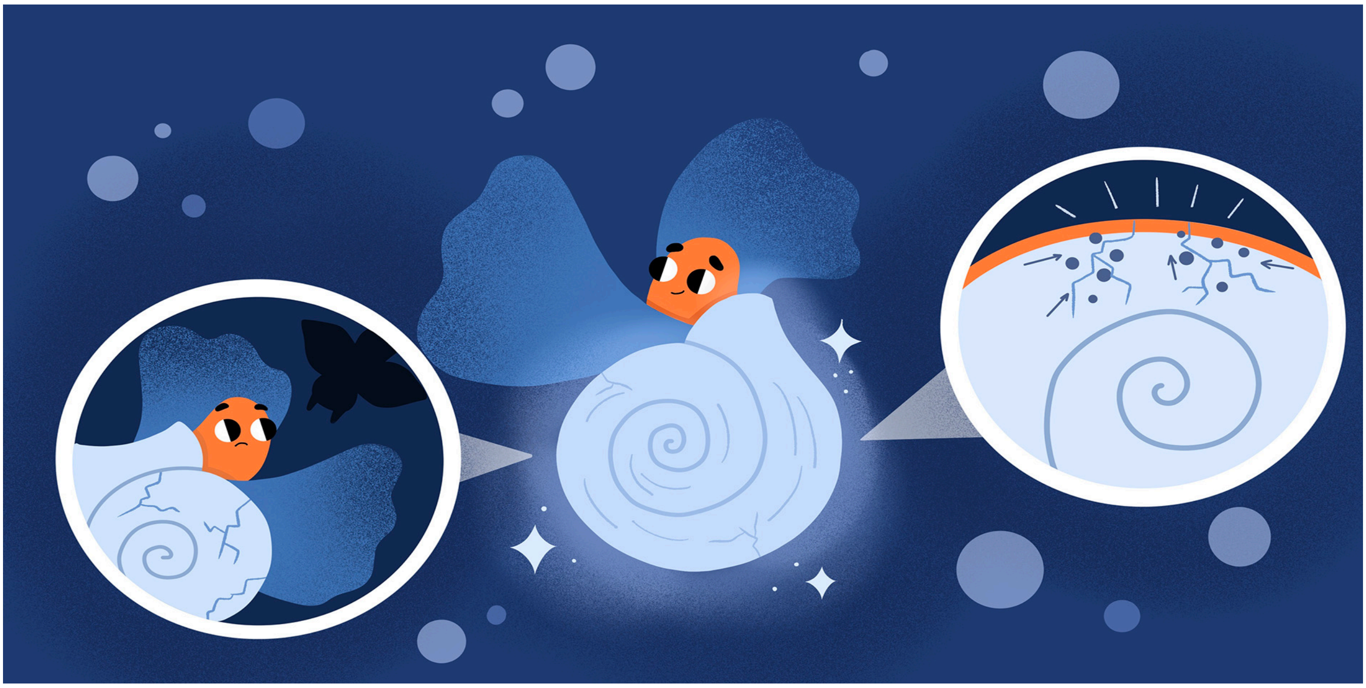
BIODIVERSITY
Published: 25 August 2023
doi: 10.3389/frym.2023.1064102



SEA BUTTERFLIES DEFEND THEIR HOMES AGAINST AN ACIDIC OCEAN

Victoria Louise Peck* and Clara Manno

British Antarctic Survey, Cambridge, United Kingdom

YOUNG REVIEWERS:

JOSEPHINE
AGE: 11

PARITHI
AGE: 10

We all know that carbon dioxide (CO_2) is produced from burning fossil fuels, and that it contributes to global warming. But have you heard about the "evil twin" of global warming, also caused by CO_2—ocean acidification? The ocean absorbs about 30% of the CO_2 that humans emit each year. As CO_2 dissolves into the ocean, it forms carbonic acid, effectively making the ocean acidic. Animals that use a substance called calcium carbonate to build their shells and skeletons are vulnerable to acidic conditions, as their hard parts may dissolve. Microscopic swimming snails called pteropods or sea butterflies are common in the Southern Ocean. With incredibly delicate shells thinner than a human hair, pteropods are often considered to be the organisms most vulnerable to ocean acidification. Using microscopes and X-rays, we took extremely detailed images of these tiny shells and found that pteropods have a couple of clever tactics to defend their "homes" against ocean acidification.

OCEAN ACIDIFICATION: THE "OTHER" CO_2 PROBLEM

As humans continue to burn fossil fuels, more and more carbon dioxide (CO_2) builds up in the atmosphere. CO_2 is a **greenhouse gas**, and for years we have understood that CO_2 is responsible for global warming, which can make life difficult for some animal species. What we *did not* understand was that CO_2 was also affecting the oceans and the animals that live there. We now know that the ocean absorbs 30% of the CO_2 human activities produce each year. While CO_2 absorbed by the oceans slows down global warming, it can be bad news for the oceans—and more so for ocean animals.

Animals such as mussels and crabs have shells made from calcium carbonate ($CaCO_3$). These animals build calcium carbonate using carbonate **ions** (CO_3^{2-}), which they find in the seawater they live in. The ease of building a shell depends on how many carbonate ions are around. When the concentration of carbonate ions is high, it is easy to build a shell.

