a crucial effect on the earth's climate. However, present-day global climate models which predict the trend of the climate make allowance for the contribution from variations in the intensity of the sun, and it is far from sufficient to explain the warming that is observed.

The research results differ substantially. It is by no means unusual that research produces results that differ. The global trend can only be studied when a wide range of research re-



The graph shows the annual mean temperature at some Arctic weather stations. On the whole, the mean temperatures on Jan Mayen and Bjornøya are higher than those at stations further north, Hopen, Svalbard Airport and Ny-Ålesund. It is nevertheless worth noting that the mean temperature at all the stations is under 0 °C. In other words, if you add together all the temperatures throughout the year and divide by the number of days, the sum is a negative value. Figure: Miljøstatus Svalbard, NPI.

sults, including local and regional studies, is compiled. Many climate researchers are surprised at the speed at which the changes in climate have occurred. The results of recent research indicate more rapid global warming than was envisaged only 5-10 years ago.

8 Climate researchers disagree. Time and time again, it is claimed that climate researchers disagree strongly as to whether we are currently experiencing human-induced changes in climate. In reality, only a very small minority of them question human-induced changes in climate and the debate among the vast majority concerns what proportion of the changes are man-made – not whether they exist.

9 The UN Climate Panel. It is claimed that the UN Climate Panel is composed in such a way that sceptics do not have a say. Some go so far as to imply a conspiracy. The panel consists of more than 2000 highly competent scientists. Researchers who have contributed most through quality-assured sci-

entific work are invited to be authors on the climate panel; in other words, the experts among the experts. In addition, the reports published by the panel are quality assured by a large number of independent experts, so-called "reviewers".

10 Little Norway makes no difference. It is correct that Norway's emissions amount to only a small proportion of the world's total emissions. But how can the global climate challenge be tackled if the responsibility is split up so that no nation sees any point in contributing? Or what if China or the USA claimed that every single province or state makes such a small contribution that it makes no difference? Quite the contrary, filthy rich Norway should be at the forefront to show the world the way. A nation that produces only a small percentage of the global emissions of greenhouse gases can have great influence by leading the way with regard to future-oriented energy production and utilisation.



Life in the Arctic is also harsh for people who visit the area. This photograph was taken during an expedition on the Austfonna ice cap in Svalbard in May 2005. The scientists were surprised by a blizzard, and both the tents and the protective fence that had been put up to scare away polar bears were almost buried by snow. Photo: Andrea Taurisano, NPI.

The climate is getting warmer

Why?

The climate is changing because systems on and beyond the earth are changing. The earth has always experienced changes in climate, but they have occurred as a consequence of natural changes like changes in the angle of the earth's axis, or in the earth's orbit round the sun, and variations in solar radiation. Natural changes are still taking place.

The use of fossil fuels increased greatly after the Industrial Revolution. Their combustion raises the concentration of greenhouse gases, including CO₂, in the atmosphere, and it is that increase which is now helping to produce a warmer climate in the Arctic. Measurements show that temperatures have risen throughout the world, and that the average temperatures in the Arctic in the last 100 years have risen twice as rapidly as they have elsewhere in the world. The reason for this is

complex feedback loops between the atmosphere, the oceans and the ice. It is therefore difficult to predict how quickly the changes will take place, but they have so far occurred more rapidly than most scientists expected.

Measurements reveal that the temperature over land areas has risen more than in the sea, and that this has been greatest in winter. Climate models which calculate the future trend in the climate show that temperatures will continue to rise, and before the turn of the century the increase will be about 3-5 °C over land and up to 7 °C over the oceans. Winter temperatures are expected to rise even more.

Observations suggest that precipitation in arctic regions has increased by almost 10 %, but lack of data and difficulties with the measurements make the results somewhat uncertain. The total annual precipitation is

expected to increase by around 20 % by the end of this century. Most of this will fall as rain in summer, but the greatest increase will occur in winter, when up to 30 % more precipitation is expected.

Mankind now has technology that can change the climate, the environment and nature. Unfortunately, we still know too little about how and why we bring about these changes, and for some parts of the Arctic we know little about their state before we began to change them. Research is needed to learn more about what has happened, what is happening and what will happen. Scientists gather data and perform detailed studies of problems such as the natural trend in the climate since the last Ice Age and the distribution of sea ice in the polar regions. This knowledge assists politicians and other decision makers to reach correct and important decisions. It helps us to take care of and preserve nature that is vulnerable to sudden changes resulting from our technological progress.

What is taking place?

Arctic Ltd gives little thought to why changes in climate occur. It is more concerned about how to deal with them.

Arctic animals are well insulated from the cold, and little heat escapes through their skin and coat. Indeed, it is said that polar bears are so well insulated that they will be invisible in pictures taken with an infrared camera. Their outstanding ability to retain heat may be a problem if they become stressed and hot – when little heat escapes from the body the risk of overheating is great and they may die. However, this is probably a bigger problem if they are being chased by camera-clicking tourists on snowmobiles than in connection with climate change.

The rising temperatures may mean that invasions of more southerly species will, by degrees, pose a major problem. New areas will be available to organisms from the south that cannot tolerate severe cold. They generally grow faster than many of the arctic organisms, reproduce more frequently and can probably easily oust the sluggish arctic species. Micro-organisms like bacteria, viruses

Did you know that:
Technological advances may help to bring major reductions in climate-impacting emissions caused by man, but they would not be sufficient. We must also moderate our energy consumption. For instance, modern motor vehicles pollute less than older ones, but as there are many more vehicles today the pollution trend is nevertheless negative.

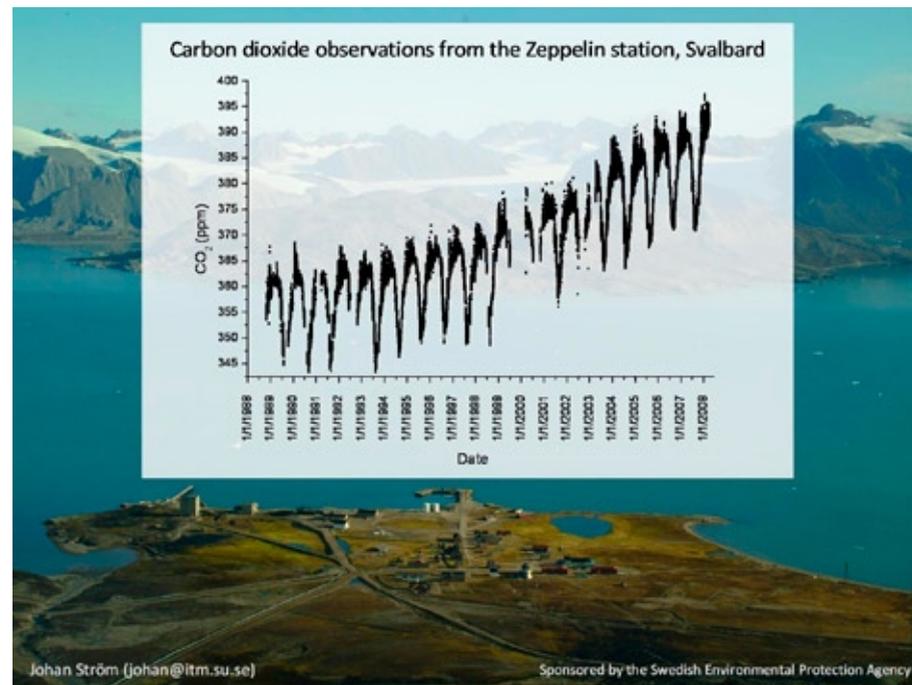
and parasites will also find their way northwards, bringing with them new diseases from which arctic animals have so far been spared and therefore lack an immune response to. Introduction of new diseases may lead to epidemics and death among arctic species.

Sunlight

Sunlight controls the pace in Arctic Ltd, even when the sun does not shine. In summer when the light is on for 24 hours a day, the area is teeming with life, production is at its maximum, and hired hands from southern parts arrive in their thousands. In winter when the light is off, all activity is at a minimum and only the most essential maintenance work is carried out.

The angle of the earth's axis means that the further north you travel, the longer the polar night lasts. Fortunately, the midnight sun also lasts longer. As the table on p. 34 shows, the polar night at the North Pole lasts from about 25 September to 18 March, all of six months. On the other hand, there is midnight sun from about 20 March to 23 September, also six months. Quite a good change!

When the polar night is in charge, it is dark more or less all the 24 hours, but when the light returns, it does so to the full. Svalbard has four months of midnight sun, and it is vital to utilise the light to the maximum then for growth and reproduction. There are several reasons why the arctic regions remain cold even though the sun can shine all day and all night long. As the figure of the earth on p. 33 shows, the rays of the sun have a long way to travel through the atmosphere to reach the Arctic, much further than to the Equator. Much of the radiation will there-



CO₂ is one of the most important greenhouse gases and it occurs naturally in the atmosphere. Its concentration there sinks in summer when plants and trees use it in photosynthesis, but it rises again in winter when photosynthesis ceases and the leaves and other parts of the plants die and decay. However, an increase in CO₂ can be observed each year and this is due to the increasing use of fossil fuels like oil and gas. This graph shows the content of CO₂ in the atmosphere over Svalbard. Each wave shows the CO₂ concentration in the course of one year. The crest of the wave indicates CO₂ in mid-winter, and the trough is the concentration in summer. The wavy pattern is repeated each year, but the total concentration of CO₂ in the atmosphere rises. Figure: Johan Ström, University of Stockholm



The photograph shows an acanthocephales (spiny-headed worm), a worm-like parasite that lives in the intestines of birds and mammals eating the food that passes through them. In a study of common eiders, researchers found as many as 152 acanthocephales in the intestine of a single bird, which actually looked completely healthy. They also found 24 tapeworms, which may be several tens of centimetres long. The researchers are studying whether the changing climate is giving more parasites. Photo: Sveinn Are Hanssen, NINA (acanthocephales) and Dag Rydmark, NPI (eider)

fore be stopped in the atmosphere and less gets through to the arctic regions. Moreover, when the sunlight shines on the white ice much of the radiation is reflected back to the atmosphere again without contributing heat.

