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THE STRESSFUL LIFE OF SEA ICE ALGAE

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The Arctic Ocean is located at the "top" of the world, and it is covered by sea ice most of the year. It experiences long periods of darkness in winter (polar night) and long periods of light in summer (polar day). During spring and summer, the melting of sea ice decreases the salinity (saltiness) in the upper part of the ocean. These differences in conditions across seasons are called seasonality, and the microscopic algae that live in Arctic sea ice must be able to cope with this strong seasonality. Are you interested in knowing how sea ice algae deal with such extreme changes in their environment? If you are, read this article to discover how sea ice algae adjust to dramatic seasonal variations in both light and salinity.

SEASONALITY

The differences in environmental conditions (e.g., light, salinity, temperature, and nutrients) which occur across seasons. The Arctic seasonality is specifically extreme as environmental changes happen between winter and summer.

ARCTIC SEASONALITY

The Arctic Ocean is located at the "top" of the world, and it is covered by sea ice most of the year. Arctic sea ice is subject to strong **seasonality**, which means that it experiences dramatic changes in its environmental conditions across seasons [1]. In winter, Arctic sea ice forms on the ocean surface due to the extremely cold temperatures and the long period of darkness during the polar night. The duration of the polar night varies with latitude and can last from November to early March. As the sun returns and the atmosphere warms in the early spring, sea ice is exposed to increasing amounts of light, which causes the snow cover and eventually the sea ice to melt. In late spring and summer, the sea ice faces 24 h of light per day, known as the polar day. As the snow cover and sea ice melt into the ocean, the **salinity** (saltiness) of the ocean's surface water decreases.

SALINITY

The saltiness or the quantity of salt which is dissolved in water. Salt dissolved in water form ion salts, that are either positively or negatively charged atoms (e.g., Na^+ and Cl^-).

SEA ICE ALGAE: THE BASE OF THE ARCTIC FOOD WEB

Tiny photosynthetic microorganisms called **sea ice algae** live in the sea ice, and they are a very important part of the food web of the Arctic Ocean. Table 1 shows some common types of sea ice algae. These algae are mainly found in the bottom of the sea ice, where the ice interacts with the ocean below. Sea ice algae may also live within super-salty pockets of liquid trapped within the ice, called **brine channels**. Sea ice algae are important because they are responsible for **primary production**, which means that they are the first organisms to bring energy into the ecosystem's food web. They do this by creating sugars through photosynthesis, which requires carbon dioxide (CO_2), light energy, water, and nutrients like nitrate, phosphate and silicate [2, 3]. Primary production in the sea ice is therefore controlled by the amount of light and nutrients available, as well as by the temperature and salinity of the algae's environment.

SEA ICE ALGAE

Simple, one-celled photosynthetic organisms that can be classified into several groups, including diatoms (pennate or centric), flagellates, and dinoflagellates.

BRINE CHANNELS

Salty pockets of liquid trapped within the ice in which some algae can grow.

Table 1

Classification of sea ice algae.

Sea ice algae	Main characteristics	Illustration
Pennate diatoms	Elongated shape with a tough coating of silica.	
Centric diatoms	Circular shape with a tough coating of silica.	
Flagellates	One or more similar flagella (i.e., whip-like structure used to swim).	
Dinoflagellates	Two dissimilar flagella (i.e., whip-like structure used to swim). One looks like a belt around the algae and the other one is hanging down perpendicularly to the first flagellum.	

Table 1

PRIMARY PRODUCTION

The production of sugars by photosynthetic organisms that serve as the base of the food web. In the sea ice environment, algae are the main organisms responsible for primary production.

Major changes in the sea ice environment can stress the algae and reduce primary production, which can affect the entire ecosystem [2]. Sea ice algae are a food source for marine organisms known as zooplankton. Zooplankton are themselves a food source for fishes, which in turn can be eaten by larger organisms like seabirds, seals, polar bears, whales, and even humans! Thus, sea ice algae are the base of the food web in the Arctic ecosystem—which is a major reason why it is important to predict potential changes in primary production that are happening in sea ice. Understanding how sea ice algae survive seasonal environmental changes can help scientists predict how climate change might affect Arctic primary production in the future.

HOW DO SEA ICE ALGAE DEAL WITH LOW LIGHT IN WINTER?

