A changing Arctic

The Arctic is a geographic region situated in the northernmost part of earth. It marks the latitude above which the sun does not set on the summer solstice and does not rise on the winter solstice. The Arctic is considered an area within the Arctic Circle that draws an imaginary line that circles the globe at 66° 34′ N. The Arctic Circle region includes the Arctic Ocean basin and the northern parts of Scandinavia, Russia, Canada, Greenland, and the U.S. state of Alaska. This region is characterized by its distinctive polar conditions caused by the angle of the Earth to the Sun, which creates strong differences in climate and photoperiod between long, dark, cold winters and the short, cool summers with a period of continuous daylight.

The Arctic is made up of several different ecoregions that support different communities of plants and animals. These include permanently frozen tundra, grasslands, wetlands, boreal forest, and glaciers and ice sheets (AMAP, 2016). Even though most of the Arctic is covered by water, the Arctic Ocean is the world´s smallest ocean, accounting for just 1% of the world´s ocean water (AMAP, 2016). This is due to the fact that most of the water in the Arctic is freshwater. The Arctic accounts for about three-quarter of the world´s total freshwater resources and the majority of this water is found in a frozen state (Reinwarth & Stablein, 1972).

Arctic freshwater systems are undergoing abrupt changes associated with global warming. The responses to these variations are, in turn, interconnected with many other processes, producing a rebound effect that ultimately has consequences that affect the whole world as we know it.

In this paper, we will present an overview of the various environmental effects caused by climate change and how they interconnect, with the aim of raising awareness of the gravity of the consequences that follow these cross-related processes and the importance of maintaining the stability of the ecosystems.

Ice bodies in the Arctic and their formation

When we talk about the melting of ice, we are referring to all perennial surface ice on land, which includes ice sheets or continental glaciers, sea ice, ice shelves, glaciers, and ice caps (UNEP, 2008). Ten percent of the total world´s rivers flow into the Arctic Ocean. The high amount of freshwater flowing into this ocean forms a less saline water layer that sits on top of a denser saltwater layer. The surface layers freeze and, in this way, sea ice is formed (AMAP, 2016). There are also other types of freshwater bodies that have different formation processes, such as ice caps and ice sheets, cirque and alpine glaciers, or valley and piedmont glaciers.

A glacier is defined as a persistent large body of ice that moves slowly over land, propelled by its own weight. Glaciers can move down a slope or valley or they can spread outwards on a land surface. They are dynamic stores of water which vary greatly in size and are constantly exchanging mass and energy with the atmosphere, hydrosphere, and other parts of the earth system (Benn & Evans, 2010).

Glaciers are formed when the snowfall accumulation far exceeds the melting and sublimation in a certain area over a period of time. They begin as snowflakes that start to accumulate and gradually, as the snow becomes denser, the weight of the accumulated snow buries the older snow and compresses it. The seasonal snow gradually densifies and becomes more tightly packed. The dense grainy ice that has survived a one year melt cycle is called firn (Paterson, 1994). When the ice grows thick enough, the firn grains fuse and the interconnecting air passages between the grains are closed off, turning into a huge mass, called glacial ice (Paterson, 1994).

The fact that they are created by snowfall means glaciers are primarily composed of fresh water. Over 68% of the world’s freshwater is held in ice caps, ice sheets, and glaciers (Shiklomanov, 1993) and out of that percentage, 20% comes from glaciers and icebergs that are in the Arctic region (National Geographic Society, 2016).

Glaciers are not static despite their appearance. When the ice reaches a certain thickness, there are constant pressures acting on it and varying levels of heat, molecular actions, and movement are produced within the glacier (Paterson, 1994).

The ice mass flows under the influence of its own gravitational weight, chemical changes in the surroundings, and the Earth’s own natural movements. It moves to lower latitudes, where it undergoes extensive loss by melting; these areas are known as ablation areas (Benn & Evans, 2010). The total glacier mass evolves through time depending on the balance between accumulation and ablation, which depend on climate and local topographic factors (UNEP, 2008). Accumulation and ablation areas are separated by the equilibrium line, where the balance between gain and loss of mass is 0 (UNEP, 2018).

Arctic's shrinking cryosphere

Some parts of the Arctic Ocean remain ice-covered all year-round, but the edges of the ice cover melt in summer, causing the ice to break off and float away with the ocean currents. Each year, Arctic sea ice follows a general trajectory, growing late September through April, and melting from April through mid-September (NSIDC, 2020). There is three times more ice in winter than in summer (Thomsen et al., 2016). However, recent years have experienced lower extents in all seasons, especially summer and early autumn, although the shape of the yearly trajectory has not changed. The most dramatic collapse in the satellite record occurred in September 2012, where the average extent for the entire month of September was 3.57 million square kilometres. This is a highly unusual drop from the previous years (NSIDC, 2020) and covers less than half the area that was occupied decades ago. In the 1970s, before the Arctic sea cover started to melt, it would average 8 million square kilometres a year (Raj & Singh, 2013).

The floating sea ice cover of the Arctic Ocean is, without a doubt, shrinking. Snow cover over land in the Arctic has decreased, notably in spring, and glaciers in Alaska, Greenland, and northern Canada are retreating. In addition, permanently frozen ground in the Arctic, known as permafrost, is warming and in many areas thawing (NSIDC, 2020).