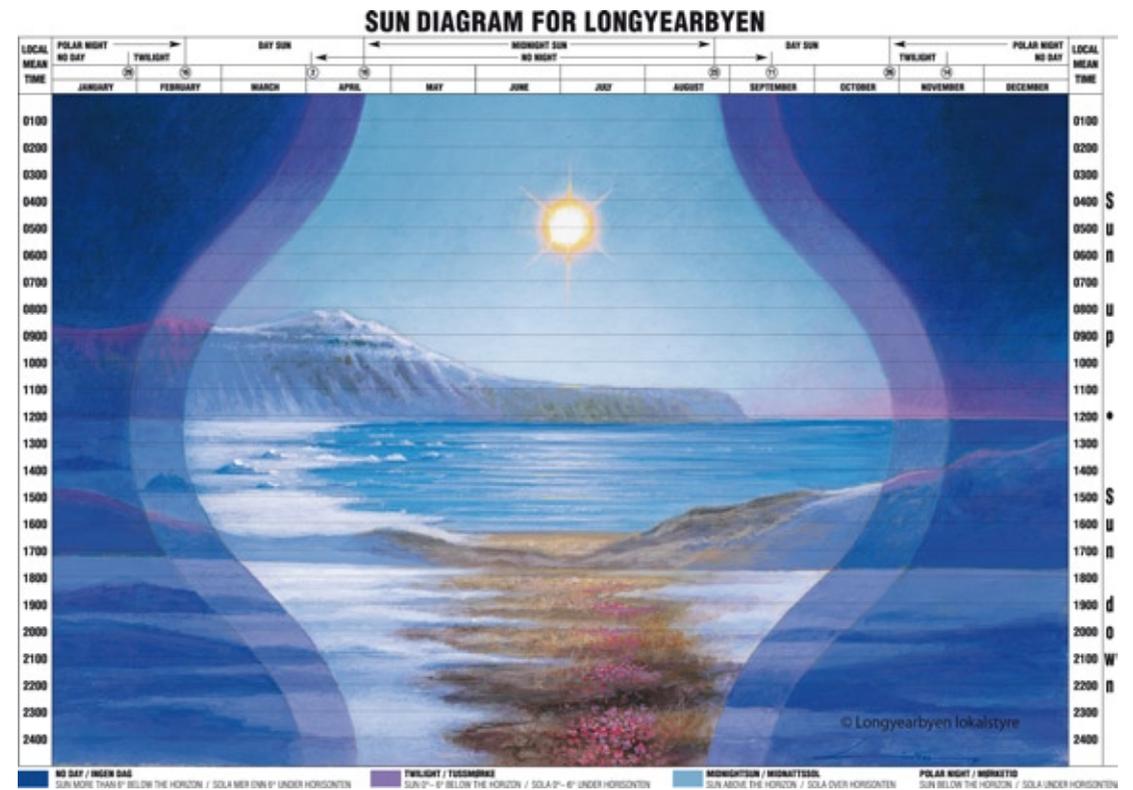
The amount of UV radiation to the Arctic is increasing

Why?

The sun emits ultraviolet (UV) rays, large doses of which are hazardous to humans, animals and plants. Increased UV radiation may cause disturbances in the immune sys-

tem, cataracts and cancer in humans. It also has damaging effects on fish and amphibians, and may disturb the photosynthesis of plants, both in the sea and on land.

The ozone layer is crucial for the amounts of UV rays that reach the earth. A thick, well-functioning ozone layer allows fewer hazardous UV rays through than a damaged ozone layer does. The world became aware of the problems associated with the thinning of the ozone layer and increasing amounts of UV radiation reaching the earth several decades ago. It was emissions of the subsequently banned chlorofluorocarbons (CFC



Sun diagram for Longyearbyen. The diagram shows the number of hours of sunshine in Longyearbyen throughout the year. December and January are the two darkest months of the year, having no daylight at all. From the end of April to the end of August, the sun is above the horizon 24 hours a day, giving four whole months of midnight sun. Figure: Longyearbyen lokalstyre.

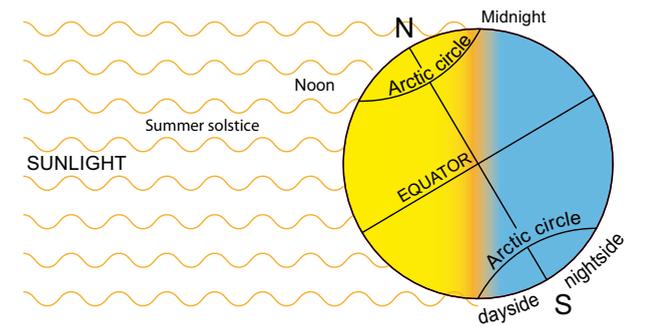
gases) from spray boxes and other sources which broke down the ozone layer. Ozone depletion was most marked over the polar regions and the ozone holes here are still large, particularly in the Antarctic.

The ozone hole and changes in climate are interlinked. The increasing greenhouse effect heats the lowest part of the atmosphere, while the upper part is cooled. The ozone layer is in the upper part, which becomes cold. When the temperature is sufficiently low in this part of the atmosphere, a larger number of beautiful mother-of-pearl clouds form, and such clouds strongly intensify the breakdown of ozone. This takes place because reactions in the clouds cause the sunlight to form chlorine compounds which, in turn, break down the ozone layer.

What is taking place?

The cold climate and the low sun make polar life particularly vulnerable. The arctic

regions receive most of the increase in UV radiation in spring. If, in addition, the layer of snow and ice disappears due to enhanced warming, species which are normally protected by snow and ice will be more exposed to UV radiation.



Sunlight reaches the Earth in this way. As the illustration shows, the rays have much further to travel to reach the polar regions, and the angle of the Earth's axis also means that the area north of the Arctic Circle experiences the polar night in winter. Figure: NPI

Place	Latitude	Midnight sun	Polar night
North Pole	90.0	20.03 – 23.09	25.09 – 18.03
Longyearbyen	78.0	21.04 – 21.08	26.10 – 16.02
North Cape	71.2	14.05 – 29.07	18.11 – 24.01
Tromsø	69.7	20.05 – 23.07	25.11 – 17.01
Bodø	67.3	04.06 – 08.07	15.12 – 28.12

The table shows the periods of midnight sun (polar day) and polar night at some places in the Arctic and on the Norwegian mainland

Did you know that:

Even though the sun is absent during the polar night in the Arctic, it still helps to produce light in the sky, the Northern Lights (Aurora Borealis). The sun emits electrically charged particles and they are influenced by the earth's magnetic field which directs them round the magnetic poles. The particles collide with air molecules in the upper atmosphere, and we can see this as lights in the sky. These lights can be seen near both poles, in the Arctic and the Antarctic. They are called the Southern Lights (Aurora Australis) in the Antarctic.

Some organisms have evolved special strategies to protect themselves from UV radiation and can also repair some UV damage. In an ecosystem, UV damage in phytoplankton can change the plankton communities and, in turn, affect higher levels in the food chain because the availability and quality of food for these species are changed. Changes in one link in the food chain will thus have impacts on the community as a whole.

The sea and ocean currents

It is said that the sea is the world's biggest breadbasket, but for the staff in Arctic Ltd it is infinitely more – a delivery room, a playpen, a means of conveyance and a workplace. Most of the production takes place in the sea, and it is the sea that forms the basis for the firm's wealth creation.

Did you know that:

UV stress reduces photosynthetic activity in some phytoplankton, which means that more UV radiation will reduce the ability of the sea to absorb CO₂.

The sunlight goes some way towards heating the Arctic, but heat also comes from the south with ocean currents and airstreams. One branch of the Gulf Stream, called the North Atlantic Current, flows along the coast of Norway and continues all the way to the Arctic Ocean. There it shifts its name to the West Spitsbergen Current, and almost 60 % of the water entering the Arctic Ocean comes with this. Even though the currents change their name as they move north, they are all part of the same system, which is an extension of the Gulf Stream.

However, some water also flows in through the Bering Strait and some fresh water enters from the big Russian and Canadian rivers, which explains why the topmost 45 metres of the Arctic Ocean are less saline than the water below.

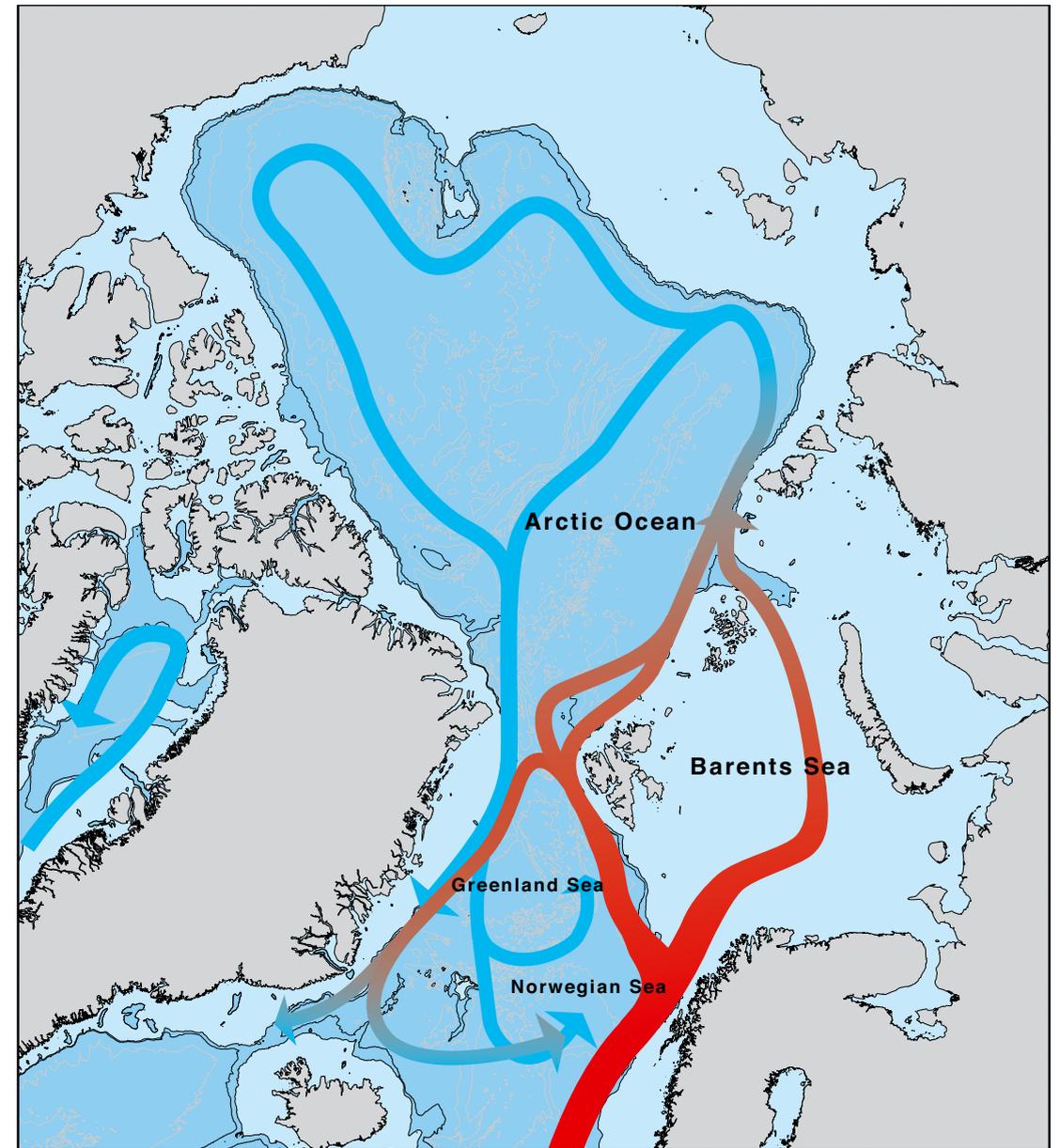
The Fram Strait between Greenland and Svalbard is therefore the major arterial route for seawater to and from the polar area. Warm Atlantic Ocean water flows north along the west coast of Svalbard, and cold water flows south along the coast of East Greenland, and also out into the Barents Sea along the east side of Svalbard.

The area of the Barents Sea where the cold, relatively fresh, Arctic water meets the warm, saline Atlantic water is called the polar front. The polar front does not lie in a specific geographical position, but may move somewhat from year to year.

The sea is getting warmer

Why?

The predominant wind systems which help to drive the Gulf Stream and which blow



The paths of ocean currents in the Arctic. The Gulf Stream, carrying warm Atlantic water, moves northwards along the coast of Norway. It divides into two main branches and continues northwards with one branch on either side of Svalbard. In the Arctic Ocean, the Atlantic water is cooled, becomes heavier and sinks. After circulating in the North Polar Basin, the now cold, Arctic water leaves the Arctic Ocean, mainly through the Fram Strait between Svalbard and Greenland. Figure: NPI.

water up to the Arctic have changed in recent years. Measurements show that they are dragging with them more Atlantic water that is warmer and has a higher salinity than the Arctic water. However, the measurements also show that even though the Gulf Stream has recently become warmer, it has not grown weaker.

