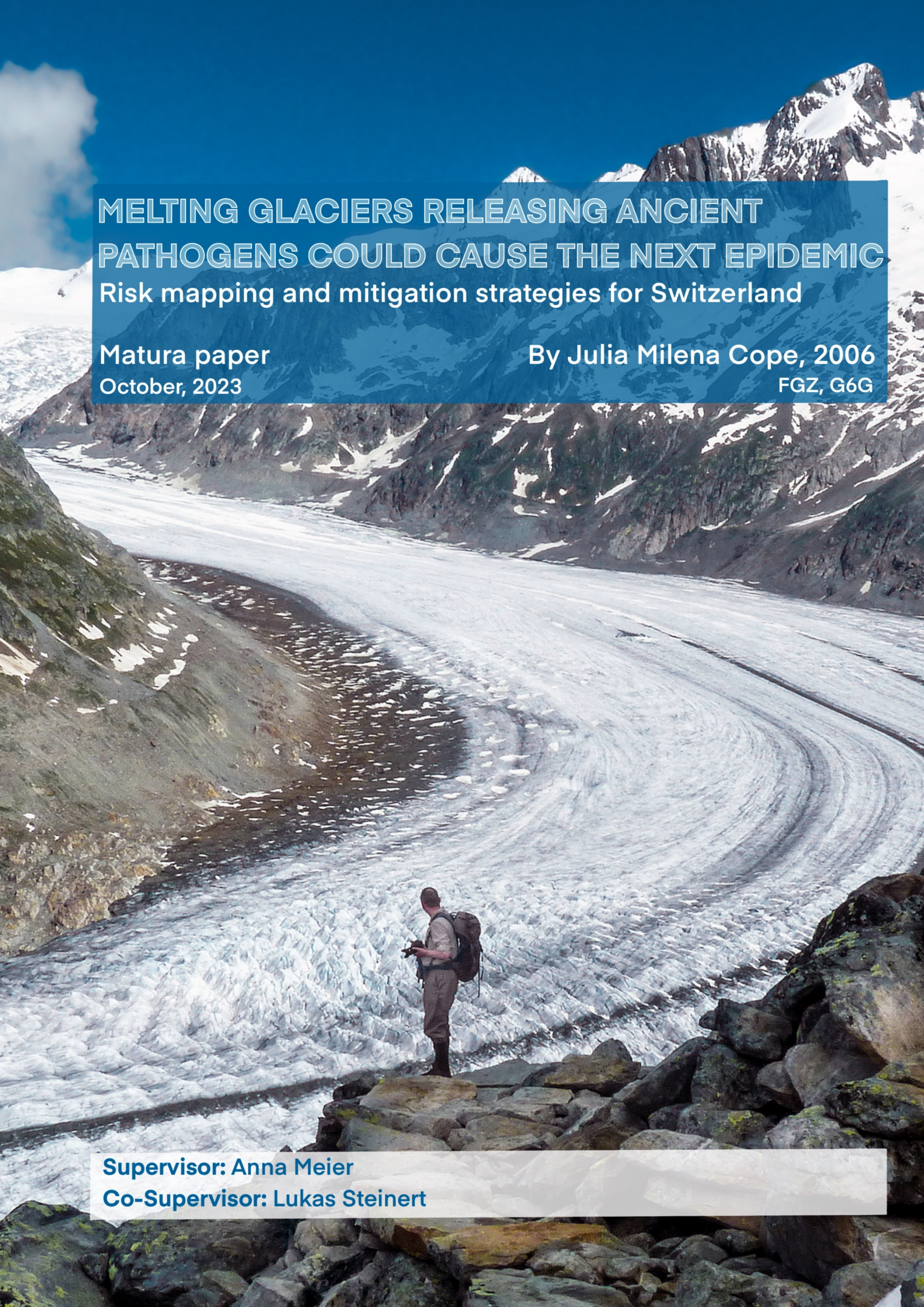

MELTING GLACIERS RELEASING ANCIENT PATHOGENS COULD CAUSE THE NEXT EPIDEMIC

Risk mapping and mitigation strategies for Switzerland

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1. INTRODUCTION

Storytellers have been describing the apocalyptic outbreak of dangerous diseases from melting glacial ice for decades. These stories were classified as science fiction and never taken seriously by scientists. But recent scientific studies have shown that the significant volume of ancient microorganisms released into communities present substantial risks (Strona et al., 2023).

Environmental change is moving from a theoretical concept into reality. Humans are emitting billions of tons of CO2 and other greenhouse gases every year. These gases are heat-trapping and augment our earth's greenhouse effect. This causes atmospheric warming, starting a domino effect impacting many ecosystems worldwide. One of the most concerning impacts is on the cryosphere, the part of the earth that is frozen. Our glaciers and major bodies of ice are melting at an alarming rate, including the ones here in Switzerland.

Within the melting ice, scientists have discovered an unprecedented volume of ancient microbes that were previously trapped, and to which we are now being exposed. Estimates suggest that up to 4 sextillion (10^{21}) microbes are being released annually from the melting cryosphere (Yarzábal et al., 2021). Even though the vast majority of microbes are not harmful and only a small percent of all microbes are disease-causing, the vast scale of the released microbes makes the occurrence of an ancient and deadly disease-causing agent a substantial danger.

This paper analyzes the danger of human diseases for the population, originating from disease-causing microbes released from melting glacial ice in Switzerland, and defines potential mitigation strategies to determine concrete measures that can be taken. In defining danger I use the Cambridge dictionary definition: „the possibility of harm to someone“ (www.dictionary.Cambridge.org). My analysis of the danger will be to relay what that danger is and to identify where it is of most significance. As a mitigation strategy I understand a „risk handling strategy used to lessen the likelihood and/or consequences of a risk“ (www.directives.doe.gov, 2011), which is slightly adapted from the United States Department of Energy's definition. I will be introducing a mitigation strategy that aims to raise awareness, prevent, and prepare for such an outbreak occurring.

In the chapter following this introduction, I introduce glacial bodies and how they are affected by climate change, including glaciers in Switzerland.
The third chapter will take a look at microbes and identify those that are pathogenic and can survive when trapped in glacial ice. I will identify the disease-causing agents most dangerous to public health and assess the probability of an outbreak occurring.
The fourth chapter outlines examples of past outbreaks and discoveries of microbes in ice bodies and glaciers, showcasing how this danger is already becoming a reality.
In the fifth chapter, I construct a geomap, which will present my data in the form of a digital map, and interpret which glaciers pose the greatest danger to releasing microbes.
The sixth and final chapter proposes a set of actions that should be taken in Switzerland to help raise awareness to the general public as well as affected communities, prevent outbreaks through surveillance and monitoring strategies, and prepare an emergency response.

2. GLACIOLOGY

This chapter explains what a glacier is, how it moves, and how glaciers are classified. It's discussed how glaciers are affected by global warming and what consequences this has on humans. Given that the scope of this paper is focused on Switzerland, it will take a deeper look at the local glacial landscape.

2.1 WHAT IS A GLACIER?

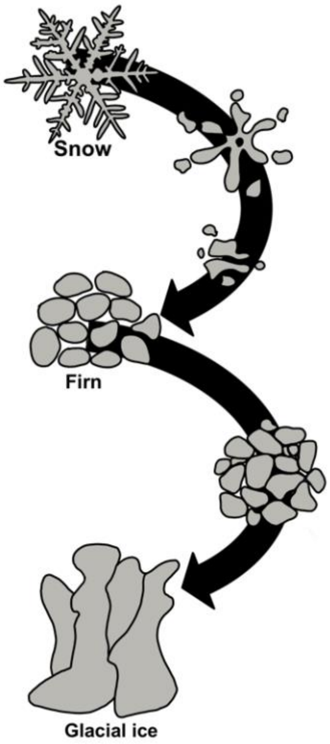


Fig. 1: Diagram of process by which snow turns to glacial ice.

Glaciers are formed by the transformation of snow into ice. They are large bodies of frozen water, made up of ice, snow and firn. Firn is compact and granular snow that is in the intermediate phase between snow and ice (Kalsang Bhutia, 2014). The snowflakes compress to form harder granulates, whose density is made up of 50% water. This process of creating firn usually takes around 1 year. Glaciers form on land over many centuries. In order for a glacier to survive, the winter snowfall must be greater than the loss of snow through melting in the summer. This accumulating snow is compressed under its own weight. Over many years a thick ice mass will form (Hambrey & Alean, 2004, pg. 11-24). Because of this unique formation of the glacial ice, you can find veins of liquid water between the ice. These are central for the ability of microbes to survive in the ice. Glaciers are constantly in motion, moving slowly downward due to the pull of gravity (National Geographic Society, 2022).

Glaciers can be found in cold areas where the mean annual temperature is freezing and where there is a significant amount of precipitation in winter. The snowfall that grows the glacier in winter can be partially lost in summer, however it is also not possible for a glacier to exist in a region where the temperatures in the rest of the year lead to the ice melting (Www.USGS.gov). Most glaciers can be found in polar regions or in mountain regions, most commonly in Antarctica. Approximately 2% of all water on Earth is stored in glaciers.

2.2 GLACIER BUDGET

A glacier is always in motion. Its movement is determined by the gain and loss of mass of the glacier, as a balance of the accumulation (the increase of ice created by compression of snow) and ablation (the loss of mass by down-slope movement). This balance is called the mass balance or mass budget. When a positive mass balance exists, the glacier gains more ice through accumulation than is lost during ablation. A glacier with a negative mass balance has a higher mass loss due to ablation than gain due to accumulation (Hambrey & Alean, 2004, pg. 25-42).

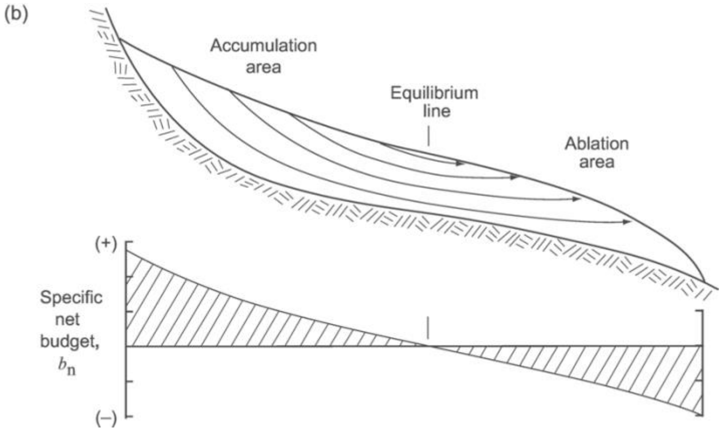


Fig. 2: Graph of mass balance budget of glacier. Source: www.cambridge.org, 2023

Based on the glacier budget, scientists divide glaciers into different areas.

The first area is the accumulation zone where mean temperatures are colder and there is a net gain of ice. This is the highest point of the glacier where there is more accumulation than ablation. It is a dry zone with no surface melting (Hambrey & Alean, 2004, pg. 25-42).

Further down, the glacier is still growing in mass, however there is some surface melting that refreezes seasonally (Hambrey & Alean, 2004, pg. 25-42).

In the wet snow zone, the snow becomes slushy. In winter this slushy snow can refreeze to so-called “superimposed” ice. This has a different composition to firn ice. The two are separated from each other at the ‘firn line’ (Hambrey & Alean, 2004, pg. 25-42).

Below this zone is one of the most important points of the glacier: the equilibrium line. It is defined as the area in which the profit of accumulation is equal to the loss of ablation. This line separates the accumulation area and the ablation area. The ablation area has less accumulation of ice than lost mass, therefore it is defined as having a net loss of ice.

The firn line and equilibrium line do not have to coincide, however they do when the glacier has a net neutral balance. If the mass balance is negative the equilibrium line will generally be above the firn line, if the balance is positive the equilibrium will be below (Hock, 2010).

At the bottom of this area, snow swamps form in summer. The ice melts and becomes saturated (Hambrey & Alean, 2004, pg. 25-42).

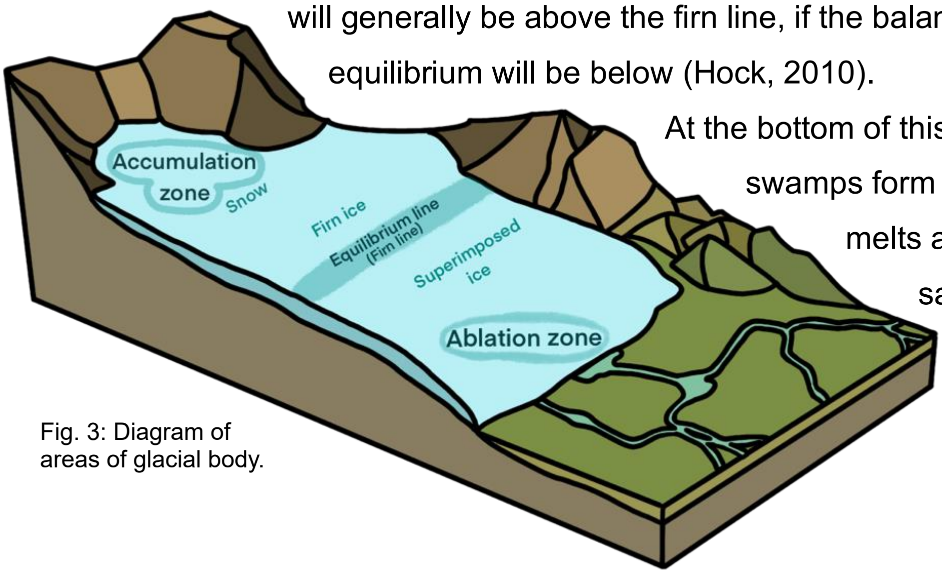


Fig. 3: Diagram of areas of glacial body.

