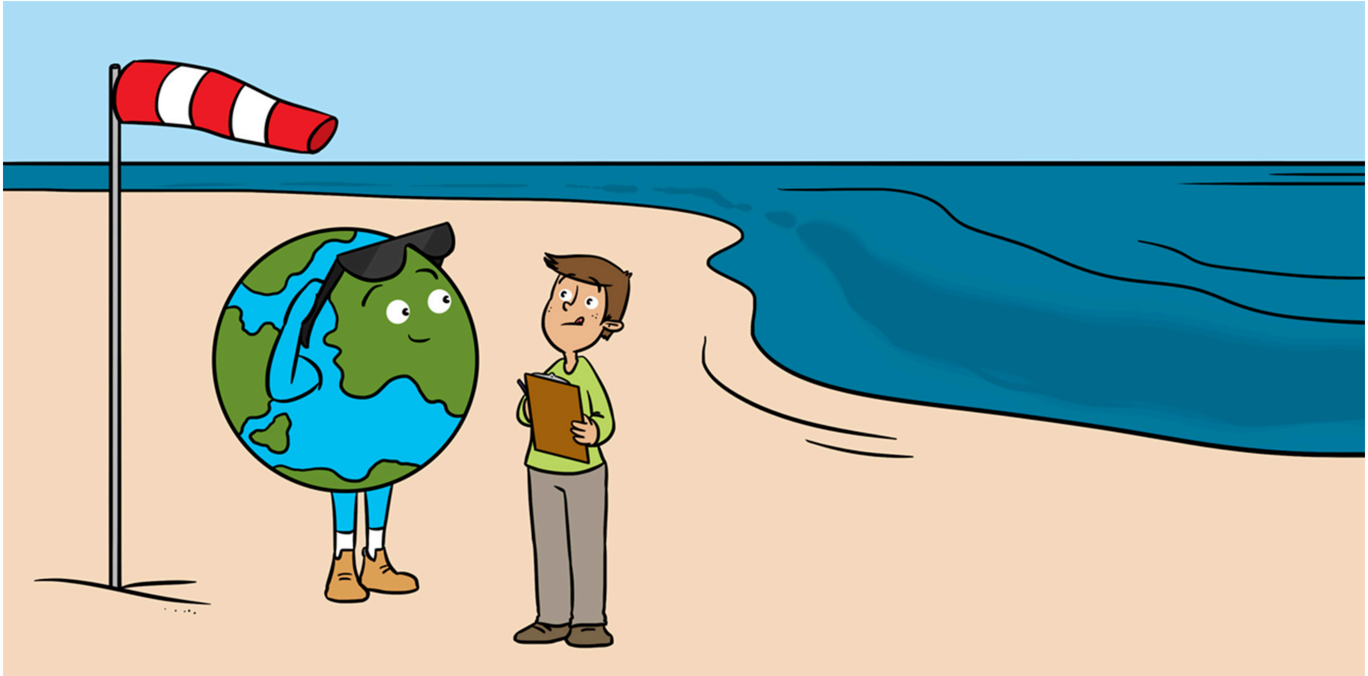
EARTH AND ITS RESOURCES
Published: 02 December 2022
doi: 10.3389/frym.2022.704120



WHY ARE THE EASTERN MARGINS OF OCEAN BASINS FULL OF FISH?

***Sara Miller*[1,2]*, Luisa Lopera*[3] *and Annalisa Bracco*[1*]**

[1] *School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, United States*
[2] *Department of Astronomy, Cornell University, Ithaca, NY, United States*
[3] *Ocean Sciences and Engineering Program, Georgia Institute of Technology, Atlanta, GA, United States*

YOUNG REVIEWERS:

AVENTURA CITY OF EXCELLENCE SCHOOL (ACES)
AGES: 11–12

AVERY
AGE: 13

ELENA
AGE: 14

JAETHANIEL
AGE: 12

LUKE
AGE: 12

At the eastern side of the Atlantic and Pacific Oceans, Earth's rotation combined with winds blowing toward the equator push water away from the coasts. Deep ocean water rises to replace what was pushed away, in a process called upwelling. The colder, deep water that rises to the surface is rich in nutrients and oxygen, and it supports healthy ecosystems. That is, upwelling in coastal oceans equals lots of fish! There are four coastlines where upwelling is crucial, known as eastern boundary upwelling systems (EBUS for short). These regions cover <3% of the world's ocean area, but they are responsible for 20% of the global fish catch. EBUS change constantly along with Earth's changing climate. Given their extraordinary biological productivity, it is very important to understand how global warming may impact EBUS. In this article, we describe what EBUS are and discuss how climate change may affect them and the fish populations in their ecosystems.

