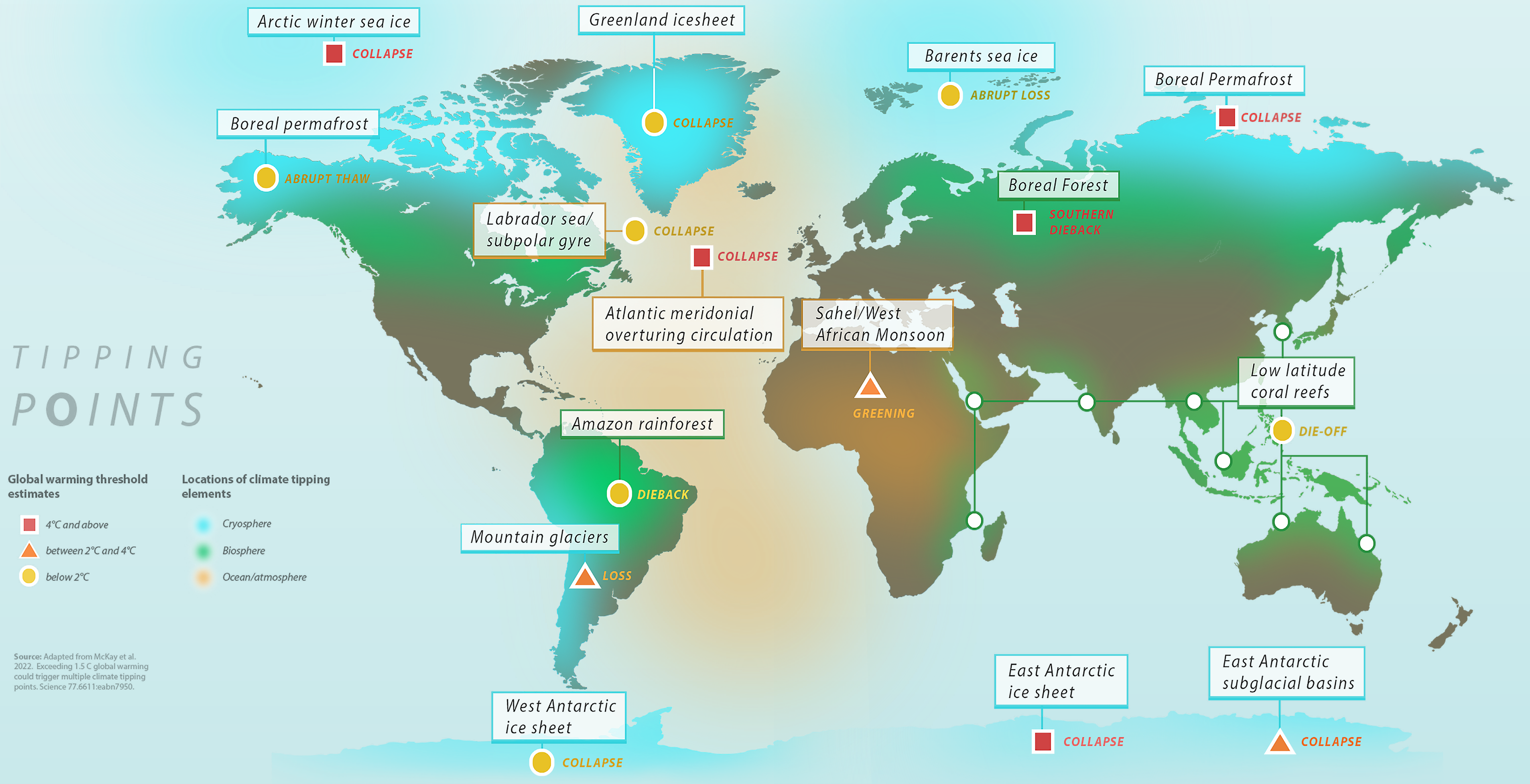
TIPPING POINTS
AT THE POLES



Source: Adapted from McKay et al. 2022. Exceeding 1.5 C global warming could trigger multiple climate tipping points. Science 77.6611:eabn7950.

A tipping point is the critical threshold at which a relatively small change can bring on sudden and profound impacts. Like the proverbial straw that broke the camel's back. A tipping point is a change that can have major and rapid impacts on ecosystems of our planet.

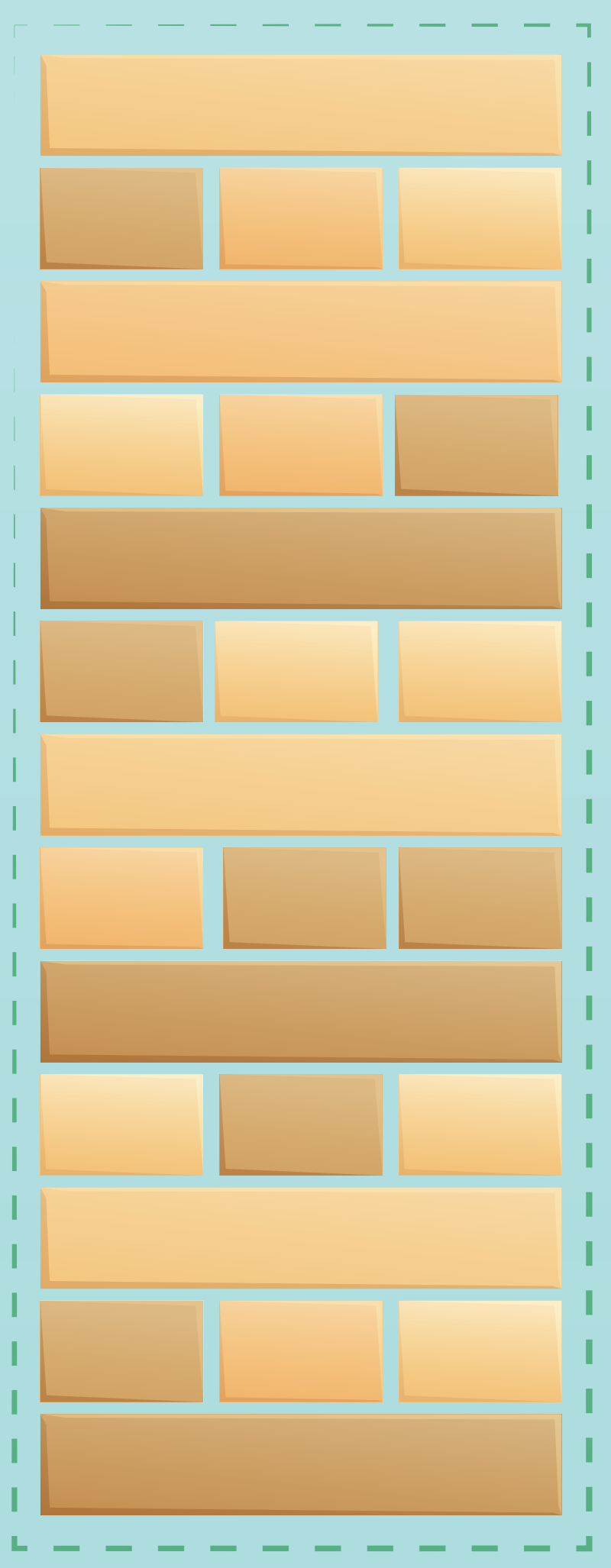
In gradual climate change, the changes occur over a very long period of time, often decades or more. The impacts may be significant, but there is time to adapt. A tipping point change, however, is abrupt and can have immediate, large-scale, and often irreversible effects. Think about a massive volcanic eruption where impacts may be felt within hours, days, or weeks, rather than years.

Scientific evidence shows that we are nearing several climate tipping points indicating that we are in a climate emergency. Many of these tipping points are found in polar regions like the Arctic, an area that is currently warming four times faster than the global average.

While reaching just one tipping point is serious, tipping points do not occur in isolation. When a threshold temperature is reached, it may trigger other tipping points to occur in a tipping cascade, pushing temperatures even higher. For example, the melting of the Greenland ice sheet contributes to the freshening and slowing of the Atlantic circulation which, in turn, contributes to drought in the Amazon and ice loss in the Antarctic. Everything is connected. There is a real potential to trigger these tipping points in a global tipping cascade, leading us to a dangerously over-heated planet.

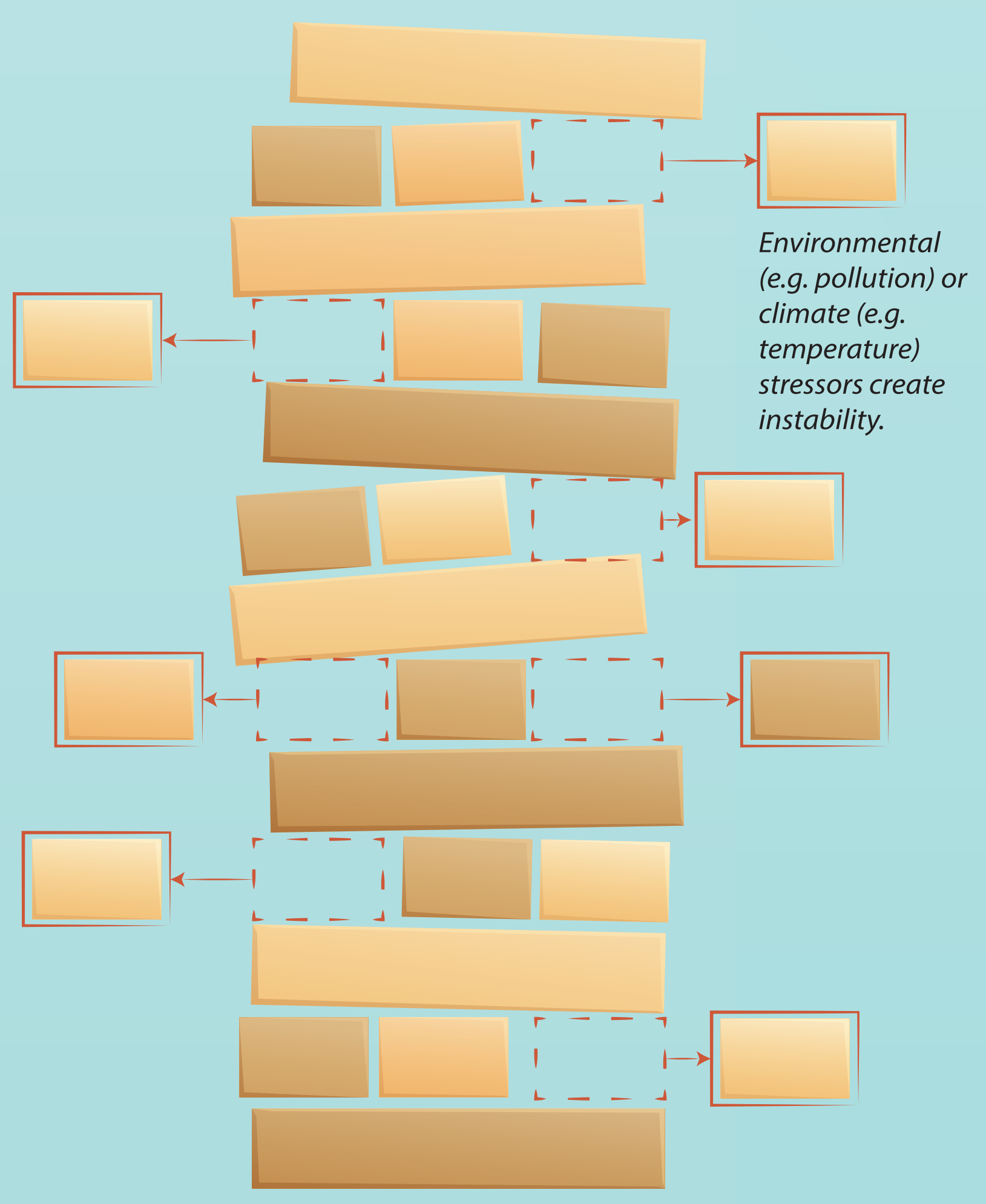
How quickly we reach these tipping points depends on how much the atmosphere warms. While some may be triggered at 3°C or even 5°C of warming, others, such as melting of the Greenland ice sheet, may already occur with less than 2°C of additional warming. These findings underscore the urgent need to reduce emissions to limit global warming. Under the Paris Agreement, the world agreed to limit global warming to well below 2°C.

If you imagine an ecosystem was a fully stacked structure like in a Jenga game....