2.3 GLACIER CLASSIFICATION

Glaciologists differentiate glaciers based on their shape, relation to the underlying topography, and temperature distribution within the glaciers.

The topographic settings are subdivided into ice sheets and ice caps, ice shelves and mountain glaciers (Hambrey & Alean, 2004, pg. 11-24).

Ice sheets are per definition larger than 50’000 km^2 (www.NSIDC.com). They are compositionally made up of many different individual glaciers that are connected in an ‘ice field’. Ice sheets are the largest glaciers. Although most of the earth was once covered by ice sheets, their abundance has rapidly decreased. Today only two are left: the Antarctic and Greenland ice sheet. Together they contain 99% of the freshwater on earth (National Geographic Society, 2023). The Antarctic sheet is much larger than the Greenland sheet, and it alone

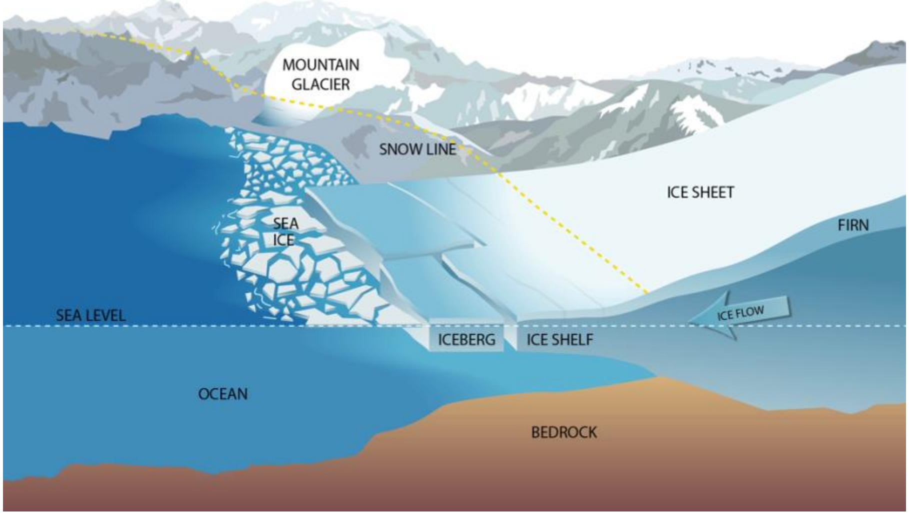


Fig. 4: Diagram showing different bodies of ice. Source: www.icesat.gsfc.NASA.gov, 2019

stores 91% of the worlds fresh water. Ice caps are much like ice sheets, in their composition and thickness, however, they are much smaller than ice sheets and are defined as being smaller than 50'000 km^2. They are commmonly found in polar or subpolar regions, where they develop on high plateaus.

Ice shelves are large ice slabs that float on the sea. They range in thickness from 200m to 2km at their terminus. They can range in size between 800 km^2 and 500'000 km^2(Hambrey & Alean, 2004, pg. 11-24). They are not land bound and are therefore more at risk for calving off large pieces of ice.

Mountain glaciers are semi-continuous sheets of ice that occupy a large area. Most commonly, they are found in polar and sub-polar regions, but they also exist in more temperate regions in highland areas. Mountain glaciers can be very diverse and can be classified as valley glaciers, outlet glaciers, tidewater glaciers or piedmont glaciers (Hambrey & Alean, 2004, pg. 11-24).

A valley glacier flows down through valleys. If the glacial ice is coming from an icesheet or ice cap instead and flows through a valley it is called an outlet glacier. Tide water glaciers flow directly into the sea. A piedmont glacier flows into a flat lowland area where it becomes spread out over a larger area (www.dkfindout.com).

We can differentiate glaciers based on their temperature distribution. This is defined by how wet- or dry-based a glacier is, and also how much liquid water there is in comparison to frozen ice.

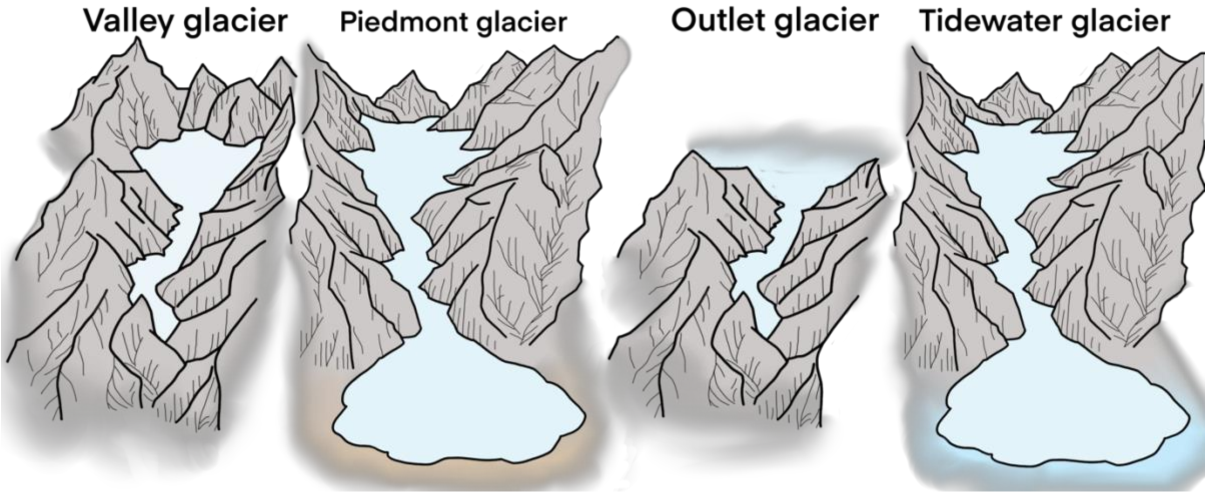


Fig. 5: Diagram of different types of mountain glaciers.

The first type is a warm glacier: warm glaciers are at the melting point year-round. In winter a small layer at the top freezes, however, water melts all year around and is abundant in summer. This glacier is wet-based. The meltwater leaves through a so-called glacier portal in the middle of the glacier snout. A characteristic feature of warm glaciers is that they have a very well-developed drainage system. You find these glaciers in mountain regions outside of the Arctic and Antarctic (Hambrey & Alean, 2004, pg. 11-24).
The second type are cold glaciers: cold glaciers are found in polar regions where the average temperature is below zero, and the majority of the local temperature is below the melting point. They are dry-based glaciers. Ice at the top of the glacier (around 12 m of the upper ice) fluctuates due to seasonal temperature changes. Towards the glacial bed, the ice is warmed due to heat flow from the bedrock, causing this ice to melt, leading to basal sliding. These glaciers do not usually have a drainage system as the melted ice refreezes in the streams it flows into (Hambrey & Alean, 2004, pg. 11-24).
The last type of glacier is a polythermal glacier. Polythermal glaciers have both characteristics from warm and cold glaciers (Hambrey & Alean, 2004, pg. 11-24). These glaciers have a complex temperature system. The snout and margin areas of the glaciers are below the melting point, whereas thicker ice is warm-based. Water is drained through glacial channels in the glacier (Davies, 2020). Warm glaciers are the most common glaciers for mountain regions outside the Arctic or Antarctic. Cold glaciers are found in Polar regions, where the temperatures are cold all year around. Polythermal glaciers can be found in the high-arctic and sub-arctic regions, although they are also found on very high mountains in more temperate regions as well (Hambrey & Alean, 2004, pg. 11-24).

2.4 GLACIERS IN GLOBAL WARMING

The cryosphere is affected by the atmospheric warming caused by climate change through the so-called “human-induced greenhouse effect” (Hambrey & Alean, 2004, pg. 43-68). Glaciers are some of the ice bodies most affected by global warming. In order to understand the effects of global warming on Swiss glaciers, it is therefore imperative that these glaciers be studied.

Glaciers act as a record of past climatic changes. Historical documentation of glaciers includes farmer's notes of the advances and recessions of glaciers, as well as drawings and images of artists and tourists dating back to the the 17th century. In 1890, systematic measurement of glacial ice in the Swiss Alps was instituted. These documents and satellite images have shown a general trend of glacier recession since the beginning of the 21st century (Hambrey & Alean, 2004, pg. 43-68). For example, throughout the 20th century, the Grosser Aletschgletscher was recorded to have receded by 2.2km, averaging 22m of movement annually. A significant contribution to the increased recession of these glaciers is the warming of the summer seasons. Glaciers can be very sensitive to temperature changes. Through the study of the Grosser Aletschgletscher we could learn that even a temperature increase of 1-2°C could cause kilometers of glacial recession. However, not all glaciers melt at the same rate and a few of the larger glaciers seem almost unaffected by global warming. This is because larger glaciers take much longer to react to changing climates. Even in the European Alps, we can observe adjacent glaciers where one glacier is receding while another is unaffected or even advancing (Hambrey & Alean, 2004, pg. 43-68 & Louwerens, 2021). In studying ice sheets and ice caps, this theory is further reinforced. The large bodies of ice respond to climatic changes very slowly, so much so that they seem not to be affected by the last 10'000 years of warming. Ablation of these ice sheets and caps is therefore for the most part due to the calving of large ice masses because of an increase in water temperatures where ice sheets meet the sea. In the case of ice sheets and caps, ablation is more controlled by oceanographic factors such as sea temperatures and level, than mass balance changes (Hambrey & Alean, 2004, pg. 43-68).

Fig. 6: Side-by-side images of the Grosser Aletschgletscher 1880 (top) and 2015 (bottom). Source: www.swisseduc.ch, 2021

2.5 SWISS GLACIERS

Switzerland is home to approximately 1’800 glaciers. In Switzerland we find many warm glaciers and few polythermal glaciers, such as the Grenzgletscher in the Canton Valais. There are no cold glaciers in Switzerland as these are typically found in the Antarctic and in Greenland.

All glaciers are located in the Swiss Alps, generally between the Pennine and Bernese Alps (www.wikipedia.org, 2023). The 3 largest glaciers are:

1. The Grand Aletsch in canton Valais, comprising an area of $84.8\mathrm{km}^2$(2017) www.GLAMOS.ch, 2022). Its highest point is the Aletschholn at a 4’193m (www.wikipedia.org, 2023). This glacier is Europe’s longest valley glacier with a length of 23km. (Hambrey & Alean, 2004, pg. 11-24)
2. The Gorner glacier in the Pennine Alps, located also in canton Valais with an area of 54.5 km^2(2015). Its highest point is the Dufourspitze at a height of 4’634m (www.wikipedia.org, 2023). This glacier is also a valley glacier (www.gornergrad.ch, 2023).
3. The Fiesch glacier in Valais, located in the Bernese Alps (www.wikipedia.org, 2023). It covers an area of 33.2 $\mathrm{km}^2(2009)$. Its highest point is at the Finsteraarhorn at 4’273m (www.Wikipedia.org,2023). It is a valley glacier as well (www.wikipedia.org, 2023).

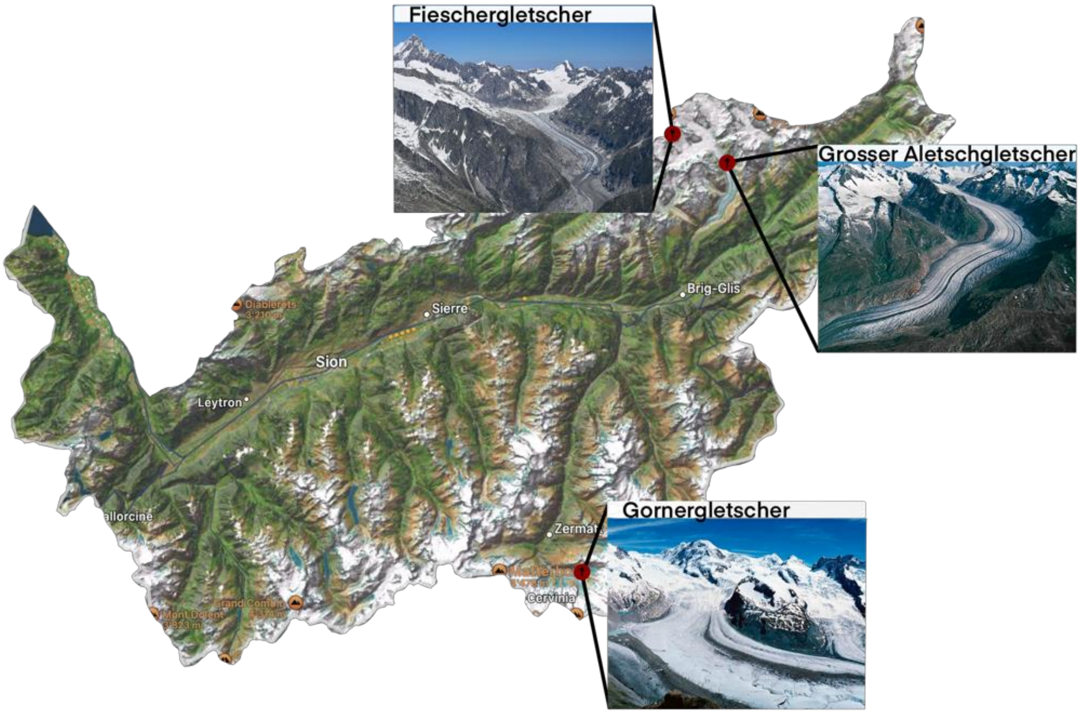


Fig. 7: Map diagram of Canton Valais, marking the three biggest glaciers in Switzerland.