INTRODUCTION

"Small, but mighty" is a good way to describe the tiny fish that live in the upper ocean. Sardines and anchovies, for example, may be small, but they play an extremely important role in the ocean food chain and in the marine ecosystem. These small fish are a major food source for bigger fish, which are a major food source for humans all around the world! The largest populations of sardines and anchovies live in regions of the ocean called **eastern boundary upwelling systems (EBUS)**. EBUS are formed by a combination of the Earth's rotation and the surface winds that blow toward the equator along the direction of the coastline. These factors work together to push the water at the surface of the ocean away from the coasts. This horizontal water movement forces deeper water, which is usually colder and richer in oxygen and nutrients like nitrogen and phosphorus, to rise into the upper layer of the ocean where sunlight reaches. When nutrient-rich water reaches the sunlit layer, **phytoplankton blooms** result. **Phytoplankton** are tiny drifting plants. Like plants on land, phytoplankton use **photosynthesis** to transform the sun's energy into complex nutrients and oxygen, and support the whole food chain of the ocean. **Zooplankton**, the tiniest animals in the ocean, eat phytoplankton, while zooplankton themselves are the preferred food of larger fish. The physical process behind this beneficial movement of ocean water is called oceanic **upwelling** (Figure 1).

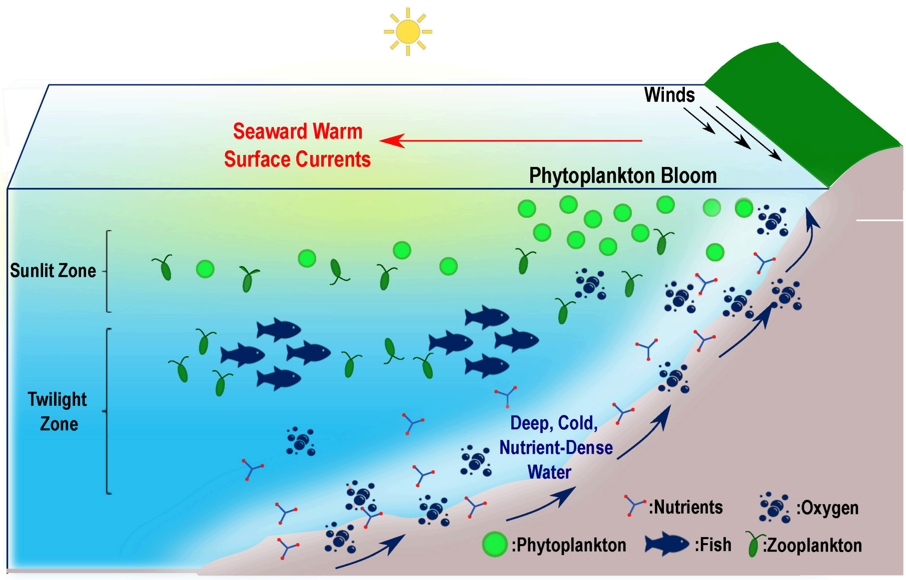


Figure 1

EASTERN BOUNDARY UPWELLING SYSTEMS (EBUS)

Regions of the ocean where water at the ocean's surface moves away from the coasts and is replaced by colder water, rich in oxygen, and nutrients.

PHYTOPLANKTON BLOOM

Rapid increase of phytoplankton in a particular region, associated with high amounts of nitrogen, phosphorus, and silica—the main nutrients for plants—along with abundant light and oxygen.

PHYTOPLANKTON

Microscopic, drifting plants that live in the sunlit zone of the ocean, and perform photosynthesis.

Figure 1

Upwelling is the process by which warm surface water in the upper, sunlit region of the ocean is replaced by deeper, colder, nutrient-rich water from the deeper regions (twilight zone). In EBUS, upwelling is caused by the wind that blows along the coastline and toward the equator, combined with the Earth's rotation. The wind forces the surface water away from the coast.

