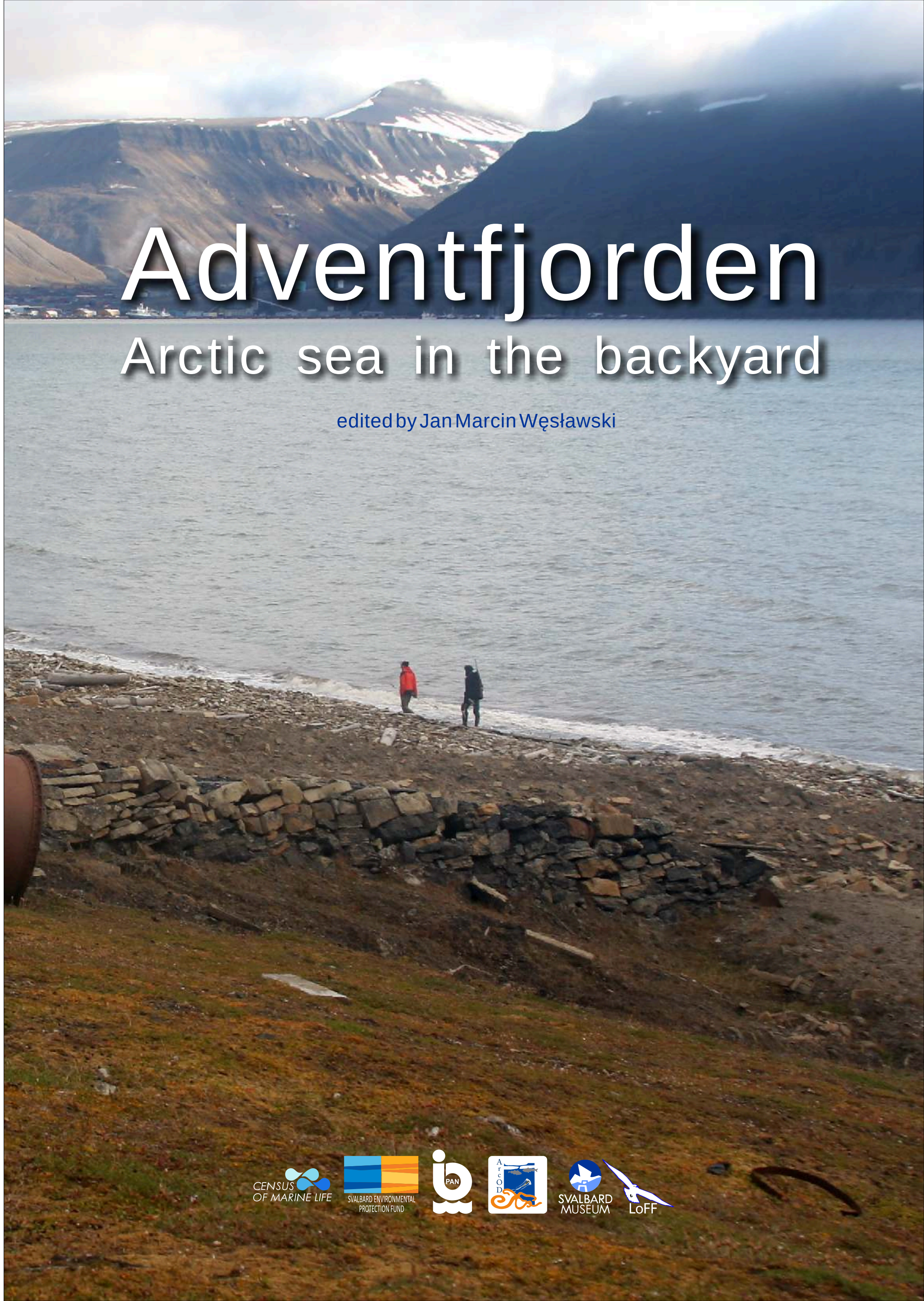
Adventfjorden

Arctic sea in the backyard

edited by Jan Marcin Węsławski



CENSUS OF MARINE LIFE

SVALBARD ENVIRONMENTAL PROTECTION FUND

SVALBARD MUSEUM

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About this booklet

Longyearbyen is a gateway for scientific, sporting, and recreational Arctic expeditions. Spectacular scenes from the ice-covered Greenland Sea and the wildlife of the remote northwest coast of Svalbard are frequent destinations of Arctic visitors. Adventfjorden, a small body of water at the foot of Longyearbyen, is somehow forgotten, or even regarded as uninteresting.

We believe that learning about and gaining an understanding of our own backyards is important. To familiarize you with the marine environment of Longyearbyen, the team of marine biologists from the Institute of Oceanology, Polish Academy of Sciences (IO PAS), in co-operation with the Longyearbyen Society for Field Biology (LoFF), presents this booklet as part of the series about the nature of Longyearbyen.

This volume focuses on the marine environment of Adventfjorden. It explains to residents and visitors alike topics such as what can be found on local shores, what is below the turbid water surface, and what birds find to eat in the water. Our aim is to provide easy-to-understand, yet scientifically sound, information. The booklet presents the basic characteristics of Adventfjorden, which are described based on data from our studies in this area. The IO PAS research vessel Oceania has sailed the Svalbard shelf and fjords on research cruises every July since 1988, and during crew exchanges in Longyearbyen, we have had plenty of time to explore Adventfjorden. So, our experience comes from these brief but numerous visits, and we would like to share it with you. We owe sincere thanks to all our colleagues and friends in Longyearbyen, the University Center in Svalbard (UNIS), the Norsk Polarinstitutt, the Sysselmannen Office, and also to the citizens of this unique city who always make us feel at home here.

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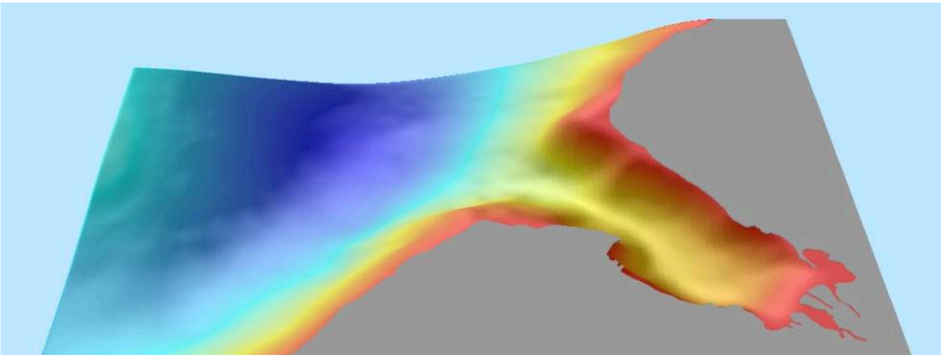
How was Adventfjorden formed?

Adventfjorden as we know it today was not formed by a single event in the past. Rather, it has taken shape through the influence of myriad processes over several million years. And it continues to change even today. The ancient history of Adventfjorden region is told by the many old rock types found in the basin such as shale, siltstone, sandstone, and coal. The oldest rocks can be found on the northern shorelines, and they were formed in the Cretaceous period more than 100 million years ago when the oceans were home to large dinosaurs. Of course, these rocks were not formed in the fjord, which was not a feature of the landscape at that time, but they later served as the material for the various earth surface processes that sculpted the landscape we see today. For instance, the presence of cliffs and gentle slopes is the result of the weathering of resistant sandstone and the erosion of softer shale.

The formation of the valley with its submerged part, which is known as the fjord, is mainly the result of erosion during the Quaternary period, which is approximately the last two million years. During this time, the valley was formed and shaped by rivers during interglacial periods and by glacial processes during glacial periods. It is likely that the initial valley shape was similar to the letter "V", as is typical of river valleys. However, glacial activity deepened and reshaped the valley into the shape of the letter "U", which is typical of sites with a glacial history.

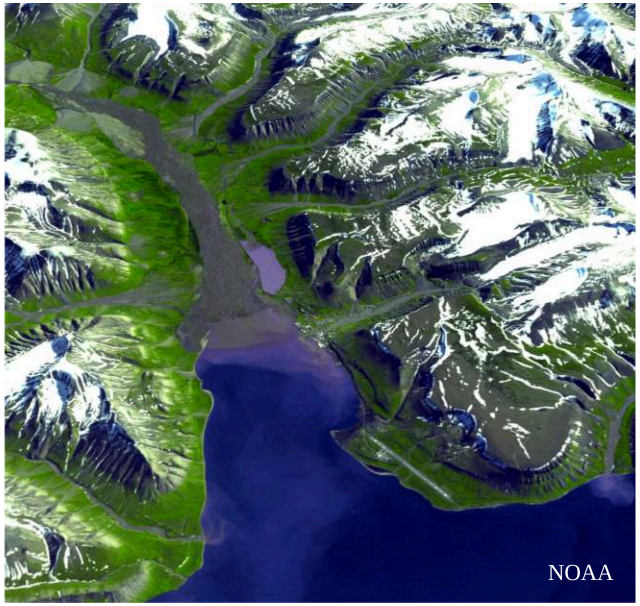
In comparison to these long periods of rock formation and the shaping of major landscape features, the fjord itself is quite young. The last part of the story of how the fjord came to be, can be traced through the last glacial maximum around 20,000 years ago. At that time, the fjord was filled with a tributary glacier joining a large ice stream that filled today's Isfjorden. About ten to eleven thousand years ago, the glacier had already begun to retreat from Adventfjorden, and the fjord was created as a bay supplied with freshwater and sediments by rivers flowing from the terrestrial glaciers. This was not the end of the changes. At this time, the fjord was probably up to 60 m deeper than it is presently. Spitsbergen carried an enormous load of ice during the last glaciation maximum, and this weighed the island down, but when the ice melted away the island began to uplift in a phenomenon known as glacio-isostatic rebound. The effects of this phenomenon can be seen as many beach sediments and marine terraces around Adventfjorden located at various elevations above sea level; these were formed up until about 5,500 years ago when the relative sea level stabilized. Since then, the deltas at the fjord head have started to prograde and form extensive tidal flats. Throughout the period of the fjord's existence, rivers have supplied terrigenous sediments that have covered the fjord floor with approximately 10 to 20 m of sediments over the last 10,000 years. The fjord has also been shaped by human activities; the most striking example of this is probably the artificial coastline along the road from the airport to the town of Longyearbyen.