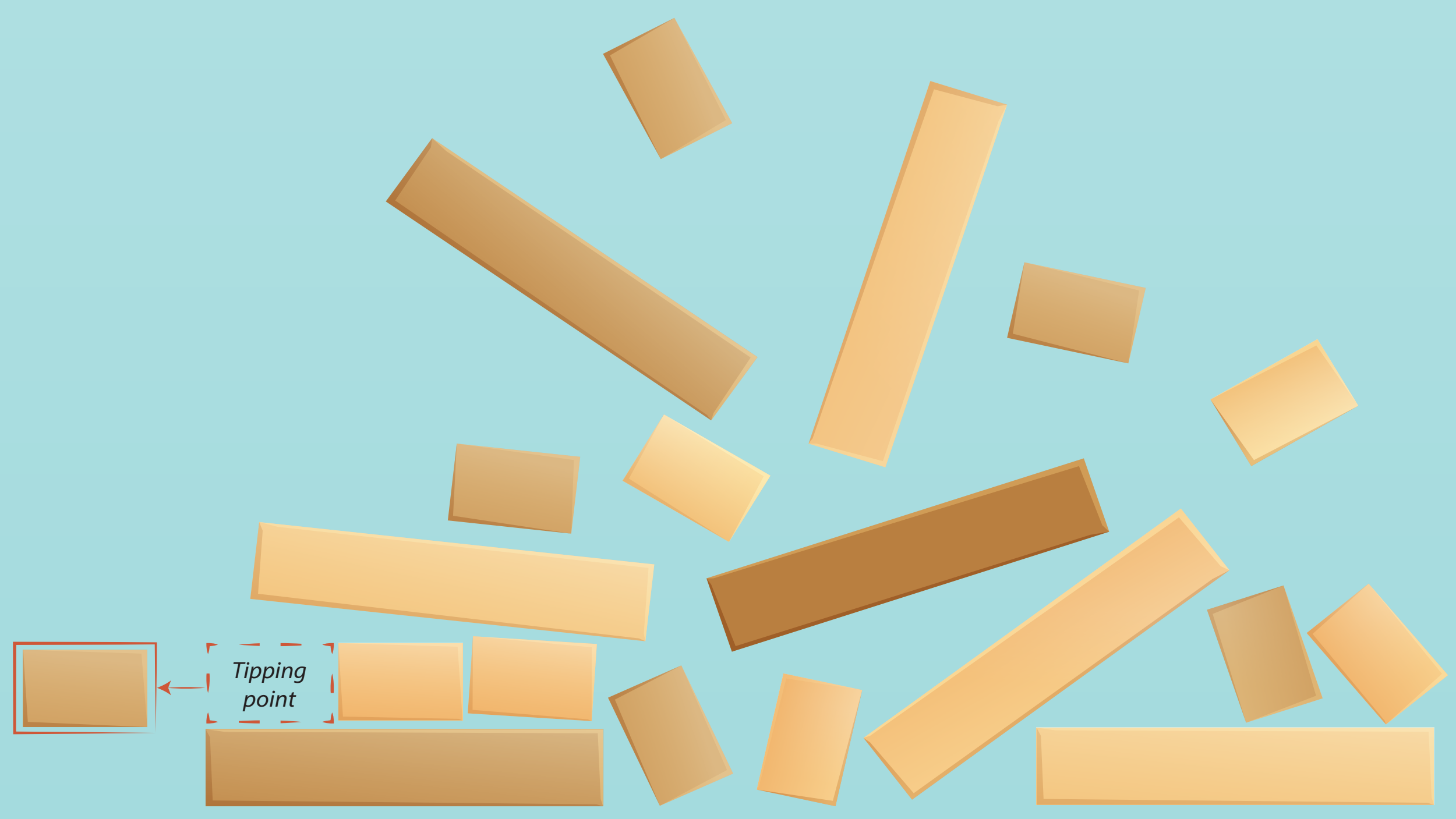
STABLE ECOSYSTEM

The ecosystem, represented by this standing tower, is stable.



UNSTABLE ECOSYSTEM

The ecosystem in its current form is still functioning, but becomes more unstable with each new stressor.

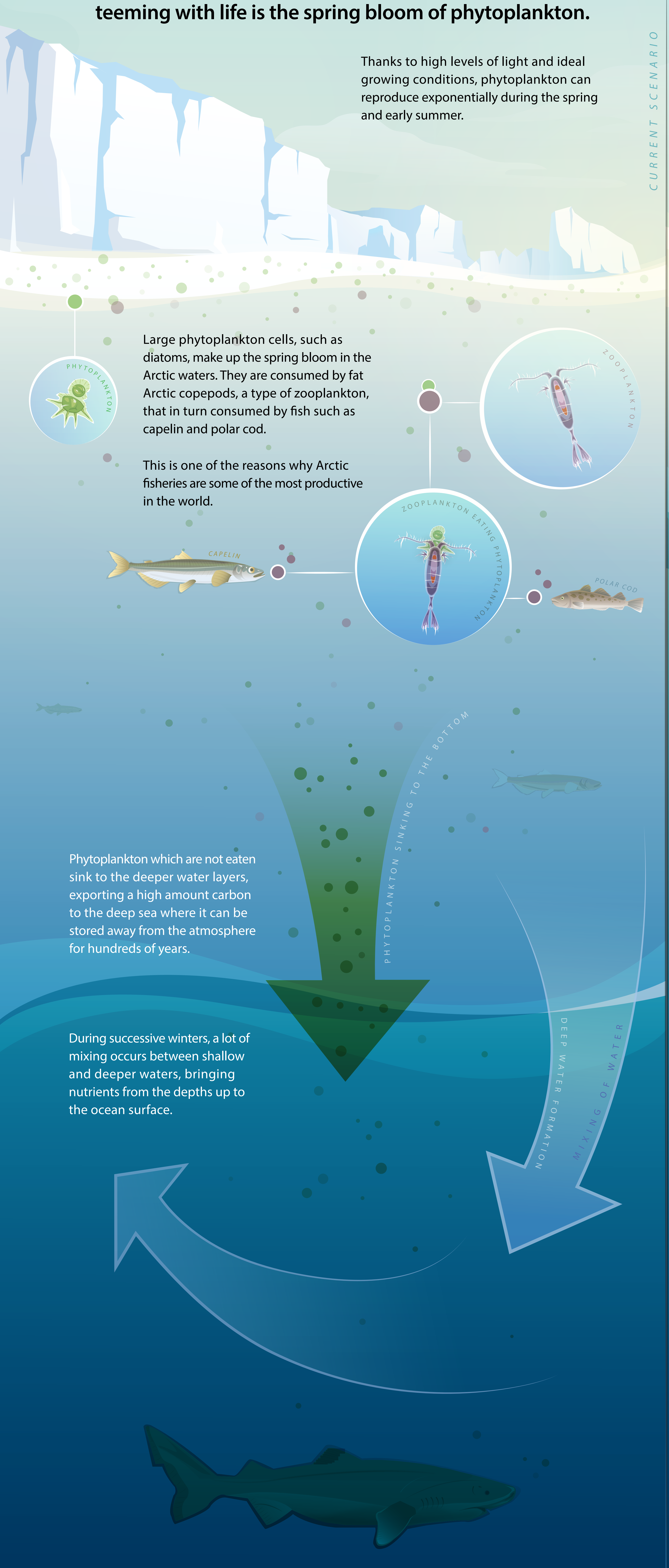


COLLAPSE OF ECOSYSTEM

A final trigger or push, however small, leads to the collapse of the unstable ecosystem. A new state or ecosystem is formed.

Source: *Adapted and inspired from illustration by Carbon Brief (https://www.carbonbrief.org/explainer-nine-tipping-points-that-could-be-triggered-by-climate-change/)*

GREENLAND'S MARINE *TIPPING POINT?*



What makes Arctic marine ecosystems in many places so teeming with life is the spring bloom of phytoplankton.

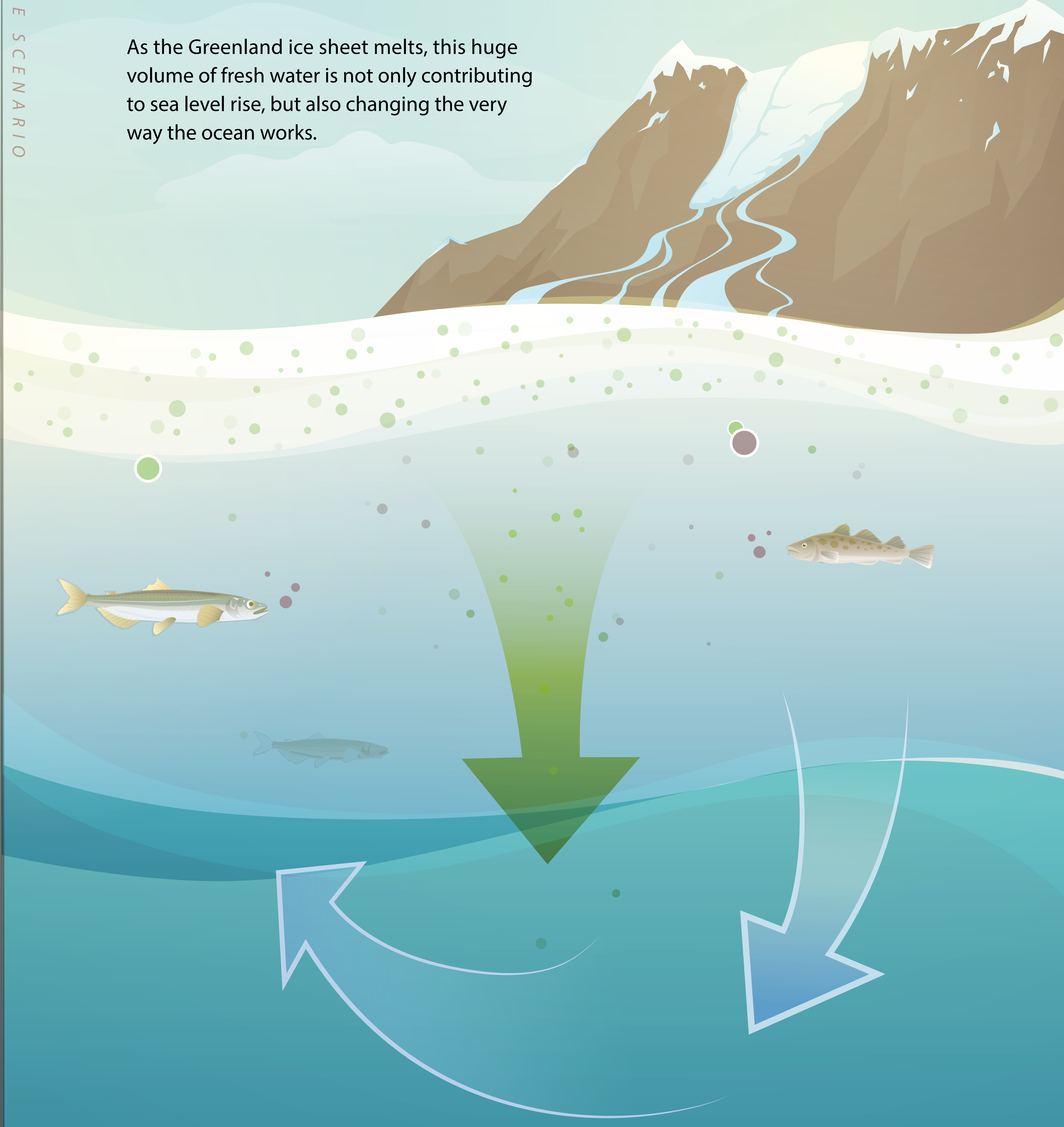
Thanks to high levels of light and ideal growing conditions, phytoplankton can reproduce exponentially during the spring and early summer.

Large phytoplankton cells, such as diatoms, make up the spring bloom in the Arctic waters. They are consumed by fat Arctic copepods, a type of zooplankton, that in turn consumed by fish such as capelin and polar cod.

This is one of the reasons why Arctic fisheries are some of the most productive in the world.

Phytoplankton which are not eaten sink to the deeper water layers, exporting a high amount carbon to the deep sea where it can be stored away from the atmosphere for hundreds of years.

During successive winters, a lot of mixing occurs between shallow and deeper waters, bringing nutrients from the depths up to the ocean surface.



Greenland holds enough ice to raise global sea level by over 7 meters and has already lost about 5 gigatons of water since 1972.

As the Greenland ice sheet melts, this huge volume of fresh water is not only contributing to sea level rise, but also changing the very way the ocean works.

As fresh water is less dense than salty sea water, it floats on top, increasing the layering of the ocean.

This layering is blocking the natural cycle of water exchange which the polar seas typically experience: both the upward mixing of nutrients that sustain ocean life, and also the sinking of cold, salty water that drives global circulation patterns and deep ocean currents – which play a crucial role in sustaining a livable climate for humans.

What all this disruption means for fisheries production and carbon sequestration in Arctic waters is the subject of intense interest by scientists.

One possibility is that the phytoplankton community would become dominated by smaller species since fewer nutrients are available. This effect would cause a ripple up the food chain, including less food available for zooplankton such as the large copepods that normally feed on them and in turn serve as a food source for fish that thrive in polar seas.

A less productive system would also mean less carbon export to the deep seas.

This is a possible ecosystem tipping cascade, which moves from melting glaciers to deep water formation to plankton and up to fish.

WATCH THIS VIDEO TO LEARN MORE ABOUT THE IMPLICATIONS OF INCREASING FRESHWATER IN GREENLAND

HOW GREENLAND´S GLACIERS
RESPONDED TO PAST WARMING

WHAT CAN PALEOCEANOGRAPHY TELL US?

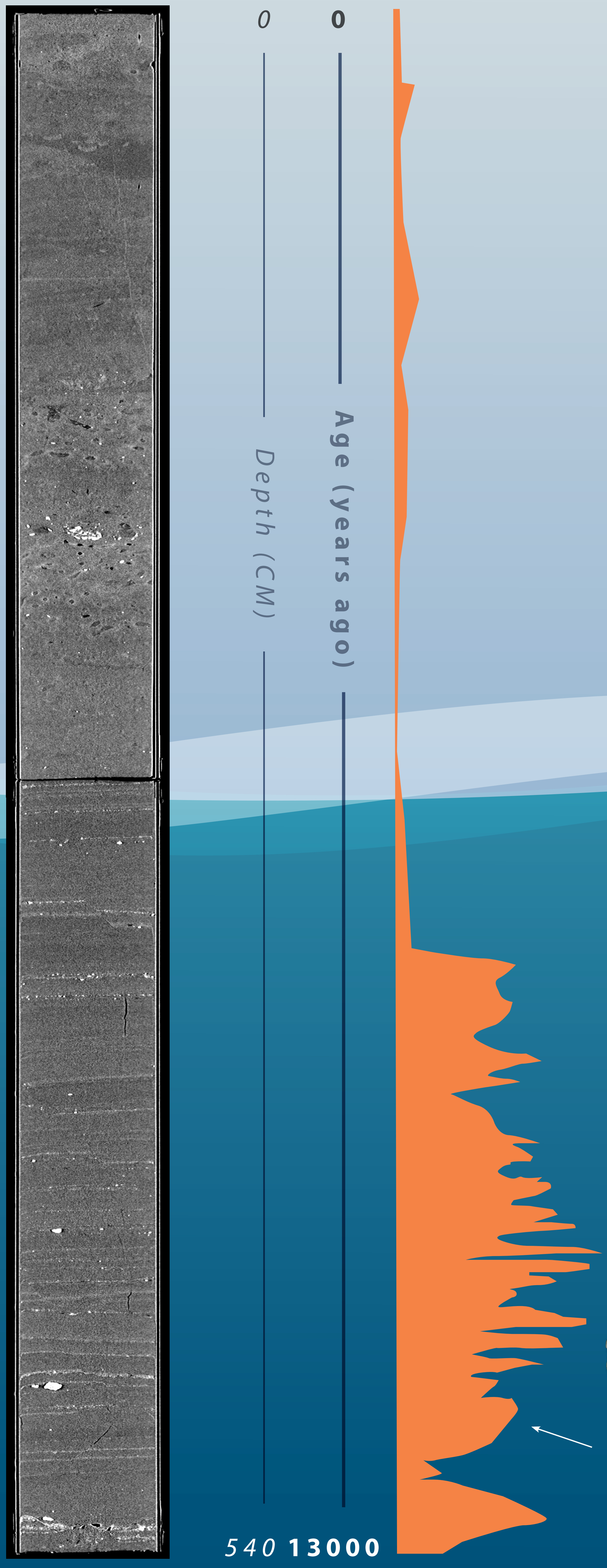
Marine-terminating glaciers, as the name implies, extend right down to sea level to meet the ocean. Ocean water comes into contact with the calving front of the glacier and its floating underside, if one exists.