Most Swiss glacial water flows into the Rhône and the Rhine. Some glaciers' run-off goes into the Danube or Po rivers (www.wikipedia.org, 2023).

Researchers have been monitoring the volume of Alpine glaciers since 1850 and have observed a decline in mass of over 60%. The rate of melting seems only to be increasing and accelerating since 2011. In 2017 to 2018 alone, 1'500 glaciers were recorded as having lost 2.5% of their volume. If this rate is upheld, half of our Swiss glaciers will disappear in the next 30 years, and all glaciers will have melted by the year 2100.

The loss of the glaciers doesn't only have an environmental effect, it also has an economic effect, because glaciers benefit the use of hydroelectric power and revenue from tourism. It also affects Swiss national identity (Jorio & Reusser, 2019).

It is important to study the mass balance changes of glaciers, because their melting has a direct impact on humans. With increasing glacial recession, we will see an increased risk of natural catastrophes. Such natural catastrophes include hazardous lakes, which form between moraine and glacier that are at danger of bursting, or newly exposed rock and debris slopes, which threaten to break off and form landslides (Hambrey & Alean, 2004, pg. 43-68). There are also many other new and emerging dangers arising with the ever-increasing glacial recession, such as the release of microbes through meltwater. In following chapters, I will take a closer look at the last-mentioned danger.

Fig. 8: Burst Glacial lake. Source: www.en.wikipedia.org, 2020

Fig. 9: Rock debris slope exposed from glacial recession. Source: www.geoengineer.org, 2023

3. MICROBES

In the previous chapter we showed that it is possible for material to be released out of glacial ice. This chapter is devoted to taking a closer look at what is being released. This chapter will introduce microbes, classify them, analyze their pathology (ability to cause diseases), and examine their ability to survive in freezing temperatures. From this I will conclude which are the most dangerous known organisms to public health that can survive the conditions in a glacier.

3.1 DEFINING MICROBES

The term ‘microbe’ is an umbrella title that classifies microorganisms that cannot be seen by the naked eye. Within this term there are two major categories: prokaryotic and single-celled eukaryotic organisms. The most important distinction is that prokaryotes do not have a defined nucleus, while eukaryotes do. This is a morphological characteristic. Other characteristics that distinguish the two groups include: cell function, chemical composition, immune responses and ecological relationships. Figure 10 defines the differences between an eukaryote and a prokaryote (www.sciencefact.net, 2023).

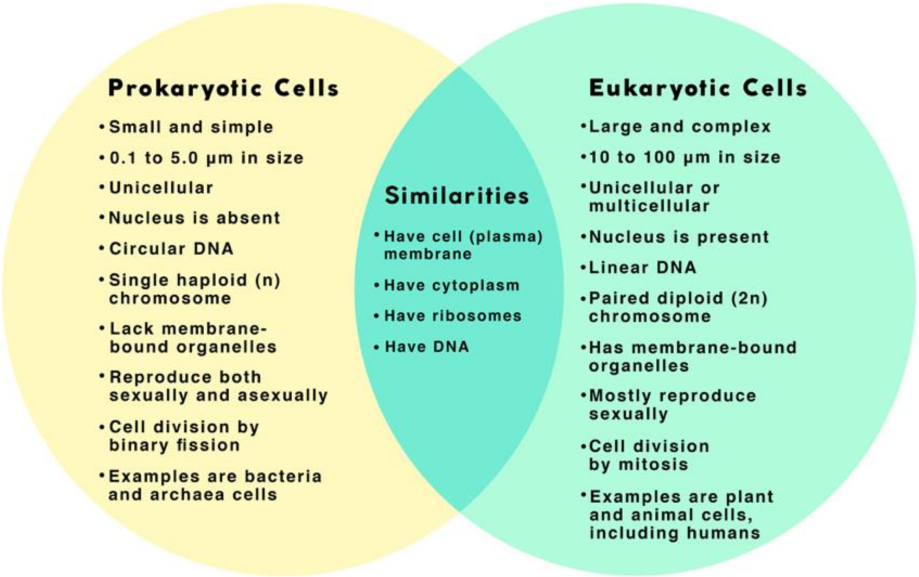


Fig. 10: Venn diagram displaying differences between a prokaryotic and eukaryotic cell.
Source: www.sciencefact.net, 2023

While viruses are not living microorganisms, microbiologists often broaden the term “microbes” to include them as well.

Microbes are commonly referred to in connection with infectious diseases, but it is important to note that not all microbes are dangerous. In fact, it is only a small minority of microbes that are harmful to us, whereas most are neutral or beneficial for humans. An example of beneficial microbes are lactic acid bacteria that live in our bowels and help us to digest food. Microbes can be found everywhere and can live in water, soil and air. Even in the most extreme climate conditions, you can find microbes that have adjusted to survive.

Whereas eukaryotic microorganisms can be further subdivided into fungi, algae and protozoa, prokaryotic organisms can be divided into bacteria and archaea (www.amnh.org).

We will consider eukaryotes, prokaryotes and viruses in turn.

3.1.1 EUKARYOTIC MICROBES

Eukaryotic microbes are a diverse group of organisms. These include fungi, protozoa and algae.

3.1.1.1 FUNGI

Fungi can occur as yeasts, molds or as a combination of both forms, known as diamorphs. Yeasts are unicellular, molds are multicellular and diamorphs can be found in either unicellular or multicellular state depending on the environmental conditions (www.bio.libretext.org). In this paper we will only be looking at unicellular microorganisms, so we will not study molds, as these don't fall under the term 'microbe'.

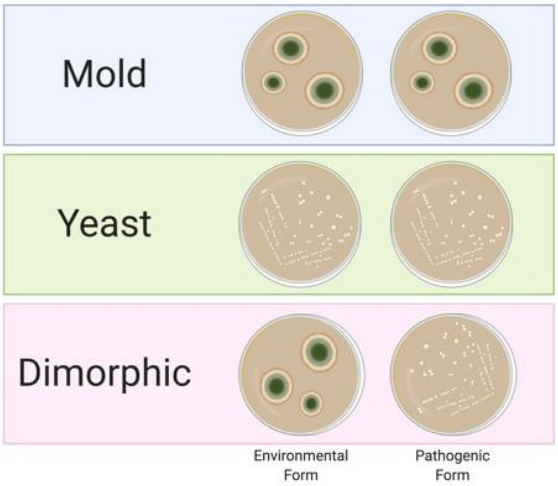


Fig. 11: Differences between molds yeasts and diomorphics. Source: www.pathelective.com, 2023

Fungi are heterotrophic organisms (McGinnis & Tyring, 1996). Most fungi retrieve their nutrients from dead and decaying organic matter, mainly plant material (www.bio.libretext.org).

Yeast cells are spherical and have a diameter between 4-6µm (www.book.bionumbers). Fungi have rigid cell walls made up of chitin, which protects the cell and allows for stability. They have a membrane which allows for the nutrient uptake (McGinnis & Tyring, 1996). Fungal cells have nuclei that contain the genetic DNA information. Other organelles include the cytoplasm, Golgi apparatus and vacuole, as well as ribosome and other organelles needed for DNA translation (Feldmann, 2012).

Yeasts are unicellular microscopic fungi that can procreate through budding. Budding is a process by which a daughter cell grows out of a parent cell until it splits off. Fungi are most commonly found on land, in soil or plants, while it is also possible to find microbes that are in water, it is much less common (www.microbiologysociety.org, 2016).

Around 80% of all fungi are microscopic (Casañeda-Ramírez et al., 2022), and there are an estimated 5.1 million species of fungi (Blackwell, 2011), which would suggest that there are around 4.1 million species of microscopic fungi.

An example of a microscopic fungus is saccharomyces cervisiae, a yeast used in baking, winemaking and brewing. It is particularly helpful to us as it ferments sugars and starches into alcohol and carbondioxide (www.rochester.edu, 2021).

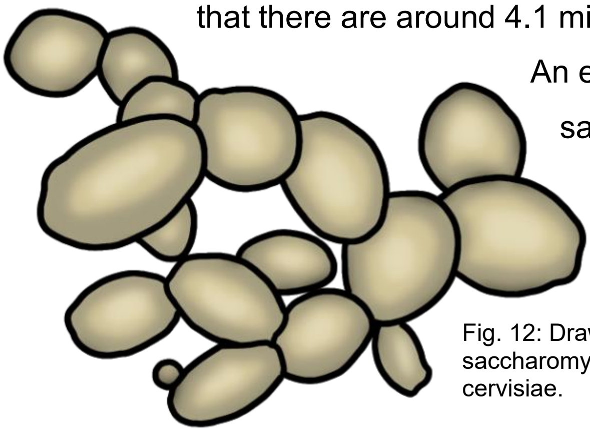


Fig. 12: Drawing of saccharomyces cervisiae.

3.1.1.2 ALGAE

Microscopic algae or Microalgae are unicellular species of algae that live individually or live in chains or groups (www.nomorfilm.eu). They range from 5-100μm in size (www.feedipedia.org) and can be autotrophic, heterotrophic or mixotrophic, although most are autotrophic (www.nomorfilm.eu).

Algae have complex cell structures. They have one or more chloroplasts that contain pyrenoids, structures that synthesize and store starch.

Microalgae reproduce by asexual cell division and don’t create spores like larger algae do (Andersen & Lewin).

Microalgae are most commonly found in freshwater systems and marine systems. They have adapted to various kinds of water salinity levels and temperatures. It is estimated that around 200’000 - 800’000 species of microalgae exist (www.nomorfilm.eu).


Fig. 13: Drawing of a Chlorella.

An example of a Microalgae is Chlorella, a freshwater algae that is used for nutrition and medicine. It is used as an iron supplement, favored by pregnant women (www.webmd.com).

3.1.1.3 PROTOZOA

Protozoa belong to the kingdom of Protista. They are eukaryotic organisms, which range in size from 1-50µm, there are some rare larger species that are up to 150µm large. Protozoa are heterotrophic. They consume and digest organic compounds. They take up these compounds through endocytosis, for which they sometimes have a defined ‘mouth’ where they take up the compounds. The organelles of protozoans resemble those of higher animals. They have a cell membrane that encloses their cytoplasm. They have vacuoles where they store nutrients and perform metabolic reactions.

Protozoa are a very diverse subkingdom and can be found in almost all environments. They exist in freshwater, marine and soil environments, among others (www.microbioogysociety.org, 2023). The most common form of reproduction is through asexual mitotic cell division (Yaeger,1996).

An example of a Protozoa is an amoeba, known for their form of movement by forming temporary extensions of their cytoplasm, this form of movement is named after them as ‚amoeboid moment‘ (www.britannica.com, 2023).