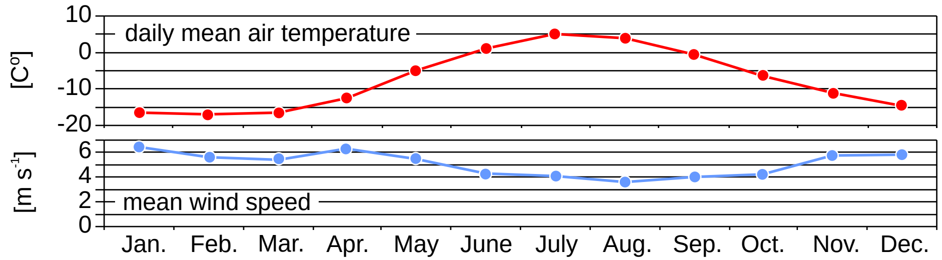
This 3D map shows the U shape of the river mouth valley, entering to the depths of Isfjorden.

Adventfjorden and its catchment

Adventfjorden is one of the southern arms of Isfjorden, the largest fjord system on Spitsbergen. It is relatively small, only 8.3 km long and 3.4 km wide. Its innermost part is composed of a tidal flat. As a coastal marine system, the Adventfjorden is affected by processes taking place within the water masses but also by those acting in the fjord catchment area (supply of nutrients, sediments, freshwater etc.). The catchment area (about 694 km^2) is about 20 times bigger than the fjord. In generals about 60% of Svalbard is covered by glaciers; however, in Adventdalen glacier cover is only 18%. Nonglaciated land area is mostly covered with weathering material and glacial, fluvial and solifluction (permafrost processes) deposits. During approximately the four months of the ablation season, with air temperatures above 0°C, the glaciers contribute most of the sediment and freshwater to the fjord via the systems of two braided rivers – the Adventelva and the Longyearelva. During winter, when the rivers are frozen, the supply of terrigenous material to the fjord is cut off. The average annual air temperature of this region is about -6°C, and the total annual precipitation is as low as 200 mm.



Vast expanses of the Adventelva valley the murky river plume in the dark blue fjord and the extensive tidal flat.

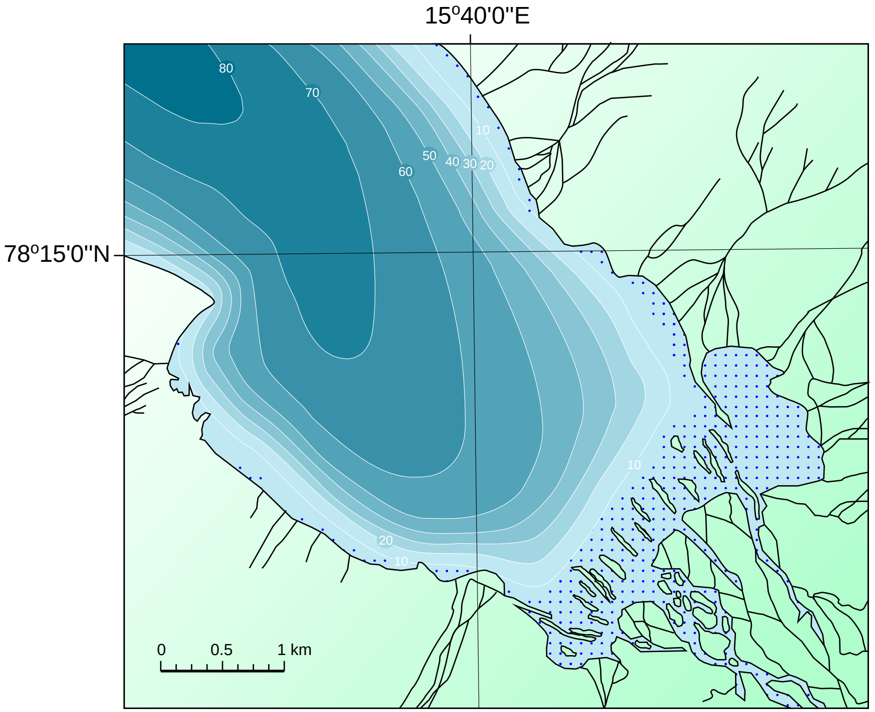


Meteo data from Longyearbyen, courtesy UNIS 2010.

Bathymetry, sediments

The sediments supplied by the glacier-fed rivers Adventelva and Longyearelva are deposited at the river mouths, and they form extensive tidal mudflats. As fjords are typically deep and narrow, shallow mud flats at river mouths progress quickly into steep, unstable slopes. High sediment flux to the bottom, slope steepness, and the high hydrodynamic energy of the shallow proximal zone can cause repeated sediment gravity flows and turbidity currents in the center of the fjord and in the mouth.

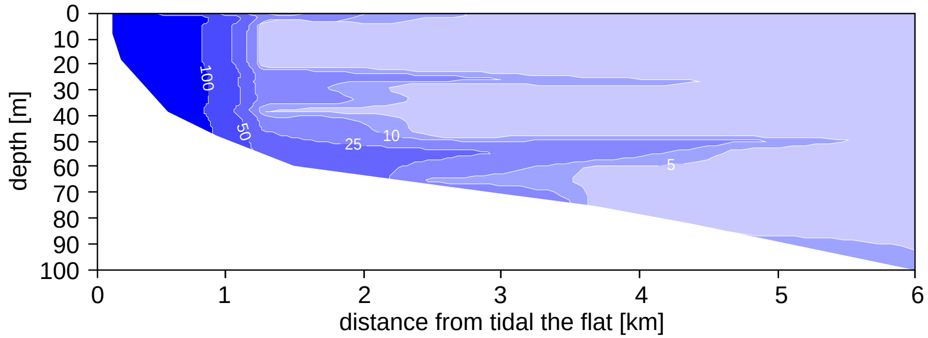
The turbidity of surface waters and the overall turbidity of the entire water column decrease with increasing distance from the river mouth (data from July 2002). Peaks of turbidity in the water column detected at depths of 25 m and 50 m in the central fjord could have been due to the fine-scale density stratification of the water column. Finally, turbid water plumes can form a kind of interflow, which dissipates depending on the tidal phase. Sediment is deposited on the tidal flat during floods (as much as 3000 g m^{-2} per day), only to be resuspended and redeposited during ebbs. Such episodic events of the massive displacement of surface tidal flat sediments explain the difference between the high deposition rate and real multiannual accumulation that maintains the tidal flat surface at a relatively stable level. Gravity flows on the steep slopes of tidal flats and turbidity currents in the center of the fjord explain why sediment accumulation is high (32–71 g m^{-2}) despite low sedimentation rates from suspensions (8–29 g m^{-2}).



Adventfjorden is not very deep, yet isobaths are rather steep.

Fresh water

Fresh water is of great importance for coastal marine ecosystems since it acts as a selecting factor that limits the occurrence of many marine species that do not tolerate lowered salinity. Fresh water that flows into the the sea stays at the surface because it is lighter than salt water. Adventfjorden experiences three types of freshwater inflows throughout the year. The first inflow is in the spring when fresh water from snow cover and sea ice melts from April to June; its volume is relatively small and its temperature is low. The second and largest inflow comes from the fresh waters of the two rivers that discharge into the fjord (summer daily discharge ranges between 2 and 3.5 m^3 of water per second in each river). These waters are laden with sediments and they impact the whole surface layer of Adventfjorden between May and late September. These waters are also significant because they are the main cause of light inhibition in the water column and nearly the only source of the sedimentation or precipitation of solids to the seabed. The third source of fresh water is rain. Although this is of minor importance, all climate models predict increased precipitation as the Arctic warms.



Cross section of Adventelva mouth, with isolines indicating amount of suspensions (mg dm^{-3}) carried by fresh water to the fjord.

One of many tributaries to Adventelva, the river carries as much as 3.5 m^3 of water per second in summer.

The coast

The shores of Adventfjorden are quite diverse. The gravel beaches near the airport were formed by sediment accumulation processes. Waves play the dominant role in the formation of the coast here, which is why the gravel is well rounded. Traveling from the airport or the coal harbor, you will notice various constructions and the artificial coast built to secure roads and installations. The cliff that overhangs the road was formed by sea erosion in the past. There is very little life here since organisms are very slow to colonize these kinds of habitats in the Arctic. A very large part of the shore at the fjord head is covered by tidal flats, also known as mud plains or watts, that are formed by both tides and the Adventelva and Longyearelva rivers that discharge huge amounts of fine sediment particles. This soft sediment shore is very unstable and it is continually reworked by waves, tidal currents, and ice. Nevertheless, there is plenty of life in this muddy landscape – mainly minute interstitial organisms dwelling below the surface (see section on meiofauna). The tidal flat is also important for migrating wading birds which feed on the small crustaceans such as *Onisimus litoralis* (see p. 27) that are very abundant here. The gray-brown mud is treacherous, and it can stop you in your tracks, pull your boots off, or even worse. All visitors to these tidal flats should exercise great caution when making their way through the patches of consolidated muddy/sandy sediments. The tidal flat is controlled mostly by tides (semidiurnal, with some about 1m in amplitude); however, waves on either side have created initial gravel beaches. Typical gravel and coarse sand beaches are found in the front of the Zodiak and kajak "harbour" in town, and on the extensive northern shore opposite Longyearbyen. In this location, the material comprising the beaches is rounded to various degrees depending on wave energy. With the exception of 1-cm-long gammarids that hide under flat stones at low tide, there are practically no macroorganisms inhabiting this area. This type of coast is dynamic, and some places undergo wave-driven erosion, which threatens huts located too close to the shore line. The last type of coast comprises rocky and boulder shores. These begin at Bjorndalen and continue towards Grumant along the southern side of Adventfjorden. These shores host macroalgae, mainly green *Enteromorpha* spp. and brown *Fucus* spp., with their rich associated fauna.

Erosion is a problem on sandy-gravel shores with the steep depth profiles, where waves with build great force at the northwest corner of the fjord.