Another important reason for the warming of the water masses is the albedo effect. When the sea gets warmer and the white ice melts, more solar heat is absorbed by the dark seawater and the water temperature rises (see also the figure on page 42). This explains why several fjords in Svalbard have been ice-free in recent years.



Did you know that:

The predominant wind direction over the Arctic Ocean rotates the surface water in a large circle, called the Beaufort Gyre, which makes the polar ice move slowly in the same direction, too. Sea ice that lies close to the centre of the gyre can complete a full 360° circle in a matter of 2 years, but that which is furthest from the centre requires 7-8 years to complete the same circle. In addition to the Beaufort Gyre, the surface circulation in the Arctic Ocean is dominated by the Transpolar Drift, which consists of wind and ocean currents that cross the entire ocean from Siberia to exit through the Fram Strait. Fridtjof Nansen discovered this drift and proved its existence by allowing his ship, the 'Fram', to freeze into the ice off Siberia. It escaped the grip north of Svalbard 3 years later (1893-1896). In 2006, the schooner, 'Tara', did the same, but because the wind systems have changed and the sea ice has become thinner the journey took only half the time, 16 months.

What is taking place?

Even though there is no reason to worry that the ocean currents will halt or collapse, the amount of new heat may bring major changes, both locally in the Arctic and globally. Owing to more movement of molecules, a warm sea has greater volume than a cold sea and when the sea is heated it will increase in volume, leading to changes in sea level (thermal expansion).

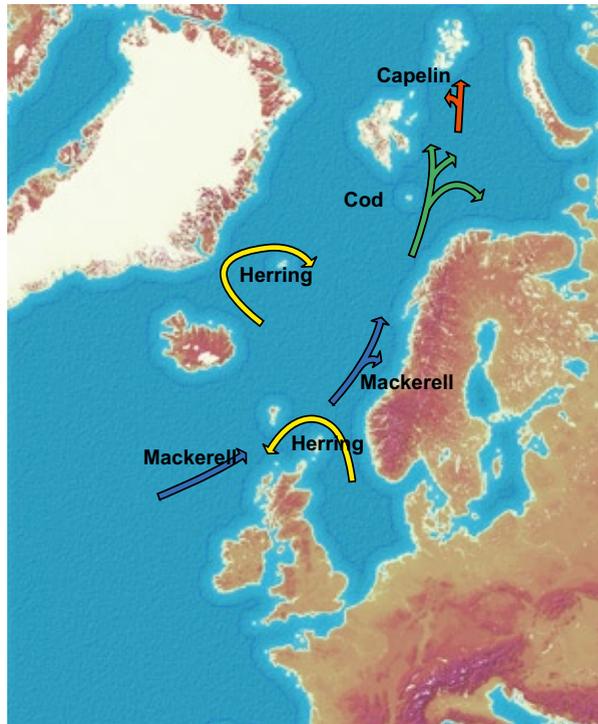
The oceans are large and are enormous energy stores. They are heated slowly and retain the heat for a long time, long after the heating has ceased. It takes years to transport heat down to the ocean depths. Even if we stop emitting greenhouse gases today, the sea will get warmer and warmer, and rise for the next 20 years. Half of the present-day change in sea level derives from thermal expansion, and measurements show that between 1993 and 2003 the sea rose by about 1.6 mm per year due to thermal expansion alone; the supply of meltwater from glaciers comes in addition to this. The sea level is thus rising because the seawater is getting warmer and glaciers are melting.

In a warmer sea, the composition and properties of the water column shift and this may be important for plankton production in the Arctic. When the sea gets warmer and the salinity changes, this may lead to changes in the vertical mixing and have a negative effect on plankton. A change in the circulation pattern will affect the production of plankton which, in turn, will influence life higher up the food chain (see page 14).

On the other hand, it is conceivable that a warmer sea and less extensive sea ice will give more plankton production and an expansion in the fish stocks in the area because the fish will have a larger area to live in. It is expected that cod, capelin and herring will all move further north. A rise in the water temperature will also give higher growth rates in farmed fish. However, there are also negative prospects, even though fish stocks will rise. An increase in temperature will probably mean a decline in the shrimp stock. At the same time, shrimps are important food for cod, and if this food disappears, the cod will



Scientists use an instrument called CTD to find out how warm and salt the sea is. CTD is an abbreviation for Conductivity, Temperature, Depth. It measures the salinity and temperature of the water at various depths as it descends through the water column, thus providing information on how the currents move at various levels in the sea. Photos: Tor Ivan Karlsen, NPI (CTD being put out) and Sebastian Gerland, NPI (CTD in the water)



The figure shows the expected movement of various fish as the sea gradually gets warmer – cod and capelin will emigrate further north in the Barents Sea. This not only has consequences for the creatures that feed on these species, but also for us who fish them. In a few years, the traditional Lofoten fishery may be history, whereas the fishery along the coast of Troms and Finnmark may experience a boom. Figure: NPI, after ACIA

not derive any benefit from having warmer water and a larger area to live in. If the water becomes much warmer, the aquaculture industry will also experience a negative impact in that the temperature tolerance of salmon and trout will be exceeded and pens will have to be moved, which will be costly. Moreover, diseases and toxic algae that are harmful to the industry are likely to appear.

The sea ice

The sea ice is the quay for Arctic Ltd; it is the direct extension of the land and the link between the sea and the land. For some animals, it is a place where they can rest and find protection, but for others it offers better opportunities for hunting.

The majority of the Arctic consists of sea, and as temperatures are low, large amounts of sea ice form every winter. Because it does not completely melt each summer, the ice lying over the North Pole region is formed over several years. However, the summer sea ice in the Arctic has decreased in extent over the past 30 years, and in 2007 and 2008 it covered an area of only about 4 mill. km² instead of the 7 mill. km² it covered previously. In winter, the area of sea ice is trebled,

but because more new ice must continually be formed, there is less perennial ice in the Arctic than there used to be.

The formation and melting of sea ice depend upon many factors. The water and air temperatures play the most obvious role, but the frequency and strength of the wind are also important. New ice is not so easily formed if the wind continually breaks up and carries away the sheets. The salt content of the sea also plays an important role. Salt water has a lower freezing point than fresh water and the saltier the water the lower the temperature has to be before it freezes. The salt content in the sea is related to the precipitation in the area, melting of sea ice, and also melting and runoff in summer in surrounding land areas.

The summer ice is disappearing Why?

The sea ice is disappearing partly because the sea and the climate are getting warmer, and the rise in temperature in the Arctic really moves apace when the ice disappears and there is open sea. Open sea and land absorb a great deal of solar energy and are quickly heated. This heating helps to steadily reduce



The photograph shows a sheet of sea ice that has been thrust onto another sheet by dynamic processes. This sheet consisted either of thick one-year-old ice or thin perennial ice. The uppermost layer, just above the hand of the scientist, is most likely snow which has fallen on the ice. Photo: Sebastian Gerland, NPI.

the snow and ice, and more energy is continuously being absorbed. The heating is a self-energising effect, and steadily increases as the ice melts. This is one reason why the Arctic is now warming much faster than the rest of the world.

Satellites have monitored ice distribution in the Arctic since the 1970s and have provided a much more detailed picture of the annual extent of the ice. It can therefore be stated with certainty that great changes have occurred in recent years. However, it is not just the extent that has changed, the type of

ice is also different, and the ice is thinner.

On the basis of the changes that have already occurred, scientists use climate models to predict what will occur in the future. The results show that the Arctic may become ice-free in summer between 2070 and 2100, i.e. in about 60 to 90 years, but in view of the rapid melting that has been observed in the last few years, some scientists now think that the Arctic Ocean will be ice-free far sooner.

Another factor that contributes to ice melting is the occurrence of soot. Soot particles enter the air when such materials as fossil fuels or biomass are incompletely burnt, and they accompany the airstreams to the Arctic, where they land on the ice. The white snow reflects most of the sun's rays, but when it is darkened by soot particles it absorbs more warm rays and therefore melts more rapidly on the surface, too.

Did you know that:

90 % of the ice that leaves the Arctic Ocean exits through the Fram Strait between Svalbard and Greenland. Thin, one-year ice is less resistant than the thicker, multi-year ice and is more easily swept along by the wind.



A completely different type of sea ice is pancake ice, which is common when new ice forms. It mostly consists of almost circular plates between 30 centimetres and 3 metres in size, and up to 10 centimetres thick. The raised lip forms because the plates are continually colliding with each other. Photo: Hallvard Strøm, NPI.

What is taking place?

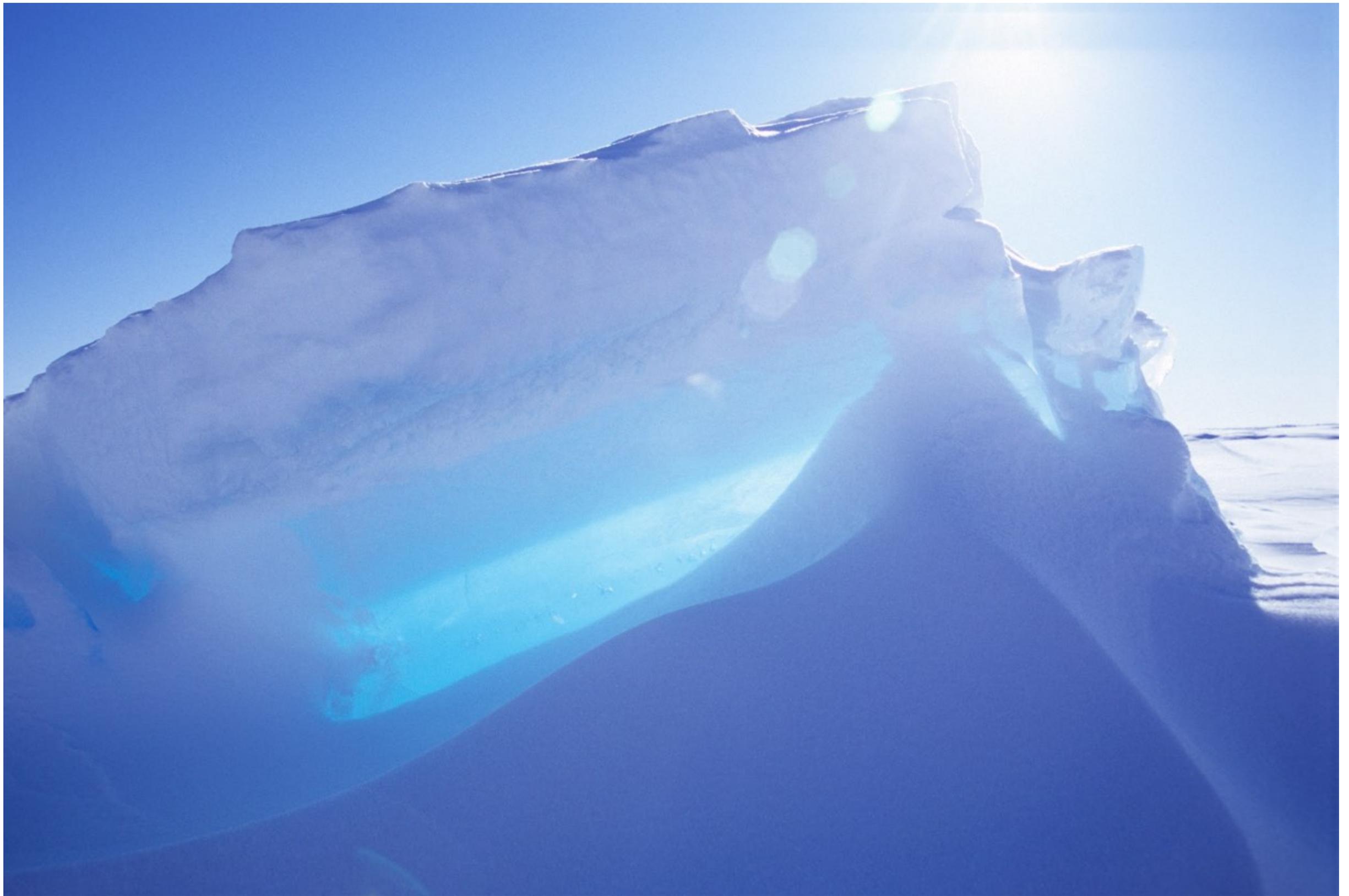
The sea ice is very important for life in the Arctic, and also for the physical environment. Sea ice forms from frozen seawater. When the ice freezes, the salt separates out along brine channels, and the actual ice consists almost solely of fresh water. During the winter, snow falls on the ice and a large reservoir of frozen fresh water forms. When the fresh ice melts, the lighter fresh water forms a lid above the heavier salt water. Like the fresh water from glaciers and rivers, this can cause the circulation in the ocean to change, and should extreme melting take place the ocean currents may change.