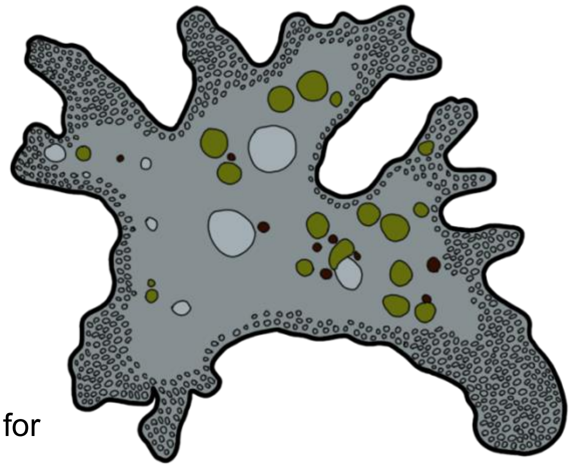
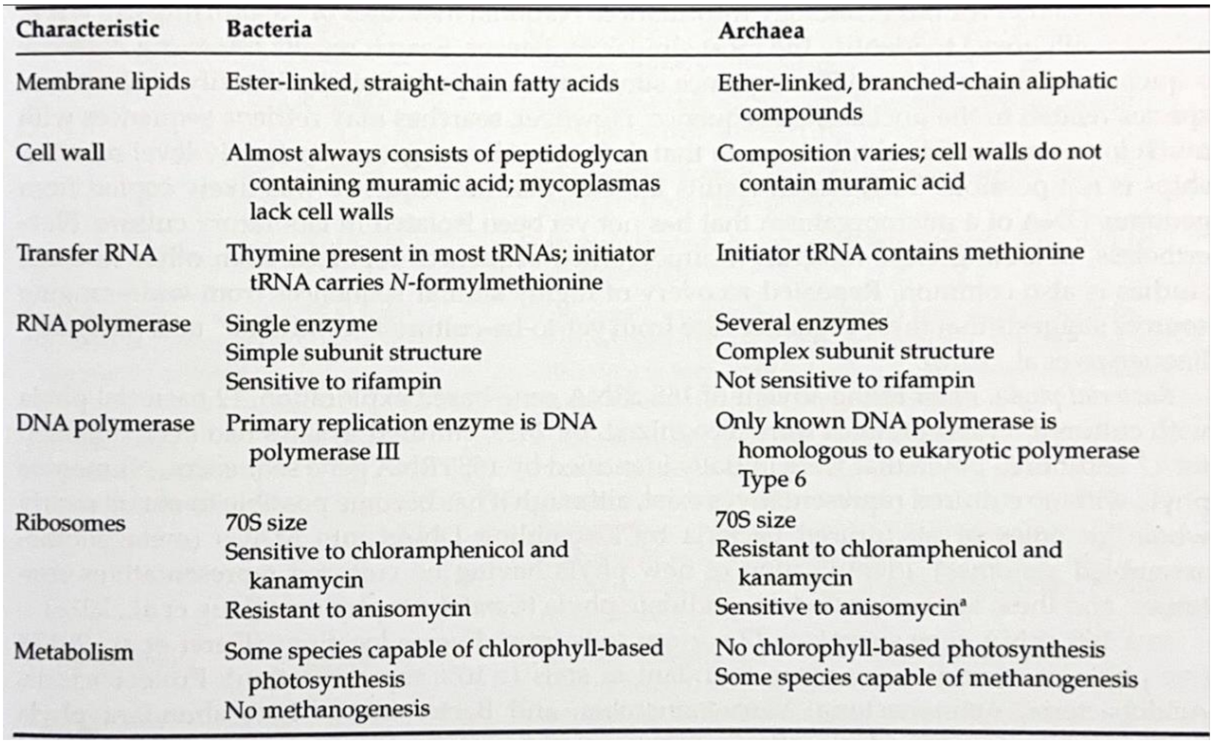


Fig. 14: Drawing of an Amoeba cell.

3.1.2 PROKARYOTIC MICROBES

Prokaryotic microbes can be differentiated into archaea and bacteria. These two are differentiated based on morphological composition and have very different compositions of many vital organelles (Fig 15), such as their membrane, cell wall, tRNA, RNA polymerase, DNA polymerase, ribmosomes and metabolism (Burns, 2021).



Characteristic	Bacteria	Archaea
Membrane lipids	Ester-linked, straight-chain fatty acids	Ether-linked, branched-chain aliphatic compounds
Cell wall	Almost always consists of peptidoglycan containing muramic acid; mycoplasmas lack cell walls	Composition varies; cell walls do not contain muramic acid
Transfer RNA	Thymine present in most tRNAs; initiator tRNA carries *N*-formylmethionine	Initiator tRNA contains methionine
RNA polymerase	Single enzyme Simple subunit structure Sensitive to rifampin	Several enzymes Complex subunit structure Not sensitive to rifampin
DNA polymerase	Primary replication enzyme is DNA polymerase III	Only known DNA polymerase is homologous to eukaryotic polymerase Type 6
Ribosomes	70S size Sensitive to chloramphenicol and kanamycin Resistant to anisomycin	70S size Resistant to chloramphenicol and kanamycin Sensitive to anisomycin[a]
Metabolism	Some species capable of chlorophyll-based photosynthesis No methanogenesis	No chlorophyll-based photosynthesis Some species capable of methanogenesis

Fig. 15: Differences between Archaea and Bacteria. Source: (Burns, 2021, page 113)

Archaea and bacteria are very diverse microbes, most are heterotroph, although a few are autotroph. The heterotrophic prokaryotes eat starches or sugars from organic matter and some feed on dead and decaying matter. Others eat waste products like oils. The diet of these organisms are very diverse and species-dependent (www.microbemagic.ucc.ie, 2007). They are 1-2µm (10^{-6}m) and the three main shapes are bacillus (rod shaped), spirillus (spiral shaped) or coccus (spherical) (www.microbemagic.ucc.ie, 2007). Prokaryotes are made up of a cell wall, which gives them their shape and acts as a structural support. Underneath is a cell membrane that allows for the transmission of important nutrients. As the prokaryote doesn’t have a defined nucleus, its genetic information is floating in the cytoplasm, which is the liquid in the cell where many metabolic processes take place. There are small vacuoles that hold waste products and food in the cell. Further you might find a flagellum, which is a tail-like structure that helps them move forward (www.microbemagic.ucc.ie, 2007).

Prokaryotic cells reproduce through mitosis, a process of cell division where a diploid cell with two complete sets of genetic information splits into 2 identical daughter cells which are also diploid.

Some prokaryotes, many of which are bacteria, are able to form dormant structures called endospores. These endospores are extremely resistant structures that can survive in very hostile physical and chemical conditions, such as UV radiation, heat, disinfectant and also very cold environments (www.microbiologysociety.org). Spores are structures that hold genetic information in cytoplasm, surrounded by multiple hard cell wall layers (Tankeshwar, 2023).

Bacteria have adapted to live in many conditions and can be found everywhere: on land, in water, suspended in the air, or living in another organism. Bacteria can even be found in extreme temperatures (www.microbemagic.ucc.ie, 2007).

Prokaryotes are extremely widely spread; it is estimated that there are 5 nonillion $(5 * 10^{30})$ bacteria on earth (Čirjak, 2020).

An example for bacteria would be E. Coli. It is a coccus bacteria that lives in human intestines and help us break down food. When consumed, it can also cause life-threatening disease (www.my.cleavelandclinic.org). An example of an archaea is the Methanococcoides burtonii, which is a psychrophilic organism (Yang et al. 2007).

Fig. 16: Drawing of E. Coli.

3.1.3 VIRUSES

Viruses have no cells of their own and are not deemed living organisms, but they do contain genetic information in their protein shell that allows them to reproduce (InformedHealth.org, 2019).

Viruses cannot reproduce on their own and instead rely on a host cell to reproduce their DNA (Essential Human Virology, 2016). They invade cells and start to multiply from these (InformedHealth.org, 2019). Once they have entered into the host cell, they instruct the cell to replicate the viral organelles, which can form together to create a new virus.

Viruses are very small, most range from 20nm-100nm (10^{-9}m) in length. There are some exceptionally large viruses that are up to 400nm. Viruses carry genetic information as genomes. These genomes can be made up of either RNA or DNA strands. Surrounding and protecting the genomes is a protein shell called the capsid, made up of 1-2 proteins that are repeated and build up this shell. Many viruses will also have an envelope made of a lipid membrane around the capsid. This envelope is commonly derived from the membrane of a cell, which allows it to enter or exit a cell by endo- or exocytosis.

Viruses can be found in almost all environments; in water, on land, and suspended in the air. This is because viruses have been able to adapt to these many conditions (Essential Human Virology, 2016). There is estimated to be around 10 nonillion (10^{31}) viruses existing on earth (Wu, 2020). A very current example for a virus would be the SARS-CoV-19 virus that caused the corona pandemic.

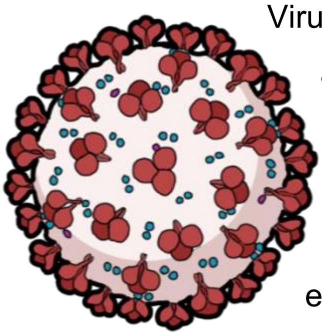


Fig. 17: Drawing of SARS-CoV-19 Virus

3.2 PATHOGENS

It is important to understand that not all microbes cause diseases, and most are actually beneficial for the host. Less than 1% of microbes are actually harmful, and these are called pathogens.

This harm can be characterized by a pathogen's virulence, which describes the severity of the disease symptoms. Pathogens are a diverse group of organisms that can be made up of bacteria, eukaryotic organisms, or any other microorganism, as well as viruses. Pathogens can infect any living organism and can be found in essentially every environment.

We can divide pathogens into two major categories: obligate and facultative. Obligate pathogens are organisms which depend on their hosts for fulfillment of their life cycle. All viruses belong to this category. Some pathogens require multiple different hosts across their life cycle and can form alternating generations of pathogens (Balloux & van Drop, 2023).

On the other hand, facultative pathogens can use a host as a medium for reproduction, however they do not need to in order to fulfill their natural life cycle and can be found naturally in the environment, living independently from a host.

Pathogens are transmitted through air, direct physical contact, fomite transmission, oral consumption or vector-borne.

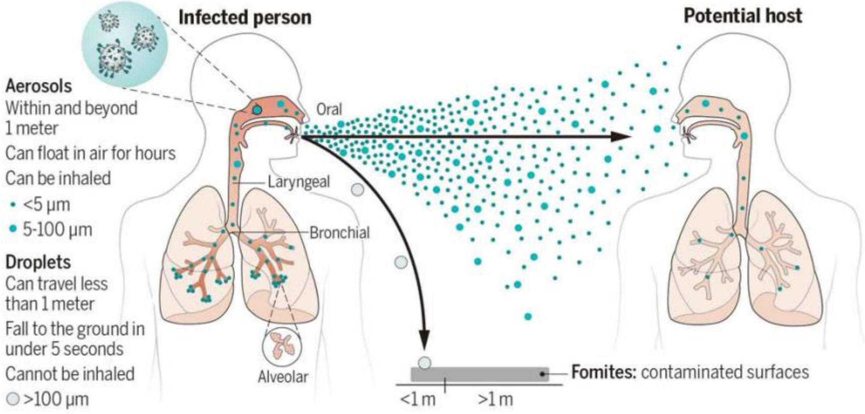


Fig. 18: Transmission through air or formites. Source: www.today.ucsd.edu, 2021

Airborne pathogens are suspended in air in the form of tiny droplet nuclei, which are aerosols formed by evaporated respiratory droplets (www.wikipedia.org, 2023). These can stay suspended in the air for several hours or even days. The suspended bio-substances are referred to as bio-aerosols. Contact-transmitting pathogens are spread through direct contact between the host and the skin or bodily fluids of an infected person. Fomite transmission is caused by a contact of a person with an inanimate object that has been contaminated by someone who has been infected. Oral transmission results when a person consumes a pathogen. Pathogens can be consumed in foods, water or from environmental contamination from for example feces, urine (orofecal) or saliva. Vector-borne transmission comes from contact to living organisms who have been infected with a pathogen, often these vectors include arthropods, rodents and other vermin (www.aaha.org).

After contact, the pathogen clings to a host surface: skin, mucosa (including oral passages, nasal passages and the genital area) and deeper tissue (including lymphoid tissue, alveolar lining and endothelial lining). The skin is the body's primary defence organ to protect from foreign pathogens, by acting as a barrier between the environment and our bodies (Lopez-Ojeda et al., 2022). The body attempts to destroy the pathogens with motor forces such as saliva efflux, choking, mucus flow and blood flow.

If the pathogen can survive these forces, it will invade the host cells. We can differentiate between intra- and extracellular invasions. Both invasions penetrate the tissue barrier; however, the extracellular invasion spreads without entering the host's cells, whereas the intercellular invasion takes place when the pathogen enters the cells and survives in their environment.
The term 'human-pathogenic-interaction' is central in the study of human pathogens and describes how a pathogen lives and maintains itself in the human host. It is defined by the kind of pathogen, the modes of transmission, the routes of entry, the reservoir host, the susceptibility of the host, and how a pathogen releases other pathogens when occupying a host. Depending on how disruptive a pathogen is to its host, we can differentiate between three different host-pathogen-reactions: commensalistic, mutualistic, and parasitic relationship. Commensalism refers to interactions in which the pathogen benefits and the host is not significantly affected. The mutualistic relationship describes a relationship in which both pathogen and host benefit. Parasitism describes the state in which a pathogen benefits at the cost of its host (Ahmad Mir, 2022).

It is difficult to identify which microbes are most pathogenic given the vast variety in each category, however, my research shows that some microbe types have very rarely if ever been discovered to be pathogenic.
The first is algae. Some algae can produce toxins which can impact human health, but they are not pathogenic. Secondly, there has never been an identified pathogenic archaea discovered (Cavicchioli et al., 2023). Therefore, I will not include these (www.bio.libretexts.org) in further analyses.

The remaining microbe types are bacteria, viruses, fungi and protozoa. Next, I will compare these pathogens in order to understand their potential to be disease-bearing agents posing a risk to public health in the table bellow. I want to study if they are intracellular or extracellular, defining if they can live outside of a host cell. Intracellular organisms cannot, whereas extracellular organisms can. I also want to compare how many of these different pathogens exist. I also compare how the pathogens enter the body. To make the differences more concrete I will present an example of a pathogen from each.