Raj and Singh report in a new study that the radial decline in sea ice around the Arctic is at least 70% due to human-induced climate change. Climate change induces complex responses to the Earth's cryosphere (Bamber & Payne, 2004) because there is a complex chain of processes linked to climate change; changes in atmospheric conditions, such as solar radiation, air temperature, precipitation, wind, cloudiness, etc. (Kuhn, 1981). This means that the increase in glacial melt is related to the fact that the earth's average temperature has been increasing dramatically for more than a century. Since scientists first started to see evidence of changes in Arctic climate, the changes have only become more pronounced. Nowadays, glaciers and ice caps are used to act as indicators of climate change and global warming (UNEP, 2018).

The Arctic is changing faster than any other place on our planet. In fact, the global warming rising temperatures have been twice the global average over the past 30 years. This phenomenon is known as Arctic amplification (NSIDC, 2020; IPCC 2007). Most glaciers around the world are presently retreating; the ice is declining by more than 10% every 10 years (Dyurgerov & Meier, 2005). However, The Fifth IPCC Report (2013), shows that areas in the Arctic, such as Alaska and Northern Canada, are among the areas where glaciers have lost most ice mass over the past decade. Continued sea ice declines are expected and a seasonally ice-free Arctic is predicted to occur well before the end of this century (Kwok et al., 2009).

Glaciers play a huge role in Earth’s water cycle and condition in all Arctic ecosystems. As the ice cover shrinks, balance between all of the interconnected factors that make up the ecosystems is lost. All of the processes are cross-related and when they are subject to changes, they have repercussions on other processes that in turn cause responses on others, creating feedback loops that lead to further warming. This feedback is the reason climate change affects the Arctic more and faster as we move forward in time. As crucial biological and biogeochemical processes suffer variation, ecological regime shifts associated with possible losses of biodiversity are induced (Agustí & Duarte, 2010). The rapidly diminishing ice cover has also unlocked opportunities that set even more pressure on the biodiversity of the Arctic ecosystems, such as the exploitation of natural resources that were unreachable until now, increased tourism, as well as new transportation and shipping routes (Michel et al., 2012).

Glacier retreat compromises glacier ecosystems and the loss of a pool of genes adapted to the cold that live only in these ecosystems (Vincent, 2010). These changes are linked through different atmospheric, marine, and terrestrial systems and they cascade through the entire food chain, from small ice-associated species, such as microbes, to megafauna and marine mammals (ACIA, 2004; Mueter et al., 2009). It also affects terrestrial species and overall all ecosystems, landscapes and environmental systems because it brings climate feedbacks that cause major changes to the earth surface (Ims & Ehrich, 2013).

These changes impact processes that set the framework for the global climate system, influencing regions all over the world (White et al., 2010). Some of these changes are well understood, while there is a considerable uncertainty around other projected changes. The impacts it will have on human society range from the decrease of water that will be available for consumption and irrigation because of long-term loss of natural freshwater storage in frozen form, effects on hydroelectric energy generation capacity, to the emergence of new diseases, parasites and contaminants (Kutz et al., 2005; Sommaruga, 2014).

As climate change leads to glacial melt and feedback loops conducive to further warming are created, all ecosystems are being affected. In this paper the cross-related processers caused by climate change are linked to one another in order to explain the consequences this has on ecosystems and the biodiversity that we rely on. Biodiversity keeps the ecological system we live in working. Changes in the Arctic ecosystem affect our resources directly and indirectly, having an impact on our society as we know it. These ecosystems ultimately influence us by conditioning science, development, management, recreation, economy, religion, cultural heritage, and resources for the maintenance of human livelihoods.

The goal is to raise awareness about the importance of this biodiversity that is being destroyed and to gain consciousness on how important it is to cooperate in implementing a conservation management plan that relies on sustainability and makes ourselves responsible for the alterations to the earth that we are causing.

Biodiversity and Climate Change

Biodiversity in the arctic

The Arctic is made up of a number of different communities of plants and animals supported by specific ecoregions; permanently frozen tundra, boreal forests, grasslands, wetlands, and ice sheets and glaciers (AMAP, 2016). Arctic biomes are often defined by how water moves through or is stored within them because they are characterized by a variety of freshwater ecosystems. As the Arctic water cycle changes, the biomes and their ecosystems are changing as well.

Without taking into account the microorganisms, the Arctic ecosystems support more than 21,000 species of plants, fungi, and animals, or even endoparasites (Barry et al., 2013). This is without taking into account that many species remain yet undescribed or undiscovered (Bluhm et al., 2011). If we compare this to other areas, the Arctic has relatively few species, but even though they are less rich in species, the Arctic region contributes significantly to global biodiversity. This is because Arctic ecosystems are recognized for their highly adapted, extreme environment-resistant species that fill multiple unique ecological niches.

According to the Convention on Biological Diversity (CBD), the term “biodiversity” means the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and ecological complexes of which they are a part. This includes diversity within species, between species, and of ecosystems.

Biodiversity is important because it refers to the variety of life on earth that keeps the ecological system we live in working. Each species has a unique niche or role to play in an ecosystem since living creatures depend on each other to survive. The strong interaction between species leads to cascading impacts from one species to another, which is why the loss of specific species greatly conditions the survival of others that benefit from the previous.