The sea ice is important for most organisms in the Arctic. Plankton production is especially active near the ice margin and it influences all life in the area. Less sea ice may be favourable for plankton which live in the open water masses. However, there are bio-

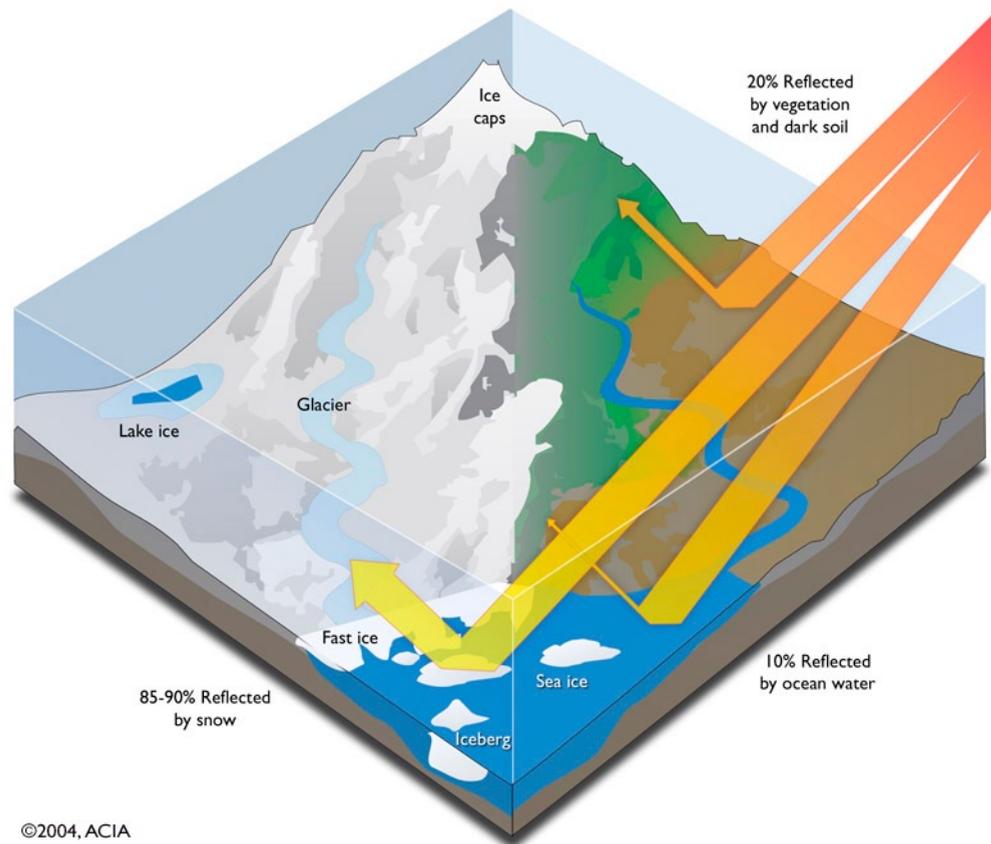
chemical differences between the ice algae and the plankton in the open sea; ice algae have a higher content of polyunsaturates, which are important for the organisms which live on ice algae. A change in their diet may therefore give less energy yield and poorer ability to survive, grow and reproduce, and a reduced ability for survival will be transmitted up the food chain and may affect populations of fish, birds and mammals.

Did you know that:

Openings in the sea ice that are larger than 10 km² are called polynya. This is a Russian word which has been adopted into Norwegian and English because these languages did not have an adequate word. A polynya may form because wind and ocean currents drive the ice away so that the area has no chance to freeze, or it may also be formed by warm water flowing up from depth so that the surface water never reaches freezing point.



Sun shining through ice in the Fram Strait. Photographed by Rudi Caeyers, NFH/UiT, on an Integrated Arctic Ocean Observing System cruise in 2007.



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The figure shows that sea ice which is covered by snow reflects a great deal of sunlight back to the atmosphere. The surface of the sea, which is much darker than the ice, reflects less sunlight and absorbs more of the heat. Gradually, as the sunlight is absorbed, the sea gets warmer, more of its surface becomes visible and more sunlight can again be absorbed. This is one of the complex mechanisms which mean that the Arctic is getting warmer faster than other parts of the world. Figure: ACIA

However, it is the large mammals which may experience the melting of the sea ice as a disaster. That is where they find their food, give birth to their young and find places to rest. The ringed seal is particularly dependent upon the ice, especially land-fast ice, to be able to maintain its mode of living. It brings forth its pups in cavities which it excavates in the snow above its breathing hole. The pups weigh only 3-4 kg at birth and without their protective cavities, many will fall prey to predators like polar bears, Arctic foxes and glaucous gulls.

Most of the ringed seals that are going to pup live in the fjords around Svalbard, on fast ice that is attached to land or glaciers. This is the only species of seal that excavates breath-

ing holes in the ice and therefore has access to large areas beneath the ice which other mammals cannot reach. If the ice disappears, it will have to compete with the other species for habitats and food, and pup mortality will rise dramatically without the ice.

The polar bear has become the very symbol for climate change in the Arctic, and not without good reason. It generally lives its entire life in the sea ice, and the ringed seal is its favourite dish. So when the ringed seal gets problems, the polar bear gets them too. Polar bears mostly follow the ice edge northwards in summer, finding sufficient food there to survive a long winter when little food is available. Bears which stay on land in summer find little food there and must wait for the



A flock of kittiwakes bathing in a meltwater pool that has formed in the sea ice. Kittiwakes nest in colonies along the coast. They often seek food in flocks, and the food is taken on or just beneath the surface while they are flying or sitting on the sea. Kittiwakes also seek food in ice-filled waters and in upwelling zones in front of glaciers where fresh meltwater meets sea water. They use meltwater pools in the sea ice for recreation and for drinking water. Photo: Andrea Taurisano, NPI

ice to form again in the autumn to enable them to build up their reserves for the winter. A female polar bear needs to gain some 200 kg during the summer to survive the autumn and winter in her den with her cubs. Pregnant bears enter a den in the autumn, bring forth their cubs around New Year and stay in the den until March or April before leaving its vicinity to search for food. Because the cubs are small and cannot travel long distances, females with cubs stay on the summer ice around Svalbard, but if this ice disappears early in the season they will be forced to suffer a meagre life on land. When the ice season gets shorter every year, the "fattening-up season" for the bears will also be shorter, and a difference of a few weeks may mean many tens of kilograms less.

Some birds, like the ivory gull, are also highly dependent upon the ice. Ivory gulls stay in ice-filled waters the whole year round, living on small fish and zooplankton. How-

ever, they are also scavengers and often eat the remains left by polar bears. They are found in Arctic Canada and Russia, as well as Greenland and Svalbard. In Canada, the ivory gull has declined by more than 80 % since the mid-1980s, possibly because of changes and reductions in the extent of the ice, high levels of pollutants and illegal shooting. Scientists at the Norwegian Polar Institute have found that the populations in Russia and Svalbard are smaller than assumed and that the species has high levels of pollutants. They found that eggs which contained a considerable amount of the pollutant DDE had thinner shells than those with low values.

Glaciers

Even though you perhaps would not think so, in general little precipitation falls in the arctic regions. The glaciers therefore act as reservoirs for Arctic Ltd. Most animals are dependent upon fresh water to quench their



A polar bear that has been confined to land has limited possibilities for finding food. Stories are sometimes told of polar bears which have eaten snowmobile seats in summer, broken into huts, or in extreme cases attacked people, either out of curiosity or because they were starving. Hungry polar bears are often dangerous. This bear was clearly emaciated after spending a summer on land, but it had not given up and was very aggressive towards the scientists who happened to be in the vicinity. Photo: Kit Kovacs, NPI

thirst or to wash, and the glaciers help with this in the shape of meltwater. In addition, they act as thermostats for Arctic Ltd. They reflect the sun's rays, and thus help to control the precipitation and ensure that the temperature in the production halls is comfortably low.

Over half of Svalbard is covered by glaciers – there are more than 2100 small and large glaciers here and nearly 60 % of the land area is covered by ice. The largest glaciers are

called ice caps and are mainly found on the east side of Svalbard. The largest one is Austfonna on the island of Nordaustlandet. It is about 8450 km² and is the largest ice cap in the world apart from the enormous ones in the Antarctic and Greenland.

The glaciers in central parts of Spitsbergen are much smaller than those further east, due to the drier climate and less snowfall in winter. They are called cold glaciers because they are frozen fast to the bedrock beneath and move only about 1-2 metres a year. Out on the coast, on the other hand, there are warm glaciers which are not frozen fast to their sub-surface and which can move a long way in a short time.

Many glaciers in Svalbard are surge glaciers. Surge glaciers are so called because they can undertake rapid advances; the snout may move several metres a day before it stops and melts slowly back. Such glaciers are only found in Svalbard, on the islands in Arctic Canada and in Alaska. Little is known about what triggers such an advance and how much



Glaciers may function as enormous climate archives. As time goes by, more and more snow falls on the glacier. If the snow does not thaw, it is stored deeper and deeper in the glacier as new snow falls above it. When a drill core is brought up from a glacier, it can be understood as a time line where the bottom is oldest and the top youngest. When tiny air bubbles and particles inside the ice are analysed, scientists can obtain information about the climate and how the conditions around the glacier have changed during its lifetime, which may be 100 000 years. Photo: Elisabeth Isaksson, NPI.

Did you know that: Measurements show that the average extent of the sea ice in summer has been reduced by 8 %, or 1 million km², since 1978. This is nearly as large an area as Norway, Sweden and Finland together. The sea ice is not only declining in extent, but also in thickness. Off the island of Hopen in Svalbard, the ice has got 40 cm thinner in the past 40 years and is now less than 1 metre thick in summer, according to the Norwegian Polar Institute.