Table 1: Comparing different pathogens:

Pathogen	**Intracellular/ Extracellular**	**Estimated number of human-infecting pathogens**	**Modes of transmission**	**Examples (Bell, 2020)**
Bacteria	Usually extracellular (Ahmed et al., 2016).	1513 bacterial pathogen species were described (Bartlett et al., 2022).	Transmission through contact, vectors, airborne, droplets (Doron, 2008)	-Tuberculosis -Anthrax -Typhoid
Virus	Always intracellular (Summers, 2009)	There are about 270 pathogenic viruses recorded (Forni et al., 2022).	Transmission can be respiratory, orofecal, contact of bodily fluids, direct contact, blood or though a vector (Summers, 2009)	-Influenza -HIV -SARS-CoV-19
Fungi	Usually intracellular (Gladieux & Giraud, 2017)	There are about 300 fungi documented (www.nature.com, 2017)	Transmission can occur through skin contact with human or animal vectors, contact with contaminated items or with contaminated soil (www.sahealth.gov).	-Meningitis -Skin infections -Lung infections, such as pneumonia
Protozoa	Always intracellular (Sibley, 2013)	There are around 30 identified Protozoa species that infect humans (Vaccaro, 2000)	Transmission routes include ingestion, contact with a vector, contact with a human and respiration (Vaccaro, 2000).	-Dysentery -Malaria -Trypanosomiasis /sleeping disease

From this table I can conclude that bacterial and viral pathogens pose the biggest danger to humans, as they have the highest diversity in mode of transmission and in diversity of pathogenic organisms.

This paper addresses virulent pathogens that could pose a danger to the Swiss people. I will be addressing pathogens that have caused outbreaks in the past and pose the biggest danger to a large demographic. Beyond these known pathogens, there are many unknown and undiscovered ones that could pose a threat in the future as well (Hunt, 2023). This is a viable threat that Switzerland needs to be aware of, but that is out of the scope for my paper and that I will not consider further.

The seven most dangerous known pathogens are described in the table below and are all bacterial or viral pathogens. They are bacillus anthracis, yersinia pestis, francisella tularensis, staphylococcus aureus, ebola virus, influenza virus, coronavirus (Janik et al., 2020).

Table 2: Comparing the pathogens that are the most dangerous to public health:

Pathogen / Disease	**Bacterial or viral pathogen**	**Vector**	**Portals of entry**	**Location prevalence**	**Treatment**
Bacillus anthracis / Anthrax	Bacteria	Grazing herbivores, such as sheep, cattle or goats ingest or inhale bacterial spores and can be passed to humans over contact with infected animals.	Humans can be infected by uptake through inhaltation, ingestion, through the skin or injection. Human to human transmission is not possible.	Asia, Haiti, Africa, South America and the Middle East.	Anthrax is treated with immediate antibiotic therapy, supported by an availiable vaccine.
Yersinia pestis / plague	Bacteria	Fleas carry the pathogen, this is then passed on to small mammals, often rodents. Humans are infected either through contact with the infected animals or bites from infected flees.	The bacteria is taken up through inhalation of pathogen aerosols. It can be spread from human-to-human.	Current outbreaks are in China, Uganda and the DRC.	Patients are treated immediately with antibiotics.
Francisella tularensis / Tularemia	Bacteria	The main vectors are arthropods, mainly tics. These infect small mammals, which can pass the disease onto humans.	Oathogens can be taken up by inhalation of aerosols, contact with tissues or liquids of infected animals.	Found in North America.	Patients are treated with antibiotics.
Staphylo-coccus aureus / various infections including pneumonia	Bacteria	The main route of transmission is through contact. The pathogen enters the bodies through existing skin wounds or damage (Minnesota Department of Health, 2010).	Pathogens colonize in the nasal cavity and skin of patients.	Asian regions have the highest rate of prevelance (Chen & Huang, 2014).	Patients are treated with antibiotics, but there is a new growing amount of antibiotic resistant staphylococcus aureus.

Ebola virus / Ebola	Virus	Bats are a vector, they pass the disease onto larger animals such as monkeys, antelopes or porcupines.	The pathogen enters the body through contact with meat, blood or secretions from an infected animal.	The largest outbreak spread from West Africa to Spain, the US and Italy.	There is a vaccine for Ebola virus prevention.
Influenza virus/ Flu	Viruses: Such as Influenza A, B, C and D, of which the Influenza A virus is the most dangerous.	The virus is transmitted through human contact, but as it can also infect domestic animals, wild aquatic birds, poultry, swine and horses, contact with these infected animals can also cause infection.	The virus enters the body when contaminated aesorsols are inhaled.	The virus has been found all over the globe, most commonly in cold seasons.	There an available seasonal vaccine.
Corona virus/ Various including Covid 19	Virus	The virus is transmitted through human-to-human contact.	The virus is transmitted when contaminated aerosoles are inhaled.	The virus is found in every country.	There are available vaccines.

This chapter concludes that the most dangerous microbes to human health are bacterial and viral pathogens. The 7 most dangerous known diseases to public health are anthrax, plague, tularemia, Staphylococcus aureus infections, ebola, influenza and covid. In the following section, I will compare these diseases and analyze which which can survive in glacial ice.

3.3 SURVIVING IN ICE

In cold environments, it is difficult to find liquid water necessary for organisms to survive. Furthermore, the low temperatures cause all chemical reactions in the cell body to take place more slowly. There are also few nutrients, and the access to sunlight is limited. Because of these harsh conditions, there are only very few organisms that can survive in ice, such as psychrophiles or psychrotolerants. The main difference between these two types is that psychrophiles are adapted to thrive in freezing conditions, whereas psychrotolerants can survive in these temperatures, but thrive in warmer climates. The cold adaptation takes place through special composition of their phospholipid layer. By modifying the fatty acid composition, they can ensure the fluidity of the bilayer at low temperatures (Castello & Rogers, 2005, pg. 50-68). Microbes in glacial ice live in tiny veins of liquid water trapped in the ice when it is formed (Lopes dos Santos et al., 2023).

Winds pick up particles including dust, dirt and microbes, and carry them in the air until they eventually become affixed to raindrops or snowflakes and fall to the ground (Castello & Rogers, 2005, pg. 1-4). These particles can also fall onto glaciers, especially if they are close to temperate climates. They land on the surface of the glacier and are seeded into the matrix of the ice in a “top-down” process (Castello & Rogers, 2005, pg. 50-68). This process takes places through the continuous thinning of the ice (Castello & Rogers, 2005, pg. 159-180). Most microorganisms die because of the harsh conditions; however, some can survive and lay dormant, while others can even thrive in these environments (Castello & Rogers, 2005, pg. 1-4). The microbes live in the veins of liquid water, that form in the glacial ice, as explained in more detail in chapter 2.1.

The composition of the glacial ice is the main physical feature that determines the composition of microbes found within it, as the composition of microbes that fall onto the ice is very unselective (Crosta, 2023). Those microbes that can survive in these harsh conditions could be released into the environment as the glacial ice melts.

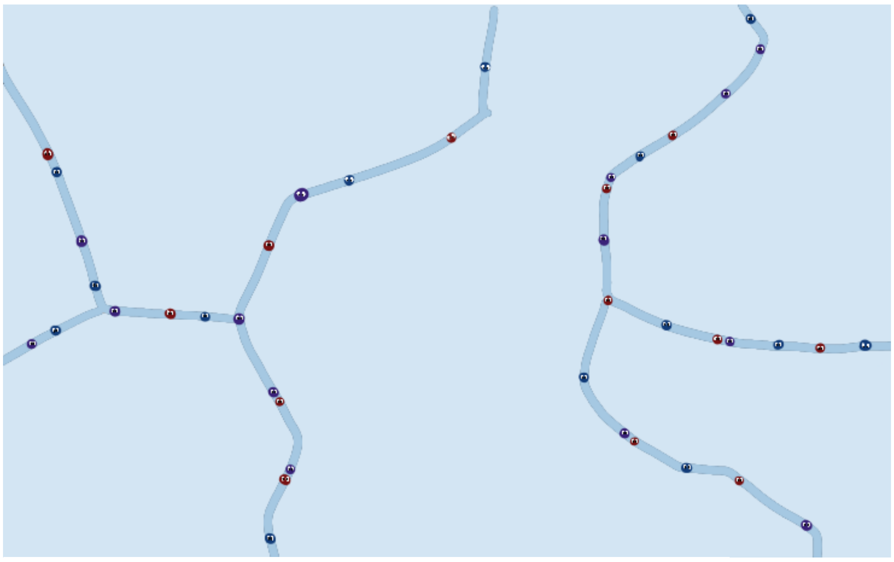


Fig. 19: Drawing of microbes in ice veins.

In this glacial ice the temperatures are freezing and liquid water is limited.

The most commonly found microbes in glacial ice are viruses and bacteria. Viruses cannot survive independently, but instead survive inside an infected host cell, usually a bacterial cell. Bacteria can survive by adaptation of special organelles and compositional changes that allow them to survive in the ice (Frey & Varliero, 2023). Alternatively, they can form spores, which are highly resistant structures, usually made up of only a very resistant shell and genetic material. These spores are very resistant and can form living bacteria cells again when the conditions become more favorable (www.bio.libretext.org).

The following table cses which of the most dangerous pathogens identified in the previous chapter are most likely to survive glacial conditions:

Table 3: Comparing the pathogens dangerous to public health based on their ability to survive in ice:

Anthrax	- Anthrax is very resistant to cold and freezing temperatures (Stoltenow, 2021). - Anthrax spores can survive in anaerobe conditions (Kumar Goel, 2015)
Plague	- The yersina pestis bacteria can survive in many temperatures, including cold temperatures (Ditchburn & Hodgkins, 2019). - The bacteria is factultative anaerobic, meaning it can survive in anaerobic environments (Duhanuic et al., 2019).
Tularemia	- Tularemia is very resistant to freezing temperature conditions (www.nps.gov, 2023) - Tularemia is aerobic and can survive only in the presence of oxygen (Duhanuic, 2018)
Staphylococcus aureus	- Can survive well in temperatures below -20°C, however less viable between 0-10°C (www.foodstandards.gov.au, 2013). - It can also survive in anaerobe conditions, however growth is much slower in these conditions (www.foodstandards.gov.au, 2013).
Ebola virus	- In freezing temperatures the virus can survive and remain infectious (European Food Safety Authority, 2014) - Viruses survive in glacial ice, inside other microbes, such as bacteria. If the host cell can survive in anaerobe conditions so will the virus (Frey & Varliero, 2023)
Influenza virus	- Influenza viruses can survive in ice and freezing environments (Virol, 2006).
Corona virus	- Corona virus can survive in freezing temperatures, but it is unclear how long it can survive in these temperatures (Hilton, 2020).

In conclusion, based on this information anthrax, plague, ebola and influenza microbes seem the most lkely to be able to survive in glacial ice of the 7 previously introduced pathogens.

3.4. RISK PROBABILITY

In July of 2023 a new paper was released (PLOS Computational Biology, “Time-traveling pathogens and their risk to ecological communities” (Strona et al., 2023)) that for the first time attempts to quantify the risk of ancient, released pathogens causing harm. The study finds that in their experiments, invaders often had a negligible effect, however, in a few cases substantial losses occurred. The authors conclude that given the vast amounts of ancient microorganisms being released into modern environments, even a very low probability of an outbreak still presents a substantial risk.

4. CASE STUDIES

In section 3.3, Surviving in Ice, I have outlined the theory that proves the viability of microbes to survive in stages of dormancy or through the support of adapted mechanisms in sub-0°C temperatures. I have also described the ways in which ice is melting at an accelerated pace, because of the atmospheric and ocean warming in chapter 2.4. I now want to introduce case studies that prove that life in ice is not only possible but actually observed. These cases demonstrate the effects that a pathogenic outbreak could have.

4.1 CASE STUDY 1: ANTHRAX OUTBREAK IN SIBERIA 2016

In the Yamal Peninsula of northern Siberia, the ground is frozen as permafrost. It is frozen up to 1000m into the ground (Doucleff, 2016). Permafrost is soil that remains perpetually frozen for at least 2 years (www.climatekids.NASA.gov, 2023). It is covered by an active layer that thaws in the warm summer seasons and refreezes in the winter seasons. As a result of the long-term increases in atmospheric temperature and a heat wave in 2016 with temperatures up to 35°C in Siberia, the permafrost is rapidly thawing (www.bbc.com, 2016) . A carcass resurfaced of a reindeer that had died in the last anthrax outbreak in 1941. The bacterial pathogen *bacillus anthracis* had formed spores and survived. The exposed reindeer carcass infected and killed not only thousands of reindeer, but also infected 8 people, killing one 12 year old boy (Fetcas, 2022). These reindeer carcasses are spread across northern Russia in over 7000 burial grounds (Doucleff, 2016).