Types of shore

Sandy and gravel shores, northern side of Adventfjorden

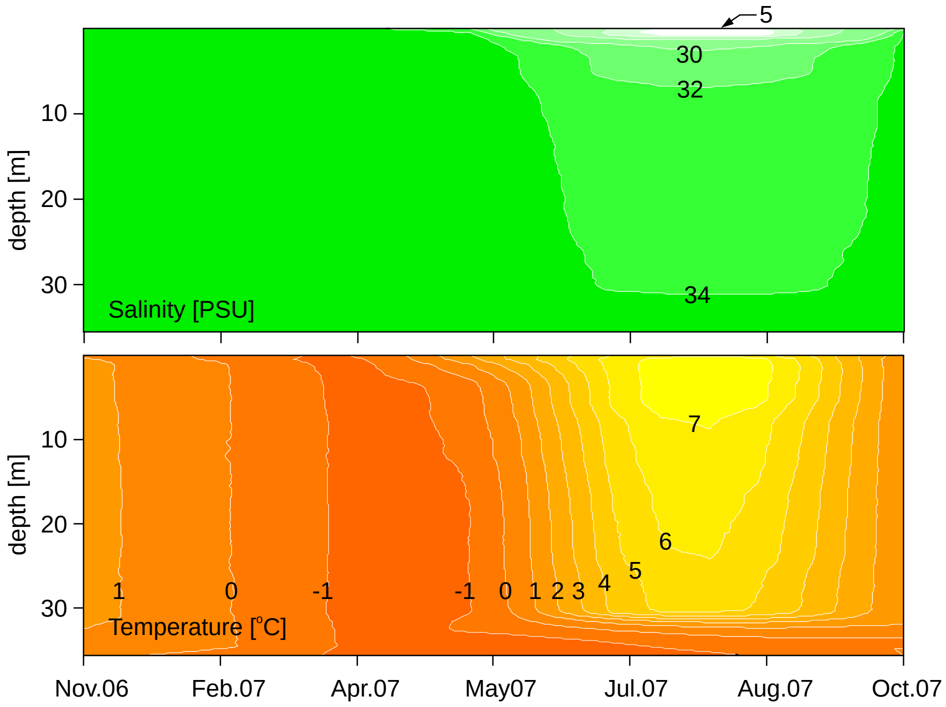
Muddy coast at tidal flat, Longyearbyen

Rocky coast at Bjorndalen

Hydrography

Generally, the waters around Svalbard are of a regular oceanic salinity (35 PSU). In coastal waters and fjords, salinity can drop at the surface, as in Adventfjorden, where the salinity of tidal flat waters is below 6 PSU. A well-mixed, one-meter-thick layer of brackish water with a salinity below 11 PSU is still detectable 400 m away from the tidal flat. A sharp density gradient, also known as a pycnocline, defines the extent of brackish water between depths of one and two meters. Further mixing between brackish waters and the underlying fjordic waters is limited by differences in density. At a distance of 1.5 km from the tidal flat, the salinity of surface waters increases to 28 PSU and the thickness of the brackish water layer increases to six meters. Because these different waters mix progressively along the length of the fjord, density driven stratification disappears at the fjord mouth.

The steep slope of the Adventfjorden tidal flat margin has an inclination of 16–19° and is characterized by numerous chutes and subsidence areas, which are signs of sediment gravity flows. Sediment movements on the slope initiate turbidity currents near the bottom. Six events of near-bottom currents were recorded one summer within 25 hours of continuous measurements. All of the currents were directed toward the sea and accompanied by increased water turbidity. The velocity of the strongest current was 7.2 cm s^{-1} with the concentration of suspended particles increasing to 174 mg dm^{-3}. Farther off the tidal flat, the number of turbidity current events increases, but their speed and the amount of sediment transported decreases.



Cross section of the yearly run of salinity and temperature in Adventfjorden.

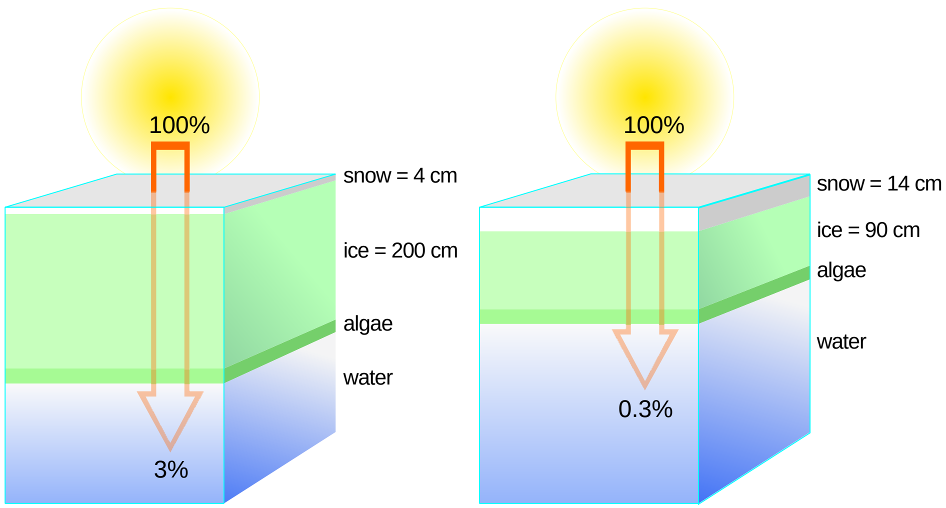
Sea ice

The fjord starts to freeze in the winter, usually in January or February, and sometimes even in December. This happens when the sea water temperature drops to about -1.8°C. In places close to glacier river run off, a temperature of -1.3°C is sufficient for freezing. This process also requires cold weather with air temperatures below -15°C for a few days. As the cooling water on the surface becomes denser, and therefore heavier, than the water beneath, it sinks and pushes the warmer water up. This cycle repeats until the whole surface layer, which is usually as thick as 50 or even 100 meters, reaches freezing temperature. As soon as this happens, tiny icy needles, called frazil ice, form. Since these are lighter than the water, they emerge and form a delicate, oily film on the surface known as grease ice. Over time, the film becomes thicker and finally forms into solid ice when seas are calm or, pancake ice, which, of course, resembles pancakes, when seas are rough.

After a few days, the so-called young ice is about 10 to 30 cm thick. As thickness increases, the water underneath is more isolated from the cold air, which means that the ice forms more slowly. At its maximum in May, the ice can be as thick as three meters. The mean ice thickness in the Arctic is about two meters; however, in warmer areas such as West Spitsbergen it is usually not much thicker than a meter. Although ice appears to be solid, this is not entirely true. It is more like a floating, semi-elastic coating. Tide currents and swells mean that the sheet ice is constantly moving, and this is why the ice surface near the shore is not smooth and flat. Farther from the shore, ice uplifts known as hummocks can be seen.

When the ice cover is stable, it becomes so strong that it can support planes or trucks, and people often taken advantage of this by using the frozen sea for roads or runways. It is no wonder then that animals, which are much lighter, also take advantage of these ice formations. Seals breed on it, because their pups are relatively safe there, and the fish that feed underneath the ice are easy prey. The ice absorbs most of the light so it is limited to the thin layer just beneath the ice, and this is why all sorts of life forms concentrate there.

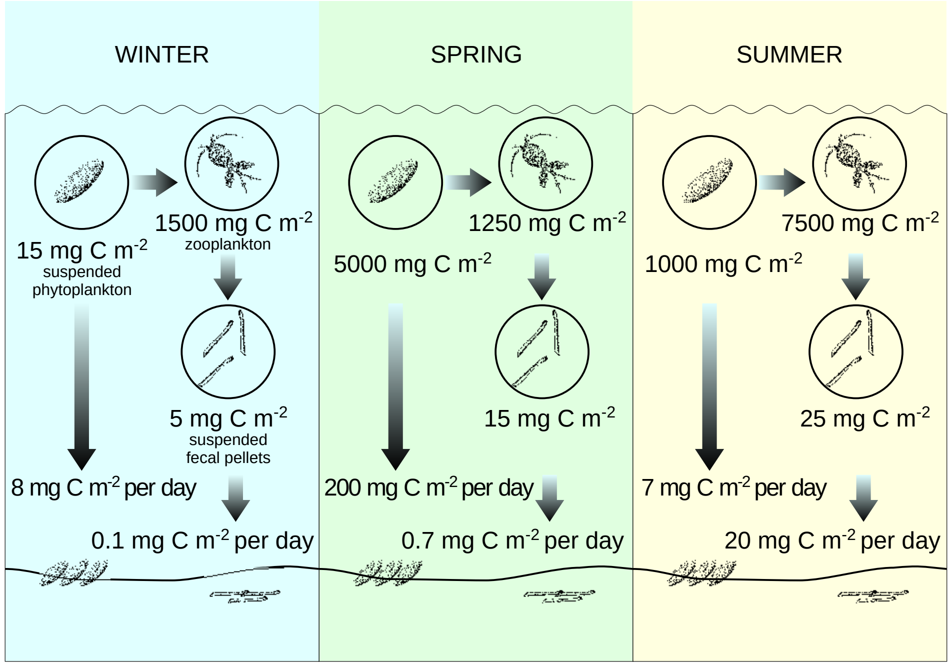
The other type of frozen water that is observed in Adventfjorden is glacier ice. These small rounded chunks are the remains of larger icebergs and are called growlers.



Ice and snow are very important for light transmission to the water column (expressed as the percentage of sun radiation on the surface). Even thick ice cover is very transparent, while a thin snow layer inhibits light strongly.

Seasonality

The climate of Adventfjorden, like that of all of the west coast of Spitsbergen, is moderated by the warm West Spitsbergen Current, which is the northernmost extension of the Norwegian Atlantic Current. This renders the climate very mild considering its northerly position. The average annual temperature is about -6ºC. The warmest month is July with temperatures of 5 to 6ºC, and the coldest period is from January to March when the temperature is about -15ºC. Precipitation is very low, with only about 200 mm annually, and snow cover on the land is strongly modeled by winds. The mean wind speed ranges from 3.5 m/s in summer to more than 6 m/s in the winter months. During the winter from November to March, salinity throughout the water column exceeds 34 PSU, and water temperature drops below 0ºC, with the freezing point at -1.8ºC. The fjord remained ice free throughout the winters during the period from 2005 to 2010. The water column of the fjord is well mixed from November to April, and there is no distinct stratification during this period. The water masses begin to warm in May, and this proceeds into summer, until the maximum surface water temperature of >7ºC is noted in August. Surface water salinity decreases to less than 5 PSU in June and August, and the influence of freshwater input is observed to depths of 30 m. Freshwater input into the fjord causes significant stratification, and the strongest pycnocline at a depth of two meters remains throughout July and August.



The functioning of the Arctic marine ecosystem is highly seasonal and connected with tight linkages between the water column and the seabed. The diagrams illustrate the production and fate of organic carbon in seasonal cycles in Adventfjorden, expressed in mg organic C m^{-2} in 0–50 m of the water column.