WHERE ARE THE EBUS AND WHY DO OCEANOGRAPHERS STUDY THEM?

Oceanographers study EBUS because they are one of the ocean's most productive ecosystems, and they are very important for the

PHOTOSYNTHESIS

The process by which plants use sunlight to synthesize food using carbon dioxide and water.

ZOOPLANKTON

Small aquatic organisms including crustaceans and larvae that drift in the ocean. They mostly eat phytoplankton and they are eaten by larger predators like fish.

economies of many countries. There are four main EBUS across the globe: the California and Peru-Chile upwelling systems in the Pacific Ocean, and the Canary and Benguela upwelling systems in the Atlantic Ocean (Figure 2) [1]. Seabirds such as cormorants, pelicans, and gannets, as well as marine mammals, are plentiful and diverse in EBUS because these animals are attracted to the concentrated food source available in these ecosystems. The accumulated excrement (poop) and the remains of dead birds and seals form a very valued soil fertilizer called guano, which is supercharged in nutrients. Not only do EBUS provide up to one fifth of the world's total fish catch [2] despite making up only a very small fraction of Earth's oceans, but, due to guano, they were of crucial importance to the development of modern intensive farming in the nineteenth century!

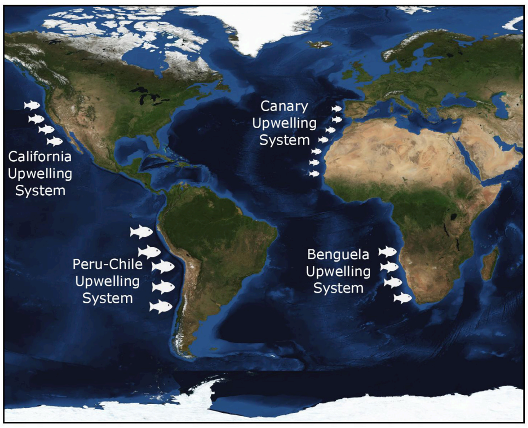


Figure 2

Figure 2

Locations of the four main EBUS. The size of the anchovy and sardine populations in each EBUS is proportional to the size of the fish symbol. The largest population is found in the Peru-Chile Upwelling System, and the smallest in the Canary Upwelling System.

EBUS AND CLIMATE CHANGE

Because fish are an important source of food and income for much of the world, scientists would like to understand how climate change will affect EBUS. Scientists believe that global warming will affect EBUS in two ways: it will change the winds that drive upwelling in EBUS, and it will change the layering of ocean water (Figure 3).

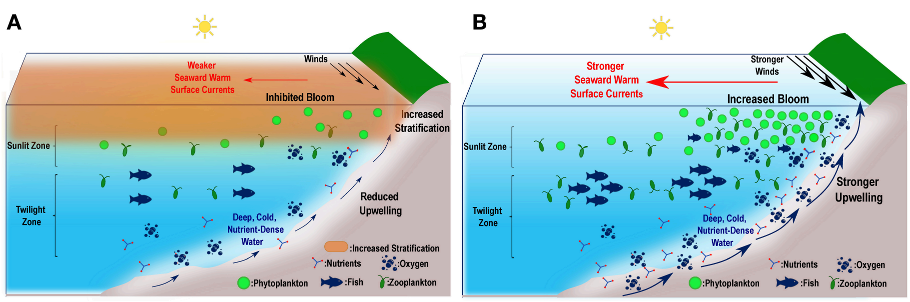


Figure 3

Figure 3

Possible future scenarios for EBUS. **(A)** As a result of climate change, EBUS upwelling may weaken because of increased stratification. Weaker upwelling results in less nutrients in the sunlit zone, which means less phytoplankton, providing less food for zooplankton and fish. **(B)** Alternatively, EBUS upwelling may strengthen because of stronger winds and little changes in stratification. Stronger upwelling results in more nutrients in the sunlit zone, which means more phytoplankton, providing more food for zooplankton and fish.

UPWELLING

Physical process in which in cold, nutrient-enriched ocean water rises from deep layers toward the ocean surface.

HEAT CAPACITY

The amount of heat required to warm a fix amount of material by 1 degree. The heat capacity of water is higher than that of rock.

STRATIFICATION

The process by which a fluid organizes into layers based on density. In a stratified ocean, warmer, lighter, less salty water rests on top of colder, heavier, saltier water.