How these types of glaciers will respond to future warming is complex and not well understood. We know that they interact with the water moving in and out of fjords, while also being influenced by ocean circulation patterns. The shape of the seabed in the fjords has an effect on glaciers too. For the Greenland ice sheet, this lack of understanding presents a major hurdle in projecting future melting and therefore how much we can expect it to contribute to future sea level rise.

Paleoceanography is the study of oceans (oceanography) in the past (paleo-), and techniques in this field are now being used to shine light on how marine-terminating glaciers in North East Greenland reacted to past warming events during the Holocene period (from about 11.5 thousands years ago until present).

This is a period of Earth's history of relative climate stability. However, there were still several warmer periods, with temperatures that were between 2°C to 4°C warmer than present-day Greenland. This period is interesting because it can give an indication of how marine-terminating glaciers may react to current and future warming.

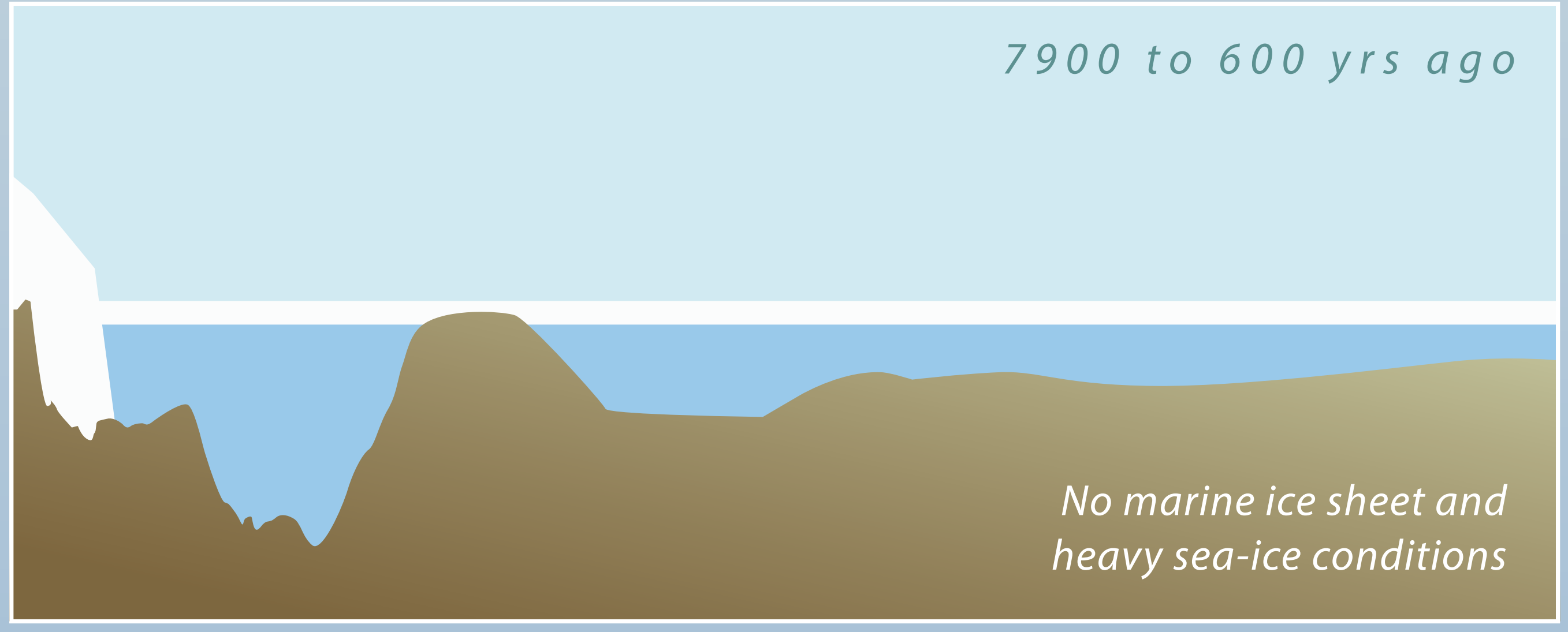
CT IMAGE
OF CORE



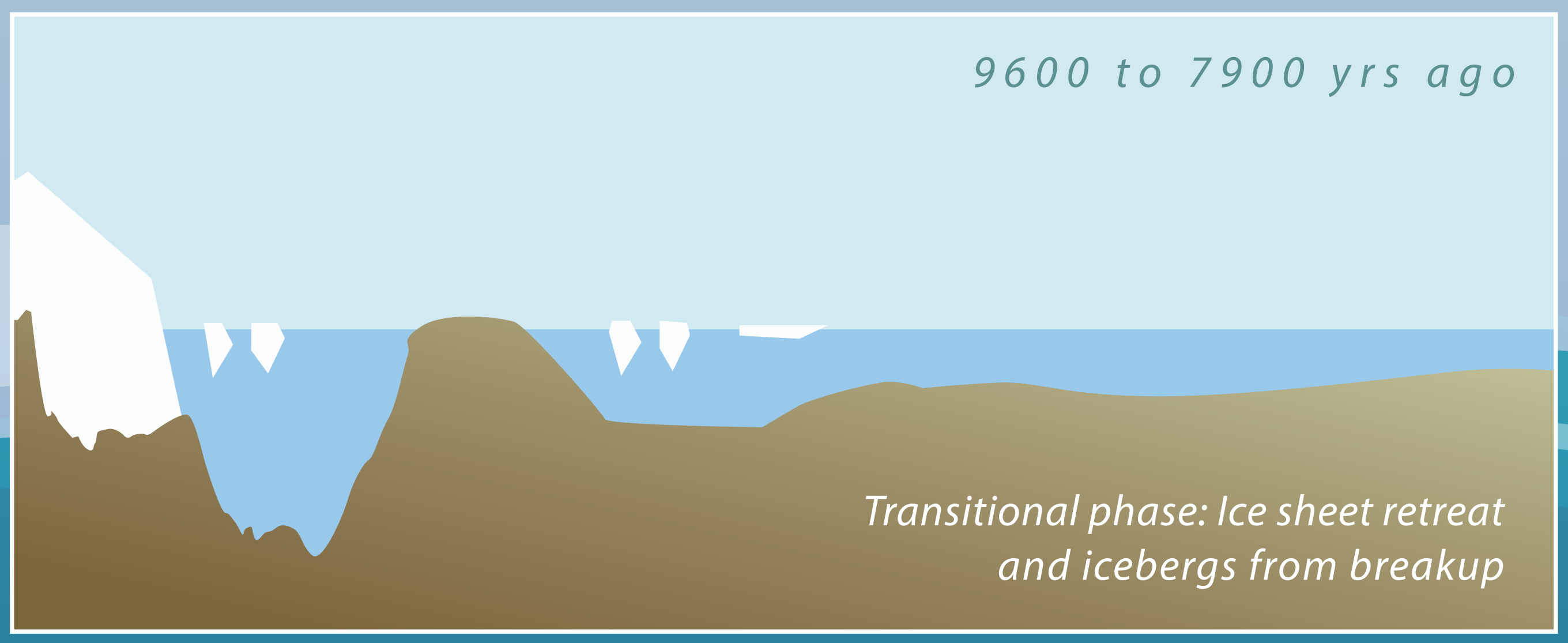
Sediments with a lot of burrows indicate lots of life on sea floor and minimal ice sheet cover

Laminated sediments indicate presence of ice sheet and fine sediment deposits.

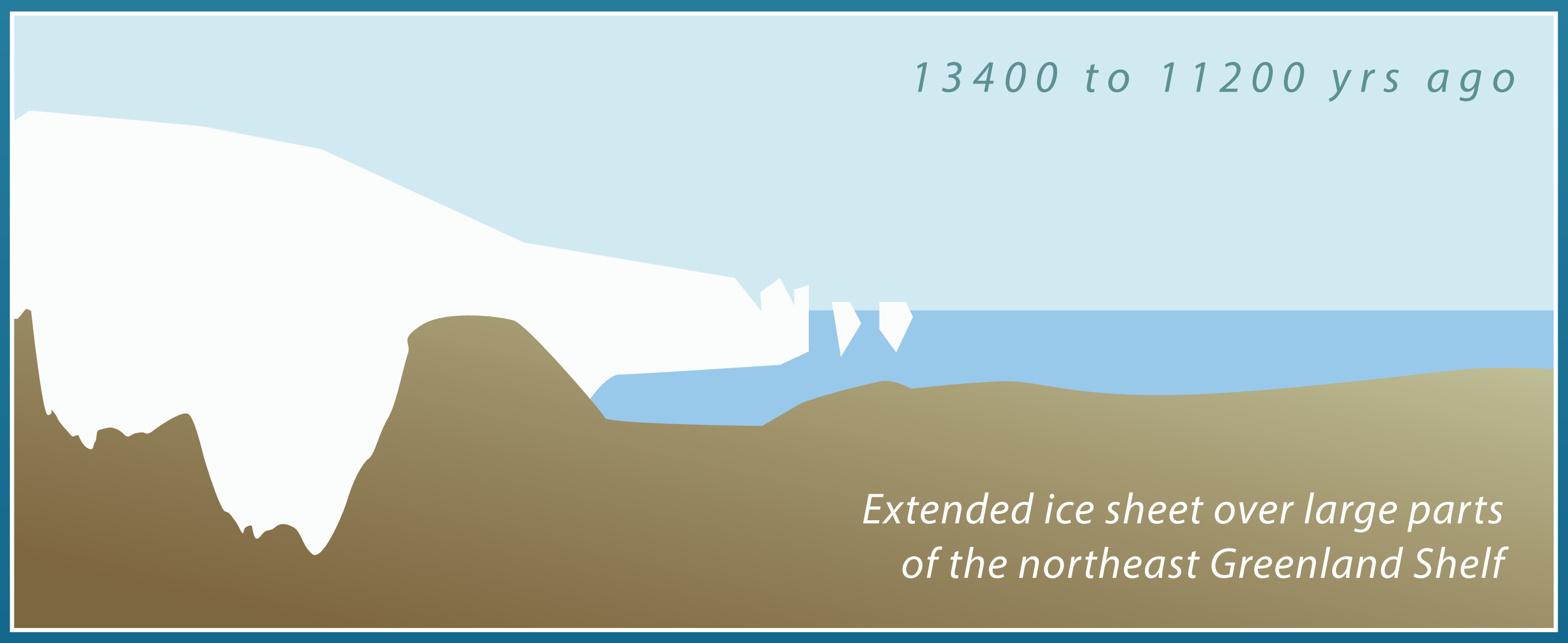
Looking East to west from the Greenland Ice Sheet to the offshore shelf


7900 to 600 yrs ago

No marine ice sheet and heavy sea-ice conditions


9600 to 7900 yrs ago

Transitional phase: Ice sheet retreat and icebergs from breakup


13400 to 11200 yrs ago

Extended ice sheet over large parts of the northeast Greenland Shelf

This shows the abundance of the seafloor-dwelling foraminifera species called *Cassidulina neoteretis* through time. Its presence is linked to the ocean currents and water masses.

In Northeast Greenland, which has several marine-terminating glaciers, a variety of paleoceanography techniques have been used to reconstruct the past 14,000 years. This has been especially valuable for scientists to better understand the roles that different ocean circulation patterns played in the rapid deglaciation events of the past to interpret what is happening now and what the outcome may be in the future.

Sediments cored from the bottom of the ocean serve as a timeline of events, as every year another layer of sediment is stacked on top of the previous layer. From these cores, scientists can use a variety of techniques to determine, for example, how old the sediments are, and whether they originate from terrestrial or marine environments.