Wildlife

As Adventfjorden is a semi-enclosed, inner fjord basin situated next to a major human settlement and strongly influenced by freshwater discharge, it is not the best place to observe Arctic marine wildlife. Yet, most of the large, free-moving marine animals visit most locations around Svalbard. This means that it is possible to encounter minky whales, belugas, walruses, polar bears, bearded and ringed seals as well as such rarities as the bowhead whale, also known as the Greenland right whale. Even the polar shark, which lives in deep, offshore waters, has been observed occasionally in Adventfjorden. The most common large marine animals in Adventfjorden are ringed and bearded seals. The first is a small, 40 kg, shy, fish eater that breeds on ice and never comes ashore. If you see a small seal on a coastal rock or on the beach, it is almost certainly a harbor seal, which is less common in Svalbard. The second common seal species in the Svalbard region is the bearded seal, which is a large, 200 kg animal with a distinctive mustache. Typically, it feeds on the seabed, and can often be seen resting on ice floes. This seal is relaxed enough to allow humans to come near.

Summer visit of a bowhead.

Bearded seal

Ringed seal

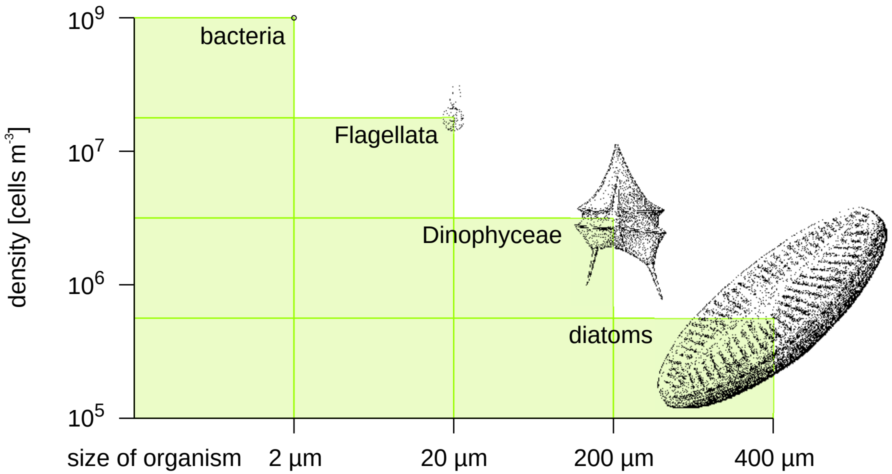
Inhabitants of the water column – microplankton

When the ice starts to break in May and June, the water turns green and smells of fish. This signals the beginning of the spring algae bloom. By this we mean the rapid increase in the amount of single-cell autotrophic organisms, which, just like terrestrial plants, use light and nutrients to bind carbon dioxide and produce organic matter. Just like solar power plants, they transform energy from the sun into forms that can be used by others, and, therefore, they run the whole ecosystem.

The main component of the spring algae bloom are diatoms, which are microscopic algae ranging in length from ~0.005 mm to 0.5 mm, that live in glassy, intricately-sculptured boxes. During the bloom, there can be billions of individuals in each liter of water. Since they are so abundant, the diatoms are the base of the entire trophic pyramid. The smell in the air during blooms, is later detected in marine crustaceans and, perhaps what is easier to imagine, in raw fish. This smell comes from the lipids that are produced by these algae in vast quantities.

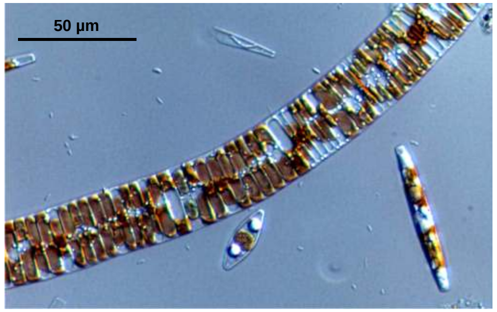
The diatoms are not alone. They are supported and assisted by numerous bacteria that feed on the polysaccharides secreted by algae in times of abundance. Microbes use carbohydrates and produce vitamins and other supplements which are crucial for algae. Bacteria populations are tenfold larger than alga populations; thus, despite their minute size, this makes their biomass tempting for the gourmets of the micro-world like flagellates. The small sizes of the bacteria are not a problem for flagellates because they are not large either and range in size from 0.002 mm to 0.02 mm. Moreover, nature equipped them with flagella that allow them to chase prey actively. During times of abundance, the flagellates graze in this bacterial soup.

By the time spring is drawing to a close, nutrients are running low since the high production depletes whole stocks from the winter. This limits photosynthesis, and the spring bloom ends. This does not mean that the sea water in the summer is free of microorganisms. Flagellates, dinoflagellates, and ciliates remain together with some diatoms. The majority of them are mixotrophic, which means that they can both feed on other organisms and perform active photosynthesis and seek out regions where nutrients were not depleted during the spring bloom. Some of these organisms can even survive in winter, but by the end of fall most of them are dead or waiting for better times by saving lipids from the spring and summer.



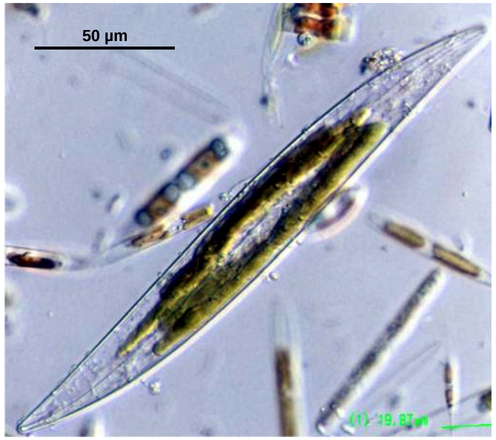
The abundance of primary producers is inversely related to their size in summer.

Representatives of microplankton

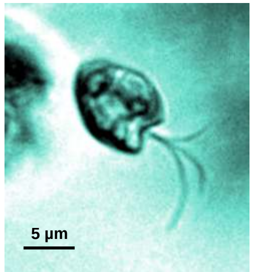


diatom (*Fragilariopsis* sp.)

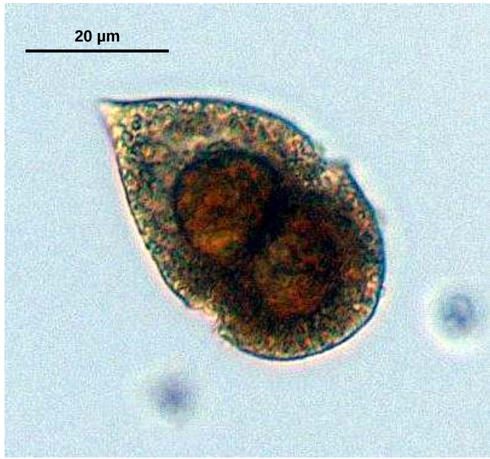
diatom (*Pinnularia* sp.)



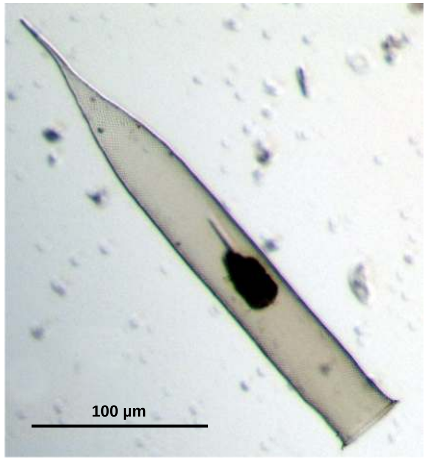
diatom (*Pleurosigma* sp.)



flagellate (prasinophycean)



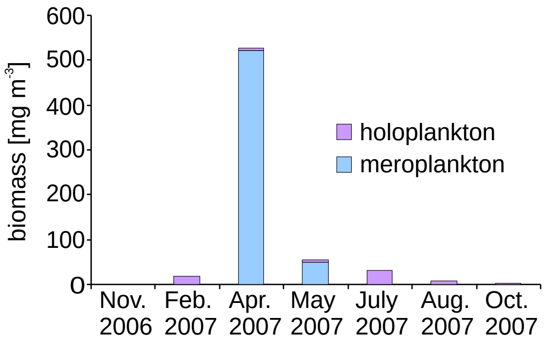
dinoflagellate (*Gymnodinium* sp.)

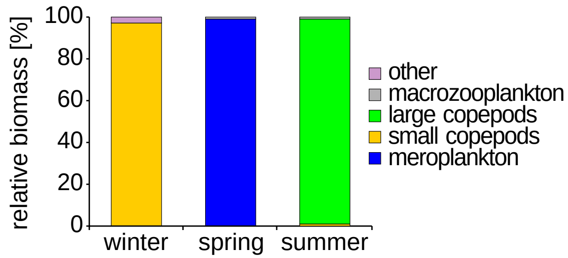


cilliate (*Parafavella* sp.)

Zooplankton (mesozooplankton and macrozooplankton)

Zooplankton is the collective name of the small animals with poor swimming abilities that inhabit the water column. The smallest of them are known as microzooplankton, which are mostly the larvae of benthic invertebrates that are roughly 0.01 mm in size. Mesozooplankton are larger at 0.1mm, and this most common fraction consists mainly of copepods, while the macrozooplankton are the largest at about 1 cm and include krill, euphausids, amphipods, medusae, and fish larvae. The size distribution of zooplankton is important since they can escape from nets and through meshes so each fraction is collected using different types of gear. The zooplankton of Adventfjorden is influenced by freshwater disacharges and in summer it comprises numerous minute cypris barnacle larvae and the smallest copepod species of genera *Acartia* and *Oithona*, which are all typical for shallow, coastal water sites. At the peak of summer, mesozooplankton density ranges from three to five thousand specimens per m^3 comprising mostly small herbivores. Larger organisms include the 20-cm-long *Beroe cucumis* pink comb jelly which feeds on *Mertensia ovum*, its smaller cousin equipped with two, long sticky tentacles. The herbivorous *Limacina helicina*, or black winged snail, is sighted frequently and is hunted by the beautiful predator *Clione limacina*, also known as the little sea angel. The abundance of larger zooplankters is important since they are prey for juvenile fish, and even seabirds and seals. The carnivorous hyperiid amphipod *Themisto libellula* and the largest pelagic marine herbivore on Svalbard, the shrimp-like *Thysanoessa inermis* euphausid that can reach sizes of 3 cm in length, are all of particular importance. While the densities of these macrozooplankton do not generally exceed a few specimens per m^3, some species can form swarms or shoals or become concentrated by hydrological forcing events such as water turbulence, gyres, and local fronts. These high concentrations of zooplankton are of great importance for the efficiency of the food web.

