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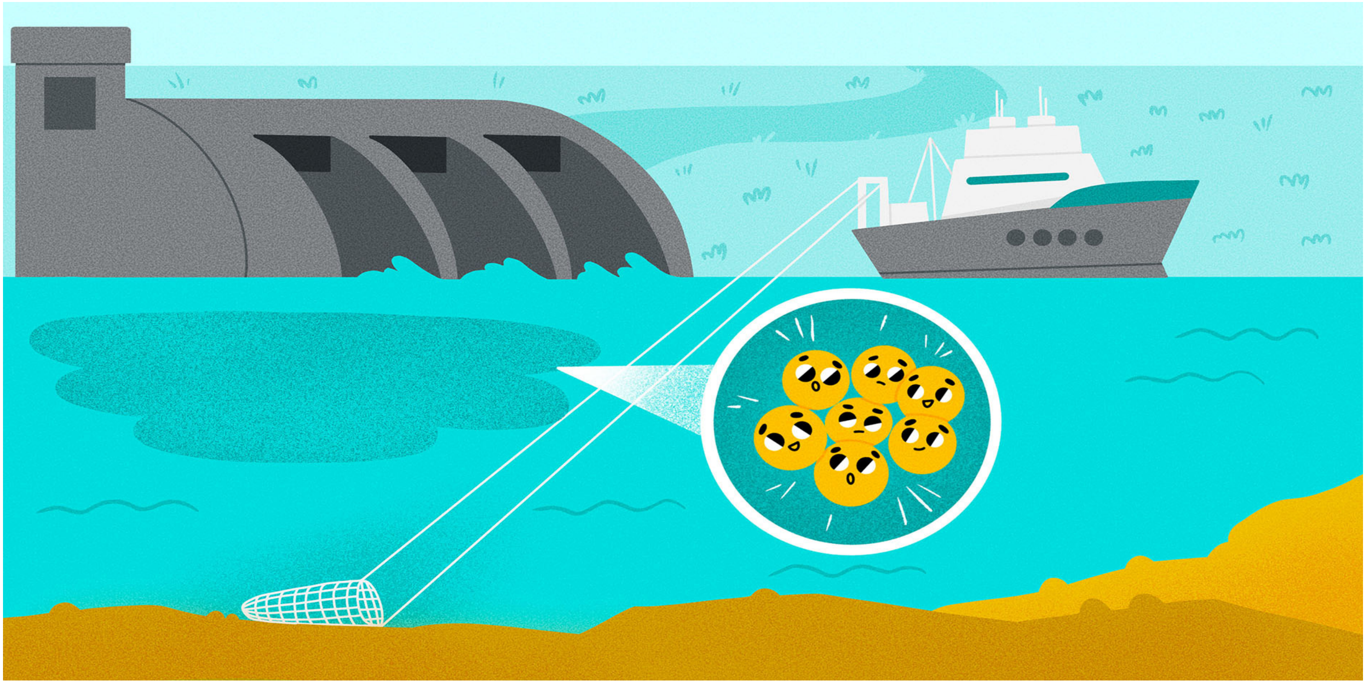

HOW HUMAN ACTIVITIES ARE DISRUPTING THE SILICON CYCLE

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YOUNG REVIEWERS:

MOMO

AGE: 11

YUHENDRA

AGE: 13

Dissolved silicon is an essential nutrient for the growth of various ocean organisms that need it to build their skeletons. Most of the dissolved silicon that sustains these organisms comes from the breakdown of silicon-containing rocks on land. In recent decades, human activities have greatly disturbed the transport of silicon from land to ocean. For example, dams built to generate electricity can interrupt the transport of dissolved silicon and starve downstream areas. Fertilizers and other human pollution add large amounts of non-silicon nutrients to rivers, lakes, and reservoirs, which can stimulate organisms to grow and use up silicon before it reaches the ocean. In addition, consequences of climate change can also impact the silicon cycle. In this article, we explain how human activities have disturbed the silicon cycle and discuss how climate change may affect it in the future.

WHY DO WE CARE ABOUT SILICON?

Diatoms are tiny single-celled algae that play an important role in regulating Earth's climate. They take in carbon dioxide (CO_2) and use it, along with the sun's energy, to produce sugars to feed themselves, via the process of photosynthesis. When diatoms die, they sink to the bottom of the ocean, removing CO_2 from the atmosphere and storing it in the ocean. Since CO_2 is an important greenhouse gas, changes in the numbers of diatoms can therefore have a significant impact on Earth's climate. The nutrient that diatoms need the most is silicon, which they need to build up their shells. There are other organisms that need silicon to form their siliceous (glassy) skeletons, such as rhizarians and sponges. Together, organisms that use silicon to build their skeletons are called **silicifiers**. To learn more about silicifiers, see this Frontiers for Young Minds article. The growth of silicifiers depends on the availability of dissolved silicon in the surrounding water. Therefore, silicon is crucial for silicifiers and the health of aquatic ecosystems [1].