The ivory gull is one of the seabirds we know least about on the world scale. The global breeding population is estimated to be about 8 000 - 15 000 pairs, 80 % of which are assumed to be in Russia. There is no reliable estimate for the Svalbard population alone, but there are probably between 200 and 750 nesting pairs. As ivory gulls are strongly attached to the drift ice and are mostly scavengers, they may be vulnerable to changes in the occurrence and distribution of sea ice and for accumulating high levels of pollutants. Photo: Cecilie Miljeteig, NPI.

time passes between each time a glacier surges, but in Svalbard it seems that the interval may be between 30 and 500 years.

Glaciers are getting smaller and are retreating
Why?

Research shows that the glaciers in Svalbard are melting and getting smaller. This is taking place because the climate has become generally warmer in the past 100 years. Higher air temperatures have brought a more rapid retreat in the last 10 years.

A glacier gets smaller because it loses more mass during the summer than it adds in the winter. It is mainly temperature and precipitation that control this relationship. Measurements of the mass balance in three glaciers in Svalbard show that two of them,

which are in the lowlands, had a negative mass balance from 1967 to today, whereas the third, which is situated higher up, had a positive mass balance until 2000, but it, too, has had a negative trend since then.

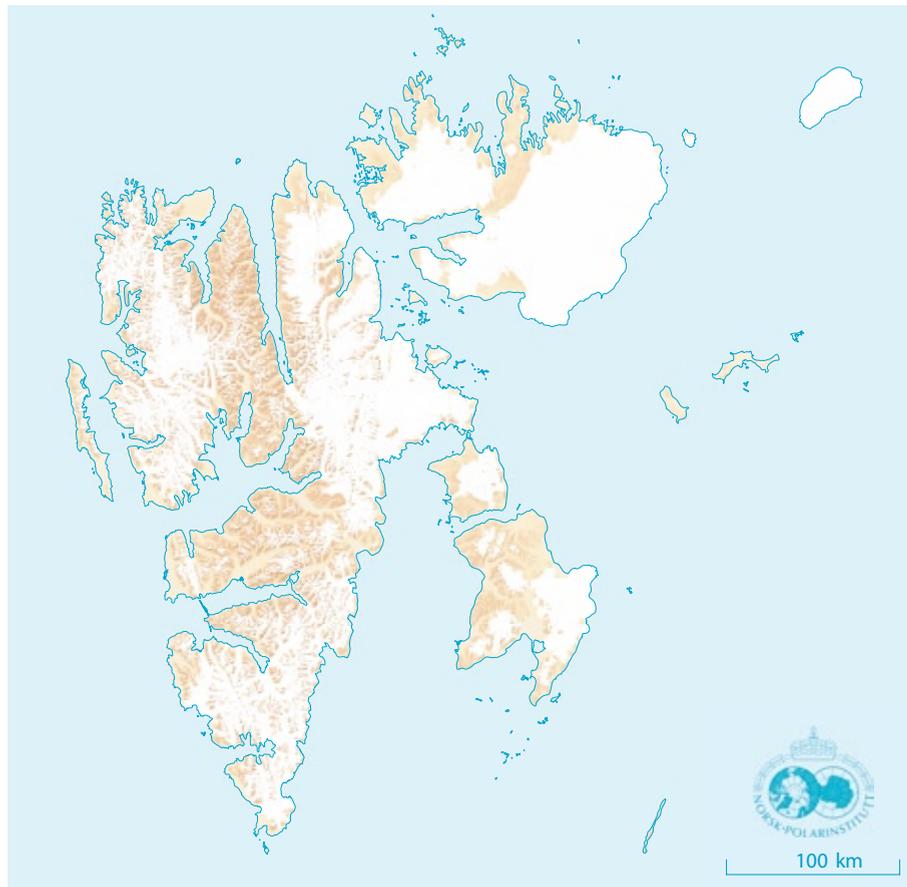
What is taking place?

Melting sea ice does not raise the water level, but ice – glaciers – melting on land does. Forecasts show that a possible total melting of the major ice caps in the Antarctic and Greenland will give the greatest change in

Did you know that: The Bråsvellbre Glacier, an arm of the Austfonna ice cap in Svalbard, surged in 1937 and 1938. This is a natural process. In the course of just over a year, the glacier advanced as much as 20 kilometres. This was how the glacier got its name, since Bråsvell means 'sudden swelling'.



Glaciers move like slowly flowing rivers. If the angle of the ground beneath them steepens, or other conditions cause the glacier to move forward more quickly, it fractures, as this photograph of crevasses shows. It is the uppermost 50 metres of the glacier which fracture; further down the pressure is so great that the glacier behaves more plastically and flows. Crevassed areas can be hazardous for both people and animals, especially if the crevasses are covered by snow so that they are difficult to see. Photo: NPI



A relief map of Svalbard clearly shows that large parts of Svalbard are covered by massive ice. Note the outstanding size of the Austfonna ice cap on Nordaustlandet. Figure: NPI

sea level, but in the near future it is expected that the total melting of smaller glaciers, like those in Svalbard, will contribute most to a rising sea level. It has been calculated that the sea may rise by up to one metre along the coast of Norway in the coming 100 years.

The ocean currents may be affected in extreme cases if the glaciers melt particularly rapidly, but the present-day melting is not strong enough for that. On the other hand, increased runoff of fresh water to the sea may affect the animal life. Several plankton organisms are sensitive to changes in salinity, and changes caused by meltwater may alter the species composition and, hence, the food available for several organisms in the region. This type of change also occurs in response to the melting of sea ice, but melting of glaciers generally generates very dramatic changes because very sudden outpourings of

large amounts of meltwater may "suffocate" the micro-organisms in the sea.

As meltwater forms on the glacier surface, it gradually finds its way down to the glacier sole along channels in the ice. The water beneath the ice lubricates the subsurface causing the glacier to glide faster, which increases the calving of icebergs and results in more mass disappearing into the sea more rapidly. Erosion takes place when ice moves over the underlying bedrock. The eroded material is transported to the sea by rivers and is deposited on the floor of the fjords. There is normally little life closest to the glacier, but if sediments build up very rapidly on the sea floor, they may bury the living organisms further out in the fjord, too. If several eroding glaciers enter the same fjord, an entire fjord ecosystem may be noticeably altered.

Mapping in the Arctic

The Svalbard landscape is continuously changing. Glaciers advance and retreat, taking with them enormous amounts of rock, gravel and sand, and rivers appear and disappear. New skerries and islands come to light in the sea, and the sea moves unconsolidated sediment around, forming sandbanks where there was previously deep water. For people travelling in Svalbard, both on land and by sea, it is vital that the map agrees with the terrain, and the mapping of Svalbard is therefore an important process.

The Blomstrand Peninsula in Svalbard is a good example of a landscape that is continuously changing. Until just a few years ago, it appeared to be a peninsula that projected into the sea beneath the Blomstrand Glacier, which calved into the fjord. Now, several hundred metres of the glacier have melted and it is obvious that the peninsula is really an island.

The geology of Svalbard

Arctic Ltd stands on a firm basis. Nowhere else in northern Europe are so many geological periods preserved in the bedrock. As there is little or no vegetation here, the bedrock is exposed over large areas. The geological succession in Svalbard can be broadly divided into three divisions, the ancient basement (Precambrian and Early Palaeozoic), non-metamorphosed sedimentary rocks (Late Palaeozoic to Tertiary), and young, unconsolidated sediments (Quaternary).

The basement is the oldest bedrock. In Svalbard, these rocks have undergone the Caledonian Orogeny and are older than 410 million years. They have suffered strong movements and alteration, and were folded, thrust and chemically transformed under high pressure and temperature at a great depth. Those which are now at the surface were formed up to 80 km beneath the surface.

The basement bedrock was eroded during the Devonian Period and vast quantities of sand, gravel and mud formed which were deposited on river plains and in the sea. In



The upper photograph was taken in 1922 and the lower one in 2002. The glacier that extended far out along the fjord in 1922 has now retreated so far that the entire fjord is ice-free. Photos: NPI (top) and Christian Åslund (Greenpeace) (bottom).

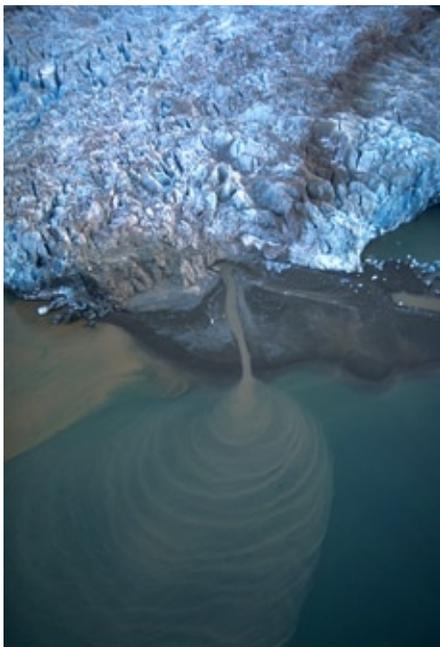
the succeeding geological periods, the area mostly lay beneath the sea and marine sedimentary rocks formed, but there were short intervals when land areas rose out of the sea. The Svalbard area was often a shallow sea and islands periodically appeared which were inhabited by such creatures as plesiosaurs and iguanodons. Ichthyosaurs lived in the sea.

The earth's crust fractured during the Cretaceous Period and a rift system formed which would subsequently develop into the Atlantic Ocean. The whole of the Svalbard region became a land area in the Late Cretaceous. The sea-floor spreading began in earnest in the Early Tertiary. The north-western



Did you know that:

Svalbard glaciers are not only retreating, they are also getting thinner. Measurements show that they are losing between 60 and 70 centimetres of their thickness each year. As the amount of ice that is weighing Svalbard down is declining, the land is rising. This land rise is not particularly rapid, but it is actually measurable with modern instruments.



Eroded material, like sand and silt, is being transported by a glacial river and deposited in the fjord. As a glacier gradually grows, it excavates into the ground beneath, picking up rocks, sand and gravel so that its lower side becomes like a gigantic sheet of sandpaper. When the glacier moves forward, this sandpaper scrapes the ground beneath, grinding material loose from even the very hardest of rocks. If water is added to lubricate this grinding process, it proceeds even faster. Running water between the sole of the glacier and the bedrock acts as a lubricant for the glacier. The glacier glides faster, the erosion gets stronger and more material is deposited in front of it or is carried into the sea by glacial rivers. Photo: Bjørn Frantzen, NPI.

Did you know that: Alex Hartley, an English artist, "discovered" a new island, the size of a football pitch, off Svalbard in 2006. He called it Nymark, demanded its sovereignty and that it should be seceded from the Kingdom of Norway. He advertised competitions to decide the future architecture of the island and a design for its flag. Owing to the Svalbard Treaty, and because the Norwegian Polar Institute had seen the "island" on satellite images as early as 1998, the demand was refused. The artist, however, would not give up hope of it being accepted as a separate nation since it was physical proof of how the effects of global warming had led to the glacier that previously covered Nymark retreating some 1.6 kilometres in just a few years. The name Nymark was, moreover, not approved and the "island" is now called Nyskjaeret.

corner of Europe was torn from Greenland along an enormous fault, and during this process western Spitsbergen was folded up to form a new mountain chain.

The present geological era is called the Quaternary and this is the first period since the Permian, 245 million years ago, when there have been real ice ages. The heavy masses of ice on land depressed the Earth's crust and the sea partly invaded the land. After most of the ice melted, the land has risen again.