Let us start with the winds. If the winds weaken, less water is pushed offshore and upwelling decreases. Likewise, stronger winds would yield greater upwelling because more water at the ocean's surface is pushed away and replaced by larger amounts of deep water. Although scientists are still debating whether it is more likely that winds will strengthen or weaken, most researchers agree that coastal winds will become stronger in the future [3]. This could happen because global warming will cause the land to warm faster than the ocean. If you leave a rock and a glass full of water out in the sun, after an hour the rock will be very hot and the water will only be warm. This is because the land and the ocean have different **heat capacities**. If the land warms up more than the ocean, the land-ocean temperature contrast will increase. Scientists predict that this increased temperature difference will produce stronger winds along the coastlines, and that these winds will increase upwelling. Increased upwelling would bring even more nutrients and oxygen close to the surface, encouraging the growth of beneficial phytoplankton blooms [4].

However, global warming will also cause air temperatures to rise [5]. When warm air heats the upper layer of the ocean, it increases what scientists call ocean **stratification**. Stratification occurs when water with different densities forms layers piled one on top of the other, from the lightest on top to the heaviest at the bottom. Warm water is less dense than cold water, so warm water floats on cold water. The lightest and warmest water is found in the upper ocean and each layer beneath is heavier and colder. Although warmer water in the upper ocean sounds nice for swimming, this warm layer acts as a barrier to upwelling. The more the stratified the ocean water is, the weaker the current that moves the surface water away from the coast. As a result, a more stratified ocean could decrease upwelling, decreasing the amount of nutrients that reach the sunlit zone where photosynthesis happens.

How does this all fit together? Although we know that EBUS' ecosystems may benefit from stronger winds and may be harmed by increased stratification, we do not know if the sum of these changes will be good or bad for the organisms that live there. Scientists are working to predict the future of EBUS with the help of computers. While it is not yet possible for a computer to model all that happens in the atmosphere and ocean, we have made huge progress representing Earth's climate in a realistic way. Results of these computer models show that each of the four main EBUS will likely respond differently to a changing climate. One group of researchers, for example, found that the two EBUS in the Atlantic Ocean may be very sensitive to climate change, whereas the two EBUS in the Pacific Ocean may not be affected by it very much [6]. Nevertheless, computer models agree that global warming will affect EBUS in summer more than in winter. Global warming will change the locations where the strongest upwelling occurs during the summer season, while changes in winter will be smaller [3].

WHAT WILL EBUS LOOK LIKE IN THE FUTURE?

With global warming, scientists predict changes to surface winds, ocean temperatures, and ocean stratification, among others [7]. While each of the four main EBUS is shaped by similar processes in the ocean and in the atmosphere, the combined effect of the expected changes will be unique to each location. As a result, global climate change will impact each EBUS differently. It is still unknown how these climate-ecosystem shifts will affect fish, seabirds, and marine mammals. Through a combination of ocean measurements and computer-based predictions, scientists will continue to study EBUS to understand how we can limit the damaging effects of climate change. While we figure it out, choosing sustainable seafood is an easy way to help sardines and anchovies from all EBUS to stay healthy!

ACKNOWLEDGMENTS

AB was thankful for the support by the National Science Foundation, (grant OCE-1658174).

REFERENCES

1. Checkley, D. M., Asch, R. G., and Rykaczewski, R. R. 2017. Climate, anchovy, and sardine. *Ann. Rev. Mar. Sci.* 9:469–93. doi: 10.1146/annurev-marine-122414-033819
2. Pauly, D., and Christensen, V. 1995. Primary production required to sustain global fisheries. *Nature*. 374:255–7. doi: 10.1038/374255a0
3. Rykaczewski, R. R., Dunne, J. P., Sydeman, W. J., García-Reyes, M., Black, B. A., and Bograd, S. J. 2015. Poleward displacement of coastal upwelling-favorable winds in the ocean's eastern boundary currents through the 21st century. *Geophys. Res. Lett.* 42:6424–31. doi: 10.1002/2015GL064694
4. Gruber, N., Lachkar, Z., Frenzel, H., Marchesiello, P., Münnich, M., McWilliams, J., et al. 2011. Eddy-induced reduction of biological production in eastern boundary upwelling systems. *Nat. Geosci.* 4:787–92. doi: 10.1038/ngeo1273
5. Bakun, A., Black, B. A., Bograd, S. J., Garcia-Reyes, M., Miller, A. J., Rykaczewski, R. R., et al. 2015. Anticipated effects of climate change on coastal upwelling ecosystems. *Curr. Clim. Change Rep.* 1:85–93. doi: 10.1007/s40641-015-0008-4
6. Bonino, G., DiLorenzo, E., Masina, S., and Iovino, D. 2019. Interannual to decadal variability within and across the major Eastern boundary upwelling systems. *Sci. Rep.* 9:19949. doi: 10.1038/s41598-019-56514-8
7. Rykaczewski, R. R., and Dunne, J. P. 2010. Enhanced nutrient supply to the California current ecosystem with global warming and increased stratification in an earth system model. *Geophys. Res. Lett.* 37:L21606. doi: 10.1029/2010GL045019