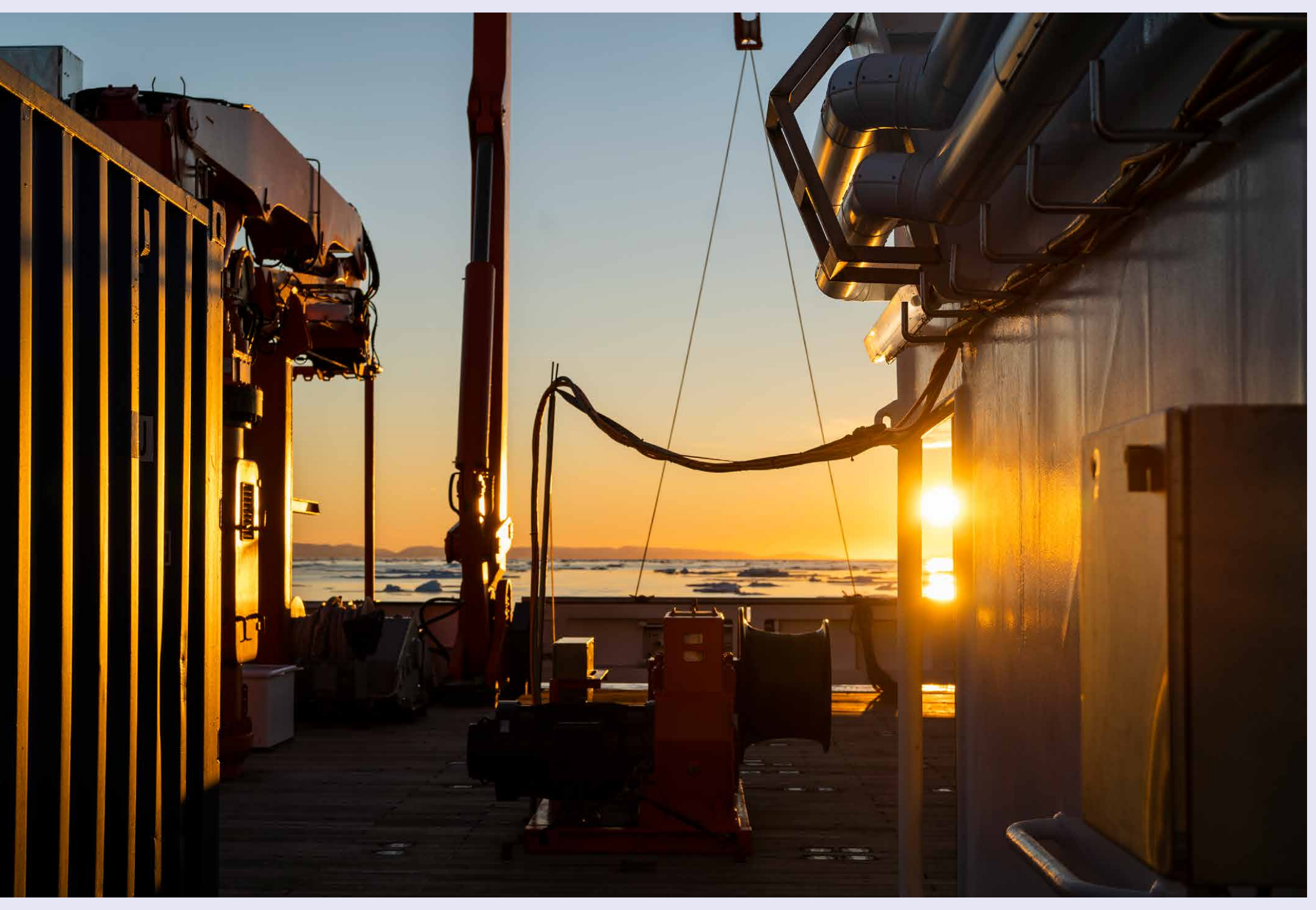
Sediments also contain microfossils. Some of them, both fascinating and useful, are called foraminifera. These single-celled, shelled organisms have existed for at least the last 550 million years, evolving over time. We can use them to understand what the climate and oceans were like in the past by seeing what species are visible in sediments and comparing these to the environments in which they live today.

WATCH THIS VIDEO TO LEARN MORE ABOUT HOW RESEARCHERS GATHER PALEOCEANOGRAPHY DATA

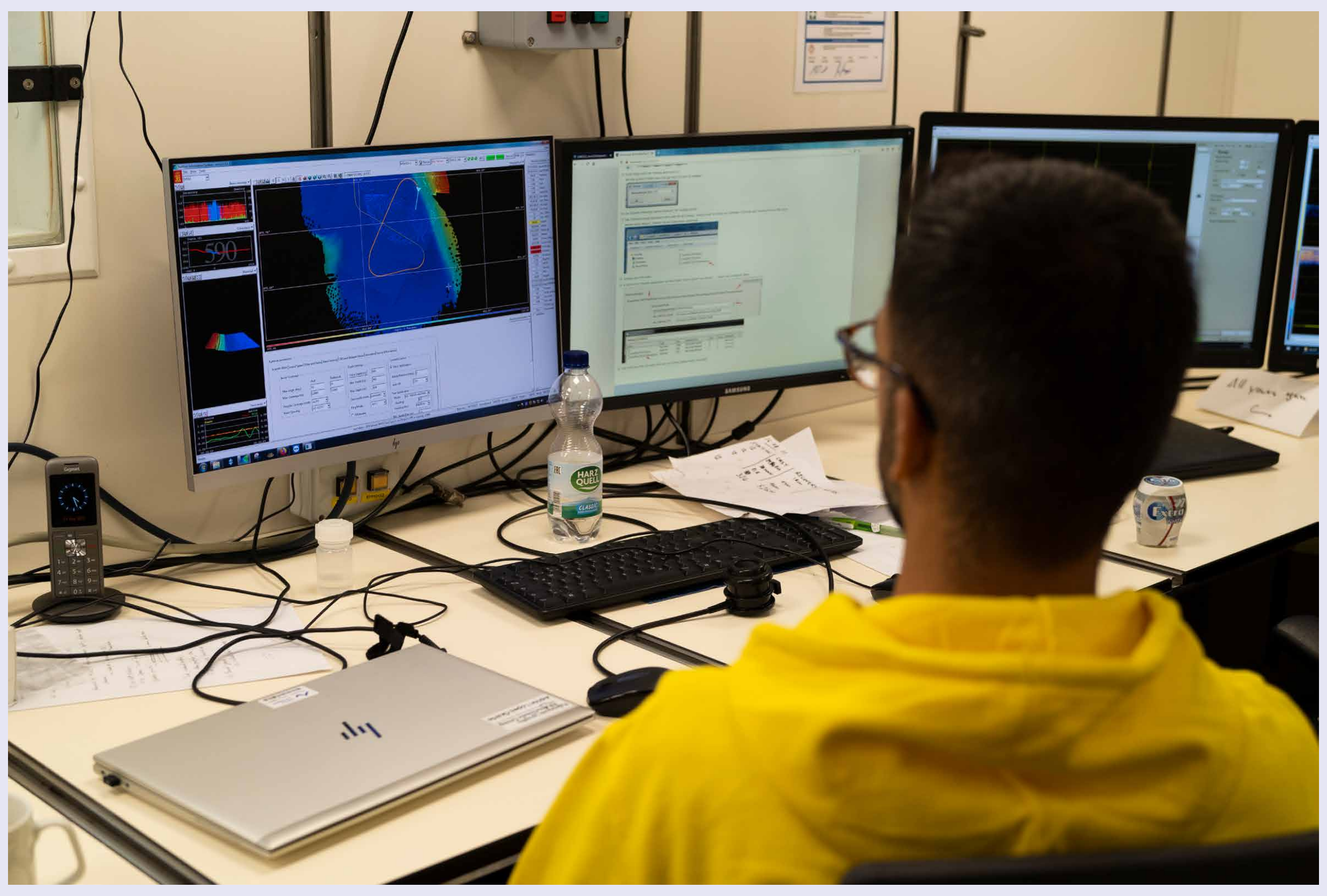
TOOLS USED TO SHED LIGHT ON ECOSYSTEM CHANGES

ONBOARD THE *MARIA S. MERIAN*

Gathering the data necessary to monitor changes in the Arctic is complex. It takes months to plan a research cruise, and the scientists on board require specialized instruments to collect data.

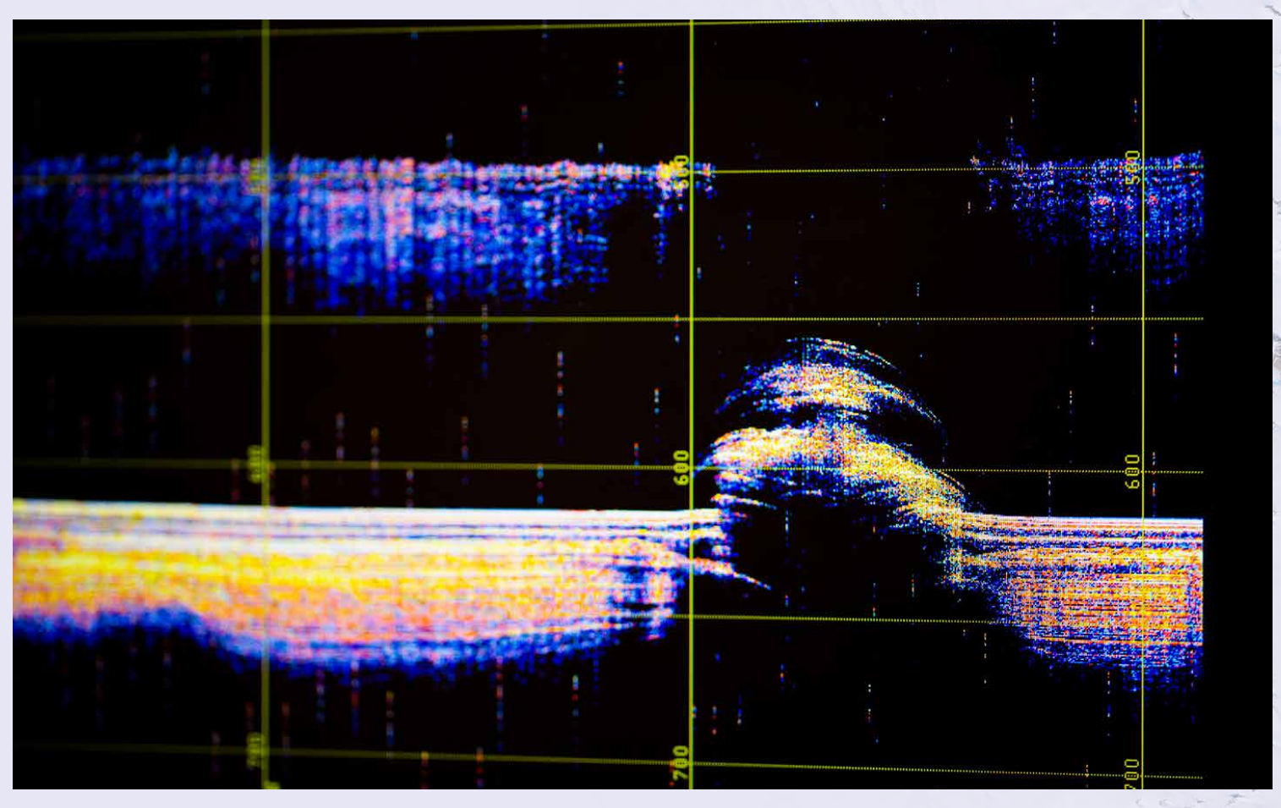


During a research cruise, the ship stops at different stations along the planned route to take samples. The ship will often stop for 24 hours for scientists to take their samples.



HOUR 0

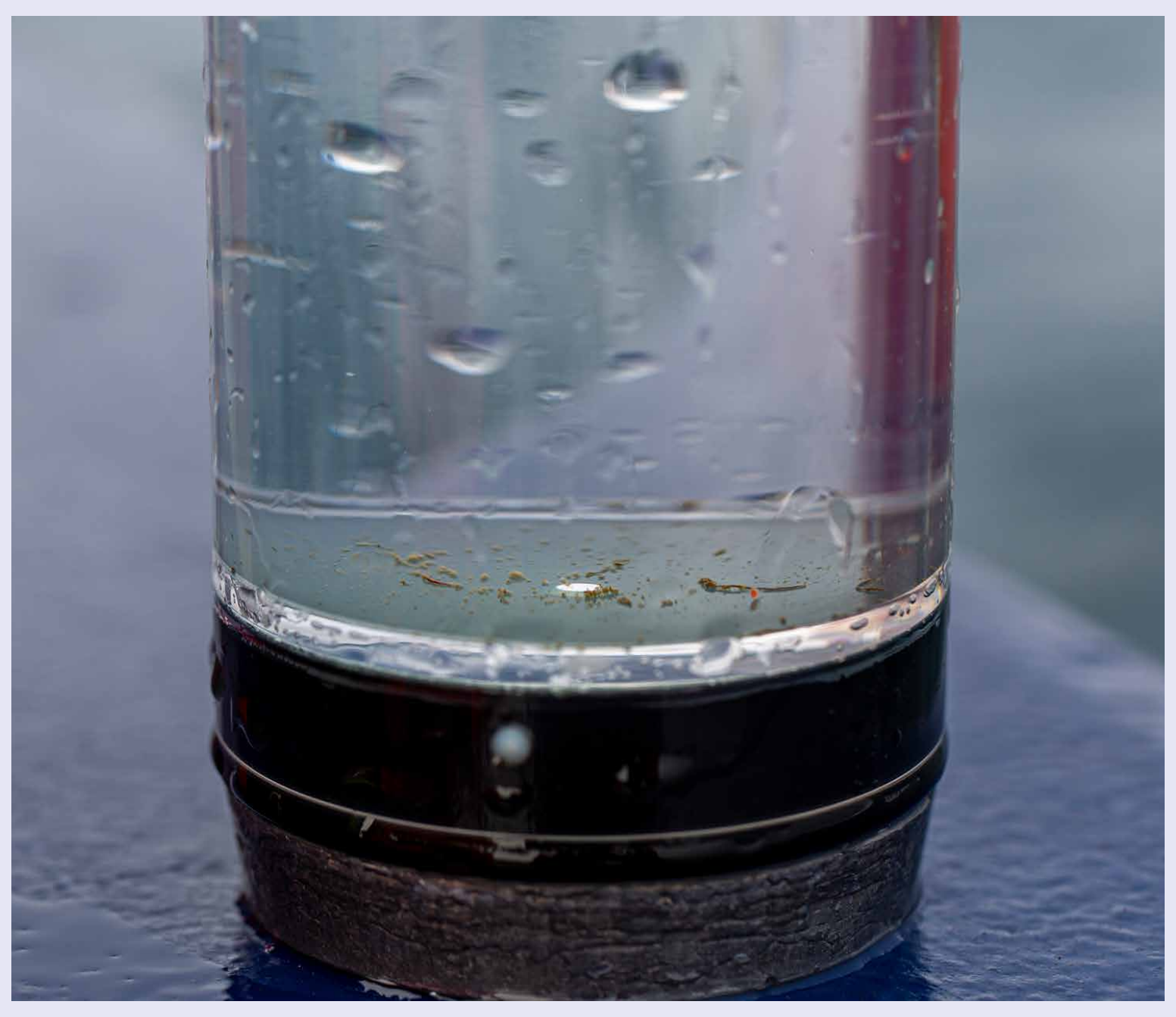
Before stopping at a station, the Merian circles around the area. This is so the parasound, equipment that maps the sea floor, can generate topographic maps.