This polar region is recognized for its cold-adapted species that have developed genetic diversity, reflecting great adaptation. The pool of genes developed in the Arctic is therefore unique and contributes greatly to planet biodiversity. In addition to these distinctive genes, the Arctic ecosystems indirectly contribute to shaping global biodiversity because of the impact it causes on the rest of the Earth’s climate and ecosystems (Michel et al., 2012).

Glacial ecosystems

Anesio and Laybourn-Parry (2012), argue that the cryosphere is a biome even though it isn’t characterized as a biome in most textbooks. Although they haven’t always been given this credit, glaciers and ice sheets are Earth’s largest freshwater ecosystems and they comprise several biodiverse habitats. Glacier ecosystems occur on the ice, in the ice, and under the ice and they can be divided into supraglacial, englacial, and subglacial ecosystems (Hodson et al., 2008). The biome they form is very distinct from others and it is dominated by microorganisms, both autotrophs and heterotrophs (Hodson et al., 2008; Anesio &

Laybourn-Parry, 2012).

Cold-adapted (psychrotrophs) and cold-loving (psychrophilic) microorganisms that are actively metabolizing on glaciers and ice sheets have a range of unique genes and adaptations. They have the ability to produce anti-freezing proteins, cold-active enzymes, and exopolymeric substances that provide cell protection against the damaging effects of the cold (Anesio & Laybourn-Parry, 2012). These microbial communities also play an interesting role in biogeochemical transformations (carbon fixation and respiration, iron cycling and methanogenesis) with implications that reach global scale (Hodson et al., 2008).

We have relatively little information about the functional diversity of glacial microbes, and their role in biogeochemical processes, but we are aware that they are valuable organisms able to adapt and thrive extreme habitats and, as explained in Green´s et al. (2008) paper, studying these organisms can offer us possible responses to climate change. Climate change compromises the survival of this pool of distinctive genes and conditions biodiversity as alterations to glaciers and ice sheets translate to surrounding ecosystems that, at the same time, have repercussions on the rest of the world. It is not just about the loss of the polar hemispheres, but about how this conditions the world as we know it.

Terrestrial Ecosystems

The Arctic terrestrial ecosystem is normally saturated with water as a consequence of always being covered in snow, excepting the warmer months of the year. Moreover, permafrost lies underneath the tundra, also helping to keep moisture, as well as nutrients, during the summer months (Callaghan et al., 2005).

Tundra plants survive by adapting to extreme conditions. In the winter, they are protected by the snow that covers them (Callaghan et al., 2005). In the spring, plants come alive by obtaining warmth from the soil, keeping moist and unexposed by growing in mats close to the ground.

The arctic terrestrial ecosystem is recognized for its low primary production and plant biomass (Schmidt et al., 2002). The low production is a consequence of the fact that the area of available tundra is small. In addition, there is a short growing season due to the temperatures, snow cover, permafrost, and the high proportion of photosynthetically less efficient cryptogams in the plant communities (Shaver & Jonasson, 2001).

There is an accumulation of organic matter, as a result of the higher production than decomposition rate, caused by the temperature dependence of microorganisms. This leads to a high food supply that diverse species, such as saprophagic arthropods as well as vertebrates, come to take advantage of (Jonasson et al., 1999). In addition, plants are generally nitrogen- and/or phosphorus-limited (Schmidt et al., 2002) and compete against microbes for nutrients, resulting in a high proportion of biogenic salts being microbially fixed (Jonasson et al., 1999; Shaver & Jonasson, 2001).

Marine Ecosystems

The Arctic Ocean is a young ocean with an evolutionary origin of seaweeds, marine invertebrates and mammals that dates back to 3.5 million years ago (Adey et al., 2008). The seasons without ice date to the last 10,000 years, which means that ecosystems belonging to Arctic coastal waters are even younger (Weslawski et al., 2010). The fact that it is a young ocean causes it to have lower biodiversity compared to marine ecosystems that are found at lower latitudes (Adey et al., 2008; Michel et al., 2012). Even though there appears to be a comparatively smaller number of species that support the marine food web, these species are of great complexity and diversity and they can be found in abundant biomasses. These species hold an immense ecological importance since they are essential to maintain diverse trophic pathways within Arctic marine ecosystems.

As stated in Michel's et al. (2012) paper, the current biodiversity estimates suggest that, while there are many species yet to be discovered, the marine Arctic includes several thousand species of microbes and protists, over 2000 species of algae, and 5000 animal species, including hundreds of zooplankton taxa dominated by crustaceans and thousands of unicellular and multicellular benthic taxa.

The Arctic ecosystem is considered phagophyllic, which means it is associated with seasonal ice and the functioning of marine arctic ecosystems is linked to key physiographic and hydrographic features of the Arctic Ocean, which include temperature, salinity, stratification, connection to other oceans, etc. (Michel et al., 2012). Fluctuations in these features affect the organisms that are conditioned by them. The Arctic ecosystem is based around algae which is one of the most abundant organisms and depends on this sea ice and is at the bottom of the food chain, supporting all other species (Barnes & Tarling, 2017).

