Algal Populations as an Indicator of a Shifting Arctic Ecosystem

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Coastlines all around the world are subject to rising sea level. Homes, livelihoods, and industries are being washed away by ever-warming seawater. The exponential rise in greenhouse gas output contributes to an undeniable rise in worldwide temperatures and melting arctic sea ice. The sea ice model suggests a loss of multiyear ice by the year 2042. Such warming trends are already having a profound effect on species around the world and are irreversibly altering ecosystems.

The Chukchi Sea is one of many key places destined to lose its summer ice, the effects of which are becoming more evident. Scientists are unsure what these changes will entail, or how to address the issues. It will be difficult to replace the melting ice, limit the algal growth, and stabilize our current ecosystem, although equilibrium will be reached regardless, the new ecosystem may not support humans or a diverse number of species. For the environment of the Chukchi Sea, a temperature decrease is necessary to maintain equilibrium; a temperature decrease that defies the trends of increased greenhouse gas production and will be impossible with the current state of climate change throughout the world.

*Melosira arctica* Dickie, 1852, (an arctic algal species), is a key indicator species in the Chukchi Sea. In recent years, *M. arctica* has increased in abundance, showing large algal blooms in some areas of the sea, causing depletion in nutrient availability, reducing benthic oxygen concentrations, and a rise in zooplankton – all of which have significant effects on the ecosystem.
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Introduction

Increasing quantities of scientific evidence support a rising trend in temperatures in arctic regions (SOTC: Introduction: Are Global Temperatures Rising?, 2004) As temperatures increase, Arctic Ocean sea ice declines, leaving increasingly large regions of water free of sea ice. The change in surface properties alters the average albedo of the Arctic (Winton, n.d.), increasing the quantity of energy absorbed in the pan-Arctic zone, changing the temperature of the upper pelagic zone, further altering ecosystems and melting even more sea ice. As ecosystems warm, it is expected that there will be a shift in relative populations of organisms. In addition, the organisms that originally inhabited the environment can no longer prosper and are replaced by better suited organisms introduced from other areas.

In the Chukchi Sea, rising temperatures and declining sea ice cover are changing the ecosystem and populations of sea life in the area. One such organism is Melosira arctica Dickie, 1852. Populations of M. arctica have grown rapidly in recent years as environments become more suitable for growth. The increased populations of M. arctica have powerful impacts on benthic organisms throughout the Chukchi Sea, and may potentially be of use as an indicator species to infer the state of ecosystems.

Sea Ice Projections for the Arctic

Although historical arctic sea ice data is not widely available, enough data can be analyzed to produce a mathematical model to predict future behavior of arctic sea ice. Using data from the annual period of least extent from 2002 to 2013, as well as the average least extent from 1979 to 2000 and 1981 to 2010 [Table 1], a combination of quadratic and exponential regression models can be calculated.

To account for the exponential rate at which temperatures are increasing in the Arctic, a negative quadratic regression was calculated to best fit the available data [Figure 1]. The regres-
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The quadratic regression closely follows the available data, continuing on past the observed period of time. When the quadratic regression is run independently, it predicts that sea ice will disappear at its period of least extent, generally toward the end of July and August, in the year 2034.

To account for other factors that may decrease the rate of melting, such as the physical characteristics of sea ice, an exponential decay regression was calculated [Figure 2]. The exponential decay formula decreases its rate of change as the quantity of sea ice decreases on an annual scale. When the exponential decay formula is run independently for future years, the decay regression predicts that Arctic sea ice will continue to deplete, yet at a decelerating rate. However, the exponential decay model decreases in accuracy as it progresses along the x-axis due to the property of exponential decay formulas maintaining the variable Y as greater than zero.

In order to nominalize the inaccuracy of the exponential function and to account for both the accelerating rate at which temperatures are changing in the Arctic and the physical characteristics of melting ice, a hybrid function was derived [Figure 3]. This function combines the accuracies of both formulas into one prediction by calculating individual, intermediary value using both the exponential and quadratic based formulas and calculating the mean of the two. When
this function is run for future behavior, it predicts that the Arctic Ocean will be free of sea ice by the year 2042 [Figure 4].