SUBMITTED: 01 May 2021; **ACCEPTED:** 16 November 2022;
PUBLISHED ONLINE: 02 December 2022.

EDITOR: Sanae Chiba, North Pacific Marine Science Organization, Canada

SCIENCE MENTORS: Madina Makhmutova and Josephine Jacob-Dolan

CITATION: Miller S, Lopera L and Bracco A (2022) Why Are the Eastern Margins of Ocean Basins Full of Fish? Front. Young Minds 10:704120. doi: 10.3389/frym.2022.704120

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.

YOUNG REVIEWERS

AVENTURA CITY OF EXCELLENCE SCHOOL (ACES), AGES: 11–12
ACES is a Charter School in South Florida that adds depth and breath of real world to its curriculum by engaging our eagles in various community activities and science projects. It has been an honor for the advanced 6th grade Science class to participate in the scientific process by reviewing the manuscript. Students were excited to see how their suggestions were taken into account and made the article more understandable for middle schoolers like them.

AVERY, AGE: 13
Avery is an avid fan of science and engineering. She mixes creativity with logic when problem-solving. Her intrigue and strong work ethic propel her when facing new challenges. She is involved in programs in and out of school supporting the environment and celebrating diversity. Additionally, Avery swims on two teams and plays lacrosse.

ELENA, AGE: 14
I enjoy reading, watching movies and tv, and playing sports.

JAETHANIEL, AGE: 12

Hi my name is Jaethaniel and I love science and Marvel superheroes. I hope 1 day to become a detective. And I would like to go to Yale for school.

LUKE, AGE: 12

Luke is a young published author who is passionate about learning American history. Sharing his expertise with friends and family motivates him. He is a Scholastic Kid Reporter; who has had the privilege of interviewing former President Barack Obama and other leaders. Also, he launched an ongoing charity: water campaign in 2019. Currently, Luke is a member of the debate club, government club, honor roll, track team, Yale Pathways to Science program, and an NYLF Pathways to STEM alumni.

AUTHORS

SARA MILLER

Sara is a Ph.D. student in the Department of Astronomy at Cornell University. Before coming to Cornell, she earned B.S. and M.S. degrees in aerospace engineering at Georgia Tech. Sara grew up in a coastal community in Southern California and developed a love for the ocean at an early age. Her research is focused on ocean worlds of the outer solar system. Specifically, Sara is interested in modeling the fluid dynamics of an ocean that exists under an ice shell on Jupiter's moon, Europa. When she is not doing research, Sara enjoys running, scuba diving, and hiking with her dog.

LUISA LOPERA

Luisa is a Colombian researcher and an ocean lover. She has been interested in earth sciences since she was a kid, and she is now pursuing a career as an oceanographer. Currently, she is a Ph.D. student in the Ocean Sciences and Engineering Program at Georgia Tech. Her research project is to assess the how connected coral ecosystems in the Gulf of Mexico are, to provide information for territory planning.

ANNALISA BRACCO

Annalisa is a professor in the School of Earth and Atmospheric Sciences at Georgia Tech. An avid sailor, she pursued a Ph.D. in geosciences and specialized in physical oceanography after a B.S. in theoretical physics. She is interested in understanding how marine ecosystems interact with ocean currents, and she uses this information to improve ocean sustainability and resilience in the face of climate change. She does so in collaboration with chemical and biological oceanographers and marine ecologists across the globe. When she is not working, she keeps busy with her two kids and three dogs. *abracco@gatech.edu