These organisms are found in such considerable biomasses that they create clear, nutrient-free water in the winter months and intense blooms in the summer (Smetacek & Nicol, 2005; Barnes & Tarling, 2017). In the summer, production becomes high due to 24 hours of sunlight that allows continuous photosynthesis to be possible. There are also high near-surface nutrient concentrations due to vertical mixing through a combination of wind-mixing and upwelling. Diatoms, which are very efficient producers, are dominant in these conditions (Dunbar, 1982).

Marine organisms are distributed unevenly in the ocean because of the uneven mixing and the upwelling (Stempniewicz et al., 2007). Regions such as glacier fronts, marginal ice zones or estuaries, where different water masses mix, are often rich feeding sites (Dunbar, 1982). Continental shelves are highly dynamic environments where most of the biological production in the Arctic Ocean takes place and a broad range of biodiversity is found. They are habitats that support unique communities of organisms because there is a wide range of environmental conditions on these shelves. The conditions go from gradients in temperature, salinity, and nutrient concentrations to changes in the biogeochemical cycling of carbon caused by the influence of the annual sea ice (Steffens et al., 2006).

Climate change impact on the biodiversity in the Arctic

Effects on the different Arctic ecosystems

The ice that covers the poles has a high albedo, which means that it can reflect solar radiation, helping to cool the earth. As this ice cover shrinks, the albedo effect that cools the poles and essentially refrigerates the earth is being eliminated (IPCC, 2007) because snow and ice have a greater albedo effect than the bare or vegetated ground that is replacing it. Surfaces with a lower albedo that are getting exposed, absorb more heat, contributing to even more warming (Raj & Singh, 2013). Less sea ice covering the ocean exposes more of its surface to solar energy and also wind. This causes a higher evaporation which increases air moisture. The warmer the atmosphere, the more moisture it can hold, which implies a feedback effect. Water vapor is a greenhouse gas, therefore more moisture also contributes to rising temperatures, thus creating an additional feedback effect that leads back to the melting of ice. Higher winds caused by the lack of sea ice ‘’protecting’’ the water provide a rise in the mixing of surface layers with underlying waters. Because deep water in the Arctic is warmer than surface waters, heat is brought up from lower depths, which results in further water temperature variations (AMAP, 2011a).

Moisture in the atmosphere contributes to more precipitation in an increasing proportion as rain, which at the same time contributes to more defrost. In addition, climate change is also leading to the transport of more moisture from lower latitudes towards the pole (AMAP, 2016). Increased precipitation, river flow, and discharge from melting glaciers and ice sheets are all channeling growing volumes of freshwater into the Arctic Ocean. This also contributes to rising sea levels. According to NSIDC (2019), if all land ice melted away, the sea level would rise by almost 70 meters with the Greenland ice sheet contributing to a rise of about seven meters, and thus submerge many of the world’s greatest cities (IPCC, 2007).
Melted fresh water causes less dense water on the surface and an increased stratification, which results in higher surface water temperatures and lower biological activity because phytoplankton can be isolated from deeper layers that are richer in nutrients (Oliver et al., 2018). Warmer water in the surface absorbs less carbon dioxide which then stays in the atmosphere and further warms the earth (Oliver et al., 2018). Alternatively, a longer open water period can also be linked to increased primary production (Arrigo et al., 2008) due to the higher wind mixing rates that create favourable conditions for upwelling of nutrient-rich waters (Michel et al., 2012). In addition, phytoplankton receives more light in the open water (Arrigo et al., 2008). This means that, as explained in Oliver’s et al. (2018) paper, depending on local conditions, sea ice losses can enhance or reduce primary production.

The layer of permafrost covers approximately 25% of the land area in the Northern Hemisphere (Yang et al., 2010). It is a significant carbon store that contains remnants of plants and animals accumulated over thousands of years; by some estimates, it contains twice as much carbon as there is currently in the Earth’s entire atmosphere (AMAP, 2016). Observations and measurements show that the temperature in the permafrost has risen by up to 2-3°C in most places in the last 40 years (IPCC, 2007). The total area of the northern hemisphere with surface permafrost is expected to decrease as much as 80% by the end of this century (IPCC, 2007). Thawing permafrost contributes to the release of greenhouse gases (mainly methane) that are currently stored in the ground which leads to the previous effects and allows microbes to break down this organic matter, producing greenhouse gases. Furthermore, when permafrost thaws, water from small lakes and tarns is drained away, affecting the hydrological cycle in the area (AMAP, 2012). Permafrost melt allows plant growth but can also cause areas to experience perennially waterlogged conditions, suppressing forest growth (AMAP, 2016).

There are important warm ocean currents, such as the Gulf Stream that brings warm water from the Gulf of Mexico into the Arctic pole. In the North Atlantic the water brought from warmer lower latitudes will be cooled. As the warmer water flows in, colder, denser water sinks below and begins flowing outwards from the Arctic Ocean and moves south. These currents circulate within the Arctic marine system, and then flow southwards, having an important role in driving global ocean circulation. Increased flows of freshwater and changes in salinity could disrupt this mechanism that plays a key role in global climate regulation and is known as the Atlantic Meridional Overturning Circulation (AMOC) (Palter, 2015). Disturbances in the Gulf Stream can dramatically impact the weather on land.