Anthrax is caused by the rod-shaped bacillus anthracis bacteria. It affects animals and can be passed on to humans if they come in close contact with an infected animal. The bacteria is found in soil, water or plants in the form of spores, the infectious anthrax particle (Dirks, 2009), which animals take up through ingestion or respiration. Once in the body, the spores activate and multiply. The pathogen releases a dangerous toxin that can produce severe illness (www.cdc.gov, 2022).

4.2 CASE STUDY 2: BACTERIAL RECOVERIES FROM GULIYA ICE CAP IN THE TIBTEAN PLATEAU IN 2015

In the Guliya ice cap in the Tibetan highlands, scientists were able to use new methods to keep their ice core samples sterilized and could extract samples of viruses that are 15’000 years old from deep within the ice cap approx 6.7 kilometers above sea level in China. In this sample, researchers found 33 viruses, 28 of which had never been seen before (Koumoundouros, 2022). The other 4 viruses could be identified as being from virus families that infect plants and bacterial hosts (Bressan, 2021). These viruses are bacteriophages whose gene signatures (group of genes with a characteristic expression pattern) allow them to infect bacterial cells in extreme weather conditions. Researchers compared the genetic sequences of the viruses to a database and identified the host as being methylobacteria (Koumoundouros, 2022). The microbes were deposited in the ice when the glacier formed. As glaciers take many years to form, dust, gases and microbes are deposited which lay in the ice matrix for thousands of years (Bressan, 2021).

4.3 CASE STUDY 3: SMALLPOX VICTIMS IN VAULT IN RUSSIAN PERMAFROST 1991

In a small village called Pokhodsk above the arctic circle in Russia, a group of 19th century smallpox victims were locked in a wooden vault. The surrounding permafrost had frozen their bodies and almost mummified them, preserving them for a hundred years. The corpses were starting to thaw and the risk of a spring flooding raised concerns that smallpox would be reexposed. Scientists from a laboratory (called VECTOR) removed the corpses and disinfected the vault, killing all present viruses (Stone, 2002).

The smallpox virus is extremely robust allowing it to survive in many unfavorable conditions (El-Sayed & Kamel, 2020).

5. MAPPING SWISS GLACIERS

In my previous chapters I have established that highly pathogenic microbes can survive in glaciers and be released with melting ice. Through previously introduced research as well as empirical examples it is suggested that this risk is real. In this chapter I want to apply these findings and consider how Switzerland is facing this risk. Using an evaluation framework as well as a geomap, I will identify which glacier poses the greatest danger of releasing pathogens threatening public health in Switzerland.

5.1 FRAMEWORK AND LIMITATIONS

It is impossible to determine with certainty if there will be a pathogenic outbreak in Switzerland, however, I want to explore if we can identify which glacier is most likely to trigger such a phenomenon. For a pathogenic microbe to escape the ice matrix and infect people, the following three criteria must be met: 1) microbial prevalence, 2) microbial release through glacier recession and 3) human contact.

1) Microbial prevalence

   The more microbes there are in the glacial ice, the more will be released when the ice melts and therefore the greater the risk is that some could be pathogenic. To determine the glacier that poses the greatest risk, the most effective method would be to collect samples from all glaciers and analyze the amount of microorganisms found. As microbes get picked up by winds flowing over the glacier, fixating onto snow and then falling onto the glacier, they are introduced into the ice. As a result it might be possible to use historical wind patterns, perception levels and glacial area data to deduce which glacier might store the most microbes.

2) Microbial release through glacier recession

   These microbes need to be released from the ice in order to start an outbreak. The faster the ice melts, the more microbes are released and therefore the risk of an outbreak is increased. The rate of melting is recorded by measurements of the glacier tongue. The recession of the glacial tongue indicates how much ice is melting.

3) Human contact

> As discussed in section 3.2, the human-pathogenic-interaction is complex and there are many modes of transmission. An outbreak out of glacial ice has the ability to cause a major epidemic, but in order for that to happen there would need to be contact between the microbes and people.
>
> The closer the glacier is to large settlements, the higher the risk of contact and spread of an epidemic. Therefore, the distance to areas of large population directly correlates to the likelihood of an epidemic outbreak. Furthermore, meltwater flowing from the glaciers may carry pathogens to humans (Varliero et al., 2023). Additionally, high rates of tourism to glaciers would increase the risk for direct contact with potential pathogens, this would include visitors to the region who may hike on glaciers, swim in glacier lakes, or archeologists who may take specimens from glaciers (Frey & Varliero, 2023).
>
> Finally, human contact with pathogens can also happen indirectly, through the contact with a vector, for example through arthopods or rodents (Černy et al. 2020).

Ideally an analysis would consider all of these criteria, however, as I have limited data I can only take available information into account. As I do not have access to either measured data on microbial diversity of different glaciers in Switzerland, nor to historical wind pattern data, I cannot project the size of the microbe biome of the different glaciers. Therefore for the sake of my analysis I will treat all glaciers as though the microbe prevalence is constant throughout all.

I chose to look at areas of settlements close to the glacier instead of mapping the major bodies of water or reservoirs they flow into. The risk of a pathogenic infection happening when the microbes flow into major bodies of water is unlikely, because the microbes become very diluted. The risk of infection from microbes stored in reservoirs is also unlikely, as the water is tested and I before it comes into contact with people.

Furthermore, another possible factor would be tourism on the glaciers, which would account for contact with microbes of people who don't necessarily live in the surrounding areas. As there is no conclusive data on visitor rates to discern the glaciers from each other, we will not consider this factor at this point.

Finally, the risk of a vector-borne infection would need to be further studied. Given that no data was available, I excluded this factor from my analysis.

5.2 GEOMAPPING WITH ARCGIS

In order to analyze these factors I use a geomap, created using the program ArcGIS.
ArcGIS is a software that manages geographic data and can create analyses, it was developed by the Esri (Environmental Systems Research Institute) as a geographic information system (GIS) (GISGeography, 2023).
The GIS geomaps are created by compiling layers of geospatial data categorized onto a geographical base map. You can superimpose data presented as points, lines, polygons (2D data) or raster images (base vectors displaying pictures of areas). The information for these layers can be correlated and analyzed (Singh Shaktawat, 2023).

Fig. 20: QR code to story map depicting chapters 5.2-5.5.

5.3 MATERIAL AND METHODS

In order to identify the glacier posing the highest risk based on the two critical factors from my framework, I created two geomaps which 1) depict the length change of the glaciers, relating to the glaciers microbial release (recession map), and 2) illustrates the surrounding settlements, to illustrate the amount of possible human contact (contact map.) I used the open data collected by GLAMOS (Glacier Monitoring in Switzerland) on their glacier inventory and their records of the length change of glaciers in Switzerland (www.GLAMOS.ch, 2022), as well as a population map constructed by Esri (Esri Suisse, 2021).

Data cleansing
I harvested my data from the GLAMOS “2020 length change” open data set, however, I needed to convert this data before using it. I did this in following steps:

1) As not all glaciers were tracked in an even time period, I created a column that calculates the average annual length change, which was set for 365 days, to create a more consistent value.
2) As many glaciers have not been tracked consistently through 2020, I reduced my data set to those where data was availiable between 2000-2020, so that I would have equal data on all the glaciers included in my analysis.
3) I included coordinates for each glacier, with the help of the website mapcarta.com (www.mapcarta.com).
4) To make sure my length change time scale does not depict data from before 2000, I truncated the start date of those glaciers recorded over multiple years, starting before 2000 and ending after to start 01.01.2000. I did not change the ‘Average Annual Change’.

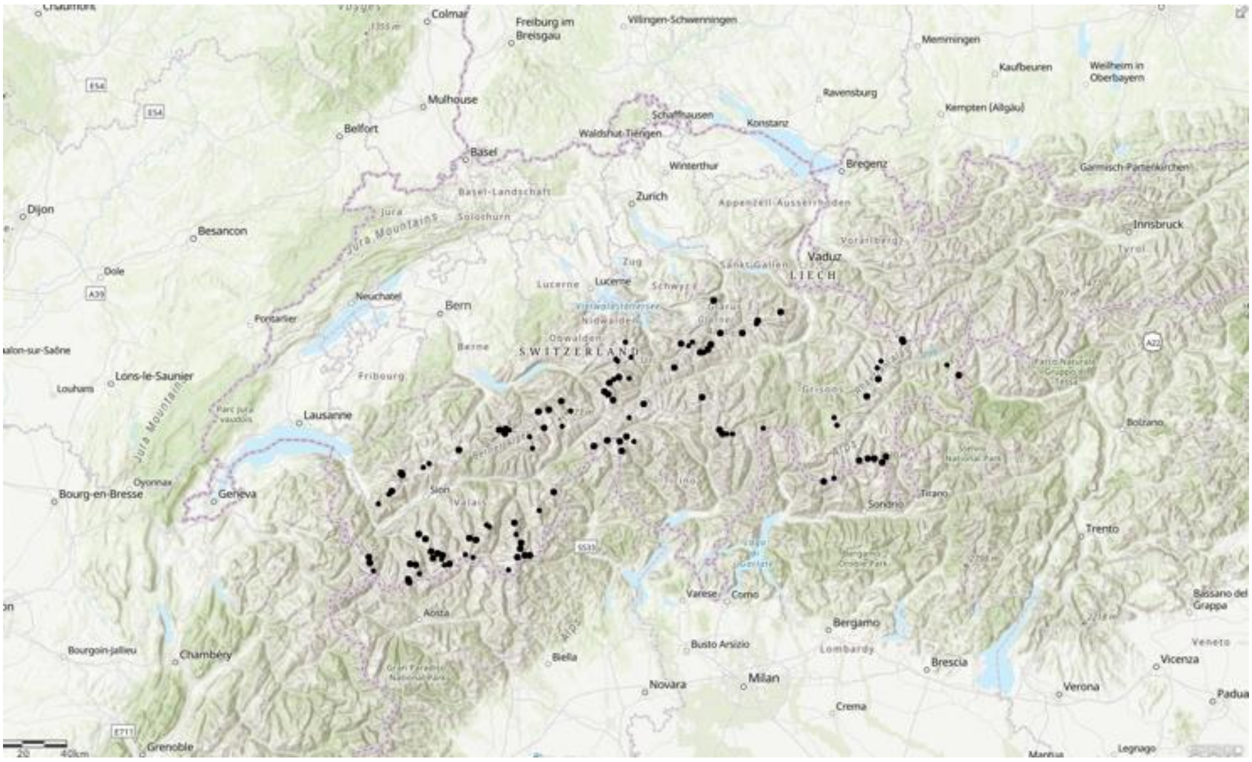


Fig. 21: GLAMOS 2020 data set before data cleansing showing 156 glaciers.

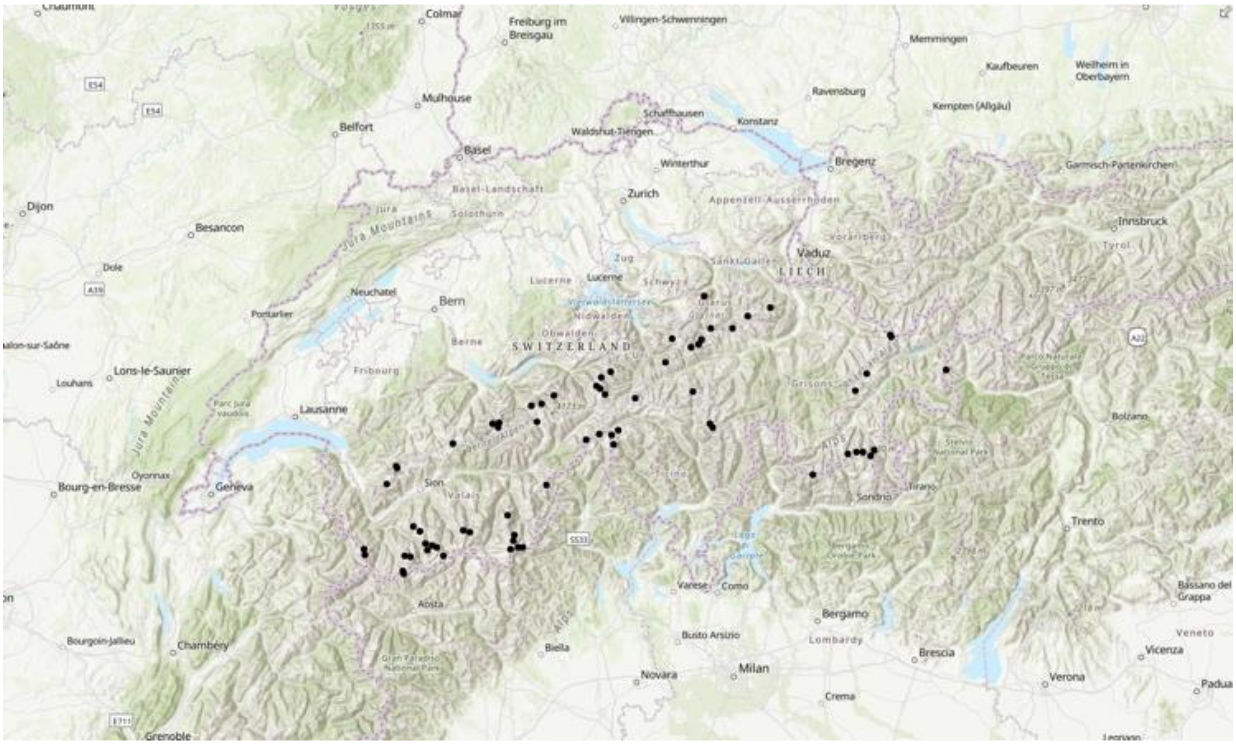


Fig. 22: GLAMOS 2020 data set after data cleansing showing 73 glaciers.