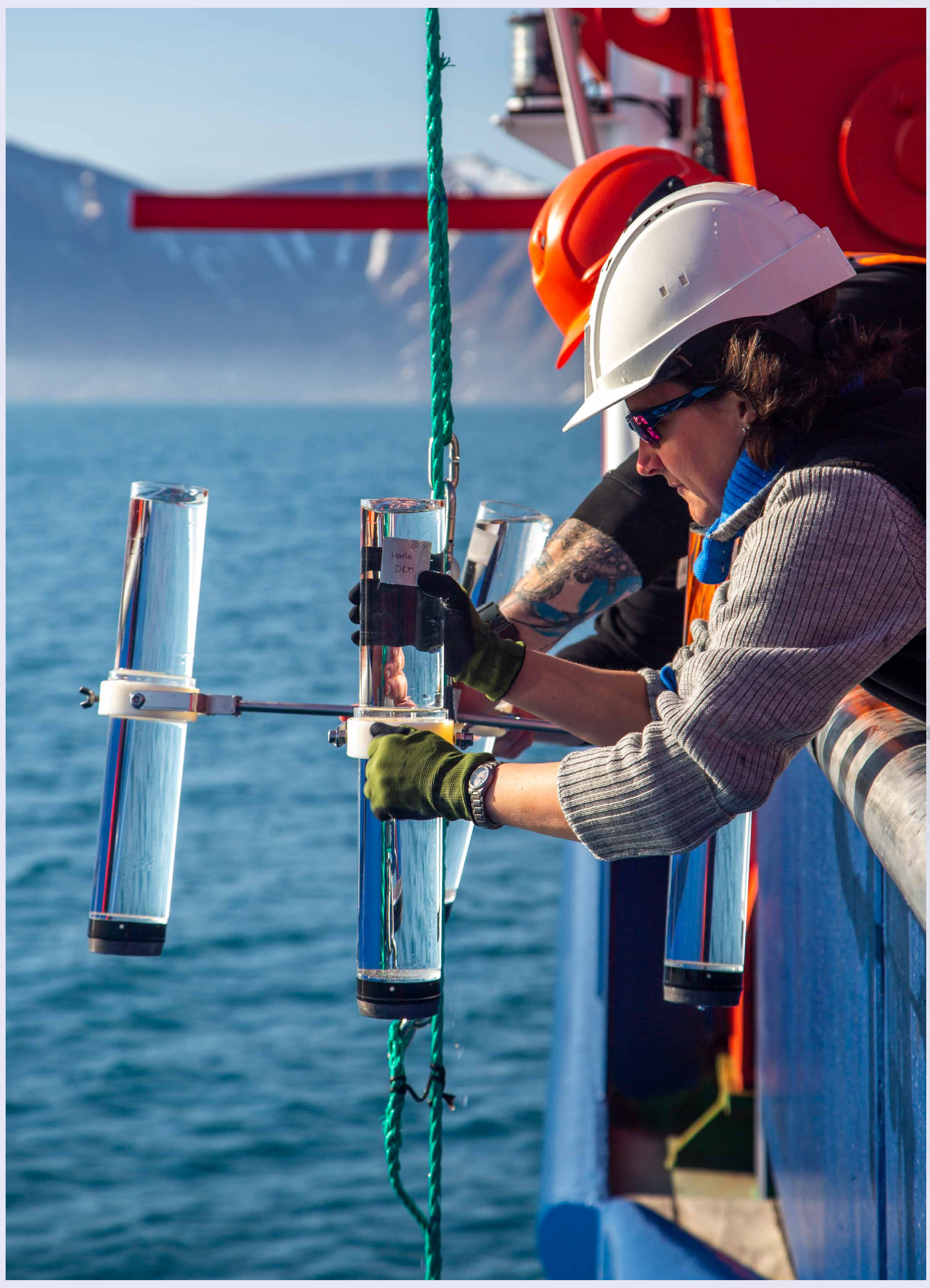
HOUR 1

The first instruments in the water are the sediment traps. These are cylinders attached to a rope with an anchor on the bottom and some buoys throughout to keep them in place.

The sediment traps need to stay in the water for around 24 hours to collect a full day's worth of marine snow.



The sediment traps collect all matter that descends from the ocean surface to its depths. This is known as "marine snow" or "ocean dandruff".



HOUR 2–9

The sediment traps need to stay in the water for around 24 hours to collect a full day's worth of marine snow.

Next it's the CTD: an instrument measuring "conductivity, temperature, and depth". The CTD onboard the Merian has a ring of 24 Niskin bottles, special cylinders that can seal at the top and bottom, each able to capture ten litres of water.

The CTD is lowered into the ocean and researchers then monitor its descent via an onboard computer. From here, they decide at which depth they want to fill a particular bottle with water, sealing it shut.

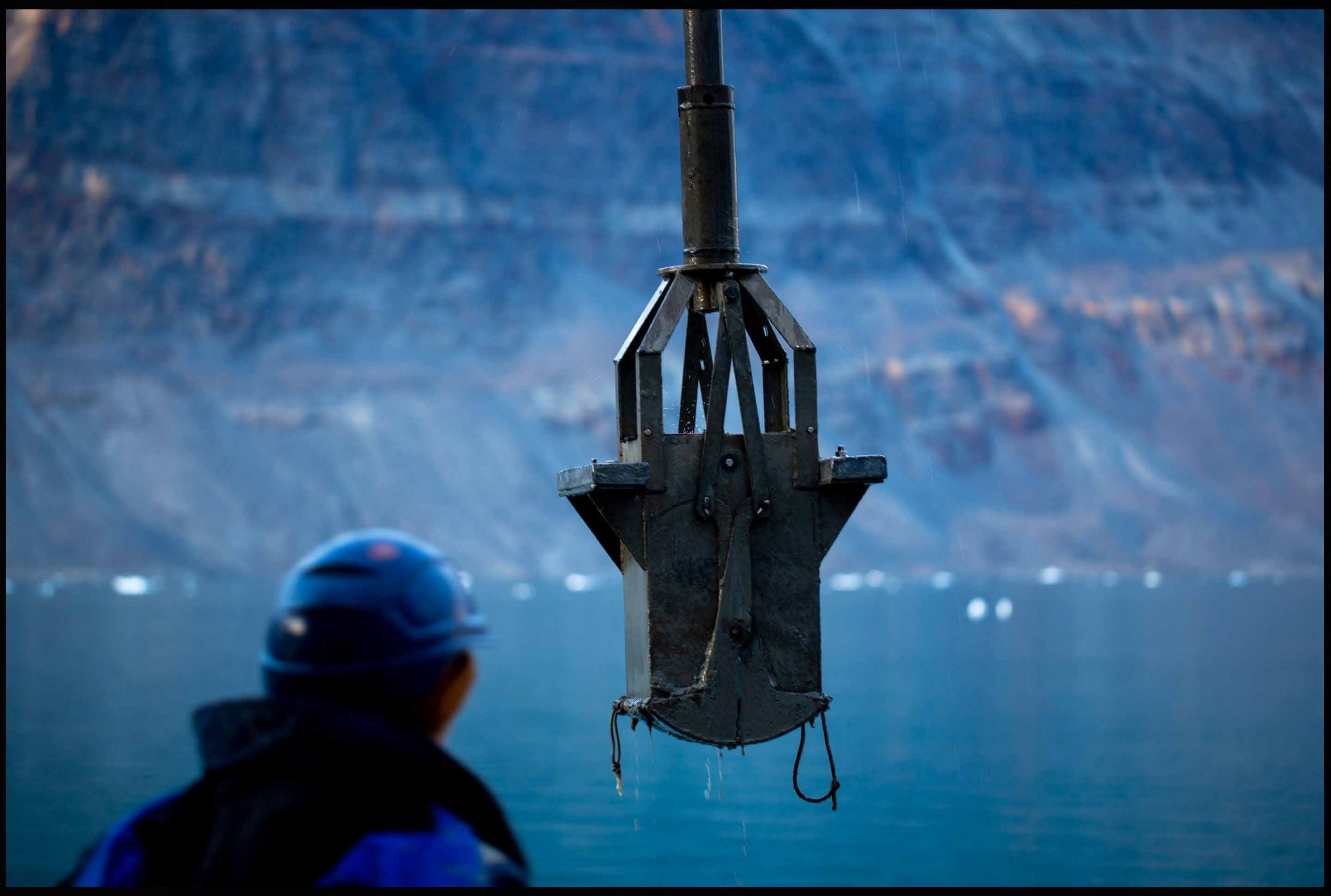
Once it returns to the surface, researchers empty the water into sample bottles or other containers to be analysed.

HOUR 10–15

After the CTD, the plankton nets go in the water. The multinet has five nets that can be opened and closed at different depths. It has a very fine mesh size of 50 micrometres, so it can capture a wider diversity of species than other nets. Another net collects live samples. Researchers can freeze live samples to learn about their diet, or they can incubate them, which involves keeping them alive to study their behaviour under different conditions.

Then it's time for the in-situ pump to go in the water. This equipment does the water filtration underwater, which produces less biased data than the water that's taken from the CTD and then filtered in the lab.

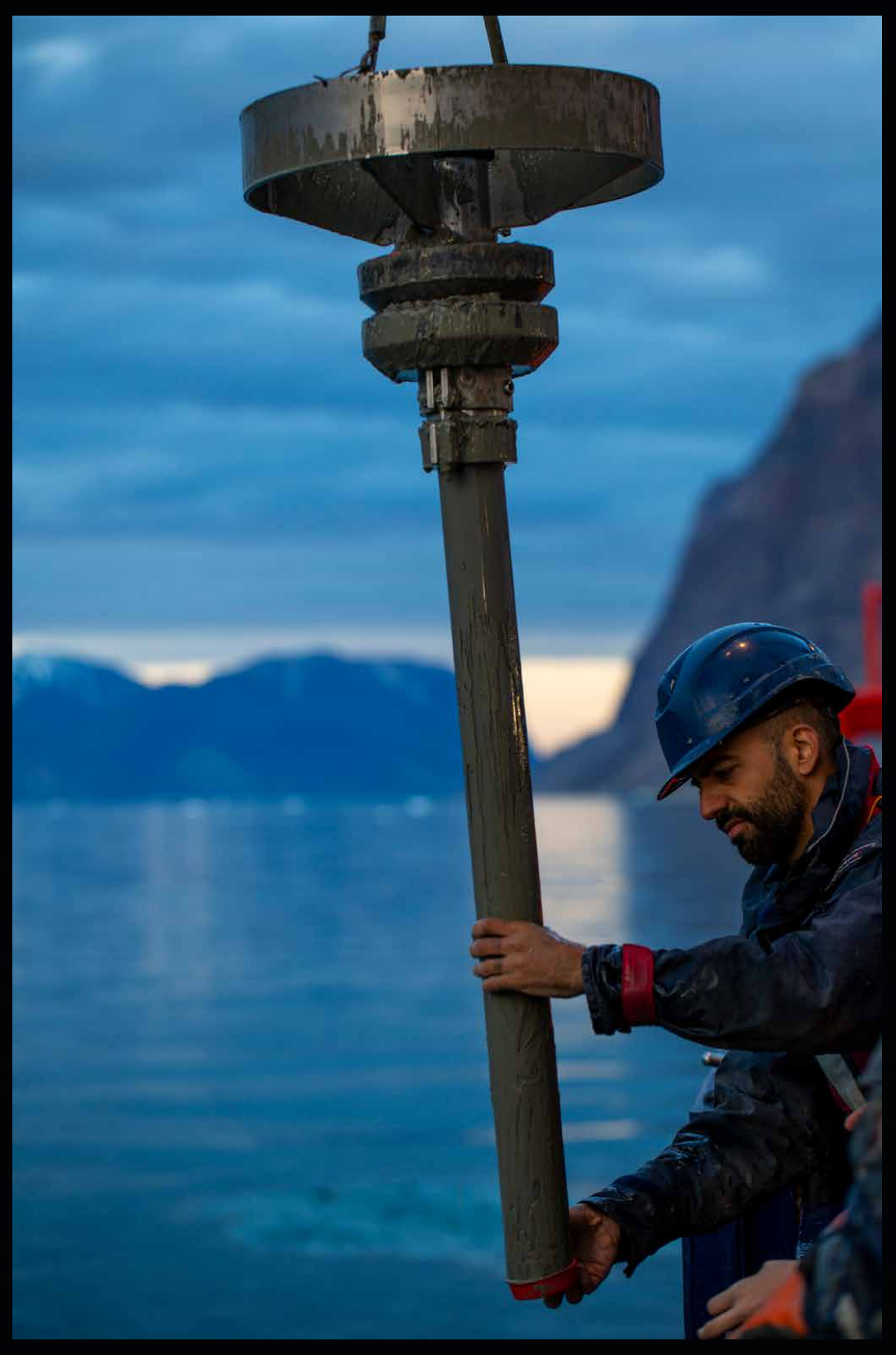
Data gathered from both the in-situ pump and the CTD helps the microbe team study the role of bacteria in the food web of East Greenland.