During the Arctic winter, sea ice algae must find ways to survive the dark and cold [1]. They do this by forming structures called cysts (Figure 1A), which are resting stages of an algal cell that have stopped growing to save energy. Cysts have thick walls that help them survive harsh conditions. Diatoms are also known to spend long periods of darkness in a sleep-like state, which allows them to survive for months to even years without light [1].

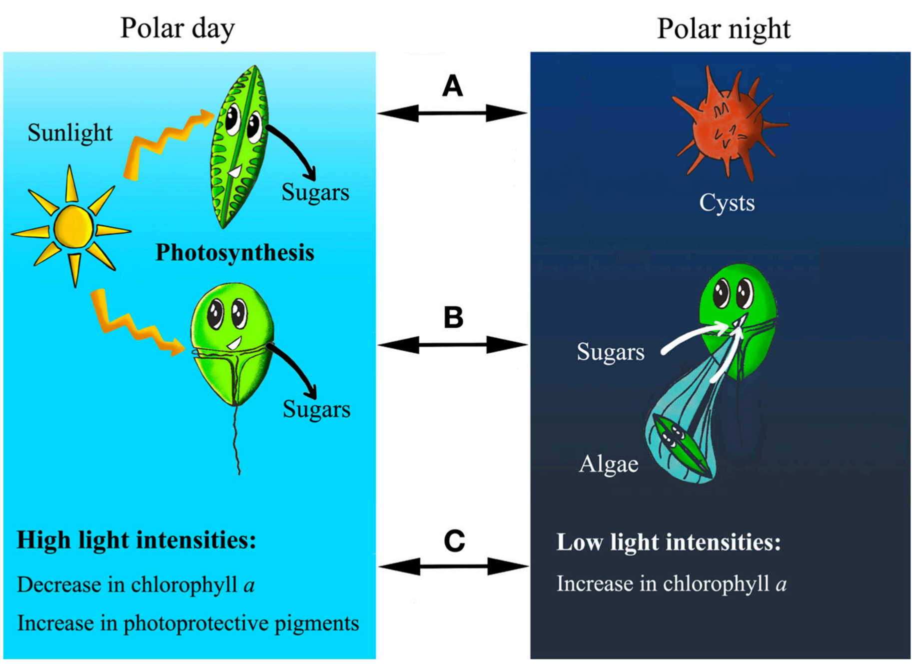

Figure 1

Figure 1

(A) During polar night, sea ice algae produce cysts, which can survive until spring. **(B)** Algae shift their nutrition modes across seasons: during the polar day, they use light to perform photosynthesis; while during the polar night, they feed on sugars or other algae. **(C)** Sea ice algae change the pigments in their cells based on light intensity. They produce more chlorophyll *a* when light is low and decrease its production when light is high. Photoprotective pigments are also produced when light is intense, to protect algae from the harmful effects of light.

PHOTOSYNTHESIS

The capture of light, carbon dioxide, water, and nutrients by photosynthetic organisms (e.g., algae and plants) to produce sugars and oxygen.

Some sea ice algae can also shift nutrition modes to survive the winter (Figure 1B). Most capture sunlight to produce sugars and oxygen *via* **photosynthesis**. For example, diatoms mainly use light to grow and

PIGMENTS

Coloring molecules in cells or tissues. In algal cells, there are photosynthetic pigments, that absorb the light required for photosynthesis, and photoprotective pigments, that protect them from intense light.

survive. But what about when light is not available in the dark of winter? Some sea ice algae can feed on sugars or other algae instead of light, especially when it is dark! This is the case for many flagellates and dinoflagellates.

Sea ice algae can also change the photosynthetic **pigments** within their cells in response to changes in the amount of available light. Photosynthetic pigments are small molecules that absorb the light required for photosynthesis. In the winter, when there is little light available for photosynthesis, sea ice algae tend to increase their production of a photosynthetic pigment called chlorophyll *a*, so that they can absorb more light (Figure 1C) [3].

HOW DO SEA ICE ALGAE DEAL WITH INTENSE LIGHT IN SPRING/SUMMER?

As the sun returns in early spring, the light in the Arctic begins to increase. Through summer, there is an increasing amount of light during the polar day. In early spring, the increase in light allows sea ice algae to grow rapidly, and they become highly abundant. But why? Cysts can germinate as the amount of sunlight increases (Figure 1A), which basically means the sea ice algae wake up! Some sea ice algae may also switch their nutrition mode back to using light as their main energy source (Figure 1B) [1].