SILICIFIERS

Organisms that use dissolved silicon from their environments to build their skeletons made of glass. Some examples are diatoms, rhizarians, and sponges.

Silicon in ocean water comes from the breakdown and **weathering** of rocks on land. It is then transported to the ocean by various waterways. Before it arrives at the ocean, silicon travels through rivers, lakes, and reservoirs, where it is consumed by silicifiers or incorporated into clay minerals. All these processes move silicon around and change it creating a cycle that we call the silicon cycle. The amount of silicon that is delivered to the ocean is often in excess compared to other nutrients essential for the growth of silicifiers, such as nitrogen and phosphorus. So, in the past, the availability of dissolved silicon was never a concern, especially near the coasts. However, in the past few decades, human activities have changed this status, disturbing the transport of silicon from land to ocean and thus its availability in coastal seas (Figure 1).

WEATHERING

The process by which rocks, soil, and other materials are broken down and worn away by the effects of wind, water, and other natural forces over time.

DAMMING AND EUTROPHICATION

Hydropower technologies, such as **damming**, can interrupt the transport of silicon to the ocean (Figure 1). Dams are structures built to hold back flowing water in rivers and raise its level to form a reservoir. Dams are used for a variety of purposes, like generating electricity and controlling river flow. Europe and the United States started the first boom in hydropower development at the end of the 19th century, while other countries, such as China, Brazil, and India, boosted a second boom in the 21st century. Damming changes the way river water and sediment flow. As water flows through the dam, it slows down and sediment particles settle out, accumulating at the bottom of the reservoir. Over time, this sediment accumulates upstream of the dam, forming a thick layer of material that may include a lot of silicon. Dams also impact the transport of silicon by altering the flow and velocity of the water. By slowing the water down, dams increase

DAMMING

The construction of a barrier, typically a concrete wall, across a river to control the flow of water, often for flood control, hydropower generation or water storage purposes.

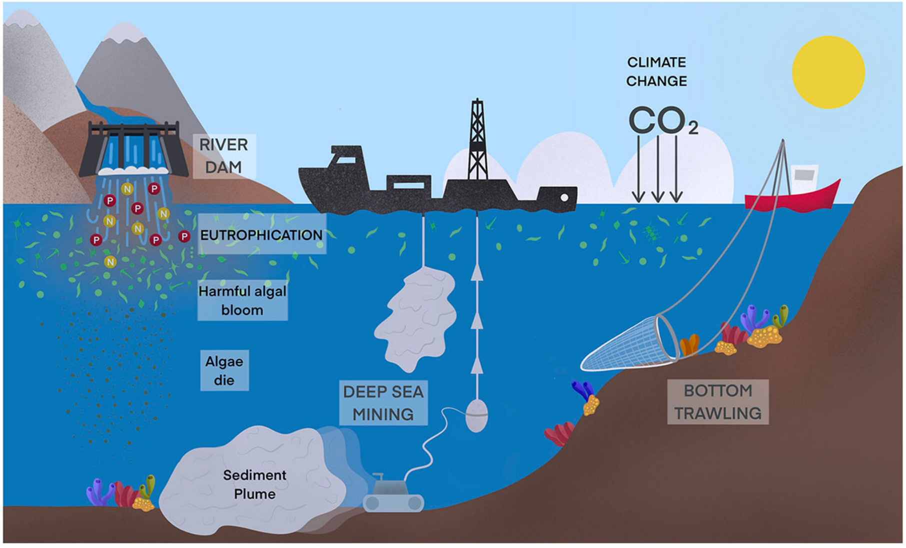

Figure 1

Figure 1

Human activities can disturb silicifiers and the silicon cycle in the ocean. Some activities, such as bottom trawling and deep-sea mining, can negatively affect bottom-dwelling silicifiers and movement of silicon from the sediments into the deep ocean waters. This can form a sediment plume, which is like a cloud of dirt or mud occurring when sediments get stirred up and float around in the water, negatively affecting organisms living on the seabed. Other human activities that can lead to a decrease of silicon in seawater include ocean acidification due to climate change, river dams, and eutrophication. N and P represent excess nitrogen and phosphorus causing eutrophication.

the time water stays in the reservoir, which stimulates diatom growth there. This can result in more silicon remaining in the reservoir and never making it to the ocean. Globally, dams retain 5.3% of the active silicon loaded into rivers by rock weathering [2].

