Introduction

Ice environments are not typically associated with biota due to the harsh, cold, nutrient poor environment found in such regions. Nevertheless ice sheets, glaciers and permafrost have been proven to harbor microorganism ecosystems varying in diversity, structure and function. Glacial biology and the development of ecosystems within ice is a relatively new area of research, one which is proving to be significant due to the discovery of various effects of microbial life on the glacier itself both physically and chemically. Structure and movements of biotic communities at polar and alpine altitude may also give early indication to climate change, the global nutrient cycle along with insight to potential connections of life in ice on other planets. In this presentation various glacial habitats in which life can be found are discussed along with case studies in the area of Svalbard and Antarctica. In addition to this, permafrost and it’s biological significance is examined.

1. Ecological environments in glacial milieus

- Two major glacial ecosystems: supraglacial (on glacial surface) and subglacial (interface glacier – bedrock). Additionally, proof of life can be found inside the glaciers (englacial) and in the vicinity of them (periglacial).
- These ecosystems may show great differences in water content, pressure, temperature, solar radiation, nutrient supply, redox potential and pH.
- Different physical/chemical conditions means different forms and abundances of life.
- Key for life: liquid water!
- Where can we find water in a glacier? - Depends most importantly on
  - Thermal regime (cold/temperate). The three key areas were melting creates water are the snowpack, the glacier surface (shortwave radiation/ latent heat) and the glacier bed (frictional/adveected/geothermal heat). Surface and bed are also important because of the potential nutrient supply from snow/sediment/gases and bedrock, respectively.
  - Hydraulic conditions. Crevasses and moulins distribute water and nutrients throughout the glacier and link surface and bed of the glacier. The bed under the snowcovered upper part of the glacier (poorly aerated, inefficient drainage) provides better conditions for microorganisms than the well aerated, highly dynamic system in the lower part of the glacier.
**Life In Ice**

**Figure 1. Glacial development, habitats and localities.**

### a) Supraglacial milieu

- **Important habitats:** snow cover, glacial ice, cryoconite holes, moraines and surficial streams and ponds.
- **Snow cover ecology:**
  - phototrophic organisms (snow algae and cyanobacteria fixing N and P)
  - heterotrophic organisms: *Proteobacteria, Actinobacteria* etc. degrading organic compounds in snow -> influence on carbon cycle
  - Which organisms are more important may vary with temperature and season
- **Ice ecology:**
  - Algal mats (photosynthesis)
  - Debris as a nutrient supplier significantly enhances biological activity
- **Cryoconite holes (figure 2):**
  - See *Svalbard* for further details
\textbf{b) Englacial milieu}

- Extreme conditions: high pressure, no light, low temperature
- However, organisms found in ice cores
- Habitats: walls of crevasses and moulins; interstices and grain boundaries (up to 2\% interstitial water in glacial ice); hydrated mineral surfaces (~10nm thick water layer at 0°C)
- Organisms: chemoautotrophic and heterotrophic bacteria; viruses
- Substrates: hydrated minerals, dissolved organic matter

\textbf{c) Subglacial milieu}

- Habitats: The "channel marginal zone", i.e. the water-saturated till at the rock-ice interface; subglacial lakes
- Ecology of the ice-rock interface:
  - Largely dependent on the geometry of the drainage system: aerobic processes near channels, changing to anaerobic processes (for example, denitrification, methanogenesis) further away
  - In general a vast variety of different bacterial taxa (chemoautotrophic and heterotrophic)
  - Metabolisms supposedly based on oxidation/respiration of organic matter, NO$_3^-$, SO$_4^{2-}$, S, Fe(III), Mn(IV)
  - Substrates (C, N) come from supraglacial meltwater, bedrock, C from viral lysis of bacteria
- Ecology of subglacial lakes:
  - See \textit{Lake Vostok} for details

\section*{2. \textbf{Lake Vostok}}

Lake Vostok is a subglacial lake in the Antarctica beneath an ice sheet.