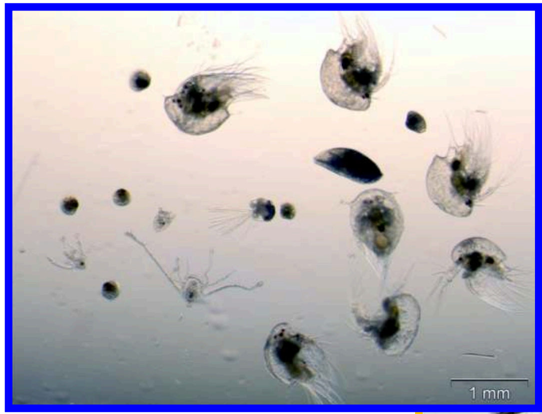




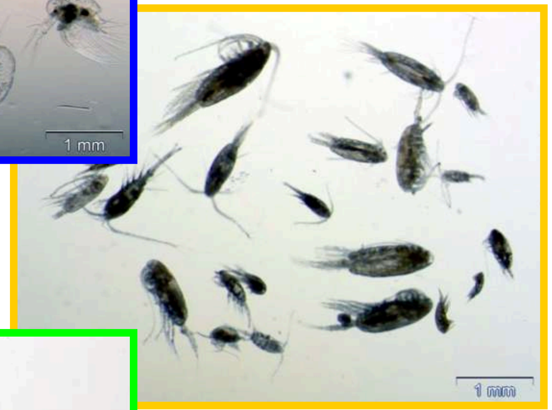
The diagrams present seasonal changes in the zooplankton group biomass (mg dry weight m^{-3}) in Adventfjorden.

Clione limacina - predatory pelagic winged snail.

Representatives of zooplankton groups from Adventfjorden



meroplankton



small copepods

large copepods

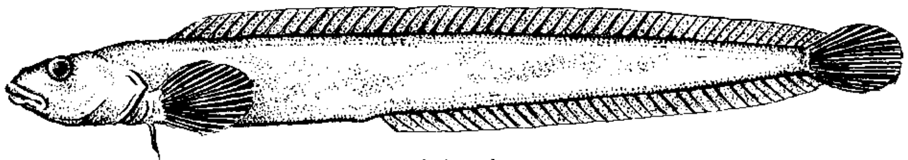
macrozooplankton

Fishes

Approximately a hundred fish species inhabit the Svalbard region, and most of them occur occasionally in Adventfjorden. These large fish are good swimmers that can cover considerable distances during seasonal or lifetime migrations. However, the fish species that are typical for land-locked, inner fjord basins are not numerous. The most characteristic species is *Anisarchus medius*, a small, eel-like fish that inhabits the sediments of the fjord, were several individuals can often be found in a single square meter. Other common, local fish include small, spiny species from the family Cottidae, genera such as *Icelus, Triglops* and *Myoxocephalus*, none of which are more than 20 cm in length. They dwell among kelp or seashells, and they prefer diversified seabeds that provide both shelter and food. The most important of all Arctic fish is the ice-associated polar cod, *Boreogadus saida*, which occurs in Adventfjorden, and occasionally forms large shoals. This small pelagic fish of less than 20 cm in length lives from three to five years, and it is the most frequent prey of seabirds and sea mammals in the Arctic. In recent years, the increasing presence of Atlantic waters has brought species to the Svalbard fjords that used to be rare, but which are now becoming abundant. These fish include the cod, haddock, pollock, and herring. Atlantic cod (*Gadus morhua*) is the most prominent of these species, and large specimens feed on shrimps and small fish near the bottom. Occasionally flatfish, mostly juvenile halibut, are noted. The largest species of fish that occurs in Adventfjorden is the Greenland shark, *Somniosus microcephalus*, which, in Svalbard, has been noted to reach weights of more than 700 kg, although it is not very common in inner fjords.

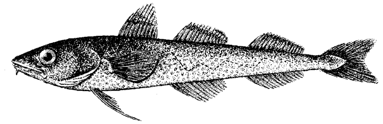
Seabed photo with small *Anisarchus* – a common inhabitant of muddy sediments.

Trophy from Adventfjorden – with the warming of Svalbard, Atlantic cod becomes more common.

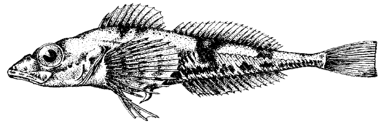


Anisarchus sp.

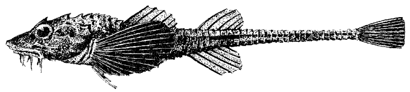
Rereresentatives of fish from Adventfjorden



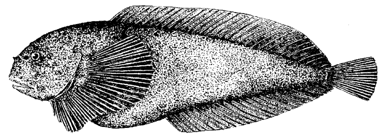
Boreogadus saida – polar cod



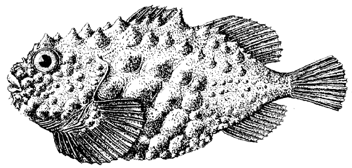
Triglops pingelli – mailed sculpin



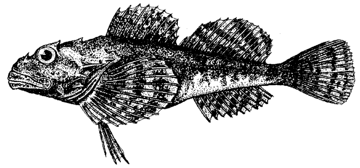
Agonus decagonus – Atlantic sea poacher



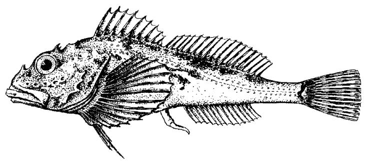
Liparis liparis – sea snail



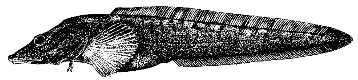
Eumicrotremus spinosus – spiny lumpsucker



Myoxocephalus scorpius – shorthorn sculpin



Icelus bicornis – two horn sculpin



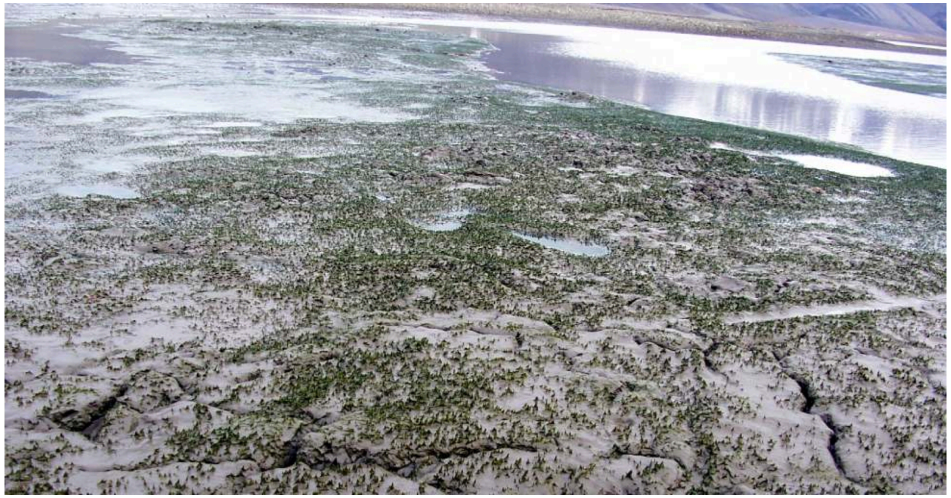
Lycodes seminudus – eelpout

Microphytobenthos

Fjords are more than just their water columns. Fjord bottoms also play roles in the functioning of these ecosystems, even if they are somewhat diminished since the area of light penetrating to the sea floor is smaller than the volume of water. Still, numerous micro-world citizens can be found on fjord bottoms, and wherever light reaches the bottom of the fjords at depths of 20 to 30 meters, microphytobenthos can survive. Microscopic algae and other protists take advantage of solid fjord bottoms as they prevent them from falling deeper into darkness, which has to be the nightmare of all autotrophic organisms. What is more, the constant rain of the remains of pelagic organisms sustain the bacterial community on the fjord floor whose job it is to turn this organic matter into nutrients. Along with light, this is all autotrophic organisms need to live and reproduce. The more primary producers and bacteria there are, the more larger animals there are that feed on this micro-world garden.

Just as in the water column above, diatoms are the most important autotrophic microorganisms on the fjord bottom. You can often see a delicate, shapeless, olive-green coating on wet rocks or in shallow waters; this is most likely comprised of diatoms. Other diatoms form colonies that resemble bushes and can be seen emerged from the water at low tide. This is how these organisms survive cyclical tidal droughts, and this also decreases the chances of being eaten by the numerous animals seeking nourishing, immobile food.

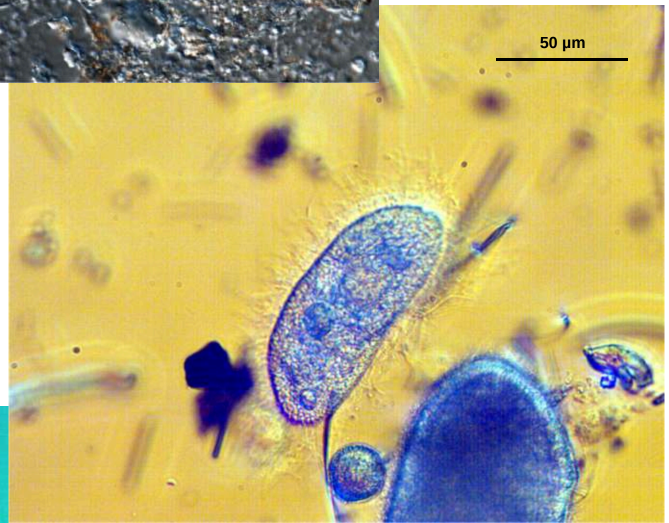
Some diatoms have developed another life strategy; instead of building complicated structures, they grow on macrophytes. Unlike their suspended relatives, which are dependent on the motion of water, diatoms living on the bottom can move actively. Lacking flagella or cilium, they slide on their own secretions that comprise mainly polysaccharides. These secretions are consumed by microbes, which are, in turn, food for tiny flagellates. The latter are then the dinner of ciliates and dinoflagellates, which are the giants of the micro-world measuring in at just under 0.1 mm. These organisms are so large that they link the micro-world with the meiobenthos that are consumed by larger animals. Dinoflagellates have motors in the form of two flagella, which allows heterotrophic individuals to leave the bottom periodically to hunt for prey or to move to locations with better light conditions or higher nutrient concentrations. Cilliates can also move thanks to their numerous cilia, some of which can also be used as hunting organelles. Finally, the mixotrophic euglenids and cryptophytes have to be mentioned, although their roles are much less important.



Clear sign of climate warming – dense mats of colonial diatoms on the tidal flat, Lobgyerbyen, August.