In spring and summer, sea ice algae may be exposed to extremely high light intensities due to the melting snow cover that normally prevents sunlight from reaching them. In response, they can produce pigments that protect them from light, called photoprotective pigments. They can also decrease their chlorophyll *a* content to reduce the amount of light they absorb (Figure 1C) [3]. If sea ice algae cannot protect themselves from the extremely high light intensities that occur during the polar day, their rates of photosynthesis may be negatively affected, and they may even die [3]! Some sea ice algae deal with intense light better than others do [4].

HOW DO SEA ICE ALGAE DEAL WITH HIGH SALINITIES IN WINTER?

Sea ice algae are exposed to various salinities depending on where and when they live. For instance, the algae living in the lowest part of the sea ice are subject to normal ocean salinities because they interact with the ocean surface water (Figure 2A) [5], while the algae living in brine channels may face extremely high salinities [5]. Ice algae must have ways to protect themselves from high salinity. When they are exposed to high salinity, the water inside the algal cell will want to move outward into the surrounding seawater or brine, because water naturally tends to move from areas of low salinity to areas of high salinity. In winter, the salty brine and seawater have a higher salinity than the algal cell does, so this can cause the algal cell to shrink as water flows out (Figure 2B) [5].

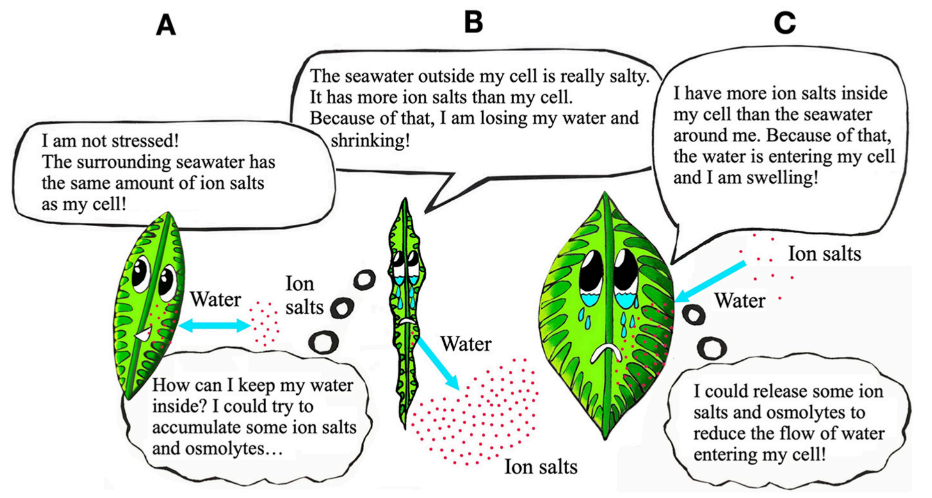

Figure 2

Figure 2

(A) At normal seawater salinities, the algal cell naturally maintains its usual shape. **(B)** At high salinities, the cell shrinks because there is more ion salts outside the cell than inside—so water leaves. **(C)** At low salinities, the cell swells because there is more ion salts inside the cell than outside—so water enters. The blue arrows show the flow of water going into or out of the algal cell. The red dots represent the ion salts.

When salt is dissolved in water, it forms ion salts. High-salinity seawater has a lot of ions, which attract water out of the algal cell. To deal with high salinities, sea ice algae may collect ions within themselves, so that the water stays inside their cells. There are multiple ways to take up ions, some of which require energy and some of which do not [5]. Sea ice algae may also produce substances called **osmolytes**, which are molecules that protect the cell from excessive water flow either into or out of the cell. At high salinities, osmolytes accumulate within the cell to increase the amount of water-retaining substances inside, and therefore contribute to prevent water flow out of the cell [5].

OSMOLYTES

Molecules that protect the cell from excessive water flow either into or out of the cell when it experiences changes in salinity.

HOW DO SEA ICE ALGAE DEAL WITH LOW SALINITIES IN SPRING/SUMMER?