Eutrophication, which is when a body of water receives an excessive amount of nutrients like nitrogen and phosphorus, also alters the transport of silicon to the ocean. Farming, factories, and people living in cities release a lot of nitrogen and phosphorus into rivers, lakes, and reservoirs. The increased nutrients can cause an overgrowth of algae in those waters and use up a lot of the available silicon in the water, preventing it from reaching the ocean. The combination of inland eutrophication and damming decrease the total global movement of dissolved silicon to the ocean by nearly 30% [3].

Eutrophication also takes place in the ocean close to the coasts, increasing the numbers of diatoms in coastal regions. When those diatoms die, their skeletons sink to the bottom in those coastal regions, which further reduces the amount of dissolved silicon in other areas of the ocean. The overall reduction in dissolved silicon may have harmful effects on the entire ocean food chain, because diatoms are a vital link in this chain. When there is not enough dissolved silicon for diatoms to grow, these conditions often trigger blooms of other organisms that do not require silicon, some of which can produce toxic substances. These are called **harmful algal blooms** and they can have significant impacts on the ecosystem and human health [3].

The Baltic Sea is a good example of the impact of damming and eutrophication on silicon balance. Delivery of silicon to the Baltic Sea is greatly reduced by inland eutrophication and damming. The recycling of silicon within the Baltic Sea is also altered by eutrophication [4].

EUTROPHICATION

Eutrophication is the nutrient over-enrichment of water, primarily nitrogen and phosphorus, causing excessive growth of algae and other aquatic plants and altering the water quality and the ecosystem.

HARMFUL ALGAL BLOOM

Rapid and excessive proliferation of certain algal species in aquatic environments, often resulting in the production of toxins that can have detrimental effects on ecosystems, marine life and human health.

This is because increased nitrogen and phosphorus entering the Baltic Sea, along with decreased amounts of silicon, lead to widespread eutrophication, which further decreases the dissolved silicon in the ocean water. Regular monitoring has shown a decrease in dissolved silicon in the surface water of the Baltic Sea from the 1970s to the end of the 20th century (Figure 2). The decreasing availability of silicon and the resulting harmful algal blooms have made the water unsafe for swimming or other recreational activities.

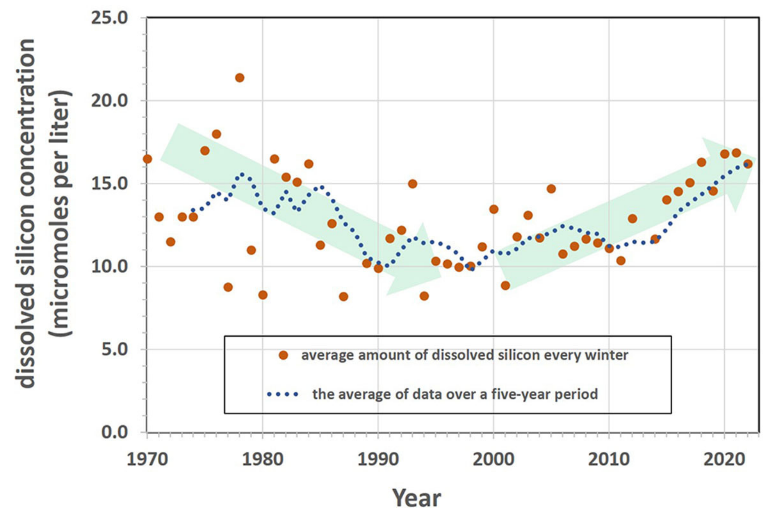

Figure 2

Figure 2

From the 1970s until today, the amount of dissolved silicon has changed over time in the surface water of the central Baltic Sea. The green arrows indicate the decreasing and increasing trends of dissolved silicon. Starting in 1970, the Baltic Sea experienced a reduction of the amount of dissolved silicon due to the construction of dams and the eutrophication affecting rivers flowing into this sea. More recently, levels are increasing because the neighboring countries are working to reduce the effect of water retention in dams and the water pollution entering the Baltic Sea. Data used to create this plot come from https://sharkweb.smhi.se/hamta-data/.

SEABED IMPACTS AND CLIMATE CHANGE

Other human activities that involve the ocean floor can also impact the silicon cycle—as well as the living things that call the seabed their home. **Bottom trawling**, which involves dragging heavy nets along the ocean floor to catch fish, and **deep-sea mining**, which involves digging up valuable minerals from the seabed, are harmful to the ocean floor and its creatures. These creatures include siliceous organisms such as sponges, and also tiny animals that live within the sediment that help transport dissolved silicon from the sediment back into to the water. Without these organisms, the movement of dissolved silicon into the deep ocean waters will decrease and silicon cycling on the seabed will be less active [5].