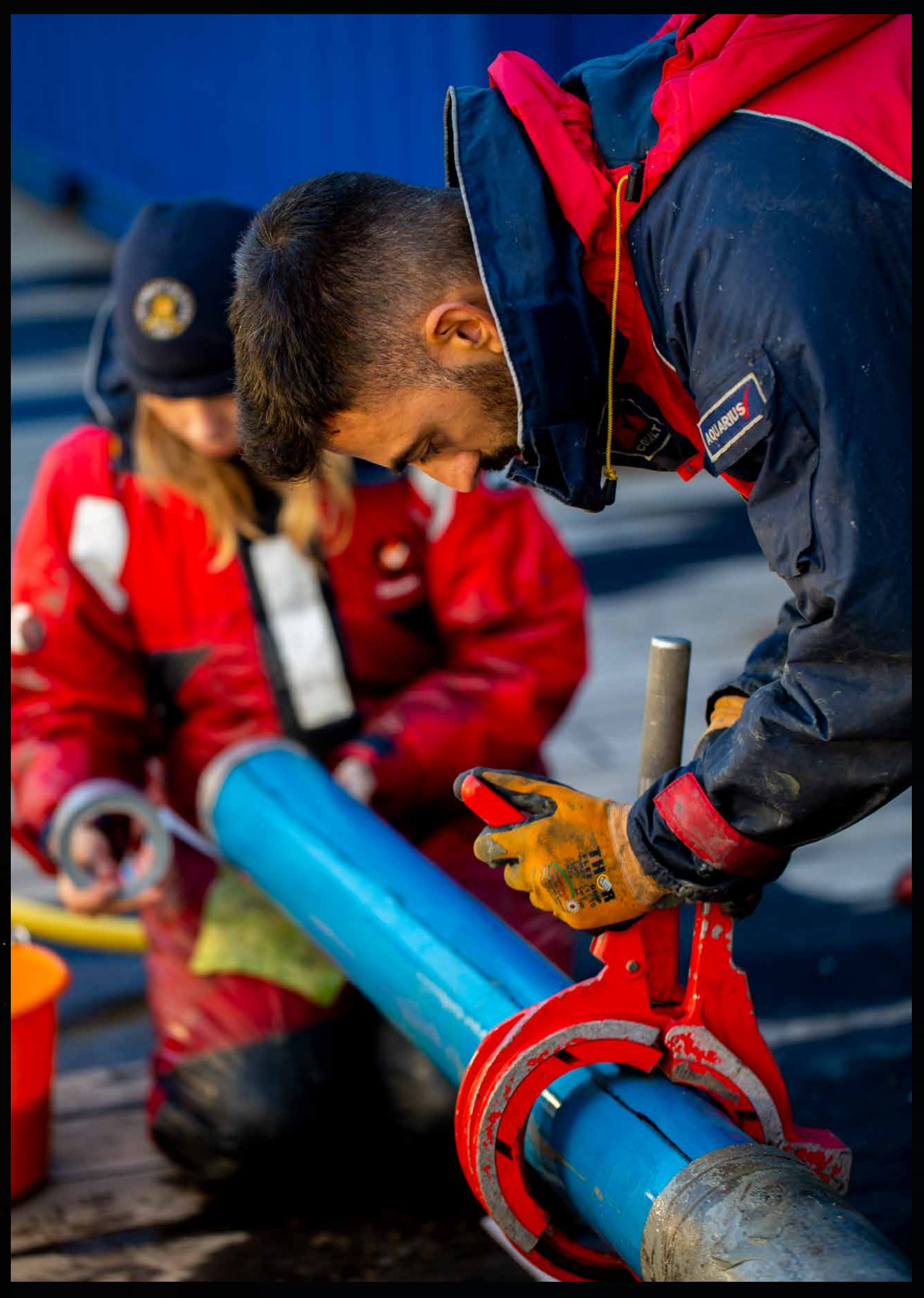
HOUR 16–20

Next, the two teams studying the seafloor get ready to take their samples. First, they use the box corer, a contraption that takes a half-metre square piece of the surface of the seafloor. Using a fine strainer, the team sifts through the muck, looking for small creatures from worms to the occasional sea star.

The paleoceanography team then sends down two different pieces of equipment to take sediment cores. They will later analyse these seafloor cores to try to reconstruct how the ocean has changed in the past, including changes in ocean currents, climate, and when the icesheet retreated.



They use two instruments: the gravity core, which takes a long core up to six metres deep, and the Rumohr core, which takes a shallow sample to gain a complete picture of the seafloor's history.



HOUR 21–23

The box, gravity and Rumohr cores make a big mess when they're lifted back on board. As the crew hoses off the deck, it creates a plume of muddy water on the ocean's surface. This is why they must go last, to avoid contaminating the earlier seawater samples.

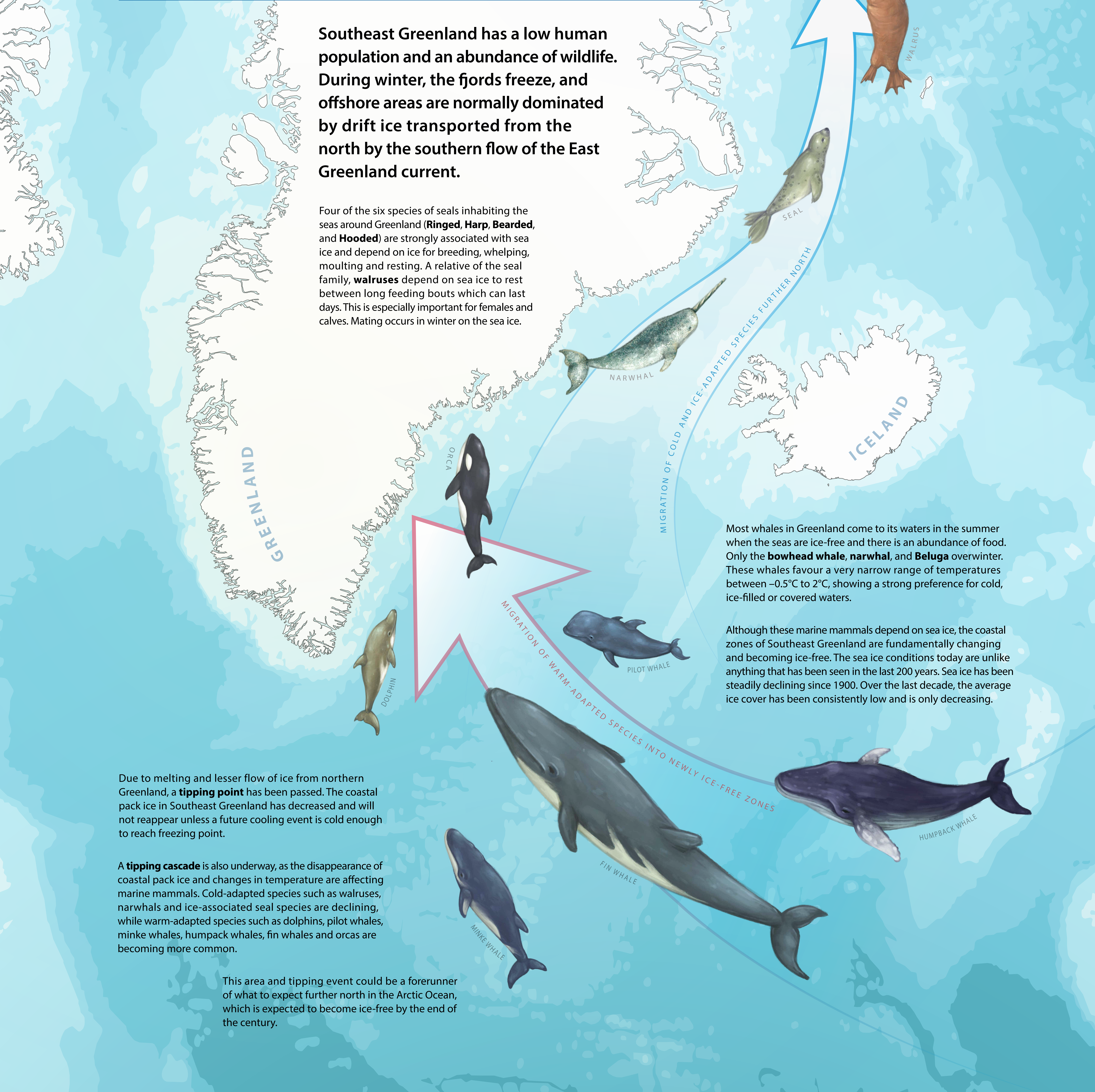
HOUR 24

By the time all of this is done, it's been nearly 24 hours since the start. The final step before the ship heads to the next station is to pull up the sediment traps for analysis. Then, it's onto the next station to begin again.

DISAPPEARING SEA ICE AND GREENLAND'S MARINE MAMMALS

Southeast Greenland has a low human population and an abundance of wildlife. During winter, the fjords freeze, and offshore areas are normally dominated by drift ice transported from the north by the southern flow of the East Greenland current.

Four of the six species of seals inhabiting the seas around Greenland (**Ringed**, **Harp**, **Bearded**, and **Hooded**) are strongly associated with sea ice and depend on ice for breeding, whelping, moulting and resting. A relative of the seal family, **walruses** depend on sea ice to rest between long feeding bouts which can last days. This is especially important for females and calves. Mating occurs in winter on the sea ice.



Most whales in Greenland come to its waters in the summer when the seas are ice-free and there is an abundance of food. Only the **bowhead whale**, **narwhal**, and **Beluga** overwinter. These whales favour a very narrow range of temperatures between –0.5°C to 2°C, showing a strong preference for cold, ice-filled or covered waters.

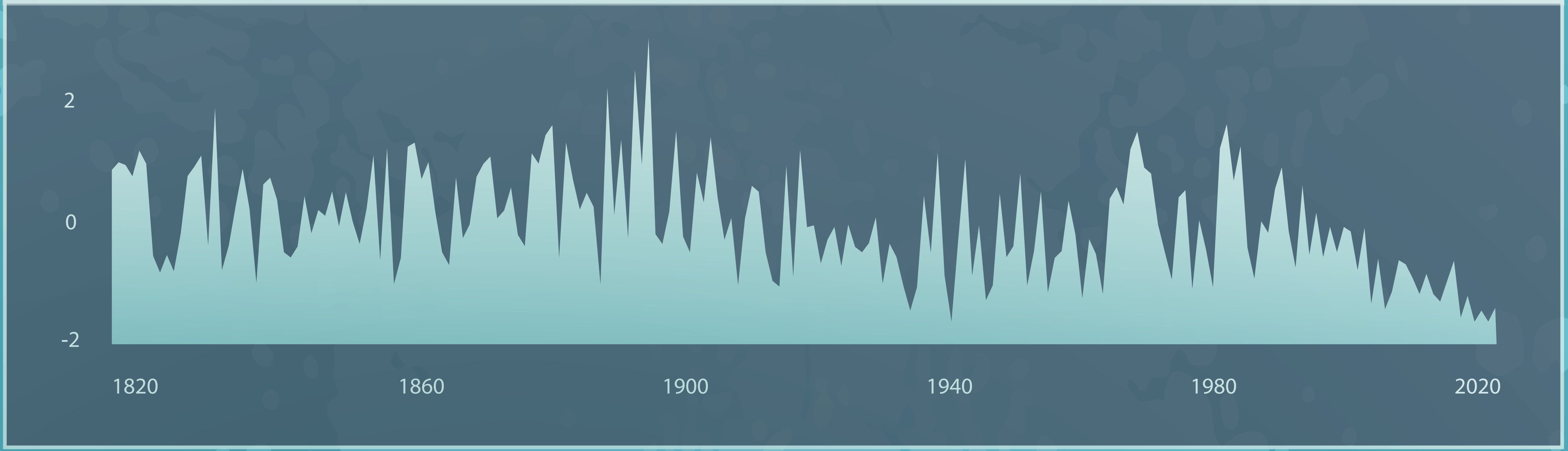
Although these marine mammals depend on sea ice, the coastal zones of Southeast Greenland are fundamentally changing and becoming ice-free. The sea ice conditions today are unlike anything that has been seen in the last 200 years. Sea ice has been steadily declining since 1900. Over the last decade, the average ice cover has been consistently low and is only decreasing.

Due to melting and lesser flow of ice from northern Greenland, a **tipping point** has been passed. The coastal pack ice in Southeast Greenland has decreased and will not reappear unless a future cooling event is cold enough to reach freezing point.

A **tipping cascade** is also underway, as the disappearance of coastal pack ice and changes in temperature are affecting marine mammals. Cold-adapted species such as walruses, narwhals and ice-associated seal species are declining, while warm-adapted species such as dolphins, pilot whales, minke whales, humpack whales, fin whales and orcas are becoming more common.

This area and tipping event could be a forerunner of what to expect further north in the Arctic Ocean, which is expected to become ice-free by the end of the century.