![Figure 4: A graph of the hybrid function showing the ice coverage prediction with data (Arthur, 2014).](image)

<table>
<thead>
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<th>Year</th>
<th>Area of Sea Ice (millions km²)</th>
<th>Year</th>
<th>Area of Sea Ice (millions km²)</th>
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<tr>
<td>2006</td>
<td>5.92</td>
<td>2013</td>
<td>5.35</td>
</tr>
</tbody>
</table>

Table 1: The data points used in the ice coverage graph (SOTC: Sea Ice, 2014)

**Physical Characteristics of the Chukchi Sea**

Geographically, the Chukchi Sea is located on the southern edge of the Arctic Ocean, between Alaska and Russia above the Bering Strait [Figure 5]. It began forming in the Permian era with the shift of the north trending Hanna Trough Basin. Today, this basin separates the Arctic Shelf and

![Figure 5: A map of the Chukchi Sea and the surrounding land masses (Chukchi Sea, n.d.).](image)
main Chukchi Shelf. The Barrow and Hana trenches are notable features in the main shelves causing a hiatus (Miller et. al., 2002). Due to the sea’s formation, today it is home to many oil and gas reservoirs, estimated to hold 724 million barrels of oil. Major reservoirs are located slightly west of Barrow, Alaska on the edge of the Arctic shelf (2006 Oil and Gas Assessment, 2006) [Figure 2].

The Chukchi Sea is one of the larger seas in the Northern hemisphere, at 595 thousand square kilometers. The Sea’s average water depth, however, is not nearly as great, the average depth of the sea is 50 meters, a relatively shallow depth for a large body of water (Summertime Circulation and Water Mass Transformation, n.d.). The shallow nature of the Chukchi Sea makes melting ice have a larger impact on the area. Many rivers run into the Chukchi Sea, including major waterways such as the Kivalina, Kobuk, Kokolik, and Amguyema rivers.

Overall, the Chukchi Sea is a unique geographical body of water that holds a lot of biological and political interest due to its formation and location.

**Ecological Characteristics of the Chukchi Sea**

The Chukchi Sea is one of the most productive ocean ecosystems in the Arctic. Its seasonal ice and shallow seafloor provide a habitat for innumerable organisms. Its environment fosters organisms such as *M. arctica*, algae that thrives in association with sea ice. *Melosira arctica*
is an influential producer affecting organisms up and down the food chain, especially in its decay (Chukchi Sea, nd).

First, as *M. arctica* falls through the pelagic zone, copepods such as zooplankton [Figure 7] consume the algae and their populations rise. Then the remaining algae fall to the seafloor where *Ophiuroidea* (brittle star) and *Holothuroidea* (sea cucumber) feast on the algae. Additionally, the algae are consumed by bacteria in the benthic zone causing bacteria populations to grow. Bacteria then consume large quantities of oxygen and create anoxic zones (Laura Nielsen, February 26, 2013). The benthic populations are crucial for larger organisms such as *Odobenus rosmarus* (walrus) who feed on the invertebrates on the sea floor. The Chukchi Sea is also home to species higher on the trophic pyramid organisms. *Monodon monoceros* (narwhal), *Delphinapterus leucas* (beluga whale), *Pusa hispida* (ringed seal), and *Ursus maritimus* (polar bears), which rely on the intricate food web for population stability. Even humans play a role as a predator of species (Chukchi Sea, 2013).

All of these species are carefully connected, relying on lower trophic levels for energy. A change in the population size of any organism could disrupt this balance and could indicate an impending collapse, especially the arctic producers (Protecting Life in the Arctic, January 29, 2013).

**Biology of Melosira arctica** Dickie, 1852

*Melosira arctica* [Figure 8] is an autotrophic, diatom in the taxonomic genus *Melosira* and the family *Melosiraceae* under the kingdom *Chromista* (Guiry, 2014). It makes its habitat on the bottom of ice floes, in the pelagic zone of the ocean in the northern latitudes of the Arctic.
Circle and in small bubbles of the ice. It is a photosynthetic organism using chloroplasts with pigments chlorophyll a and chlorophyll c.

The algae can grow in bubbles near the surface of the ice to gain enough light energy for photosynthesis; it binds to the ice by secreting a protein connecting the algae to the ice, allowing the bubbles to maintain liquid water for photosynthesis (Krembs et al., 2011). However, when the ice becomes thin enough for additional light to pass through, the algal growth rate increases significantly. The warmer temperatures of the ocean also increase metabolism and subsequently algal population growth rate (Melosira arctica, n.d.). This additional algae growth causes thick ropes of algae to grow on the underside of the ice reaching lengths of up to five meters long. As the ice melts, large algal growths fall to the bottom of the ocean and provide food for many benthic organisms.

As algal aggregates are consumed by benthic organisms, benthic populations increase dramatically, causing ecosystem instability. Subsequently, bacteria feed on the algae that have fallen to the ocean floor. This rapid proliferation of heterotrophic bacteria causes anoxic zones on the bottom of the ocean as the bacteria consume all of the available oxygen in the area.