Ocean currents and rivers also play a big part in supplying nutrients that form the basis of marine food webs of global importance (Palter, 2015). For example, extensions of the Gulf Stream, such as the North Atlantic current, have branches that are warm-water currents that carry small calanoids that impact Spitsbergen. Other currents like the Sørkapp Current, influence Spitsbergen by bringing cold, Arctic water from the northeast with a zooplankton community (Stempniewicz et al., 2007).

The jet stream is a high-level airstream that circles the globe at mid-latitudes and affects the track of pressure systems and storms over North America, Europe, and Asia (Raj & Singh, 2013). It can also be influenced by glacial melt because it is driven by the difference in temperatures between cold Arctic air and warmer air from the south.

When the ice melts into freshwater and precipitations increase, there is plant growth (Callaghan, 2001). A surface covered by plants has a lower albedo and, therefore accentuates climate change and leads to some of the effects we explained previously. In the ocean, the lack of cover provided by the ice, will also result in new habitats available for seaweed colonisation in the ocean (Weslawski et al., 2011).
In both terrestrial and aquatic ecosystems, more plants mean more photosynthesis. This could be counterproductive due to an enrichment in nutrients and minerals from permafrost and the enhanced flow of water that could potentially support excess heterotrophic activity and cause eutrophication. As explained in Agustí et al. (2010), a transition towards an ecosystem with a reduction in export matter that causes an increased heterotrophy is taking

place (Agustí et al., 2010). The shifting of the net metabolism of the Arctic Ocean from autotrophic to heterotrophic implies a change from a net sink to a source of CO2 (Agustí et al., 2010).

In terrestrial ecosystems, this can alter local food webs and the range of wildlife supported by an ecosystem (Zarnetske et al., 2012). It also leads to an abundance of commensal species impacting Arctic endemics, such as predators or competitors and outbreaks of insect herbivores and plant pathogens (Ims & Ehrich, 2013).

In aquatic ecosystems, this leads to blooms of algae that reduce water quality, crowd out other species, and are toxic for animals. Cloudiness can block the light needed for photosynthesis and potentially clog filter-feeding fauna (AMAP, 2016). The supply of clean water is also an important service provided by natural systems. Again, toxic algae blooms caused by excessive nutrient inputs can affect drinking water quality.

Other changes being experienced in the Arctic tundra are small variations in nitrogen (N) and phosphorous (P) The Arctic tundra is dominated by plants that have low nutrient requirements (Jonasson et al., 1999). Small variations in N and P cause a strong increase in plant productivity (Shaver & Jonasson, 2001), which is why changes in the cycling of nutrients will bring changes to the community structure (Stempniewicz et al., 2007).

As explained on the Arctic Biodiversity Assessment (Barry et al., 2013), changing landscapes and vegetation will bring loss of unique animal species from certain areas of the Arctic. Species rely on seasonal indicators that are changing, and they have different ecological responses to these variations. Changes in the sea ice or sea ice surface generates the direct loss of habitats. Fluctuations in stratification, light attenuation, and nutrient availability indirectly affect unique communities of organisms, such as pelagic and benthic communities. These communities support associated food webs having repercussions on higher trophic levels and also impact the reproduction and foraging success of ice-associated species (AMAP 2011; Michel et al., 2012).

While it is hard for specific species to adapt to these gradual changes in the timing of the seasons, new species from the south that are already accustomed to those parameters can expand their breeding ground and have access to places they could not before (Jensen et al., 2008). The pattern that will be most often repeated will be that milder environmental conditions in the pole may provide new habitats for temperate species that may outcompete polar species and disrupt the ecosystem (Michel et al., 2012). Replacement by subarctic species that have extended their distribution range northward have been observed in the last 30 years for different animal species (Michel et al., 2012). Increased human activity in the Arctic also contributes to bringing invasive species (Kortsch et al., 2015). There will also be alteration to the predator–prey interactions because of the change in habitat and seasonality. Many species depend on sea ice for their dispersal and access to feeding (Descamps et al., 2017). Although these species could have a short-term benefit because there will be higher prey densities gathered in smaller ice-covered areas, in the long term it will result in their extinction (Thomsen et al., 2016; Descamps et al., 2017).

Variations in diversity are taking place, with a trend towards a community of smaller cells, such as bacteria, small algae, and zooplankton. If these organisms, which are a strong determinant of trophic pathways and carbon fluxes in marine ecosystems, continue having a competitive advantage, it can lead to reduced biological production at higher trophic levels (Li et al., 2009). Changes in the size and energy content of key zooplankton prey affect energy transfer in the pelagic food web having important consequences for the animal species that tap into this food base (Weslawski et al., 2000).

An increase in bacterial respiration which is also supported by an increase in temperatures, increased inputs of carbon, and the strengthening of the pycnocline, also means a challenge for the capacity of the Arctic Ocean to act as a sink for CO2 (Cai et al., 2010). The dominant microbial loop in the upper water column will lead to decreased exports of biogenic material to the sea floor. This will again help the planktonic ecosystem shift from a CO2 sink to a CO2 (Agustí et al., 2010). Bacteria and other microorganisms will have a higher supply of organic matter that they can convert to carbon dioxide and the ocean can experience a reduction in calcium ions and higher ocean acidification generated by an increase in carbon dioxide. The ocean also absorbs CO2 from the atmosphere which will be at higher concentrations. This means more dissolved CO2 in the ocean which is a threat to calcareous organisms and may have cascading impacts on marine ecosystems, biodiversity, and fisheries. Calcium ions and carbonate are used to build shells and skeletons which species rely on (Barry et al., 2013; AMAP, 2016). Studies have detected an undersaturation in aragonite which is essential for the formation of the shell of an important plankton species in the Arctic caused by ice melt (Yamamoto-Kawai et al., 2009).