\textbf{Characteristics:}

- length: 250 km north to south
- width: 50 km east to west
- depth: >800 m;
- overlaying ice sheet: 3620 m
- ice thickness: in the north: 4300 m; in the south: 3700 m
- covered by ice: circa 25 million years
- mean age of lake water: 1 million years

\textbf{Origin:} probably tectonic origin:

- depth > 800 m
- support rich mineral fluid flow

\textit{Figure 2. Location of Lake Vostok.}
steep, rectilinear morphology

distribution of most subglacial lakes in Antarctica: in old active tectonic basins or inactive and weakness structure zones

**Water circulation** 2 theories:

- *salinity water*: vertical and horizontal variation of salinity -> salinity comes from accreted water
- *pure water*: geothermal heating on the ground. motion caused by different temperature layers therefore different density

Independent from both theories, ice melts in the north and flows to the South before it refreezes.

**Conditions for living at Lake Vostok:**

- No input from the atmosphere
- Absence of light

**Forms of ice at Lake Vostok**

- Glacial ice
- Accreted ice

**Results of research**

- Life in total isolation
- Life in form of cells in both kinds of ice
- Theory of evolution and 2 theories of origin
  a.) Vostok as relatively unproductive and undistinctive system
  b.) Vostok as a unique evolutionary system

- Effect of water circulation

**3. Svalbard**

**Brief overview**

Svalbard is a group of islands situated between 74° - 81° N and 10° - 35° E (Figure 3). They cover a total area of 63 000 km² which 59% of is covered by glaciers (Liestøl, 1993). The hostile climate of Svalbard with low temperatures, lack of precipitation and low nutrients in soil proves for a very harsh climate with only 6-7% of the land-area covered by vegetation. Svalbard is covered by more than 2,100 glaciers with most common types being valley and cirque glaciers, together with several large ice caps (Liestøl, 1993). Several microorganism species have also adapted to living on glaciers and endure extreme cold, periods of lack of nourishment and the lengthy Arctic nights.
Supraglacial – cryoconite holes

Particular field of research covered specifically in Svalbard includes that of supraglacial deposits and the habitats created to harbor various forms of microbial life. The habitats in which life is found include cryoconite holes, medial moraines and kames (mounds of sediment deposited on the front of a melting glacier). Regarding physical and chemical characteristics cryoconite holes are the most distinct of the glacial habitats studied in Svalbard (Kastovska, 2005). Cryoconite holes are cylindrical melt holes filled with water and sediments which are created when windblown material lands on the glacier and promotes melting in the area due to its relatively low albedo (Figure 4). This material then accumulates to formed dark coloured sediments referred to as cryoconite. Cryoconite sediments play an important role in glacial ecosystems as they are one of the most suitable habitats for development of microbial communities (Kastovska, 2005).

The species found in these areas are considered opportunistic organisms with wide ecological valency (Stibal, 2006) and a strong colonizing potential as opposed to organisms which have evolved to be purely "glacial specialists". Differing chemical and physical properties of Svalbard supraglacial habitats favour diverse microbial communities including bacteria, cyanobacteria and algae. These properties include pH, texture (grain size), concentration of organic matter and available nutrients.

The sources of microbial cells on most glacial surfaces are considered to be carried in by local aquatic and terrestrial habitats (Stibal, 2006), however in the case of Svalbard it is soil carried in by snow which populates the snow on glacier surfaces.

Periglacial soils

Soils in polar regions are subject to extreme environmental stress with harsh climate and freezing temperatures. Studies in Svalbard have shown that not only supraglacial but also periglacial habitats provide living space for numerous organisms (Kastovska, 2005). Periglacial refers to locations in the rim of glacial areas. These areas are not buried by glacial ice but are subject to intense freezing cycles and erosion characteristics.
Figure 5 illustrates areas in which samples have been taken including newly deglaciated barren soils and vegetated soils with vascular plants and mosses. Recolonisation of newly deglaciated soils is one of great interest. Not much is known about primary colonizers but the succession of plant community depends on cyanobacteria, algae and bacteria development within the soils.

Similar types of microbial communities have been found in supraglacial and periglacial habitats which indicates the ability of cells to survive on or within the ice before taking part in the recolonisation processes of newly exposed soils. Although the types of microbial communities are similar between cryoconite holes and newly deglaciated sediments, the structure of these communities are quite different due to physicochemical parameters.

**Significance of studying life in supra and periglacial environments**

Variations of population distribution and abundance help predict early signs of global warming. Initial effects of global warming on biotic communities are most likely to be manifest at high latitudes as they are more sensitive ecosystems compared to that at the tropics or other regions.