Representatives of microbenthos from Adventfjorden

diatom
Gyrosigma sp.



cilliates

dinophycean
(*Gymnodinium* sp.)

Macrophytes

The most distinctive group of ocean dwellers is the macrophytes. In most cases these very large algae mainly concentrate in shallow, coastal waters. These organisms resemble plants, but they are, in fact, relatives of the tiny, single-cell, microscopic protists described previously. These macrophytes have developed into better organized forms of multi-cellular thalli which increase their ability to compete for resources and thus their chances of survival. While microalgae are hundredths of millimeters in size, these larger relatives range from a few centimeters to a few meters, and even tens of meters when conditions in Adventfjorden are just right. Macrophytes play a much more important role in the fjord ecosystem than do microphytobenthos. These large algae can be compared to terrestrial forests: they provide a supply of organic matter; they produce oxygen during photosynthesis and they bind carbon dioxide. Moreover, dense communities of giant algae provide shelter to smaller animals like crustaceans or juvenile fish. Smaller individuals and some colonial animals grow on larger specimens. Communities such as these can be observed along rocky shores during low tide, where dense masses comprised of various species retain water and protect whole communities from drying out.

Strolling along the coast, especially near the entrance to the fjord, you will notice a lot of small wracks a few centimeters long as well as much larger *Laminaria* spp. and *Alaria* spp. kelp that can reach lengths of two or even three meters. Although they are reminiscent of big leaves with short stems, the only thing they have in common with plants are photosynthetic pigments. Inhabiting depths of three to ten meters, these algae form extensive underwater forests, and a spectacular example of this type of kelp forest is located nearby in the shallows of Bohemanflya on the opposite side of Isfjorden.

In addition to the brown algae the sea deposits on the shore, there are smaller species with shrubby, hairlike, or even bladed red thalli. Thanks to the color of their photosynthetic pigments which permits them to make better use of the sunlight that penetrates the waters, red algae can grow at depths not available to other macrophytes.

When storms and ice scrape algae from the bottom, the detritus sinks into the dark depths of the fjord and supplies bacteria with food, thus supplying larger animals as well. The rest of the plant detritus are washed up on shore where they mix with sediments to form a rather unpleasant, slimy mass. Unappealing as they might be, these depositions are very important for the enrichment of nutrient-poor arctic terrestrial ecosystems. Similarly to other examples, these are first decomposed by microbes, and later are an important source of food for higher trophic levels. This is yet another example of land-ocean coupling.

Rich kelp beds on the stony bottom at Bjorndalen – about 6 m deep.

Representastives of macrophytes from Adventfjorden

Saccharina latissima

Palmaria palmata

Alaria esculenta

Laminaria digitata

Fucus distichus/evanescens

Acrosiphonia sp.

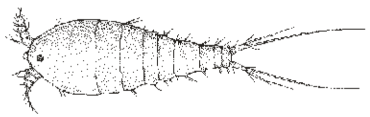
Desmarestia aculeata

Ulva sp.

Inhabitants of the sediment – meiofauna

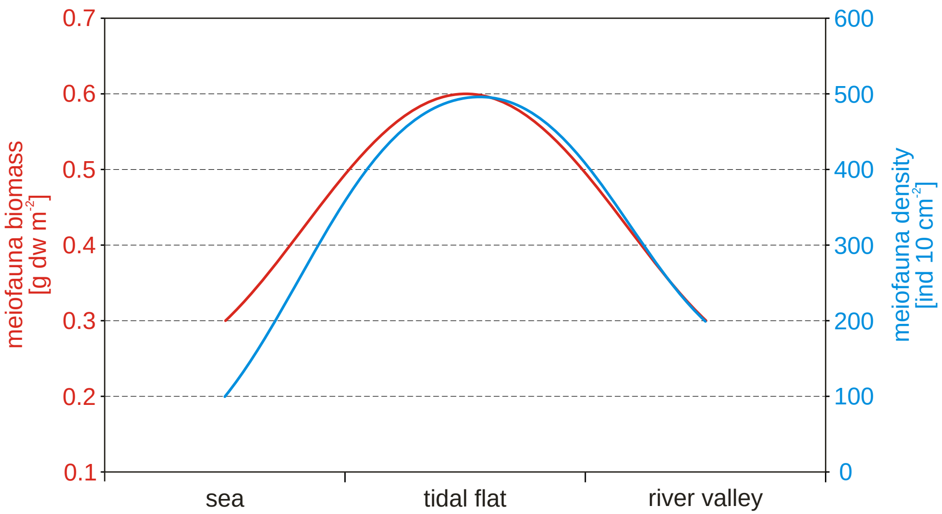
The animals that live among sand grains in marine sediments and are smaller than 0.5 mm are known under the collective name meiofauna. This is a highly variable and diverse category of organisms, from tiny Nematoda to microscopic Tardigrada, which resemble bears. There are twelve major taxonomic groups of meiofauna in Adventfjorden, and the number of local species probably well exceeds two hundred. All of the meiofauna are inconspicuous, almost colorless, and extremely difficult to identify, but they do play important roles as miniature herbivores, predators, and carrion feeders. They interact with microbial life in the sediments and transfer organic carbon to larger animals. The highly permeable sandy and gravel shores of Adventfjorden are dominated by Turbellaria, a suite of small, soft-bodied species, most of which prey on ciliated protozoans. In areas where soft, fine-grained sediments prevail, such as tidal flats, the Nematoda dominate, and several tens of species can be found in Adventfjorden. Minute Harpacticoida crustaceans and the spider-like Halacarida prefer sediments with fine algae fronds since many of these animals are herbivores that prey on the cells of benthic diatoms or suck fluids from larger algae. The densities of meiofauna in coarse sediments range from 10 to 100 individuals per 10 cm^2, while on the rich, soft organic sediments of tidal flats they can reach densities of 10,000 individuals per 10 cm^2.

Nematoda



Harpactoida

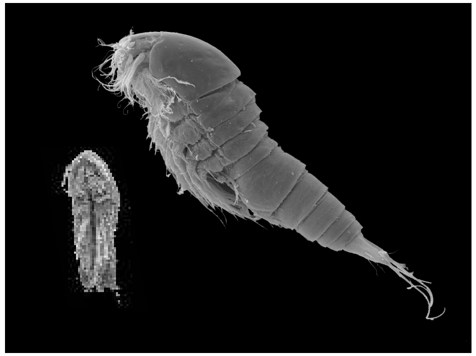
The proportion of worm like minute Nematoda, to crustaceans Harpacticoida in the sample of sediment (N/H ratio) indicates the quality of the environment – worms dominate in oxygen poor and organic rich sites.



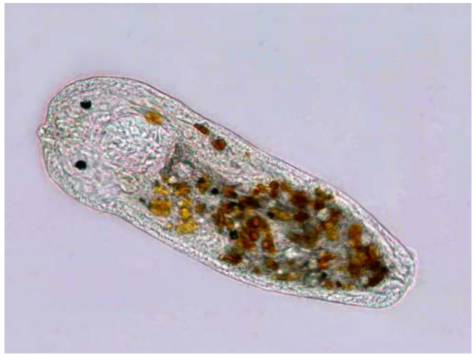
The tidal flat is the richet in meiofauna biomass and density as compared to the adjacent seabed and river valley.

Representatives of meiofauna living in the Adventfjord

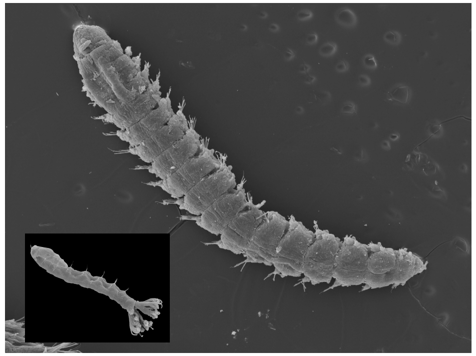
Nematoda



Harpacticoida



Turbellaria



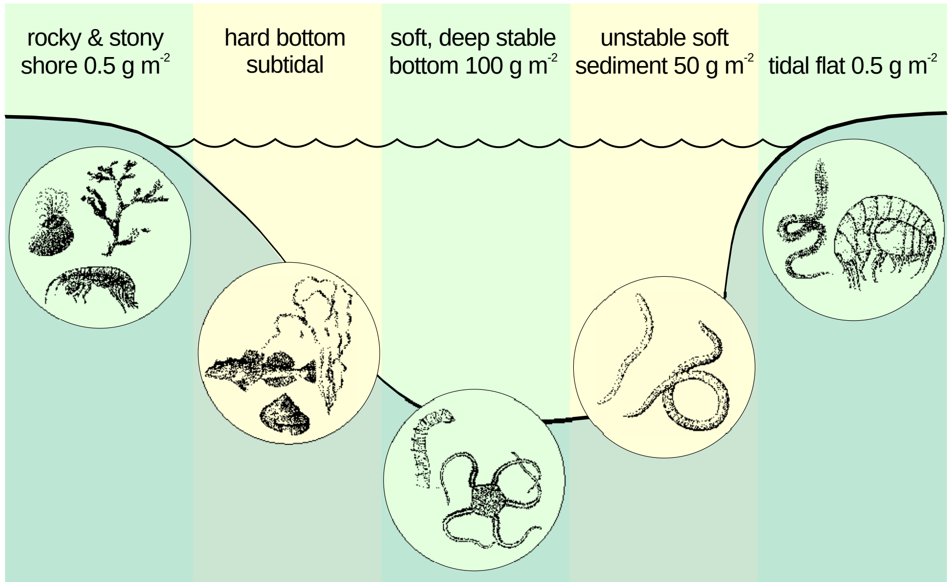
Polychaeta

Tardigrada

Ostracoda

Benthic fauna - macrozoobenthos

The occurrence of animals and algae living on the seabed is primarily connected to bottom type, (i.e.rocks, gravel, sand, or mud) and characteristic assemblages of benthic fauna can usually be distinguished in different benthic habitats (see page 29). In Adventfjorden, the shallowest areas at the edges of sandy tidal flats are occupied by species-poor mixtures of minute polychaete worms and amphipod crustaceans (*Onisimus litoralis*). These animals can withstand the strong fluctuations in salinity that happen during tidal cycles as well as the force of waves breaking on the shallows. Stony or rocky intertidal shallows provide habitats for animals that require hard substrata, such as barnacles (*Semibalanus balanoides*), tiny hydroids, and a variety of filamentous green and brown algae. Numerous amphipods of *Gammarus* spp. can be found under the large stones at the low tide. In shallow sublittoral areas where light permits, giant *Laminaria* spp. and *Alaria* spp. algae, known commonly as kelp, grow to lengths of two meters. A rich and diversified fauna inhabits the kelp beds including small snails (*Margarites helicinus*), crustaceans (*Caprella septentrionalis*), and fish (*Myoxocephalus scorpius*). At greater depths, below twenty meters, the Adventfjorden seabed is muddy, with few or no hard elements. Here, the rich sediment dwelling fauna exists - dominated by delicate polychaete worms and small bivalves that feed on particles of organic matter falling from water column. On steep fiordic slopes, where the bottom is frequently disturbed by massive gravity flows of sediment, mostly small mobile worms persist (*Chaetozone setosa* and *Cossura longocirrata*). Sedentary, tube-dwelling large worms (*Maldane sarsi*, *Pectinaria hyperborea*) can live only in stable sediments of the central deep bottom. Carnivorous snails - tiny *Cylichna occulta* and large *Buccinum undatum* are also common on the Adventfjorden seabed. Large echinoderms (e.g. brittle star *Ophiocten sericeum*) are most conspicuous representatives of benthic megafauna occurring in the fjord.