Conclusion

The Arctic is undergoing crucial changes in many of its elemental physical components. These alterations have important impacts on the chemical and biological processes, having repercussions that are coupled with many ecological feedback processes and will cause unpredictable reorganizations of ecosystems in the region and potentially on a global scale.

Loss of biodiversity is one of the effects we are already experiencing due through climate change and we need to be aware of why this is so severe. Biodiversity keeps the planet healthy since it keeps a balance. If there is a big change and functioning ecosystems disappear, then the earth might not be able to ever recover from this loss of balance. It is not just for the wellbeing of other organisms, but our own wellbeing is affected, too. They are just the first to experience it. It also impacts our lives in a direct way because less biodiversity compromises the resources that we take advantage of. Since we need these resources to survive, we must learn to take care of them. That is why it is of great importance that we combine our interests with sustainability, promoting an innovative and respectful society that is dependent on stability and well-functioning cooperation. There are ways to use our knowledge in technology, but the upcoming efforts to preserve Arctic biodiversity and resources must be as innovative and wide-ranging as the unknown stressors that are being experimented by Arctic ecosystems now. The impacts of climate change will give rise to coordination challenges among nations, as well as for regional levels of government.

The Arctic offers major opportunities for development with multiple sectors that have a great potential for economic growth and requires a management plan based on sustainability that takes account of environmental and social considerations. The fact that the Arctic is an unexplored source of unique resources joined with the current situation that demands solutions to remediate global warming, makes research related to new industries, such as marine bioprospecting, indispensable. Science plays a crucial role in the adaptation and mitigation of climate change since it has the ability to positively reduce the effects that have been explained. The upcoming efforts to preserve Arctic resources and ecosystems, as well as to study and understand them, must be as novel and expansive as the unknown challenges that are being experimented by the Arctic region now.

References

ACIA (2004). Impacts of a warming Arctic. *Arctic climate impact assessment (ACIA)*.

Adey, W. H., Lindstrom, S. C., Hommersand, M. H., & Müller, K. M. (2008). *The Biogeographic Origin of Arctic Endemic Seaweeds: a Thermogeographic View*, Journal of Phycology, 44(6), 1384-1394.

Agustí, S., Sejr, M. K., & Duarte, C. M. (2010). Impacts of climate warming on polar marine and freshwater ecosystems.

Anesio, A. M., & Laybourn-Parry, J. (2012). Glaciers and ice sheets as a biome. *Trends in Ecology and Evolution*, Vol. 27, 219–225. Retrieved from https://doi.org/10.1016/j.tree.2011.09.012.

AMAP (2011a). AMAP Assessment 2011: Mercury in the Arctic. *Arctic Monitoring and Assessment Programme (AMAP)*. Oslo, Norway.

AMAP (2011). Snow, water, ice and permafrost in the Arctic (SWIPA): Climate change and the cryosphere. *Arctic Monitoring and Assessment Program (AMAP)*. Oslo, Norway.

AMAP (2012). Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011 Overview Report. *Arctic Monitoring and Assessment Programme (AMAP)*. Oslo, Norway.

AMAP (2016). The Arctic Freshwater System in a Changing Climate. *Arctic Monitoring and Assessment Programme (AMAP)*. Retrieved from https://oaarchive.arctic-council.org/handle/11374/1854.

Arrigo, K. R., van Dijken, G. L., & Pabi, S. (2008). Impact of a shrinking Arctic ice cover on marine primary production. *Geophysical Research Letters*, 35, L19603. Retrieved from https://doi.org/10.1029/2008GL035028.

Bamber, J.L., & Payne, J. (2004). Mass balance of the cryosphere. Observations and modelling of contemporary and future changes. *Cambridge University Press*, Cambridge, 644.

Barnes, D. K., & Tarling, G. A. (2017). Polar oceans in a changing climate. *Current Biology*, 27(11), R454-R460

Barry, T., Berteaux, D., Bültmann, H., Christiansen, J. S., Cook, J. A., Dahlberg, A., … & Wrona, F. J. (2013). *Arctic Biodiversity Assessment 2013.* Conservation of Arctic Flora and Fauna (CAFF).

Benn, D.I. & Evans, D.J.A. (2010). Glaciers & Glaciation. Glaciers and Glaciation, 2nd edition. *Hodder Education*, UK. Retrieved from https://books.google.no/books?hl=no&lr=&id=dkjKAgAAQBAJ&oi=fnd&pg=PP1&dq=Benn,+D.I.+%26+Evans,+D.J.A.+Glaciers+and+Glaciation,+(Hodder+Education,+UK,+2010).&ots=I7q-eD84qi&sig=VqeXXS-nxB3tsG5qRwZJM_HTr94&redir_esc=y#v=onepage&q&f=false.