Increasing temperatures in spring and summer cause the snow cover and the sea ice to melt. This adds fresh water to the salty ocean and brine channels, which decreases their salinity. When sea ice algae are exposed to low salinities, the concentration of salt inside their cells is higher than that outside their cells. Therefore, the surrounding water tends to enter algal cells, causing them to swell (Figure 2C). This is the opposite of what happens when algal cells are exposed to high salinities. Thus, when salinities are low, algae must have ways to reduce the flow of water entering the cell. To deal with low salinities, sea ice algae can release ions. Similar to the process of collecting ions, some methods of ion release require energy while others do not. Flagellates and sea ice diatoms may also release osmolytes to prevent water from entering their cells, as these are water-retaining substances [5].

Some sea ice algae can adjust to low salinities better than others can. Pennate diatoms—elongated cells with a tough coating of silica—are often the best at adjusting to dark, salty winter conditions (Figure 3A) [4]. On the other hand, flagellates—cells with one or more similar flagella (i.e., whip-like structure used to swim)—and centric diatoms—circular shape cells with a tough coating of silica—often adjust better to low salinities than pennate diatoms do [4]. As a result, pennate diatoms are the first algae to be lost from the bottom-ice during melting in late spring, while other groups thrive like flagellates and dinoflagellates—cells with two dissimilar flagella, one looks like a belt around the cell and the other flagellum hangs down, perpendicular to the first (Figure 3B). Flagellates and dinoflagellates tend to dominate in late spring-summer because flagellates typically adjust better than diatoms to low salinities and reduced nutrients (Figure 3C) [4].

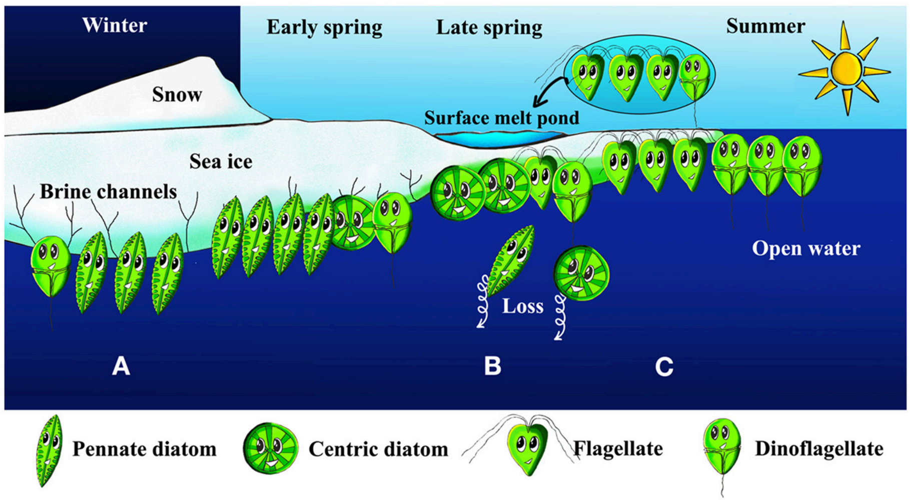

Figure 3

Figure 3

Changes in salinity across seasons favor the growth of different types of sea ice algae. **(A)** Pennate diatoms are often the best at adjusting to the high salinities in the dark, cold winter. They also typically dominate the bottom-ice in early spring. **(B)** Centric diatoms, flagellates, and dinoflagellates adjust best to the low salinities in late spring. **(C)** Flagellates and dinoflagellates adjust best to the low salinities and limited nutrients in late spring/summer.

KEY MESSAGES

Arctic sea ice is subject to strong seasonal changes, as it undergoes extended periods of darkness (polar night) and daylight (polar day). Tiny, photosynthetic sea ice algae living in this environment must adjust to cope with extreme seasonal changes in light intensity and salinity. To do so, they can form cysts, shift their nutrition modes, regulate their internal pigment content, and change their ion salt and osmolyte concentrations. Various types of sea ice algae may adjust differently to Arctic seasonality. Pennate diatoms typically adjust better to the dark, highly saline winter conditions; while centric diatoms and especially flagellates are believed to grow better in the warmer, less salty conditions of late spring and summer. Sea ice algae form the base of the Arctic food web, which is why it is important to predict potential changes in sea ice primary production. Scientists are currently trying to understand how Arctic sea ice algae survive seasonal environmental changes to better predict how climate change could affect Arctic sea ice primary production in the future.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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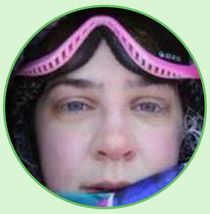

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