To add fuel to the fire, human-induced climate change also affects the silicon cycle in the ocean. To learn more about climate change, see this Frontiers for Young Minds Collection. For example, the increasing CO_2 in the atmosphere, mainly due to burning fossil fuels, causes the ocean to absorb more and more CO_2. The CO_2 changes the properties of ocean water, making it more acidic. This process is known as **ocean acidification**, and it can alter the silicon cycle and impact the growth of silicifiers. Scientists have recently discovered that

BOTTOM TRAWLING

A fishing method in which a large net, often weighted, is dragged along the ocean floor to capture fish and other marine organisms living near the seabed.

DEEP-SEA MINING

Industrial activity to extract valuable minerals and resources from the seabed at great depths.

OCEAN ACIDIFICATION

A consequence of climate change, which occurs as the ocean absorbs carbon dioxide, leading to increased acidity and harming marine organisms and ecosystems.

ocean acidification might lead to a decline in diatoms in the future [6]. When diatoms die, their shells sink into the deep ocean, where they dissolve and release silicon back into the water. This regenerated silicon moves back into the sunlit surface water due to ocean currents and mixing processes. Other diatoms then use the regenerated silicon to build their shells. However, as a result of ocean acidification, the shells of diatoms dissolve more slowly, which ultimately reduces the amount of silicon returning to the sunlit surface water. Therefore, scientists predict that ocean acidification will eventually decrease the number of diatoms in the ocean. In the future, the world will experience changes in temperature, rain, plants, and ocean currents due to climate change. Unfortunately, we still do not know exactly how these changes will eventually affect the amount of silicon and the functioning of marine ecosystems.

ACTION CAN RESTORE THE BALANCE

Human activities affect the cycling of essential nutrients such as silicon. The effects often occur far from where the human activity takes place, as happens in coastal ecosystems, for example, after a dam is built upstream. It is difficult to predict the future status of the silicon cycle. However, scientists believe that ongoing changes to the silicon cycle due to human activities and climate change will certainly harm aquatic ecosystems. It is therefore important that scientists and governments study and monitor the silicon cycle, to understand the effects of human activities and climate change and to take appropriate actions to reduce human impacts. Near the Baltic Sea, neighboring countries are working together to reduce the amount of pollution entering the water. These efforts are making a difference—we can see that the Baltic Sea ecosystem is starting to get better. The amount of silicon in the surface water in winter is even getting back to the levels seen at the beginning of the 21st century (Figure 2). This shows that we really *can* make positive changes if we take action!

Young people can make significant contributions to addressing environmental problems. They can support sustainable water management by advocating for responsible dam construction and promoting alternatives, like low-impact hydropower. They can also practice ecofriendly habits such as conserving water, using sustainable products, and saving energy. Supporting organic farming and otherwise helping to reduce the use of chemical fertilizers can help too. By spreading awareness, joining environmental clubs, and participating in community clean-up activities, young people can protect the environment and help restore balance to the silicon cycle.

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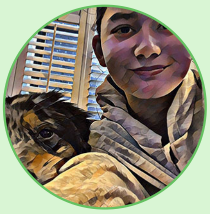
YOUNG REVIEWERS



MOMO, AGE: 11

Momo loves to travel the world and see new places. Even so, she is a self-proclaimed couch potato when she is at home. The two extremes can coexist in one person! Her favorite couchmate is her fuzzy and affectionate dog, Lita.

YUHENDRA, AGE: 13

Hi! It is great to be a reviewer. I am 13 years old and I like Science and Maths. They are my favorite subjects at school. As a past time I do Lego read books and spend time with my family. I also like to play video games.

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As a marine chemist, my research focuses on (bio)geochemical cycling and ocean circulation. I am curious about the sources of ocean essential elements, such as from rivers, sediments, hot hydrothermal vents, etc. My aim is to figure out how these elements change in the ocean because of (bio)geochemical processes. I have explored lots of different parts of the ocean from estuaries to the open ocean, like the Amazon estuary, the Congo shelf, the Baltic Sea, the South China Sea, and the South Pacific Ocean. *zzhang@geomar.de

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I am a marine ecologist interested in the role of bottom-dwelling organisms in ocean nutrient cycling, with a special interest in silicon. My model organisms are sponges, which I have been studying for more than a decade and still find as fascinating as the first day. I have studied sponges in the shallow waters of the North Atlantic Ocean and Mediterranean Sea by diving, and in the deep waters of the Norwegian Sea, Barents Sea, and North Atlantic Ocean using underwater robots. I am now studying the effects of human impacts on silicon recycling in sponges and other silicifying benthic organisms. *lopezacosta@iim.csic.es