Bluhm, BA, Gebruk, AV, Gradinger, R, Hopcroft, RR, Huettmann, F, Kosobokova, KN, Sirenko, BI & Weslawski, JM. (2011). Arctic marine biodiversity: An update of species richness and examples of biodiversity change. *Oceanography*, 24: 232–48.

CBD (2010a). Global Biodiversity Outlook 3. *Convention on Biological Diversity.*

Cai, W.-J., L. Chen, B. Chen, Z. Gao, S.H. Lee, J. Chen, D. Pierrot, et al. (2010). Decrease in the CO2 uptake capacity in an ice-free Arctic Ocean Basin. 329: 556–9.

Callaghan, T. V., Björn, L. O., Chapin Iii, F. S., Chernov, Y., Christensen, T. R., Huntley, B.,… & Shaver, G. (2005). Arctic tundra and polar desert ecosystems. *Arctic climate impact assessment*, 1, 243-352.

Descamps, S., Aars, J., Fuglei, E., Kovacs, K. M., Lydersen, C., Pavlova, O., … Strøm, H. (2017). Climate change impacts on wildlife in a High Arctic Archipelago – Svalbard, Norway. *Global Change Biology*, Vol. 23, 490–502. Retrieved from https://doi.org/10.1111/gcb.13381.

Dunbar, M.J. (1982). Arctic marine ecosystems. In: Rey, L., Stonehouse, B. (Eds.), *The Arctic Ocean*. MacMillan, London, 233–261.

Dyurgerov, M. B., & Meier, M. F. (2005). Glaciers and the changing Earth system: a 2004 snapshot. Vol. 58. Boulder: Institute of Arctic and Alpine Research, *University of Colorado*.

Green, J. L., Bohannan, B. J., & Whitaker, R. J. (2008). Microbial biogeography: from taxonomy to traits. *Science*, 320(5879), 1039-1043.

Hodson, A.J., Anesio, A.M., Tranter, M., Fountain, A.G., Osborn, A.M., Priscu, J., Laybourn-Parry, J. & Sattler, B. (2008). Glacial ecosystems. *Ecological Monographs* 78, 41-67.

Ims, R. A., Ehrich, E., Forbes, B. C., Huntley, B., Walker, D. A., Wookey, P. A., ... & der Wal, R. V. (2013). Terrestrial ecosystems. In *Arctic Biodiversity Assessment: Status and Trends in Arctic Biodiversity*. Conservation of Arctic Flora and Fauna, 560-384.

IPCC (2013). Fifth assessment report contribution. Intergovernmental Panel on Climate Change (IPCC).

Jensen, R. A., Madsen, J., O’Conell, M. A. R. K., Wisz, M. S., Tømmervik, H., & Mehlum, F. (2008). Prediction of the distribution of Arctic-nesting pink-footed geese under a warmer climate scenario. *Global Change Biology*, 14(1), 1-10.

Jonasson, S., Michelsen, A., Schmidt, I.K. (1999). Coupling of nutrient cycling and carbon dynamics in the Arctic, integration of soil microbial and plant processes. *Applied Soil Ecology* 11, 135–146.

Kortsch, S., Primicerio, R., Fossheim, M., Dolgov, A. V., & Aschan, M. (2015). Climate change alters the structure of arctic marine food webs due to poleward shifts of boreal generalists. *Proceedings of the Royal Society* B: Biological Sciences, 282(1814), 20151546. Retrieved from https://doi.org/10.1098/rspb.2015.1546.

Kuhn, M. (1981). Climate and glaciers. International Association of Hydrological Sciences Publication 131 (Symposium at Canberra 1979 Sea Level, Ice, and Climatic Change), 3–20.

Kutz, S.J, Hoberg, E.P, Polley L., Jenkins E.J. (2005). Global warming is changing the dynamics of Arctic host-parasite systems. *Proceedings of the Royal Society of London*– B, 272, 2571–2576.

Kwok R., Cunningham G.F., Wensnahan M., Rigor I., Zwally H.J., Yi D. (2009) Thinning and volume loss of the Arctic Ocean sea ice cover: 2003–2008. *Journal of Geophysical Research-Oceans*, 114, C07005.

Li, W.K.W., McLaughlin, F.A., Lovejoy, C., & Carmack, E.C. (2009). Smallest algae thrive as the Arctic Ocean freshens. *Science* 326, 539.

Michel, C., Bluhm, B., Gallucci, V., Gaston, A. J., Gordillo, F. J. L., Gradinger, R., ... & Nielsen, T. G. (2012). Biodiversity of Arctic marine ecosystems and responses to climate change. *Biodiversity*, 13(3-4), 200-214.

Mueter F.J., Broms C., Drinkwater K.F. et al. (2009). Ecosystem responses to recent oceanographic variability in high-latitude Northern Hemisphere ecosystems. *Progress in Oceanography*, 81, 93–110.

NSIDC (2020). Satellite Observations of Arctic Change subsite. *National Snow and Ice Data Center*. Retrieved from https://nsidc.org/cryosphere/arctic-meteorology/climate_change.html.

NSIDC (2019). Contribution of the Cryosphere. State of the Cryosphere (SOTC). *National Snow and Ice Data Center*. Retrieved from https://nsidc.org/cryosphere/sotc/sea_level.html.