Present-day geological processes in Svalbard are strongly marked by permafrost and glaciers. A typical feature of the Arctic is the permafrost which forms arctic landforms like rock glaciers, patterned ground and pingos, and much of the sedimentation that occurs today is linked with the transport of eroded material from glaciers and glacial rivers.

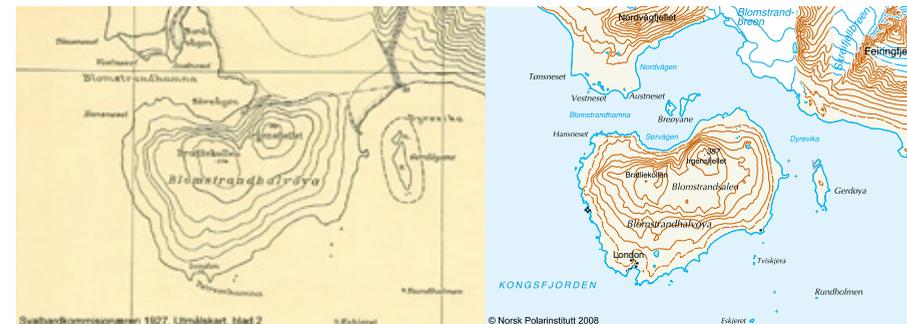
The permafrost is thawing

Why?

Obviously, nothing is going to happen to the bedrock in Svalbard as a result of climate change; extremely high temperatures would be required to achieve that. However, the rise in temperature in the arctic regions does seem to be sufficient to thaw the permafrost.

Permafrost is defined as ground whose mean annual temperature is below the pressure melting point for two years in succession. To be able to measure this without having to dig into the ground, areas with permafrost generally correspond to areas where the mean annual air temperature is lower than -2 °C. In Svalbard, permafrost is found everywhere except beneath the large glaciers, which provide insulation from the cold so that the ground does not freeze.

The permafrost may be some 100 metres deep on the coast and all of 400-500 metres deep in higher areas. As the soil is not so deep in the Arctic, this means that the bedrock itself is frozen. In summer, the uppermost layer thaws and provides a basis for plants and animals to live in. In Svalbard, this 'active' layer is about 1 metre deep.



The Blomstrand Peninsula in Svalbard. The map on the left is from 1927 and shows the whole of the Blomstrand Peninsula covered by a glacier. That on the right shows the glacier snout as it was in 1998. The peninsula has now melted completely out of the glacier and proved to be an island. Figure: NPI

What is taking place?

Permafrost that is thawing has impacts on both local and global factors. Thawing changes the vegetation cover and also affects animals that depend upon the vegetation. Wetlands, which are important for several species of birds, may dry out because the permafrost ceases to be a barrier for the surface water, which therefore drains into the ground. Important feeding and breeding sites may disappear. People are affected because roads and buildings founded on permafrost are damaged.

On the global scale, thawing ground will release large amounts of methane (CH₄) and

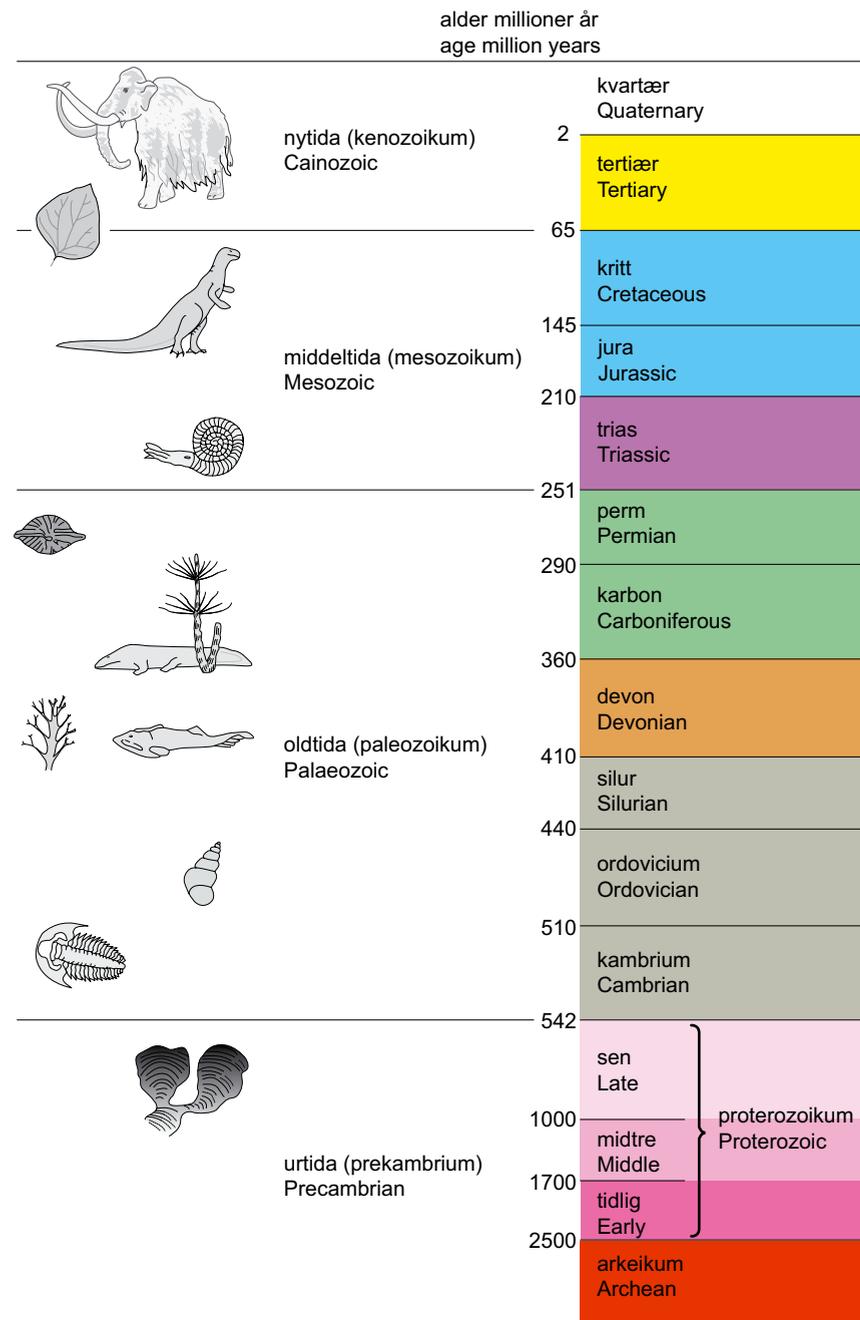
carbon dioxide (CO₂) which have been frozen into the ground. These gases will exacerbate the greenhouse effect and help to raise the temperatures still more. A warmer climate thus has a self-energising effect.

Did you know that: The southern boundary for permafrost may move many hundreds of kilometres northwards during this century. If the enormous areas of bog in Siberia and North America thaw, they will release huge amounts of methane and carbon into the atmosphere. The volume of these emissions is difficult to judge, because it will depend on a variety of factors, including the soil moisture.



The photograph shows a mountain built of limestone (white) and dolerite (dark). The dark stripes are dolerite sills, which have intruded the horizontal limestone strata. The limestone is Carboniferous in age whereas the dolerite is Mesozoic. Photo: Dierk Blomeier, NPI.

GEOLOGISK TIDSSKALA | GEOLOGICAL TIME SCALE



Geological time scale. The formation of what is now Svalbard began in the Precambrian and the Lower Palaeozoic, more than 410 million years ago. We are now in the Quaternary Era, which has lasted for the past 2 million years. Man, or *Homo sapiens*, evolved more than 200 000 years ago. The Age of Man is therefore right at the very top of the time scale, just brushing the hair on the mammoth's head. Figure: NPI

Rubbish and pollutants – a new challenge

Why?

Human technology has reached Arctic Ltd, and it is not particularly favourable for the natural environment. Instead of useful things, we are sending a great deal northwards which we do not want – rubbish, heavy metals and other pollutants.

Many ocean currents and airstreams move from the south towards the Arctic. Unfortunately, they do not just take with them heat, clean air and clean water, but also rubbish and pollutants from discharges and emissions further south. Apart from it not being particularly attractive, the rubbish also poses threats to the animal life in the region, and each year several scores of reindeer die because they get entangled in the remains of fishing nets. The low temperatures mean that rubbish decays slowly and lies around until physically removed. Plastic breaks up into smaller and smaller pieces until they can be

Did you know that:

Jotunkjeldene and Trollkjeldene are two hot springs in Svalbard. They are fed by groundwater which is heated so that the temperature at the surface is 20 °C or warmer the whole year round. This spring water contains dissolved minerals from the bedrock and these crystallise when the water reaches the surface.

Terraces, mainly composed of carbonate deposits, have therefore built up around the springs. Mosses and algae that do not otherwise occur in Svalbard grow at these springs.

taken up by micro-organisms living in the shore zone. Its effect on these organisms is inadequately known.

However, rubbish on the shores represents just the contamination which we can see. There are also pollutants which we cannot register with the naked eye, but which are a still greater hazard for Arctic Ltd than the rubbish. Pollutants are chemicals or heavy metals that are produced or become concentrated because of human activity. Several of these substances decay only very slowly in the natural environment, but as they are of-



A pingo is a gigantic blister of ice which arises in the permafrost in connection with a spring. Pingos look like big mounds of gravel, and some have a small tarn or a periodically active spring in their top. The core of the pingo is a large lump of ice. The camp and the but indicate the scale. Photo: Winfried Dallmann, NPI.

ten easily soluble in fats they are stored in the fat reserves of animals. They can therefore be taken up by both small and large organisms, and the amount of pollutants in a single organism increases as it grows up and also upwards in the food chain because a large animal must eat many small animals, each of which contains some toxicants.



Illustration: Audun Igesund, NP.

We manufacture several types of substances that do not occur commonly in the natural environment and which function as pollutants when they enter it. A collective term for some of these is POPs (persistent organic pollutants). POPs can be divided into three groups: insecticides, industrial chemicals and undesirable products from industry.

Heavy metals are naturally occurring elements, but they become concentrated by human activity. Mercury and cadmium are the most abundant heavy metals in arctic systems, and they pose serious environmental problems. Lead used to be a serious environmental threat, but substantially less lead has found its way into the environment since the 1980s, and measurements show that lead concentrations in animals and plants have declined recently. This proves that the efforts of scientists to document hazardous substances and the interest of politicians to adopt internationally binding motions have an effect.

Polychlorinated biphenyl (PCB) is a POP compound and is among the most hazardous of the known pollutants. In 1980, new use of PCB was banned in Norway, but emissions are still taking place through leakage from discarded products, contaminated ground and in connection with refurbishment. In the case of PCB, too, it has been observed that the levels in animals have declined following international agreement banning its use, but in the last couple of years scientists have recorded that the reduction of PCB has stagnated or it is on the rise again. The reason for this is not fully clarified, but it is likely to be a result of the increasing influence of southerly winds which are blowing more strongly and for longer periods and are carrying more PCB to the Svalbard area.

Brominated flame retardants are another group of substances which have negative impact on life in the Arctic. They consist of organic compounds containing bromine which is fire-retardant, and they are therefore used in televisions, computers, vehicle interiors and furniture. They are poorly degradable in the environment and become concentrated up the food chain. The level of some brominated flame retardants is rising in the Arctic, and the substances have been recorded in most animals.

What is taking place?