Additionally, as M. arctica grows at an abnormal rate on the underside of ice it sequesters the nutrients that are available to the subsurface levels of the ocean. This creates oligotrophic zones where the increased algae growth occurs making it difficult for other life in the area to sustain itself (Nielson, 2013).
While *M. arctica* provides food for benthic communities it also provides food for zooplankton. During the warmer months of the year, when *M. arctica* and other primary producers are metabolizing at a higher rate, zooplankton blooms in the pelagic zone occur as well. As the algae falls from the sub-surface areas of the ocean to the benthic zone zooplankton consume algae, before it can benefit the benthic organism. In the case of the large colonies of *M. arctica*, which occur in some areas, the algae fall to the ocean floor much faster and much is left available for the benthic organisms (Hassett, 2014).

**The Gulf of Mexico**

Located southeast of Texas, wedged between the eastern coast of Mexico and the southeastern border of the United States, the Gulf of Mexico is a vast and important ecosystem, locally and globally. It is the ninth largest body of water in the world and hosts a vast variety of flora and fauna, including many reefs (The Gulf of Mexico Ecosystem, Watershed, and Economy, 2013). It is home to some of the most productive fisheries in the world, producing 1.3 billion pounds in harvest yearly, at a value of 2.8 billion U.S. dollars (Jacob Silverman, n.d.), providing over 30 percent of the seafood consumed in the United States (What Is The Dead Zone?, n.d.).

Gulf habitats include both coastal wetlands and marine areas. Encompassing over 5 million acres, approximately half of the United States total, the Gulf's coastal wetlands serve as an essential habitat for numerous fish and wildlife species, including 75 percent of migrating waterfowl that traverse the United States. (General Facts about the Gulf of Mexico, 2014)
Every spring, the Gulf of Mexico’s coastline experiences severe algal blooms. The algal blooms are a natural phenomenon that is significantly boosted by fertilizer, sewage, and other pollutants entering the Gulf of Mexico from the Mississippi and Atchafalaya Rivers. These pollutants contain phosphorus and nitrogen that provide additional sources of nutrients for the algae, causing increase in algae populations to unprecedented levels. In 2002, the largest dead zone recorded in the area, and one of the second largest ever recorded in the world, a bloom reached 8,495 square miles. As pollutant content in the area rises the blooms are only expected to get larger. As of 2007, there was a 300 percent increase in the levels of “nutrient” providing chemicals entering the Gulf as there were in the 1950s. (Jacob Silverman, ND)

The algal blooms cause the area to become a hypoxic (dead) zone [Figure 9] because the algae exceed the Gulf’s carrying capacity. The algae grow to an extreme extent, die off, and sink, providing a large amount of nutrients for the benthic community, but creating an azoic environment from depletion of nutrients. As heterotrophic organisms consume the decayed algae, oxygen is overused creating an anoxic zone. Eventually the environment becomes a hypoxic zone and is incapable of supporting life.

The Gulf of Mexico holds much significance worldwide. It provides a home to millions of organisms, fosters a large marine industry, and has influence over many US waterways. As the Gulf becomes more affected by chemical pollution, the disturbances will become even more noticeable. Over population of the algae will result in over population of heterotrophic organisms leading to oligotrophic conditions towards the top of the marine environment, and a hypoxic environment towards the bottom. Moving towards the future the Gulf of Mexico seems destined to radically alter the current ecosystem and should serve as an example of the harm of such disrup-
tion. The Gulf of Mexico provides an example the effects of algal blooms and how they could potentially affect parts of the Arctic Ocean in the near future.

**Thirty-Seven Year Trajectory of the Chukchi Sea**

By 2042, the Chukchi Sea [Figure 5] will be completely devoid of ice. The melted environment will lower temperatures and decrease habitat for marine organisms. As ice presence decreases, the penetration of sunlight will increase, stimulating more growth amongst species. In particular, *M. arctica*, a dominating alga, will grow exponentially until the ice is completely gone. Without the dormant period and with proper sunlight, the algae population will continue to double every day. Then the population will hit a fix-point and will rapidly decline with the loss of growing area of ice.

During algae’s rapid growth, extreme changes will be happening in the Chukchi Sea environment. The algae will use up the majority of the nutrients available in the sea. These nutrients will no longer be available to the other aquatic species. These species then go into a decline and further generations become weaker.

As individual algae dies, it falls to the bottom and is broken down by bacteria. The excess dead algae, due to massive population growth, provide nutrients that increase the bacteria population. The bacteria utilize all of the oxygen for growth, which creates a hypoxic marine environment. This oligotrophic environment will limit species production even further creating a near dead zone. This dead zone will be partially remedied by natural river runoff and ocean mixing, but the environment will still be depleted.

During the flourishing period of *M. arctica*, much respiration will occur. This respiration will consume carbon dioxide. As the population grows, more carbon dioxide will be taken in from the atmosphere, creating a carbon sink in the Chukchi Sea. During this period the output of
carbon dioxide from industry will increase. In this way the algae carbon sink will help fixate the excess atmospheric carbon.