Cross section of Adventfjorden showing the occurrence of typical benthic assemblages and their biomass (g wet weight per m^2).

Representatives of macrozoobenthos from Adventfjorden

Harmothoe sarsi – carnivorous scale worm

Onisimus litoralis – typical crustacean for tidal flats

Cossura longocirrata – small detritophagous worm

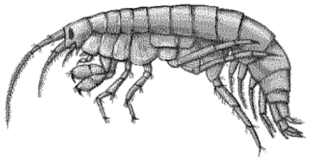
Cylichna occulta – small, common snail

Pectinaria – detritophagous worm, abundant in stable areas

Buccinum undatum – large carnivorous snail

Indicator species

A number of plant and animal species have very narrow ranges of tolerance to environmental conditions. Some are most sensitive to a single factor like salinity or temperature, while many others are linked strongly to complexes of features typical of specific water bodies such as Atlantic waters, Arctic waters, or local coastal waters. Over the course of a given year and under the influence of inter-annual variability, different water masses appear for shorter or longer periods in Adventfjorden. This is why observations of marine animals can tell us a lot about the prevailing hydrographic conditions. The rarest in this area are true Arctic waters. These occur occasionally in late spring, when, following heavy ice winters, remnants of ice pack from the Barents Sea are taken up by coastal currents and enter Adventfjorden. The indicative species of this phenomenon is *Gammarus wilkitzkii*, which is a large, delicate, ice-associated amphipod up to 4 cm long. It is easy to spot these creatures as they cling to the ice undersurface. The inflow of Atlantic waters is indicated by the presence of the conspicuous 3-cm-long krill, or euphausid, species *Meganyctiphanes* and by the tiny winged snail, *Limacina retroversa*. Species that indicate distinct water warming trends include the thermophilic blue mussel from the genus *Mytilus* that reappeared in the Svalbard region in 2005 after an absence of over 1,000 years. *Ascophyllum* spp., which is a characteristic kelp species from Northern Norway, is found occasionally on the shores of Isfjorden and Adventfjorden, but these are most likely detached fronds that drifted all the way from mainland Norway, and they have probably not yet established populations in the Svalbard area. Species frequently occur in pairs; one closely-related species prefers cold, less saline waters of the Arctic type, while the other prefers warmer, more saline waters of the Atlantic type. For example, a common crustacean inhabiting the littoral zone of Adventfjorden is the cold-water *Gammarus setosus*, while its twin species, the Atlantic *G. oceanicus*, occurs at the entrance to Isfjorden, and is noted to be moving slowly towards the inner part of the fjord each year.



Gammarus – three sibling species occur on Svalbard, indicating different water masses.

Ascophyllum nodosum – fragment found near Longyearbyen, common species in Northern Europe, might soon establish populations on Svalbard.

Mytilus edulis – common in Northern Europe, newly established on Svalbard after a long absence.

Benthic habitats

A habitat is basically the "home" of a species, and it provides all the specific physical features needed to sustain living populations. It is widely understood that protecting varied habitats is the key to successful species protection because many species can only survive in specific habitats. The more diverse habitats are, the higher regional species richness is expected to be. European marine habitat classifications include over sixty types of seabed, and several of these can been found in Adventfjorden. Habitat classification is hierarchical, and the first denominator is the type of seabed (rock, sand, mud, etc.), the second is depth, followed by light, and so on. A precise example of the classification of a habitat is as follows: “stony bottom, between depths of 2 and 20 m, full marine water salinity, overgrown with large brown algae". The majority of the Advenfjorden seabed can be classified as covered by glaciomarine mud, below the euphotic zone, at depths of 20-80 m, exposed to strong sedimentation, under the influence of ice seasonally. Only in the outer parts of the fjord the hard bottom habitats can be found. In addition to physical features, organisms themselves can play the role of "home" for other species. These are commonly known as habitat builders or ecosystem engineers. A typical example of these are encrusting, long-lived species that build erect structures that can be used for shelter or resting by other species. Such three dimensional structures are formed by moss-like colonial Bryozoa and bushy Hydrozoa, or by clumps of bivalves and barnacles and by the root-like structures of kelp rhizoids.

Soft muddy bottom, center of Adventfjord

Sandy and gravel bottom near Bjorndalen

Sample of fauna from diversified bottom near Hotelnesset – sea urchins, snails, and barnacles among stones

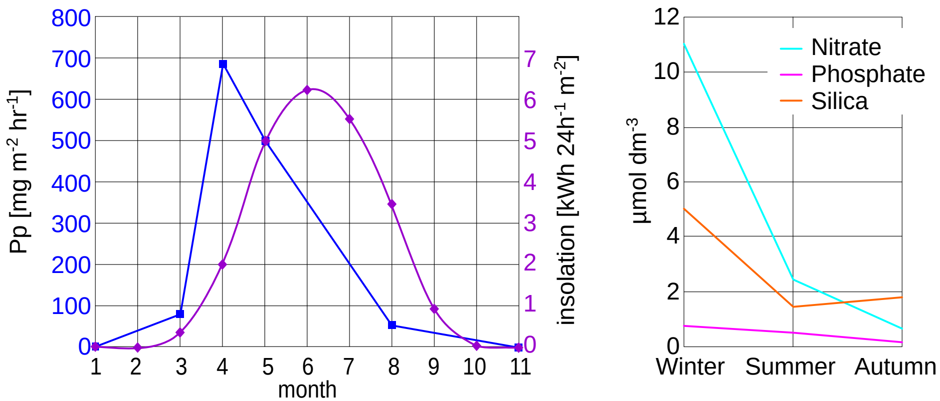
Rocky bottom within the euphotic zone near Grumant

Primary production

The importance of autotrophic organisms has been emphasized previously in this booklet. In fact, with their abilities to transform sunlight into energy and carbon dioxide and inorganic nutrients into organic matter, they actually run whole ecosystems. This name of this process is photosynthesis, or primary production, from the perspective of ecology, and it supports life on earth, with some rare exceptions, by binding the energy of photons into particles. Although the biomass of marine algae is only 1% of that of terrestrial plants, nearly half of global primary production, or 105 billion tons, takes place in the seas. In the Arctic, where terrestrial plants are rather tiny, marine primary production is relatively much higher: about 1.51 billion tons of organic carbon is produced in the Arctic seas annually as compared to the global annual tundra carbon production of just 0.81 billion tons.

Autotrophic organisms produce from 4 to 180 grams of organic carbon for each square meter of fjord water surface area that is penetrated by sunlight. Although the sun shines throughout the day in the Arctic in spring and summer, sunlight is limited. Here in the vicinity of Longyearbyen at a latitude of 77ºN, the sun dips below the horizon on October 26, and the first, weak rays do not reappear until January 29. From April 19 until August 23, Longyearbyen enjoys the midnight sun. This seems to be the perfect situation for algae, but it is not so simple. Even during the summer solstice, the maximal height of the sun over the horizon is only 35º Sunlight dissipates as it enters the atmosphere, and the majority that reaches the water surface at such a sharp angle is deflected so a relatively small amount penetrates the sea surface and can be used by marine autotrophs. This means that intense primary production does not begin before the sun reaches its highest position over the horizon, but when it does finally happen, the rate of organic matter production is enormous and can be as high as 115 mg of organic carbon per hour. As nutrients are depleted, primary production slows, and by summer the rate drops to 10 mg m^{-2} per hour. Such great differences are also linked to limited sunlight penetration caused by increased concentrations of suspended mineral particles released by melting glaciers.

Primary production also occurs at the sea bottom in sunlit areas. The most effective producers are macrophytes, and with annual production rates of up to 1 kg per square meter, macroalgae surpass planktonic communities. On the other hand, despite their high production rates, benthic autotrophs contribute a small share to the overall carbon production since they are bound to the bottom, while plankton inhabit the whole water column. The same situation applies to microphytobenthos. There is, however, one exception. A phenomenon occurs in the polar zones called inverted bottom. This is when the bottom surface ice cover is inhabited by a specific form of microphytobenthos called sympagic algae. Their production is the first dose of nourishment after the winter starvation period.



Seasonal run of primary production (g C m^{-2} day^{-1}) against a background of nutrients and light level.

Trophic net

The most important connection among species inhabiting any area is the food web, or the network of predators and prey. The foundation of these relations are the green, autotrophic algae, which are organisms that convert solar energy into organic compounds. Pelagic primary producers that include diatoms and other microalgae groups produce about 80 g C m^{-2} annually in Adventfjorden. This is the amount of organic matter that is available to herbivores, the animals that graze on minute algae both in the water column and on the seabed as the algae slowly sink down. The small size of the marine pelagic plants determines the size of the herbivores; thus, they are all small since no large animal can feed on plants that are smaller than a millimeter in size. Most of the Adventfjorden herbivores are copepods, of which there are several species ranging in size from 1 to 5 mm in length, and the largest are krill that are three centimeters long. The next step in the food web is occupied by the carnivores, and this includes all those that can catch small herbivores such as pelagic amphipods, winged snails, comb jellies, and juvenile fish. Next come the larger carnivores that prey on the smaller ones, such as fish, seabirds, and seals. The top predators include large glaucous gulls, skuas, polar bears, and killer whales, but except for the gulls, this group is not very common in Adventfjorden. One of the significant features of the food web is the 90% energy loss that happens at each level. For example, to produce 1 kg of herbivorous copepods, the system must provide 10 kg of algae, and this amount of food will sustain 0.1 kg of fish or 0.01 kg of seal. Algae that falls through the water column to the seabed in late spring provides fuel for worms, bivalves, and sea stars that are preyed upon by flatfish, wolfish, and bearded seals. Finally, all living organisms die and decompose with the help of bacteria and fungi. This is how organic mater cycles, and the basic elements are utilized again in the cells of minute algae.