4. **Life in Permafrost**

**What is Permafrost?**

Permafrost is frozen ground that remains at or below 0° C for at least two years. It represents 26% of the terrestrial soil ecosystems and can extend hundreds of meters laterally and up to 1,000 m into the subsurface. Seasonal temperature fluctuations affect the soil very weakly, just the first 10m of the ground experience a difference of ~1° C. During summer the air temperature can rise above 0° C and a thin layer of the permafrost is going to thaw. This layer is called the active layer and can reach depth up to 2m in lower latitudes.

**Conditions**

The conditions in permafrost are very harsh to form life. Depending on the geographical location the temperature can range from 0° up to 27° C and the pH, with exception of the Antarctic permafrost – soils, is almost neutral. The reduction potential ranged from +40 to -256 mV, which indicates a rather reducing environment (negative $E_h$ – values) and the salinity of the sediments is about 5-7%. The composition of the pores within the permafrost is similar to the atmosphere.
composition, but with higher amounts of \( \text{CO}_2 \) and \( \text{CH}_4 \). The permafrost itself offers mainly an anaerobic environment, but sometimes also microaerophilic or aerobic. Even though the temperature is below zero, liquid water is present within the permafrost. This is caused by adsorption forces and can lead to a very thin water film surrounding soil and ice. However, this film is too small to carry microorganisms, but is essential for nutrient flow and prevents destruction of the organism by ice crystal formation. In conclusion the conditions are very rough, but stable.

**Life in Permafrost**

In order to detect life in permafrost it is extremely necessary to prevent contamination during the drilling and the measurements. Another problem of detecting life in permafrost is to decide if an organism was alive in situ or if the detection is caused by the good preservation potential of ice. We also have to consider the “state of life” of an organism. Depending on the rate of metabolism it can be alive, stagnant or dormant. In arctic samples viable cell recovery of dormant organisms is about 0.1 to 10%.

Nevertheless, due to the hard conditions the life in permafrost stays rather simple and is less than 1μm. Microscopic observations showed mainly bacteria like:

- *aerobic heterotrophs*
- *anaerobic heterotrophs*
- *methanogens*
- *iron reducers*
- *sulphate reducers*
- *nitrifying bacteria*
- *nitrogen fixing bacteria*

but also recoverable eukaryotes could be found:

- fungi spores
- green algae
- plant seeds
- yeast

To distinguish if a microbial community was biologically active or not, we have to know the limit of microbial life. It is known that microbial reproduction has clearly been demonstrated by an Arctic sea ice bacterium at – 12° C and with bacterial growth examination at about – 10° C. A clear distinguish method is obtained by microcosm radiotracer analyses and novel fluorescent microscopy techniques. Indigenous microorganisms in Siberian permafrost were able to incorporate \(^{14}\text{C}\)-labeled acetate into lipids at a temperature range from -20 to 5° C. The rate of incorporation dropped significantly at – 1.5° C. The detection of the \(^{14}\text{C}\)-labeled acetate could therefore indicate the temperature. The biomass (either dormant or active) of the eukaryotes can be up to ten times higher than the mass of prokaryotes.
Why should we care?
Life in permafrost is a reasonably unexplored field and offers a lot of study. The nutrient flow within the permafrost caused by microorganisms was never taken into account at the global nutrient cycle and could have a big influence if we consider the mass of permafrost. Biochemical processes under cold conditions could offer new biotechnological applications (cold – adapted enzymes). Recent hints of massive permafrost amounts under the surface of Mars makes it even more interesting to study the permafrost on earth. The better we understand our permafrost, the more we can understand extraterrestrial permafrost environments.

Conclusion
Microbiological activity in the glacial system is quite diverse and, at least in places, abundant. Yet, the subject is just scratched superficially and there needs to be done more research done as many things are not yet understood/considered including:

- Influence of bacterial activity on melting of glacial ice (albedo effects, metabolic heat)
- Influence of glacial ecosystems on biogeochemical cycles of N, C and P
- The role of viruses in the glacial ecosystem (are pathological viruses which have been entombed in the glacier for thousands of years a threat to mankind?)
- Impacts and prediction of climate change on sensitive ecosystems
- Possible extraterrestrial life in connection with ice?

References:

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