EXTENT OF COASTAL SEA ICE COVERAGE IN SOUTHEAST GREENLAND

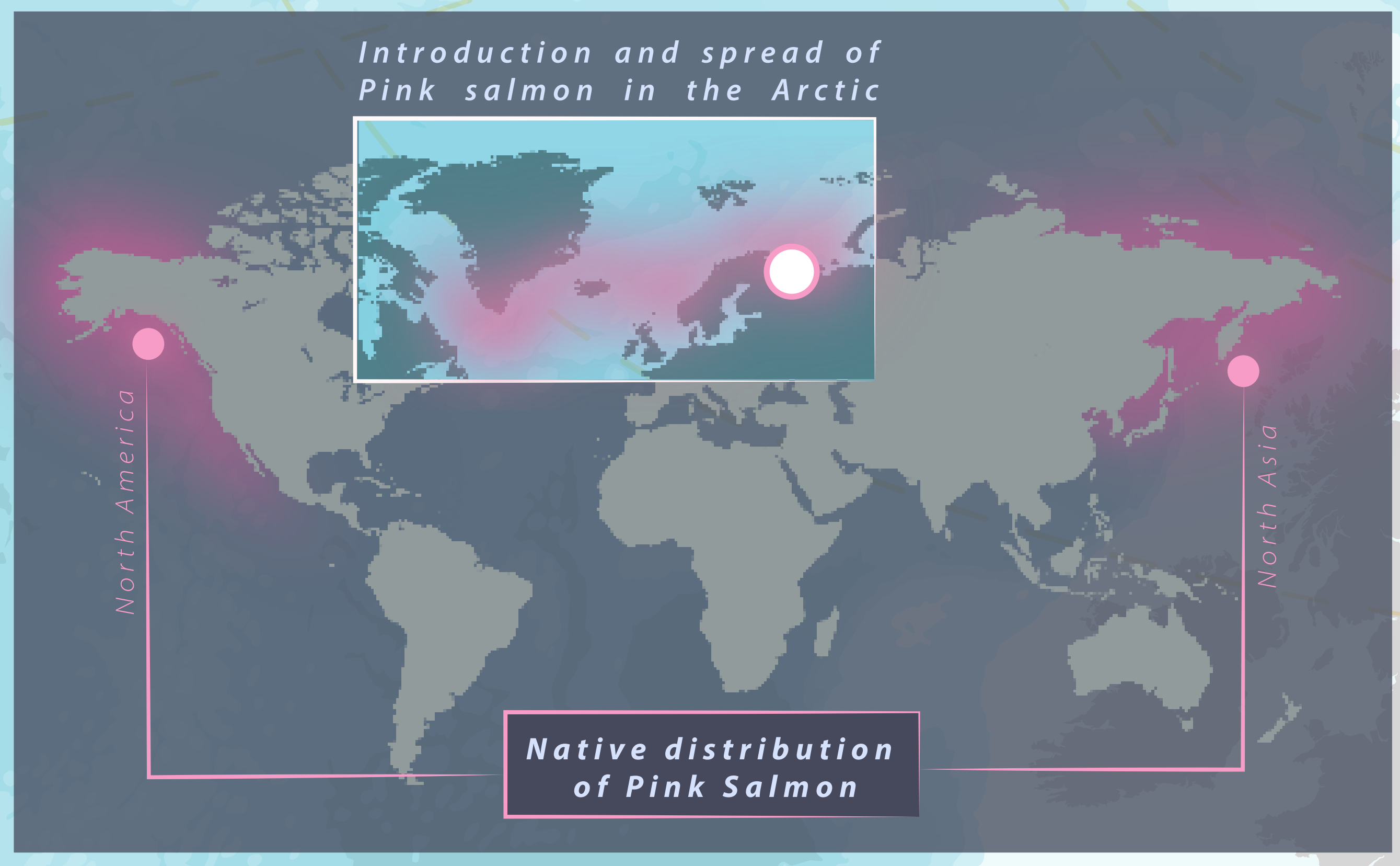


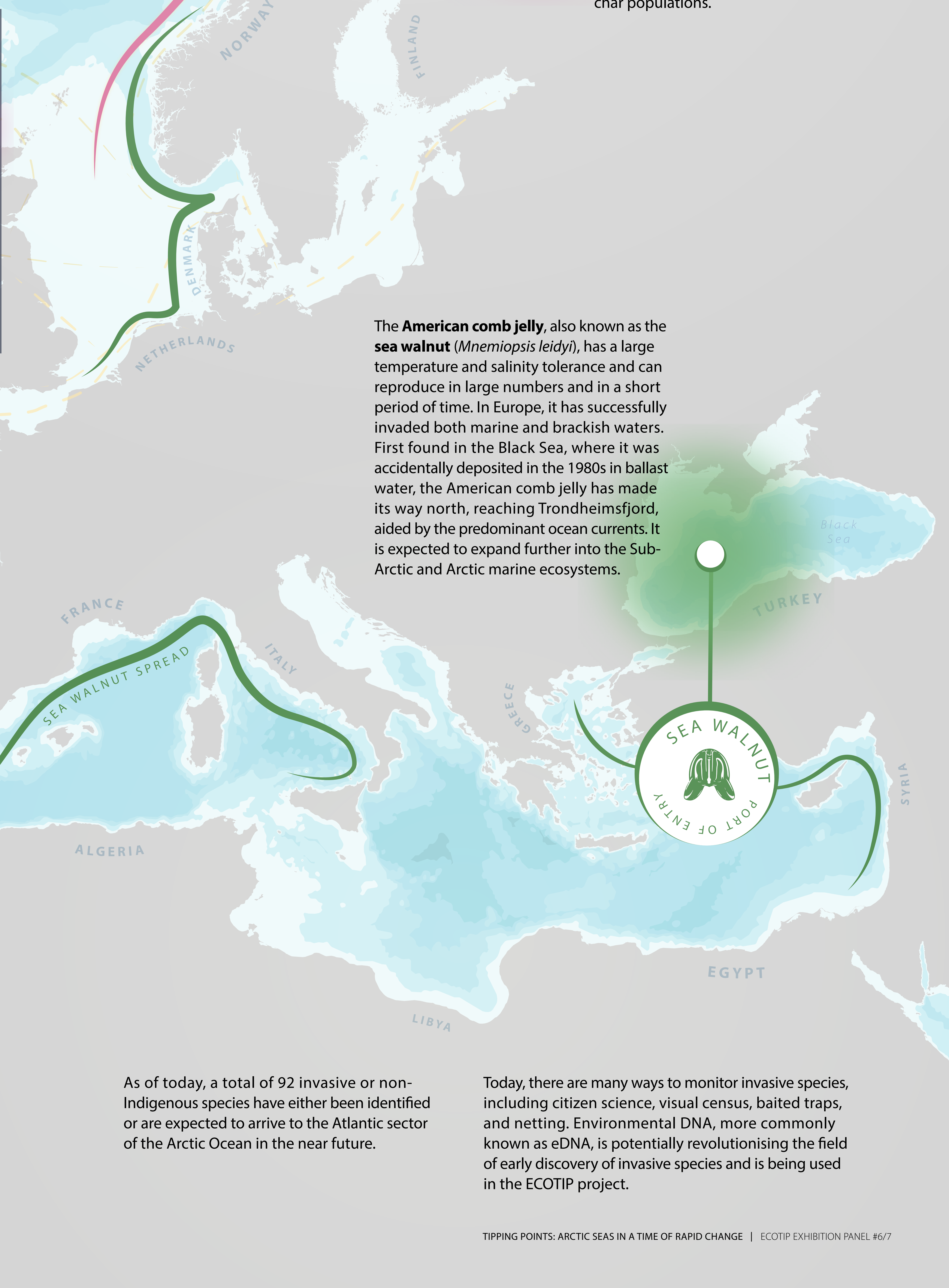
INVASIVE SPECIES
OF THE ARCTIC SEAS

All living creatures on Earth have a native distribution range. When species expand beyond their native ranges, we call them non-Indigenous. And if such species have a negative influence on the new ecosystem they move into, they are described as "invasives".

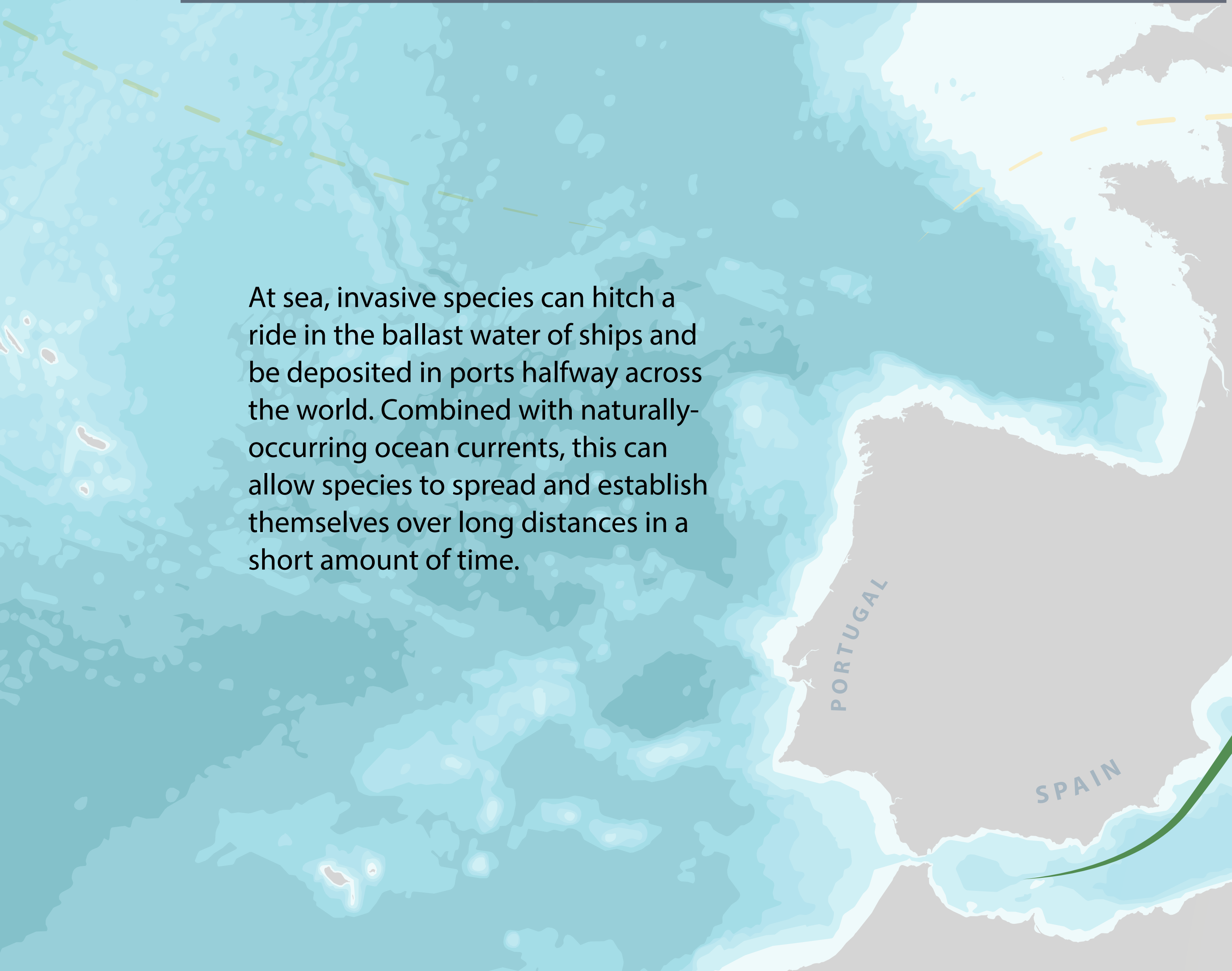
Invasive species have the potential to displace or outcompete existing species, and potentially destabilise whole ecosystems, leading to an entire shift – or tipping point – in which the ecosystem is transformed into something entirely different. Whether introduced intentionally, by accident, or through natural means, there are many examples in history of invasive species wreaking havoc both on land and at sea.

The **Pink salmon** is an example. Native to northern parts of the Pacific Ocean, it was introduced to the Kola Peninsula in the 1960s and has since spread far and wide across parts of the Arctic. It is considered a high-risk threat to local salmon, sea trout, and Arctic char populations.

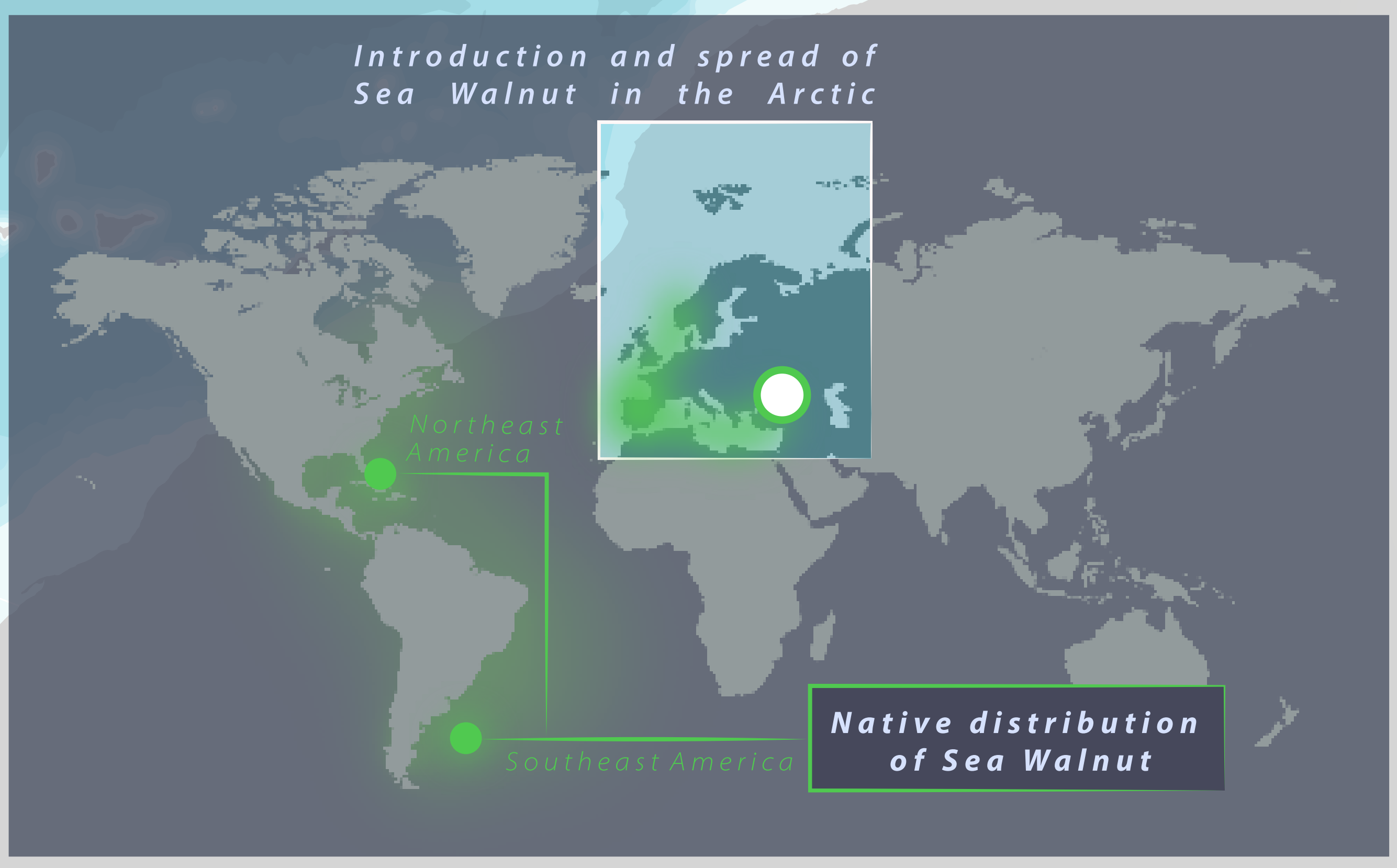

Introduction and spread of Pink salmon in the Arctic



The **American comb jelly**, also known as the **sea walnut** (*Mnemiopsis leidyi*), has a large temperature and salinity tolerance and can reproduce in large numbers and in a short period of time. In Europe, it has successfully invaded both marine and brackish waters. First found in the Black Sea, where it was accidentally deposited in the 1980s in ballast water, the American comb jelly has made its way north, reaching Trondheimsfjord, aided by the predominant ocean currents. It is expected to expand further into the Sub-Arctic and Arctic marine ecosystems.