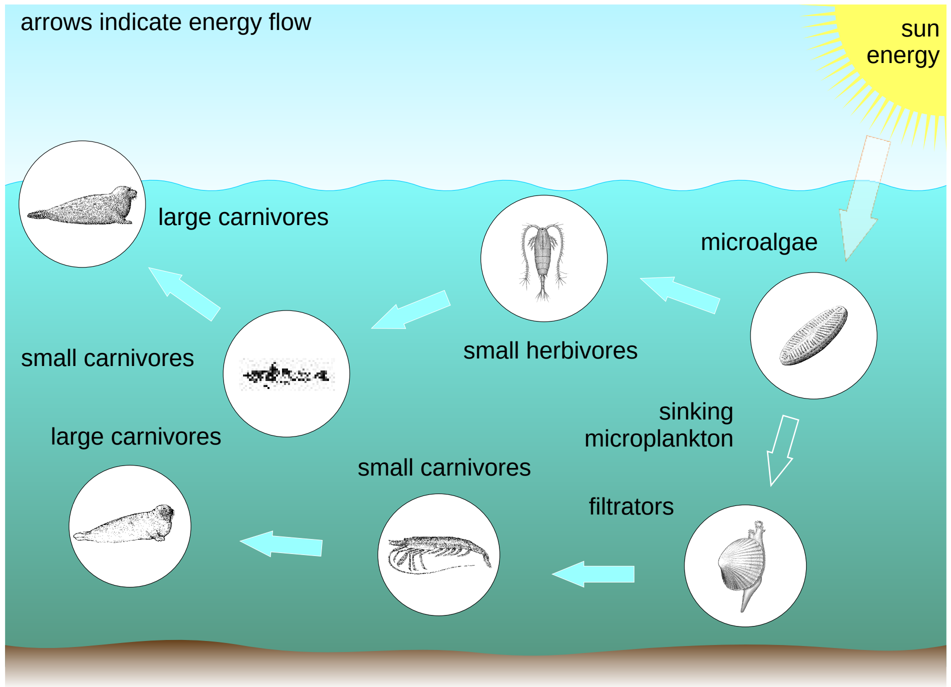


Diagram of the trophic net in Adventfjorden.

Sea uses in Adventfjorden

The environment is regarded as a source of goods and services, but these are no longer viewed as "free". Assessing the value of the marine environment is difficult, and it can be done differently. The first is economic assessment; this determines the monetary value of goods, such as the quantities of fish landed and sold from a given area, and services, such as the amount of money earned from tourists visiting a certain place. The second is socio-cultural assessment, which evaluates the importance and strength of people's feelings, beliefs, and emotions connected to a given area. The third is biological assessment in which the naturalness and integrity of nature is assessed without reference to human uses. The most obvious uses of Adventfjorden are for shipping and harbour facilities, but these uses have little to do with environmental quality since both harbor and transport activities can be conducted in degraded environments. On the other hand, tourist traffic is highly sensitive to environmental quality, and simultaneously it generates a substantial portion of local wealth. The socio-cultural value of Adventfjorden is difficult to determine without targeted research. The assessment of the biological value of this area is, on the one hand, based on the pristine quality of the area, and most of Adventfjorden is heavily impacted by municipal waste discharges, and, on the other hand, the biodiversity and complexity of marine life. Hence, the most biologically valuable algae assemblages are the rich ones at Revnesset, while the species-poor tidal flats near roads and other infrastructure, which appear to be unattractive biologically, are very important for the rich supply of food they provide to small waders during spring and fall migrations.

Adventfjorden is locally important for small water sports like kayaking and windsurfing.

Tidal flat are important seasonally as feeding ground for waders.

Threats and protection

The threats facing Adventfjorden are linked to the growth and industrialization of the area. As Longyearbyen expands and receives more tourists, increasing amounts of untreated wastewater are discharged into the fjord. The simultaneous increase in nutrients from wastewater discharge and warming in the area could lead to local eutrophication that could cause the development of microbial mats, blue-green algae, and potentially toxic algal blooms. Industrial development carries risks of fuel spills from land reservoirs or ships. The cold environment here with its slow microbial activity impedes the natural self-cleaning abilities of the sea. Oil spills persist longer on sand and gravel covered seashores because the sponge-like permeable sediments soak up oil and prevent it from weathering. Rocky shores are less vulnerable since wave action, wind, and sun light process substantial parts of spills. Habitat loss is another threat, and mechanical disturbances like sediment replacement, underwater constructions, and other activities that can compromise the natural occurrence of marine habitats are especially dangerous.

In many marine areas around the world, there is widespread concern about alien or invasive species that are not native to or common in a specific location. In an Arctic harbour like Longyearbyen, ships can potentially introduce aliens species that are either attached to hulls or living in ballast waters. Alien species are often transported as eggs, larvae, propagules, or other forms resistant to dispersion. The Arctic poses great challenges for non-native species, so only the most flexible, tolerant species will take hold here. However, despite the apparent warming of the area, increased transport of Atlantic water masses, and increased shipping traffic to Longyearbyen, there is still no scientific evidence of invaders in Adventfjorden. Occasional sightings of boreal species that have drifted from their southern home ranges are not considered to be alien invasions, and such specimens, usually singletons, are not able to establish populations. As climate change continues over time, more species from the south will certainly colonize Svalbard, but this will be geographical regime shift, and not invasion.

Fast growing number of tourists and locals in Longyerbyen increases the pressure on marine environment through wastewaters.

Practical guide for marine life observers

Amateur monitoring of environmental change and variability is both great fun and very helpful to science. There will be never enough scientists to note all the rare animals and unusual sightings or to perform basic observations over vast areas. The keys to useful environmental observations are orientation in time and space and the documentation of events. The availability of digital cameras and GPS makes meeting these requirements a lot easier. Two types of information are of scientific significance. The first is the documentation of all unusual animals, plants, or animal behavior. This includes sightings of cranes or swallows in the Svalbard region or rare sea mammals be it the narwhal, the Greenland whale, or the blue whale. This type of information is always considered to be important and is collected by the Norsk Polarinstitutt. The second type of useful information comes from simple, repeated exercises performed with the same methods. A typical example is the measurement of sea ice thickness in tidal flats; this is seemingly very simple data, yet when measurements are repeated in the same place throughout a winter and then repeated in subsequent years, these data provide information on the variability of one of the key environmental factors in the Arctic ecosystem. Other examples include water transparency measurements, reports on the timing of algae blooms, reports of animals washed ashore, etc. (see table below). Many of these observations are relatively simple, and the main challenge is the frequency of observations and continuity required, and since no research institute can conduct such extensive, frequent sampling, volunteers become indispensable. One example is water transparency monitoring. Since light is the basis for the growth of algae and higher plants in the water, the more turbid the water is, the less light reaches the sea bed. This is why water transparency is one of the key environmental characteristics that permits assessing conditions for photosynthesis. In deeper, calm waters a simple device called a Secchi disc is used to monitor water transparency, while in shallow, turbid waters the cylinder described below is more handy.

Amateur observations, such as this photo can supply important biological information: this anchor was submerged for one week in May, near Longyearbyen harbor, during this time, the carnivorous snail *Buccinuum undatum*, laid cocoons of eggs indicating precisely the timing of its breeding in Arctic waters.

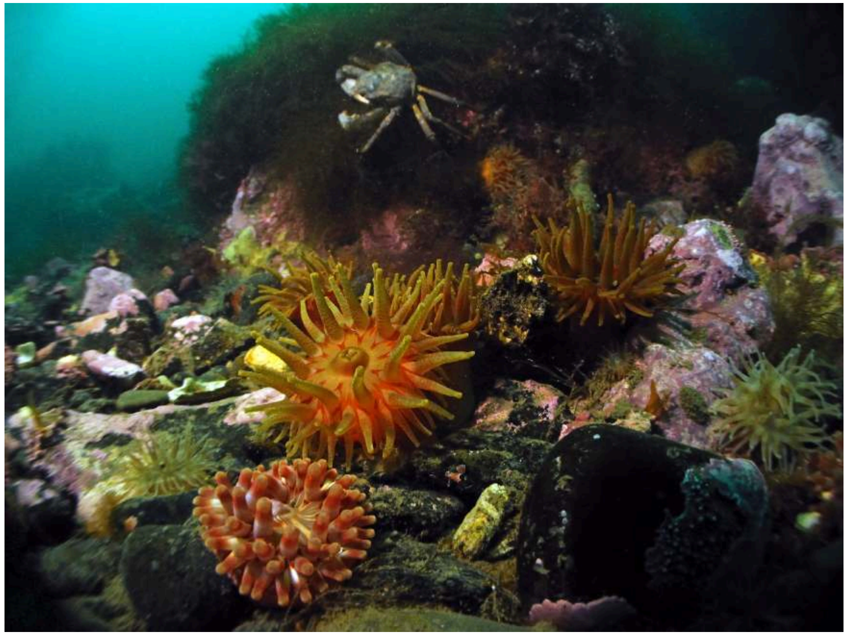
1. A Secchi disc 20 cm in diameter with a distinct black and white pattern is submerged in the water until it disappears from sight. The disc is then lifted towards the surface until it is visible. The depth at which the disc disappears from sight is noted.

2. The cylinder method is an alternative to the Secchi disc. Fill the glass or plastic cylinder with water. A black and white pattern is placed at the bottom of the cylinder, and the height of the water column is noted when the pattern is no longer visible.

Examples of marine environment observations

Object	What to measure	How (note date and location)
Fast ice	Thickness	Over the cracks or specially made holes in tidal flats – SAFETY FIRST!
Primary production	Intensity and timing	Note when the water in spring turns green, and when the color disappears
Zooplankton	Prominent or mass species	Note the presence of indicator species when you see them from piers or boat
Littoral zone	Presence and cover of algae at the low water mark	Find rocks or large stones that are exposed to air during low tide, note the % coverage of algae
Water transparency	Amount of fine suspensions in water	Submerge a white disc and note the depth at which it disappears
Wintering birds	All birds that appear between November 1 – February 28	Note species, and location
Feeding birds	All birdsfeeding during low tide in tidal flats	Note, species and how many birds are feeding
Surface water temperature, pH salinity	Temperature in ºC	Measure temperature of surface waters directly or from the bucket of water collected at the shore

Adventfjorden underwater landscapes
by Piotr Balazy



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