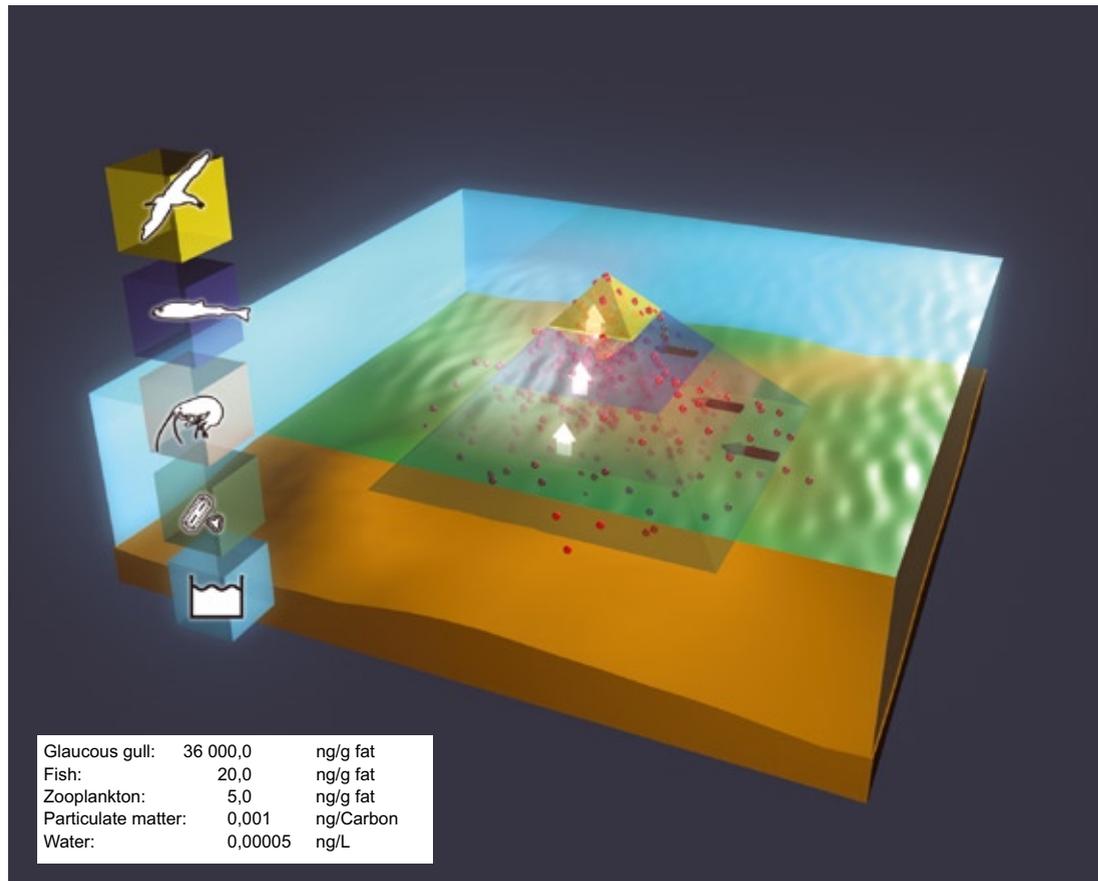
Changes in the air and sea temperatures lead to more transport of pollutants to the Arctic. In addition, we know that the ice contains pollutants which are being released into the sea and onto land. They were previously in-



Each year, the Governor of Svalbard arranges an action to clear some of the rubbish that drifts ashore. Most of it comes from fishing boats, and in 2006 alone all of 100 tons of rubbish were removed from only 33 kilometres of shoreline. Photo: NPI



Airstreams predominantly follow the same pattern as ocean currents, blowing mainly from south to north, not just over the seas but also over the continents. Air pollution from around the world accompanies these airstreams and ends up in the Arctic. The figure shows some of the substances that have been found in animals and other organisms in the Norwegian Arctic. Toxaphenes are insecticides. They are not used in Norway, but evaporate in southerly latitudes and are transported to the Arctic where they are taken up by animals and plants. They may cause cancer and mutations. Chlordane is a mixture of several compounds and was used extensively as an insecticide until the 1970s. It is easily dispersed in the atmosphere and decays only slowly in nature. Chlordane is cancerous and can also damage the nervous and immune systems. HCH is a spray that is soluble in water and was widely used as an insecticide. It can damage the liver, kidneys and nerves, and may also cause cancer. HCH is no longer used in insecticides and the EU does not approve insecticides that contain HCH. Figure: Geir Wing Gabrielsen, NPI



The concentration of PCB increases from water and particulates, which are not actually at the beginning of the food chain since they are not living, via plankton and fish at the bottom of the food chain up to the glaucous gull at the top. Figure: NPI

accessible, but now that they are thawing out of the ice they are returning to the Arctic cycle again.

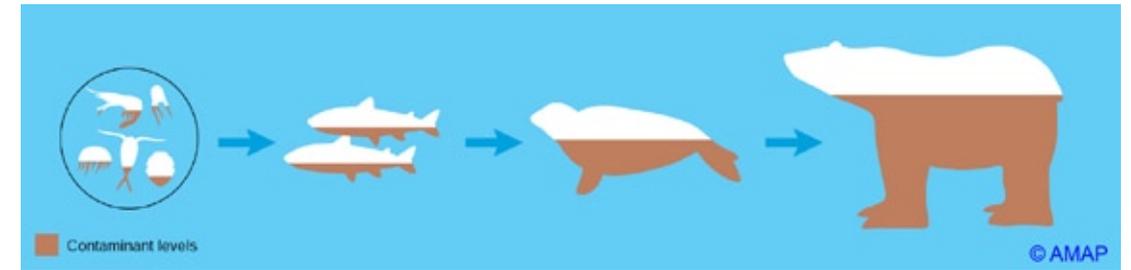
Zooplankton and fish take up the pollutants directly from the water in which they are living. Most of this occurs through food, but some enters through the gills. Studies show that species which live on phytoplankton have the lowest pollutant levels, whereas those which mostly eat zooplankton and dead material have the highest values. Large and older individuals have higher values than small and young ones. The predators have the highest values, and it is also in those that damage and diseases are recorded.

In general, pollutant levels are much lower in fish than in birds and mammals. This is because mammals are warm-blooded and

need a great deal of energy to keep their body heat stable. Since they have to eat more, they take in more pollutants, which are stored in the body. In contrast to fish and several other organisms in the sea, which can rid themselves of pollutants through the gills, mammals and birds can only reduce the level through their faeces or by transferring them to their offspring through egg yolk or milk.

Birds

A study of dead and sick birds on Bjørnøya showed that they contained sky-high levels of brominated flame retardants and PCB. Autopsies were performed on the birds to determine the possible causes of death, and the results showed that only 13 % of the birds had an obvious cause of death. Nearly half of the dead birds were highly emaciated, and



Contaminants become increasingly concentrated up the food chain. Plankton in the sea have the lowest levels, and polar bears and other predators the highest levels. Figure: AMAP.

abnormal behaviour was observed among sick birds. The parents abandoned nests that contained eggs, had poor balance and had difficulty in flying.

As they are tied to their nest and do not have chance to get fresh food, they eat deep into their fat reserves during the egg-laying and brooding period. Most of the pollutants

are stored in the fatty tissue. When the birds eat into their fat reserves, the pollutants are released into the rest of the body and end up in the brain and the liver.

In the brain, the pollutants affect the ability of the birds to take care of their offspring and to find food, which are vital activities for their ability to survive and reproduce. Tri-



A dead glaucous gull with three small chicks. The high content of pollutants in its body has probably contributed to its death immediately after it had used up a great deal of energy hatching its chicks. Some creatures are less tolerant to pollutants than others. Pollutants need not necessarily have negative impacts, but if a creature has to tap its fat reserves, the pollutants can reach other parts of the body and cause damage. Photo: Hallvard Strøm, NPI.



A biologist is examining a drugged female polar bear, with a satellite collar ready to be fitted. Research on polar bears has been intensive in many parts of the Arctic in recent decades. In Svalbard, priority is given to research on pollutants, diseases, demography and the influence of climate. Between 50 and 100 polar bears are tagged or recaptured each year. Samples are taken to perform a variety of analyses, and they are equipped with collars carrying satellite transmitters to find out where they roam during the year. Photo: Magnus Andersen, NPI

als also show that glaucous gulls which eat common guillemot and kittiwake eggs during the breeding season have higher levels of pollutants than those living a few kilometres away, which live on fish, crustaceans and shellfish.

Polar bears

Since the polar bear reigns at the top of the food chain, it is particularly exposed to pollutants; it is the final stop. Polar bears with high pollutant values have abnormal values



of hormones and little production of antibodies that are important to enable them to grow normally, develop properly and give birth to offspring normally. Research also shows that newborn cubs are especially exposed to pollutants, and if their mother has high pollutant levels in her milk, these substances are easily passed on to the cub. Many pollutants disturb and destroy the hormones that control sexual and metabolic processes, and also affect the immune system of the bears. Scientists are investigating whether the effect on the sexual hormones may lead to reproduction being reduced – the animals may come onto heat at the wrong time and have their cubs at the wrong time.

Rapid warming of the arctic regions will lead to major and rapid changes in the environment of the polar bear, which will be forced to change its behaviour in a short time. It requires healthy, well-functioning hormones to achieve this.

When can we stop saying probably?

When people offer their opinion on the changes in climate in the Arctic, it is generally accompanied by "will probably...". Most people dislike expressing themselves too categorically when something cannot be concluded with certainty. When will we stop saying "probably"? When can we say "absolutely definitely"? We don't know. We've never been here before, and we don't know for certain what will happen. We cannot be absolutely certain that the changes in climate will take place with the force and the speed which scientists believe; maybe they will be quicker, maybe slower. However, based on scientific investigations, we can assume with great probability. Is it so vital to know with absolute certainty? We can act nevertheless.

What can we lose by not doing anything? If we crisis maximise a little, the answer is everything! Species disappear, deserts spread, the sea rises, nations go to war over

water reserves, millions of people are forced to flee. However, we do not know definitely whether these things will take place – before they do so.

Even if you could not care less whether close on three thousand polar bears near the North Pole perish, it may be useful to know that the polar bear can be looked upon as an example species. It is quite simply an indicator that something is wrong somewhere. Moreover, it is like this with much of the arctic ecosystem. To reduce the problems, we must act on the basis of "probably" and the precautionary principle.

Do you want to learn more?

Go to www.arcticsystem.no. There you will find the content of this brochure and also links to more information on the Arctic, the climate and the environment.



Illustration: © Jody Barton at Big Active



Mordor, Fram Strait. Photographed by Rudi Caeyers, NFH/UiT, on an Integrated Arctic Ocean Observing System cruise in 2007

The International Polar Year 2007-2008

Home page: www.polaryear.no

Joint research is being performed in polar regions during the International Polar Year which no single nation can carry out alone. More than 50 000 researchers and technicians from about 60 countries make Polar Year 2007-2008 the largest international research programme ever. Over 200 Polar Year projects were approved and Norway is taking part in about half of them. The eight projects presented here have contributed research results, knowledge, illustrations, ideas and lectures to "The Arctic System" project. Read more about the projects on the Internet.

Arctic Predators



Photo: Christian Lydersen, NP

research methods to monitor changes in the structure and function of the tundra. Since predators at the top of the food chain may be particularly sensitive to early changes, the scientists are investigating whether they can be used as indicators of the state of the ecosystem.