Eventually the ice will become scarce giving the algae less surface for growth. The algae will remain free-floating in the pelagic zone of the ocean. Its population will continue to increase, however they will not form colonies. Growth of the algae population will contribute to an increase in zooplankton. Typically the zooplankton and algae populations decrease during the winter months and bloom during the summer months. The increased light exposure during all months will raise both populations and provide food for the zooplankton. This will damage the benthic community; however, it will provide more consumption for pelagic species, such as cod.

The Chukchi Sea will also be altered by human activity in the next thirty-seven years. The sea is a prime location for oil drilling and holds billions of barrels of oil for potential production [Figure 6]. The drilling prospects are currently being processed for lease agreements and drilling could begin as soon as 2020 (2006 Oil and Gas Assessment, 2006). Oil extraction would interrupt the current ecosystem impacting the habitats of many organisms. This change would contribute to the overall transformation of the sea. Subsequently, increased oil production would raise ship trafficking in the Chukchi Sea. Drilling would stimulate related extraneous industry growth, such as residency, supplies, travel, and general oil rig materials, as well as transportation of oil. Ship trafficking would further alter the Chukchi environment and would increase carbon production. Finally the extracted carbon would become atmospheric carbon, increasing worldwide temperatures.

The arctic environment of the Chukchi Sea will foster a very different ecosystem in the next four decades. The algae population will bloom and so will the zooplankton, creating depletions in the benthic community and more production in the pelagic zone. This may also decrease
atmospheric carbon and slightly halt temperature increases. These are effects of a melting arctic. The damage of climate change is not totally irreversible, however nothing but a halt in temperature can keep water frozen for healthy a *M. arctica* population and ultimately a stable Chukchi Sea. Unfortunately, without changes in the worldwide greenhouse gas output the Chukchi Sea’s temperature will continue to rise, providing a perfect example of the future environments from the industrial age.

**Conclusion**

Due to the recent changes in ice thickness and the increasing growth in *M. arctica* [Figure 8], there are changing conditions in the subsurface areas and the benthic zones of the Arctic Ocean. These conditions are unfavorable to the organisms that inhabit both the subsurface and benthic zones of the ocean, with the lack of nutrients, and the anoxia from bacterial respiration.

The increased growth of algae and the fact that it sinks to ocean floor has negative local impacts yet it also has the positive mark of fixing carbon dioxide from the atmosphere and transporting it to the bottom of the ocean where it can be deposited in the sediments and will not affect the climate any further. In this way, the *M. arctica* acts as a carbon sink removing carbon dioxide from the atmosphere.

These effects have several negative and positive implications, and a way to ensure that the trend toward instability does not continue any further would be to artificially cool down the Arctic and surrounding areas. There are a few ways this could be accomplished. Platforms that help reduce the albedo of the Arctic and give algae and other organisms a habitat could be one temporary solution to alleviate the harm. Another option to be considered is to create artificial cloud cover through the use of water vapor or another chemical that attracts water vapor to help form clouds. However these options have a high chance of having other ecological implications.
that may not improve the situation but rather harm it. The best option would be to alleviate the
effects global warming.

While these are issues for local areas surrounding the Arctic Ocean, one issue that will
have pan-arctic implications is the effect that increasing temperatures have on zooplankton. As
temperatures become warmer earlier in the year, zooplankton exit diapause and begin consuming
algae earlier. These increasing temperatures threaten to cause the zooplankton to consume the
falling algae all year round, preventing any algae from reaching the benthos and therefore stunt-
ing benthic organism growth and increasing pelagic organism growth.

As we move toward there being no year-round ice in the Arctic Ocean, we move toward
greater instability of the entire Arctic ecosystem. The underlying cause behind the continual
trend of rising temperatures and melting ice floes is the current issue of climate change. Climate
change has been evidenced to be caused by the increasing number of greenhouse gases released,
notably carbon dioxide. Additionally, as ice in the Arctic Ocean melts, areas for additional oil
wells open up for exploration. The addition of more oil wells and tracks for ships to travel will
increase the amount of traffic and therefore the amount of carbon contributed to the atmosphere.

The way to ameliorate the situation would be to establish legislation to help prevent ex-
ploitation of the Arctic and to reduce the amount of traffic and development of the Arctic. By
preventing the further contribution of toxic carbon dioxide into the atmosphere of our planet, the
stability of the arctic ecosystem can be ensured for the future.

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Hartman, J. Student at Mat-Su Career and Technical High School, November 17, 2014. Microscope image

Hassett, B. Ph.D student at University of Alaska Fairbanks, November 8, 2014, Interview