5.4 RECESSION MAP

My glacial recession map depicts the length change data (www.mapcarta.com) as bubbles, where the larger bubbles represent a larger recession. As I am analyzing a current threat that Switzerland is facing, I wanted to look at what glacier poses the biggest threat at the present time. Therefore, I studied the most recent year of data collection: 2020.

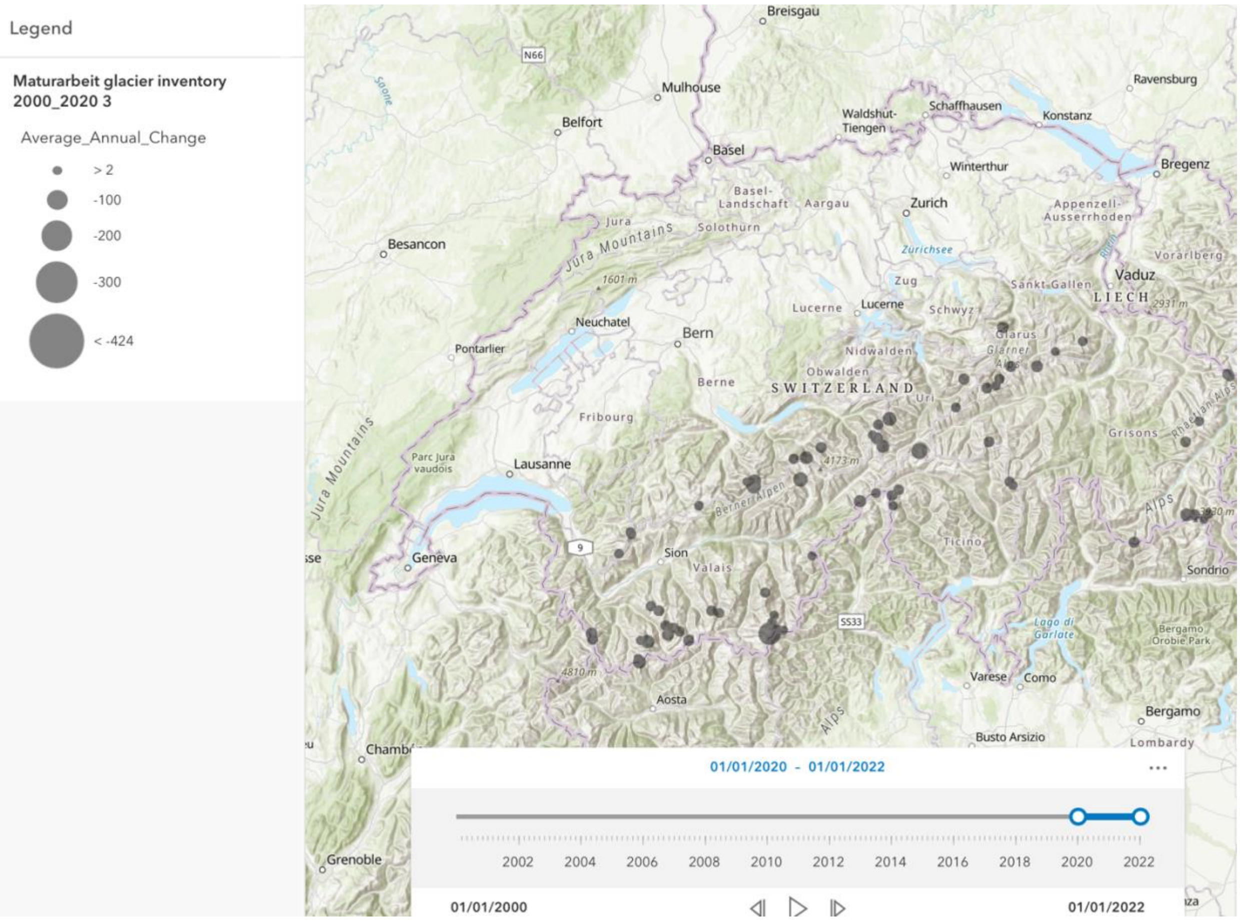
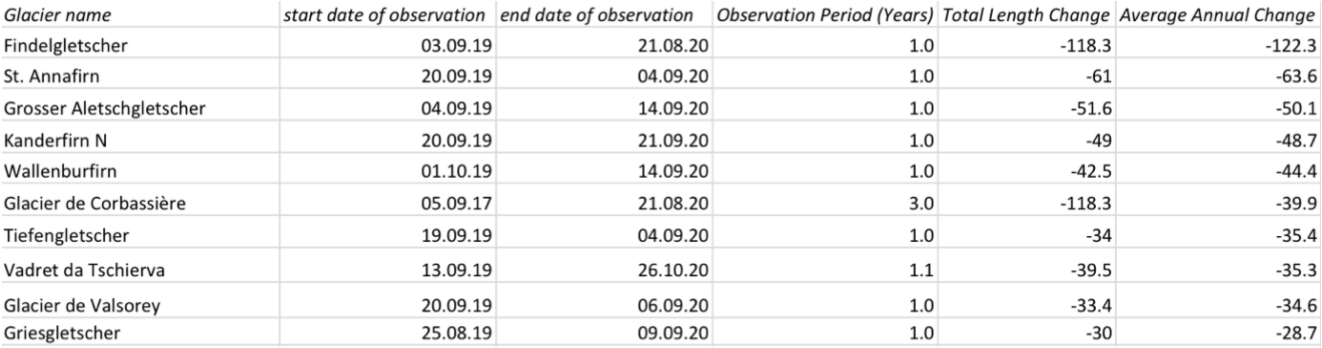


Fig. 23: Recession map: displaying average annual length change for the 73 glaciers in 2020.

The table below shows the top 10 most receding glaciers of 2020 in table form.

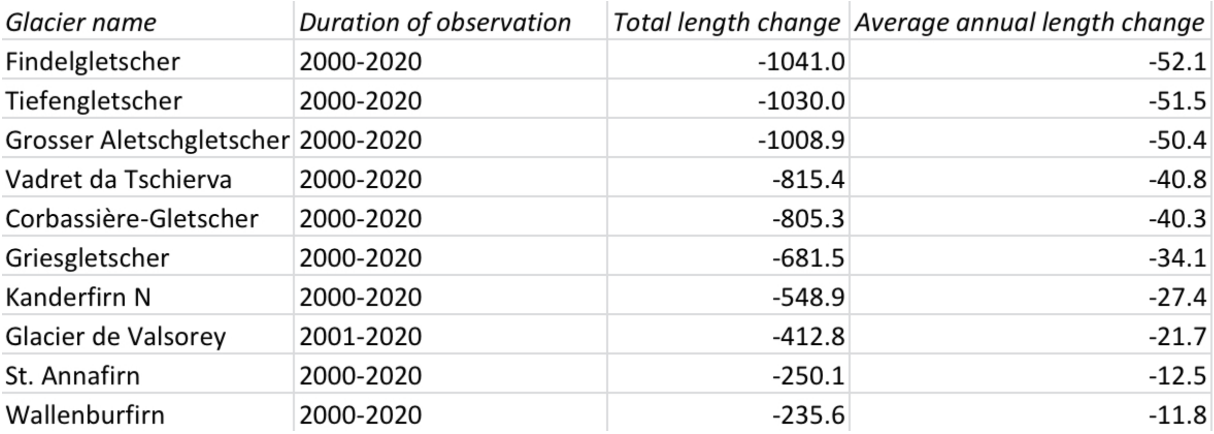
Table 4: Most receding glaciers in 2020:



Glacier name	*start date of observation*	*end date of observation*	*Observation Period (Years)*	*Total Length Change*	*Average Annual Change*
Findelgletscher	03.09.19	21.08.20	1.0	-118.3	-122.3
St. Annafirn	20.09.19	04.09.20	1.0	-61	-63.6
Grosser Aletschgletscher	04.09.19	14.09.20	1.0	-51.6	-50.1
Kanderfirn N	20.09.19	21.09.20	1.0	-49	-48.7
Wallenburfirn	01.10.19	14.09.20	1.0	-42.5	-44.4
Glacier de Corbassière	05.09.17	21.08.20	3.0	-118.3	-39.9
Tiefengletscher	19.09.19	04.09.20	1.0	-34	-35.4
Vadret da Tschierva	13.09.19	26.10.20	1.1	-39.5	-35.3
Glacier de Valsorey	20.09.19	06.09.20	1.0	-33.4	-34.6
Griesgletscher	25.08.19	09.09.20	1.0	-30	-28.7

The first glacier has a particularly high melting rate. The following glaciers also show strong differences but are less drastic than the first one. I then researched the average glacial recession of the last 20 years for these top 10 glaciers in order to ensure that there is a sustained recession being recorded, not just one outlier year. The glacier that poses the biggest danger does not only have a high recession rate over one year, but this depletion should be continuous over the past years of data collection. Therefore, I calculated the average annual length change of the identified 10 glaciers over the last 20 years.

Table 5: Glacier recession between 2000-2020 of the top 10 glaciers from Table 4:



Glacier name	*Duration of observation*	*Total length change*	*Average annual length change*
Findelgletscher	2000-2020	-1041.0	-52.1
Tiefengletscher	2000-2020	-1030.0	-51.5
Grosser Aletschgletscher	2000-2020	-1008.9	-50.4
Vadret da Tschierva	2000-2020	-815.4	-40.8
Corbassière-Gletscher	2000-2020	-805.3	-40.3
Griesgletscher	2000-2020	-681.5	-34.1
Kanderfirn N	2000-2020	-548.9	-27.4
Glacier de Valsorey	2001-2020	-412.8	-21.7
St. Annafirn	2000-2020	-250.1	-12.5
Wallenburfirn	2000-2020	-235.6	-11.8

Based on both of these analyses, the Findelgletscher and the Grosser Aletschgletscher come out on top as both, having the highest recession in the year 2020, as well as over the time period between 2000-2020. Therefore, I conclude that they pose the biggest danger of releasing potentially pathogenic microbes, as far as glacier recession is concerned.

5.5 CONTACT MAP

Next, I wanted to find out which of these ten glaciers are in highest proximity of the biggest settlements and therefore increase the likelihood of contact with humans. In order to compare these I looked at the population size of the settlements around the glaciers by adding the population layer of municipalities in Switzerland, created by Esri (Esri Suisse, 2021). The darker shaded the municipality area is, the larger the population here, collected in the layer B20BTOT (total population in 2020).

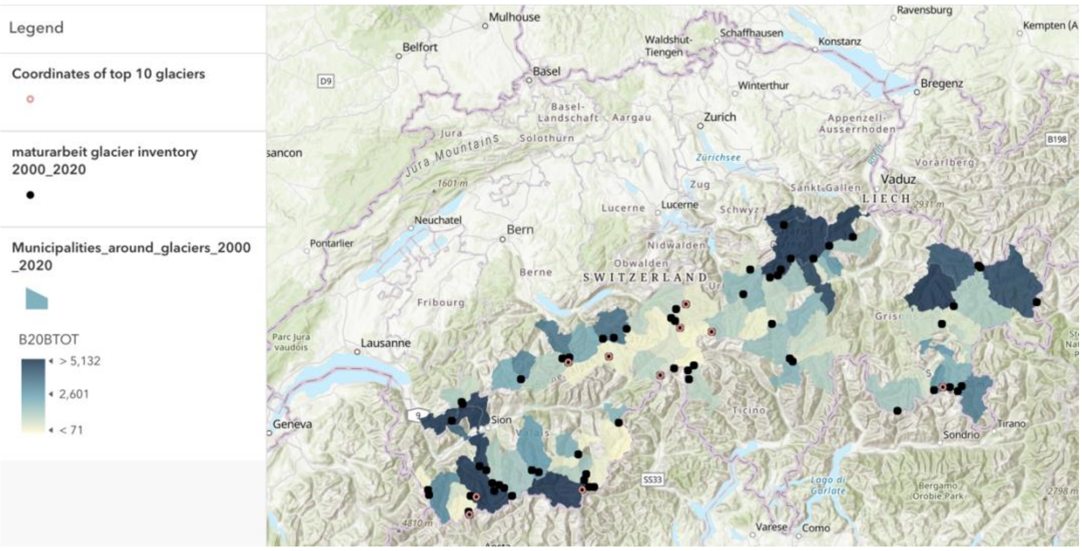


Fig. 24: Contact map: geomap depicting the 73 glaciers and their surrounding municipalities and their populations. Marked in red are the top 10 glaciers from Table 4.