National Geographic Society. (2016). *Arctic*. Retrieved from https://www.nationalgeographic.org/encyclopedia/arctic/.

Oliver, H., Luo, H., Castelao, R. M., van Dijken, G. L., Mattingly, K. S., Rosen, J. J., ... Yager, P. L. (2018). Exploring the Potential Impact of Greenland Meltwater on Stratification, Photosynthetically Active Radiation, and Primary Production in the Labrador Sea. Journal of Geophysical Research: *Oceans*, 123(4), 2570–2591. Retrieved from https://doi.org/10.1002/2018JC013802.

Palter, J. B. (2015). The Role of the Gulf Stream in European Climate. *Annual Review of Marine Science*, 7(1), 113–137. Retrieved from https://doi.org/10.1146/annurev-marine-010814-015656.

Paterson, W. S. B. (1994). Physics of glaciers. *Butterworth-Heinemann*.

Raj, B., & Singh, O. (2013). A Study About Realities of Climate Change: Glacier Melting and Growing Crisis. In *Climate Change – Realities, Impacts Over Ice Cap, Sea Level and Risks.* Retrieved from https://doi.org/10.5772/54968.

Reinwarth, O. and Stäblein, G. (1972). Die Kryosphäre – das Eis der Erde und seine Untersuchung. *Würzburger Geographische Arbeiten* 36: 71.

Schmidt, I.K., Jonasson, S., Shaver, G.R., Michelsen, A., Nordin, A. (2002). Mineralization and distribution of nutrients in plants and microbes in four arctic ecosystems: responses to warming. *Plant and Soil* 242, 93-106.

Shaver, G.R., Jonasson, S. (2001). Productivity of arctic ecosystems. In: Roy, J., Saugier, B., Mooney, H.A. (Eds.), Terrestrial Global Productivity. *Academic Press*, San Diego, 189–209.

Shiklomanov, I. A. (1993). World fresh water resources. in Gleick PH ed. Water in Crisis: A Guide to the World’s Fresh Water Resources. *Oxford University Press*. Oxford, UK, 13–24.

Smetacek, V., and S. Nicol. (2005). Polar ocean ecosystems in a changing world. *Nature* 437: 362–8.

Solomon, S. (2007). The physical science basis: Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (IPCC), *Climate change* 2007, 996.

Sommaruga, R. (2014). When glaciers and ice sheets melt: Consequences for planktonic organisms. *Journal of Plankton Research*, 37(3), 509–518. Retrieved from https://doi.org/10.1093/plankt/fbv027.

Steffens, M., D. Piepenburg, and M.K. Schmid. (2006). Distribution and structure of macrobenthic fauna in the eastern Laptev Sea in relation to environmental factors. *Polar Biology* 29: 837–48.

Stempniewicz, L., Błachowiak-Samołyk, K., & Węsławski, J. M. (2007). Impact of climate change on zooplankton communities, seabird populations and arctic terrestrial ecosystem—a scenario. *Deep Sea Research Part II: Topical Studies in Oceanography*, 54(23-26), 2934-2945.

Thomsen, P. F., Møller, P. R., Sigsgaard, E. E., Knudsen, S. W., Jørgensen, O. A., & Willerslev, E. (2016). Environmental DNA from seawater samples correlate with trawl catches of subarctic, deepwater fishes. *PLoS ONE*, 11(11), 1–22. Retrieved from https://doi.org/10.1371/journal.pone.0165252.

UNEP (2008). UNEP 2008 annual report. *United Nations Environment Programme*. Retrieved from https://www.iri.edu.ar/publicaciones_iri/anuario/Anuario%202009/Mayd/Naciones%20Unidas%20%20United%20Nations%20Environment%20Programme%20%20ANNUAL%20REPORT%202008.pdf.

UNEP (2018). UNEP 2018 annual report. United Nations Environment Programme. Retrieved from https://www.unep.org/resources/un-environment-2018-annual-report.
Vincent, W. F. (2010). Microbial ecosystem responses to rapid climate change in the Arctic. *The ISME journal,* 4(9), 1087-1090.

Weslawski, J.M., J. Wiktor Jr, and L. Kotwicki. (2010). Increase in biodiversity in the arctic rocky littoral, Sorkappland, Svalbard, after 20 years of climate warming. *Marine Biodiversity* 40: 123–30.

White JWC, Alley RB, Brigham-Grette J et al. (2010). Past rates of climate change in the Arctic. *Quaternary Science Reviews*, 29, 1716–1727.

Yamamoto-Kawai, M., F.A. McLaughlin, E.C. Carmack, S. Nishino, and K. Shimada. (2009). Aragonite undersaturation in the Arctic Ocean: Effects of ocean acidification and sea ice melt. *Science* 326: 1098–100.

Yang, Z., Ou, Y. H., Xu, X., Zhao, L., Song, M., & Zhou, C. (2010). Effects of permafrost degradation on ecosystems. *Acta Ecologica Sinica*, 30(1), 33–39. https://doi.org/10.1016/j.chnaes.2009.12.006.

Zarnetske, P.L., Skelly, D.K., & Urban, M.C. (2012). Biotic multipliers of climate change. *Science* 336, 1516–1518. Retrieved from 10.1126/science.1222732pmid:22723403doi:10.1126/science.122273.