At sea, invasive species can hitch a ride in the ballast water of ships and be deposited in ports halfway across the world. Combined with naturally-occurring ocean currents, this can allow species to spread and establish themselves over long distances in a short amount of time.


Introduction and spread of Sea Walnut in the Arctic

As of today, a total of 92 invasive or non-Indigenous species have either been identified or are expected to arrive to the Atlantic sector of the Arctic Ocean in the near future.

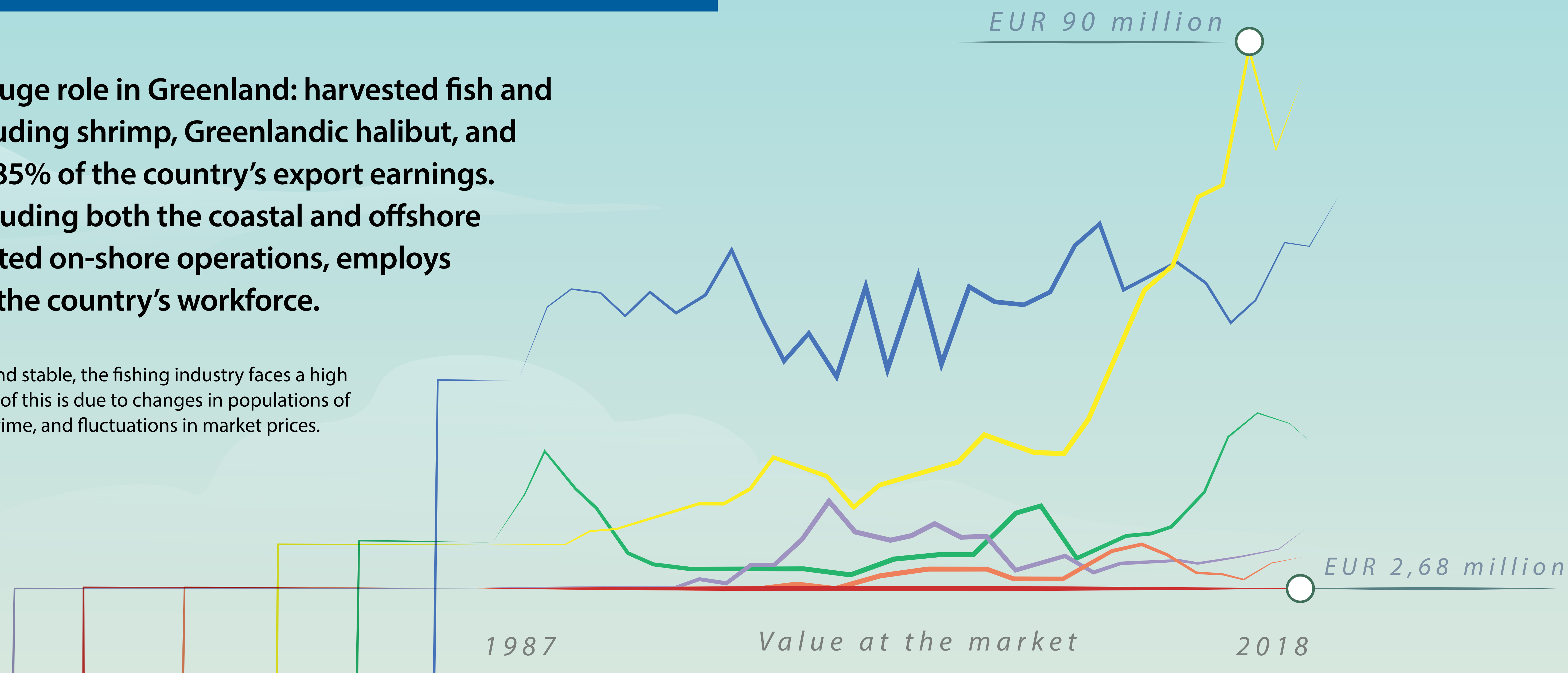
Today, there are many ways to monitor invasive species, including citizen science, visual census, baited traps, and netting. Environmental DNA, more commonly known as eDNA, is potentially revolutionising the field of early discovery of invasive species and is being used in the ECOTIP project.

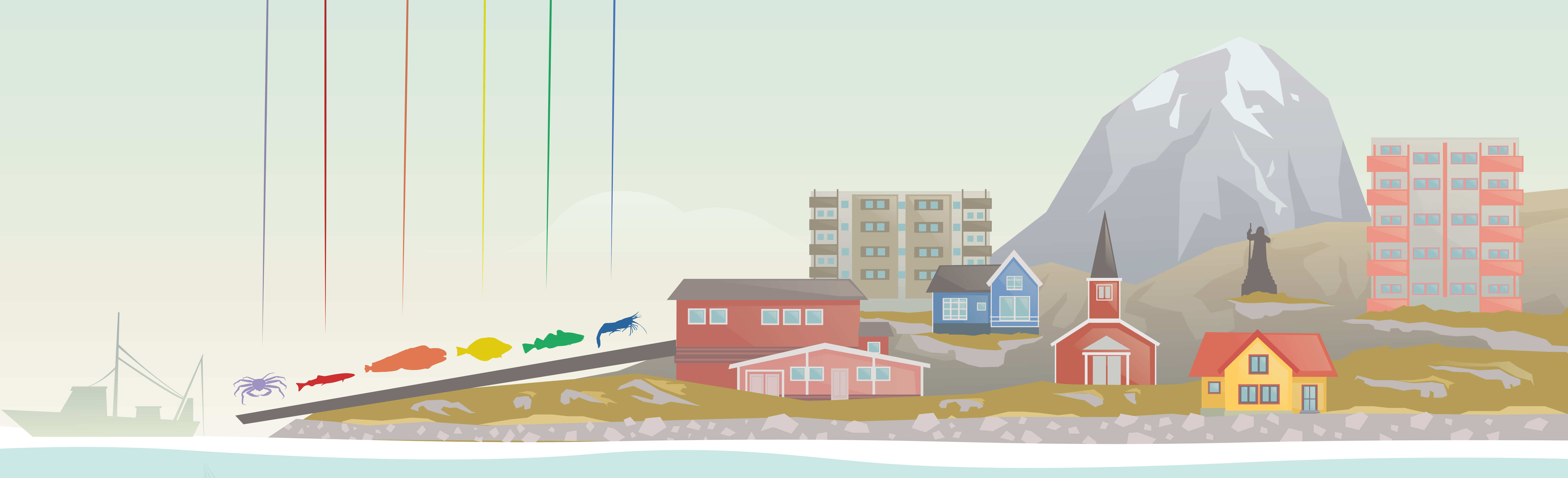
GREENLAND'S SMALL-SCALE FISHERIES

ADAPTING TO CHANGE

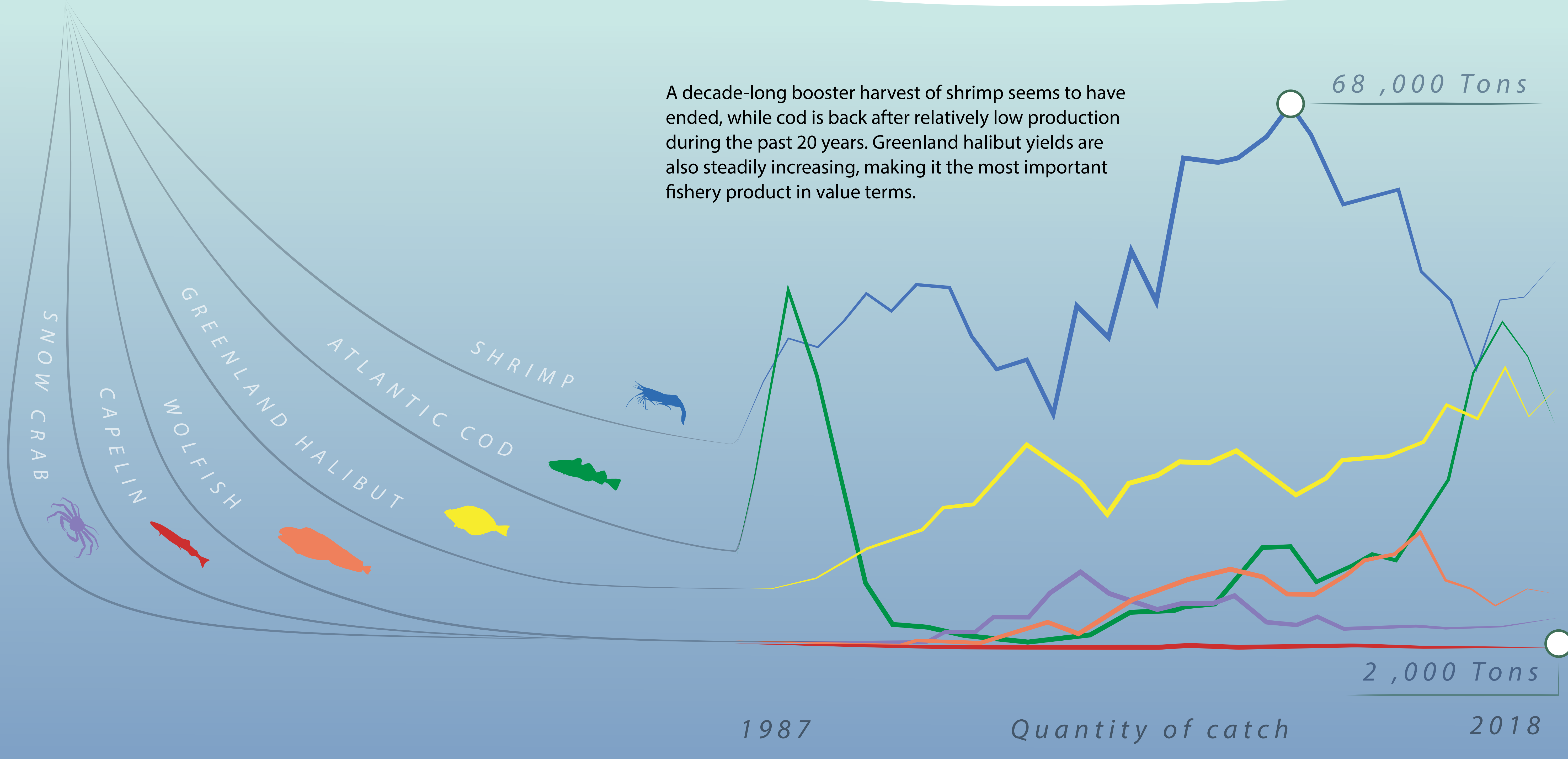
Fisheries play a huge role in Greenland: harvested fish and crustaceans, including shrimp, Greenlandic halibut, and cod, account for 85% of the country's export earnings. The industry, including both the coastal and offshore fisheries and related on-shore operations, employs over one-fifth of the country's workforce.

But far from being static and stable, the fishing industry faces a high level of uncertainty. Much of this is due to changes in populations of fish and crustaceans over time, and fluctuations in market prices.





A decade-long booster harvest of shrimp seems to have ended, while cod is back after relatively low production during the past 20 years. Greenland halibut yields are also steadily increasing, making it the most important fishery product in value terms.



As climate change leads to increasing sea temperatures, the total amount of shrimp is expected to decline, while cod and other species are expected to benefit. Given that all these species interact with each other and in some cases depend on each other, there remains a lot of uncertainty as to their futures.

The northward migration of certain fish is also occurring. For fishers in Northwest Greenland, who have targeted halibut until now, it has now become possible to gill-net cod and fish for crab. Apart from creating new opportunities, it also leads to challenges such as over-crowding.

Greenland's small-scale fishers, who operate out of the many small ports and harbours dotted around the country, have proven to be flexible to these changes and have adapted over the years.

How so? The natural fluctuations in fish availability over time, the flexibility to engage in different fisheries throughout the year, and the ability to land different types of fish in different ports all contribute to their ability to adapt to these changes.

This built-in resilience and adaptive capacity places them in a favourable position to acclimate to future shifts and is also an example of how societies can adapt to continuous changes in their environment.