Arctic Predators as Indicators of Tundra Ecosystem State

Home page: www.arctic-predators.uit.no/

Project manager: Nigel Yoccoz

Institution responsible for the project: University of Tromsø

The predators are particularly sensitive to climate change and other disturbances on the narrow belt of tundra along the coast of Eurasia. The tundra is usually marked by large fluctuations in the populations of both prey and predators, and fluctuations in the predator populations in particular can give early warning about changes in the ecosystem. The main goal of the project is to develop modern

BearHealth



Photo: Jon Aars, NP

top of the food chain. The toxicants affect the sexual hormones, metabolic hormones and immune system of the polar bears, making them more poorly equipped to meet the changes in climate. The scientists are studying the toxicant load, fitness, health state and hormone status in polar bears in Svalbard and the Barents Sea. The animals are being tagged with satellite transmitters which supply information on where they are so that the scientists can study their behaviour and the climate conditions.

Polar Bear Circumpolar Health Assessment in Relation to Toxicants and Climate Changing

Home page: www.biologi.no/bearhealth.htm

Project manager: Bjørn Munro Jensen

Institution responsible for the project: Norwegian University of Science and Technology

Global warming is causing the ice in the Arctic to melt, and the polar bear is experiencing great changes in its natural environment. Adaptations to a warmer climate require correct physiological and behavioural responses. At the same time, polar bears are being seriously affected by long-transported toxicants because they are at the

BirdHealth



Photo: Sebastian Gerland, NP

the new human-induced stresses deriving from climate change and pollutants. Higher pollution levels may disturb hormones and the immune system, and a warmer climate may increase the occurrences of parasites and infectious organisms. In this project, the researchers are studying how common eiders, which are found both in the Arctic and further south, are tackling stress from toxicants and parasites while undergoing the stress of brooding and looking after their offspring.

Mapping Threats to Arctic Bird Populations. The Effect of Infectious Organisms and Pollution on Bird Health

Home page: www.birdhealth.nl/

Project manager: Sveinn Are Hanssen

Institution responsible for the project: Norwegian Institute for Nature Research

Animals in the High North are adapted to a short, hectic summer by being able to rapidly build up body reserves in spring which they can then use to bring forth offspring that are large enough before winter sets in again. This can make these organisms especially vulnerable to

COPOL

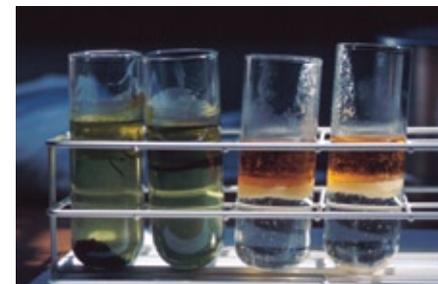


Photo: Katrine Borgå, NIVA

taminants can give serious effects in species like polar bears, Arctic foxes and glaucous gulls. The COPOL scientists are studying how the climate affects exposure to, and absorption and effects of contaminants introduced by man into the marine food web in the Arctic. An important task is to document variations in contaminant levels in the food chain during a year and from year to year. The project enhances our understanding of how contaminants are transported and taken up in marine food chains in polar regions.

Contaminants in Polar Regions – Dynamic range of contaminants in polar marine ecosystems

Home page: www.copol.net/

Project manager: Geir Wing Gabrielsen

Institution responsible for the project: Norwegian Polar Institute

Organic contaminants are stored in the fatty tissue of animals. They are transferred from prey to predators so that the highest level of contaminants is found in species at the top of the marine food chain. Changes in air and sea temperatures may lead to an increased supply and higher levels of contaminants. Large amounts of organic contaminants

GLACIODYN



Photo: Geir Wing Gabrielsen, NP

bergers are calving, resulting in more transport of ice from the land to the sea. The scientists are calculating future changes in the transport of fresh water from the glaciers and can thus provide better estimates of global changes in sea level, too.

The Dynamic Response of Arctic Glaciers to Global Warming

Home page: www.geo.uio.no/glaciodyn/

Project manager: Jon Ove Hagen

Institution responsible for the project: University of Oslo

The melting of glaciers on the planet is a prime cause of global changes in sea level. In the coming one hundred years, small glaciers and ice caps, not the huge ice masses in the Antarctic and Greenland, are expected to contribute most to the rise in sea level. In the past 10-15 years, it has been observed that glaciers are not only melting more on the surface, but in many areas they are moving more rapidly and more ice-

iAOOS



Foto: Sebastian Gerland, NP

Integrated Arctic Ocean Observing System: Closing the Loop
Home page: www.iaaos.no
Project manager: Cecilie Mauritzen
Institution responsible for the project: Norwegian Meteorological Institute

The Arctic has recently been experiencing much more warming than the rest of the planet and the ice cover has been greatly reduced. Such changes have great impacts on the climate and the environment, both locally and globally. Despite this global effect, the coverage of data from the Arctic is poorer than in more southerly latitudes. iAOOS scientists are contributing knowledge to forecast changes in the oceans, the ice and the weather, and are performing studies that will

help to improve the mathematical models that are behind such forecasts. This work ranges over several disciplines and aims to contribute to a better system of observations that can "take the pulse" of the development in arctic regions.

MEOP



Foto: Kit Kovacs, NP

Marine Mammals Exploring the Oceans Pole to Pole
Home page: www.ipy.no/prosjekter/MEOP
Project manager: Kit Kovacs
Institution responsible for the project: Norwegian Polar Institute

The MEOP Polar Year project is using four species of seals in polar regions as research assistants. The seals are equipped with newly designed satellite transmitters which transmit information about their positions and diving behaviour and report the oceanographic conditions under which they are swimming and diving. The seals are thus providing new information on their own habitat preferences at the same time as they are collecting oceanographic data from places on the planet where such data are difficult to obtain. The data are transmitted when the seals are at the surface. The information travels via satellites and is used immediately for weather forecasting! The data are important for modelling climate and ocean currents and will increase our insight into how the seals live in the ice-filled polar regions of our planet.

SciencePub

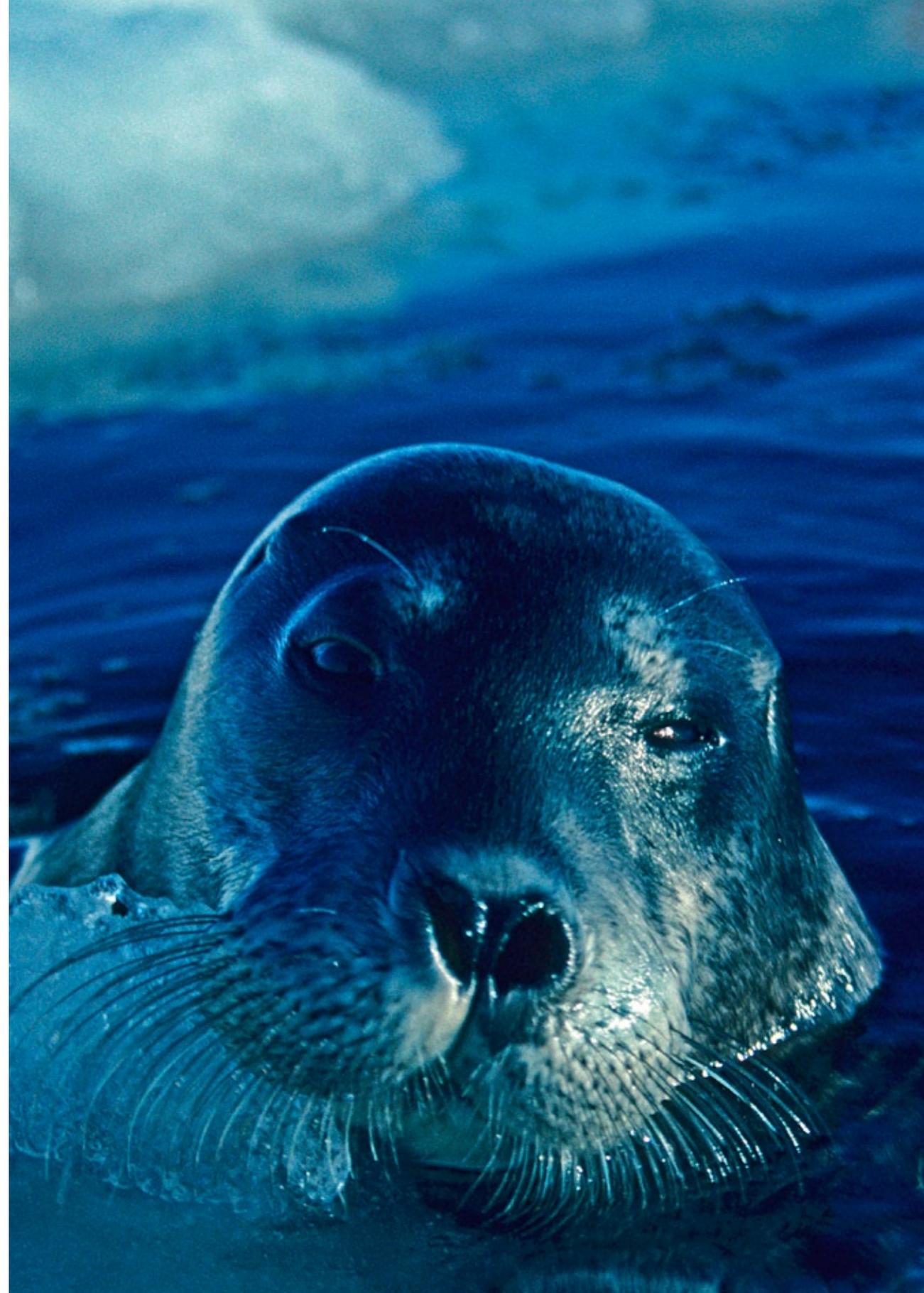


Foto: Bjørn Fossli Johansen, NP

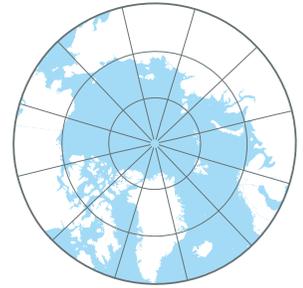
Arctic Natural Climate and Environmental Changes and Human Adaptation: From Science to Public Awareness
Home page: www.ngu.no/sciencepub
Project manager: Eiliv Larsen
Institution responsible for the project: Geological Survey of Norway

The natural trend in the climate in the Arctic over the past 130 000 years is being studied because it is important to understand the interplay between the land, the sea and the ice cover. To obtain new knowledge about present-day and past terrestrial and marine environments, the scientists are looking more closely into variations in the Gulf Stream and their significance for the ice cover in the Arctic. They are also studying changes in the supply of fresh water through the rapid

tapping of huge ice-dammed lakes, in addition to the immigration and settlement of human beings and their adaptations to the rapid changes in their environment at the end of the last Ice Age. The project has its own specialists who are engaged in passing on the new knowledge about the environment and climate in polar regions to the public.



This booklet is a result of an education, communication and outreach project called The Arctic System. The project was funded by the Research Council of Norway and the Norwegian Polar Institute (NPI) as part of the International Polar Year 2007-2008 (IPY) (www.polaryear.no). The contents of the booklet, additional information and links to other relevant sites can be found on the internet, at www.arcticsystem.no. The author Ellen Elverland has had valuable assistance from scientists, environmental managers, information advisors and others at the NPI and cooperating institutions, in particular those affiliated with the IPY science projects which are presented on the last pages.



INTERNATIONAL 2007-2008
POLAR YEAR