In the analysis of the melt rate the Grosser Aletschgletscher and the Findelgletscher were identified as the two glaciers with the biggest risk of releasing pathogenic microbes. The human contact analysis showed that the Grosser Aletschgletscher has a low surrounding population, as a result I will now treat this glacier as posing a smaller danger. On the other hand, the Findelgletscher was shown to have a high surrounding population, therefore the risk of an out breaking stemming from this glacier was reinforced.

Table 6: Population size of the surrounding municipalities of the top 10 glaciers from Table 4:

Glacier name	*Municipality name*	*Total population size of surrounding municipalities in 2020*
Glacier de Corbassière	Bagnes	8'245
Findelgletscher	Zermatt	5'820
Vadret da Tschierva	Samedan	2'923
Kanderfirn N	Kandersteg	1'288
Griesgletscher	Obergoms	654
Wallenburfirn	Göschenen	428
Grosser Aletschgletscher	Fieschertal	326
Glacier de Valsorey	Bourg-Saint-Pierre	211
St. Annafirn	Hospental	182
Tiefengletscher	Realp	142

The results of my analysis determines the Findelgletscher as the most dangerous glacier to public health in Switzerland, for the release of pathogens, based on the framework assumption and available data.

In further analyses more detailed data should be included, such as prevalence of microbes in the glaciers, quantified visitor data and risk of vector-borne infections.

6. MITIGATION STRATEGIES

In previous chapters I have outlined the dangers Switzerland is facing in light of the receding glaciers. There are however measures that can be taken to prevent a outbreak from happening or at least mitigate the impact.
This chapter proposes a set of actions that should be taken in Switzerland to help raise awareness to the general public as well as affected communities, prevent outbreaks through monitoring and screening strategies, and prepare an emergency response.

6.1 AWARENESS

One key insight I gained during my research is that the danger discussed in this paper is not well known or understood. During my interview, Mrs Gilda Varliero, one of the leading glaciologists in Switzerland, pointed out that it will be important to raise awareness to the general public to sensitize the population to this less well-known consequence of melting glaciers (Frey & Varliero, 2023).
An awareness campaign aims to inform and educate people on a topic in order to build public recognition through media, messaging and communication. The goal is to reach a large number of people over a specific period of time in order to achieve certain outcomes (Keuntjes, 2022). An example of a successful awareness campaign in Switzerland includes the pink ribbon campaign to drive breast cancer awareness. This campaign was extremely successful and was able to raise attention to this disease. It attracted attention through the little pink ribbons that represented breast cancer and aimed to encourage preventative examination in order to increase early diagnoses (www.pink-ribbon.ch).
To raise awareness for disease outbreaks from melting glacier ice I suggest considering three different aspects:

1) The first aspect is a broad awareness campaign to inform the general public about this specific consequence of the melting ice. It should be considered to embed this messaging into a broader campaign about climate change, glacier melting and its consequences. This is important, as general awareness of the effects of climate change on the cryosphere and how this is affecting us humans is becoming an increasingly important issue. By including the specific information about pathogenic microbes, people will be more careful when

coming in contact with glaciers. I suggest this campaign be implemented across schools, universities and across a wide range of media outlets, such as news publications and social media, to make sure a wide audience is reached.

2) The second aspect will focus on a targeted group of people most exposed to and in closest contact with the source. These people would need to be provided with further information and instructed on specific preventative behavior.

   The first group is medical personnel, particularly those in areas surrounding high-risk glaciers. I would recommend training them on recognizing specific symptoms of these diseases, particularly those discussed in chapter 3.3.

   The second group are glacier tourism centers and guides. These are the people who support tourism to visit glaciers and guide hikers to these regions. As they enable more contact to the glaciers and frequently come in contact with them themselves, they need to be aware of the risks and understand how to be safe around the glacier. I recommend to address this problem directly with the organizations providing these services, as well as mandate them to inform hikers of these dangers. Furthermore, I would inform glacier hikers of the risks through publications in hiking magazines and websites.

   The third group are scientists and archeologists who study the glaciers and come in contact with them frequently. I recommend these people to be further informed about risks and precaution of coming in contact with microbes. Since they take samples of meltwater and ice, which contain microbes, I would further implement rules on how these need to be discarded (Frey & Varliero, 2023).

   The final group would be the people living in proximity to these glaciers. For these people I would include targeted information on how to be safe around glaciers and how to protect others.

3) The third aspect is raising awareness on-site to visitors directly. Visitors of glaciers should be informed how they can stay safe during their trip. Potentially, other messages could be bundled, including how to protect glaciers and combat climate change. I recommend erecting physical signs at key places in and around the glaciers that provide relevant information, for example unmonitored glacier lakes that visitors may swim in, or ice caves where visitors may touch the walls. These signs could have a QR code that takes them to a website that outlines the risks further and ideal behavior. An example is the project “Mehr als Grün” spearheaded by the city of Zurich raising awareness of urban biodiversity (www.stadt-zuerich.ch).

Fig. 25: “Mehr als Grün” sign, as an example for an on site awareness campaign that uses a QR code.

6.2 MONITORING AND SCREENING

Regular monitoring and screening of melting glacial ice can help detect dangers early and potentially prevent outbreaks from happening. Screening methods were successfully implemented and played an instrumental role during the Covid-19 pandemic. Here, screening of wastewater measured levels of the SARS-CoV-19 virus, allowing researchers to estimate the next wave of infection 1-2 weeks in advance (www.cdc.gov, 2023). This was instrumental in preparing a response to a wave of infections. Glacier monitoring activities already exist, for example the research at EPFL called Vanishing Glaciers studies soil around glaciers (www.EPFL.com). I suggest these efforts be expanded to screen for pathogenic ancient microbes as well. I suggest to implement monitoring of ice, soil and water on and surrounding the glacier to most effectively track microbes that could come in contact with humans in any of those spheres. To effectively monitor for unknown pathogens, there should be regular monitoring of the most dangerous glacier in Switzerland for possible pathogens. Furthermore, there should be a regular testing of these glaciers for those pathogens identified in chapter 3.3 that would threaten public health the most. In order to do this effectively, I would promote the rapid testing for these pathogens. Examples for rapid testing include those already produced by the

Mayo Clinic, which use a PCR to identify Anthrax pathogens from human or environmental swabs (Cooley, 2001).

6.3 EMERGENCY RESPONSE

In the case of an outbreak, local and federal governments would need to act quickly, to control the effects as best as possible. To ensure such a situation would be handled efficiently, emergency plans are created to identify and prepare how to handle an emergency situation if it occurred. In Switzerland we have many such emergency plans in place already. For example, there are emergency response plans for nuclear catastrophes. These plans are organized using a zone concept. Here affected areas are divided into 3 zones: zone 1 encompasses all areas in which the hazard is arising and subsequently where measures would be required fastest. Zone 2 is an area further away in which people may be affected subsequently. Zone 3 is comprised the rest Switzerland (www.ensi.ch).

I recommend that a tailored emergency response plan will be developed, or existing ones are expanded, at the federal, canton and municipality level specific to the risk of an outbreak stemming from released pathogens from glaciers, with a focus on those diseases deemed most dangerous to public health (see chapter 3.3.) Perhaps the Federal Office for Civil Protection (FOCP) would lead such an effort.

The effort should center around the response of hospitals, including procurement of vaccines, medical suppliers, screening tests, as well as alerting relevant populations, for example via Alertswiss.

6.4 FIGHTING ROOT CAUSE

The glacial recession is driven by atmospheric warming increasing due to climate change. These changes are almost exclusively due to human greenhouse gas emissions (www.meteoswiss.admin.ch). Although Switzerland is making strides to reduce their carbon footprint, their current goals are insufficient and are not on track to meet them (www.climateactiontracker.org, 2021). Statistics are showing that Switzerland is warming at double of the global mean, displaying the dire need for change to Swiss climate response (www.meteoswiss.admin.ch).

I recommend an increased awareness campaign and further innovation in sustainable and accessible infrastructure allowing access to carbon-friendlier alternatives, to stimulate and support an enhanced domestic emission reduction. In combination to this, strengthened climate legislation, such as implementing a new drafted CO2 Act, is needed to ensure that Switzerland meets it’s intended deadlines. Switzerland should continue to seek international cooperation to achieve global goals.

7. CONCLUSION

Global warming is causing climate change at unprecedented rates and is affecting many weather and climate extremes across the world. This includes the cryosphere where glaciers are amongst the most impacted ice bodies. Switzerland is home to approximately 1800 glaciers, which are mostly warm glaciers, meaning that they are at their melting point all year around and meltwater leaves through the glacier portal in the middle of the glacier snout throughout the year. The meltwater can contain ancient microbes that were previously frozen, possibly for thousands of years, and are now being released back into the environment. Of the known microbes, less than 1% are pathogenic and of those, it is certain bacteria and viruses that are known to be especially harmful to public health, these include: bacillus anthracis, yersinia pestis, ebola virus, influenza virus, corona virus, francisella tularenis, staphylococcus aureus. Analyzing the ability of these pathogens to sustain the harsh glacial conditions, the first four of these listed are more likely to survive in freezing temperatures and anaerobic environments. Real life examples confirm that this is not science fiction. An anthrax outbreak in Siberia in 2016 from a resurfaced reindeer carcass that had died 75 years earlier and carried bacillus anthracis caused 8 people to get infected and one 12-year-old boy to die. In Tibet in 2015, scientists extracted samples of viruses that are 15’000 years old from deep within the ice cap, the majority of which had never been seen before. In 1991 a possible outbreak of small pox in Russia was apprehended, when a vault with thawing infected corpses in permafrost were neutralized. A recent study published in July of 2023 in PLOS Computational Biology attempted for the first time ever to quantify the risk of ancient, released pathogens causing harm. The paper concludes that given the vast amounts of ancient microorganisms being released into modern environments, there is76 a substantial risk that needs to be considered, even though the probability of an outbreak is low.

With both anecdotal and empirical evidence, as well as research findings substantiating that this risk is real, this paper then turns to analyzing and mapping to what extent Switzerland is in danger of a public health risk from time-traveling pathogens. Considering a number of factors, most importantly the degree of glacial recession and population density in surrounding areas, glaciers in Canton Valais, in particular the Findelgletscher near Zermatt, seem to pose the most significant danger.

I conclude that the country of Switzerland, and especially affected cantons such as Valais, need to urgently consider and implement mitigation plans to combat this risk. I had the great privilege to discuss such a strategy with two of the leading Swiss academics and researchers in this field who substantiate the need and approach for such a strategy. First, awareness needs to be raised that disease outbreak from melting glacial ice is a viable threat. This includes a broad awareness campaign to the general public, a targeted campaign to those who need specific instructions on preventative behaviors such as medical personnel, tourism staff and glacier guides who can help instruct visitors, as well as scientists and archaeologist who frequently come in contact with glaciers. Signs on-site can help raise awareness locally and most directly on how to stay safe around glaciers. Second, regular monitoring and screening of melting glacial ice can help detect dangers early and potentially prevent outbreaks from happening. A number of similar efforts are already underway in Switzerland, including research at EPFL, and should be expanded to explicitly include the high-risk pathogens identified in this paper. Finally, Switzerland needs to develop an emergency response plan in case of an outbreak, both at the local, cantonal and federal level. Many such plans already exist, for example in case of a nuclear disaster. These plans should be expanded and tailored to include the specific diseases most likely to be released from melting glacier ice and most dangerous to public health. This might include plans to procure key materials such as vaccines, medical supplies, screening tests as well as alert programs to hospitals and relevant populations. Finally, the root cause of this new and emerging danger is climate change as it causes glacial melting and the release of ancient pathogens. While Switzerland’s overall emissions continue to drop, warming in our country is still double that of the global mean. As one of the world’s richest nations, Switzerland needs to continue to be a role model and reduce carbon emissions to slow global warming.

Further research is needed to better understand, predict and prepare for this risk and Switzerland should continue to, and possibly expand, research and funding in this area.

8. ACKNOWLEDGMENTS

I have been working on this paper for the better part of this last year and one would think I am getting tired of it, but quite the opposite is the case. I would love to continue this work as there is so much more to explore and this field of research makes such an important contribution to understanding and protecting our environment.

There are lots of people to thank who inspired, encouraged and supported me along the way. First, I would like to thank Herrn Müller, my 9-12th grade biology teacher who taught me to fall in love with microbiology and opened up many doors for me, including participation in Swiss Youth in Science in Bern as well as the Schülerstudium at the University of Zurich.

One of the classes I took at University of Zurich was Ecohealth, taught by professor Dr. Marcus Hall. It was his class that sparked my interest in the field of interdisciplinary environmental science, between the environment and human health, and where the idea for this paper was born.

Mrs. Gabriela Schaepman-Strub, my professor teaching the class Klima und Ökosysteme at the University of Zurich, suggested to reach out to Mr Beat Frey, Senior Scientist at the WSL, the leading researcher in Switzerland in this field. Huge thanks to Mr Frey as well as Mrs. Dr. Gilda Varliero, a leading glaciologist in Switzerland also at the WSL whom Mr Frey introduced me to. The interview you both allowed me to conduct with you, as well as the research materials you shared expanded my horizon, added important insights, and confirmed I am on the right path.

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