When the oceans absorb CO_2, the CO_2 reacts with water to form **carbonic acid**, effectively making the ocean acidic. This process is called **ocean acidification**. In seawater, carbonic acid and carbonate ions exist in a kind of balance with each other. When CO_2 is absorbed by the oceans and more carbonic acid is produced, the concentration of carbonate ions decreases. When the concentration of carbonate ions is low, the water is said to be **undersaturated**. Animals living in undersaturated water must work harder to collect the carbonate ions needed to build their shells. Also, undersaturated water can dissolve calcium carbonate, to "take back" the carbonate ions. As we burn more fossil fuels, more CO_2 is absorbed by the oceans and undersaturated waters become increasingly common, threatening all ocean animals with shells.

WHICH ANIMALS ARE MOST AT RISK FROM OCEAN ACIDIFICATION?

Ocean acidification is most advanced in the oceans around the North and South Poles, where the concentration of carbonate ions is naturally low. Also, colder water absorbs more CO_2 than warmer water does. Thus, the Arctic and Antarctic Oceans have the most undersaturated waters in the world, and the animals living there are most at risk. Sea butterflies are animals with calcium carbonate shells that live in the polar regions—so they fit the bill! A sea butterfly is a microscopic swimming snail (Figure 1). Despite their small size, there are so many of them in the Southern Ocean that they form an important part of the food chain. The Latin name for sea butterfly is **pteropod**, which means "winged foot." What would be the foot of a "normal" snail has evolved into two wings in pteropods. The pteropod flaps its wings like a butterfly to swim through the ocean.

GREENHOUSE GAS

When the suns energy is reflected off the earth's surface certain gases in the atmosphere trap the heat, in the same way as the glass of a greenhouse.

IONS

Atoms or molecules that have either a positive electric charge as they have lost one or more electrons, or a negative charge as they have gained one or more electrons.

CARBONIC ACID

When CO_2 gas dissolves in water (H_2O) the two react to form a weak acid called carbonic acid (H_2CO_3).

OCEAN ACIDIFICATION

As the world's oceans absorb fossil fuel derived CO_2 from the atmosphere the water becomes acidic.

UNDERSATURATED

When the concentration of dissolved ions is not as high as it could be. In the case of carbonate ions, carbonate would dissolve in undersaturated waters to increase the concentration of carbonate ions until the water is saturated.

PTEROPOD

Meaning "winged foot" in Latin. A microscopic swimming snail found in the ocean. It has evolved to have two wings, rather than a foot, and is commonly called a "sea butterfly."

The homes of these pteropods are incredibly delicate shells made from calcium carbonate. Pteropod shells are about 1,000 times thinner than 1 mm—even finer than a human hair. The shells are completely see-through, and you can even see their hearts beating inside. When scientists started thinking about which animals would be most vulnerable to ocean acidification, pteropods, with their tiny delicate shells, went straight to the top of the list!

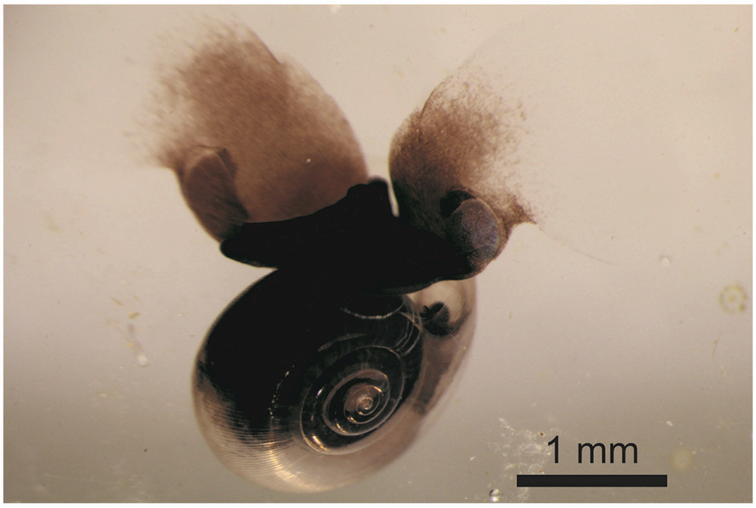


Figure 1

Figure 1

A polar pteropod, also called a sea butterfly. These microscopic snail flaps the "wings" on their feet like a butterfly, to swim.

CAN SEA BUTTERFLIES PROTECT THEIR SHELLS?

Researchers have spent years studying sea butterflies. Early research supported their greatest fear: that pteropod shells would simply dissolve in undersaturated water [1]. At that time, the future did not look good for sea butterflies. However, more recent studies found some good news—pteropods are better equipped to deal with ocean acidification than we thought. They have two lines of defense against ocean acidification. The first line of defense is a protective coating on the outside surface of their shells. This layer is like the cling film you might put over a dish of leftovers. It is waterproof and prevents seawater from touching the calcium carbonate. This means that, even if the water is undersaturated, the shell will not dissolve. The only time the shell may be vulnerable is if the protective layer is damaged—like rainwater getting in if your raincoat is torn. For a pteropod, any tear in its protective layer can be dangerous [2].

Shell cracks and scratches are common for pteropods. Pteropods are the prey of sea angels, which are not angels at all from the pteropods' point of view! Sea angels use their tentacles to grab hold of a pteropod's shell (Figure 2). They then use their mouthparts to grab the soft body inside the shell and slurp it out. Then they throw away the empty shell like we would do to a candy wrapper. If a pteropod is quick, it can retract far enough inside its shell that the sea angel cannot grab it. In this case, the sea angel gives up and moves on to its next victim. While this pteropod is lucky to have escaped, its shell will show the scars.

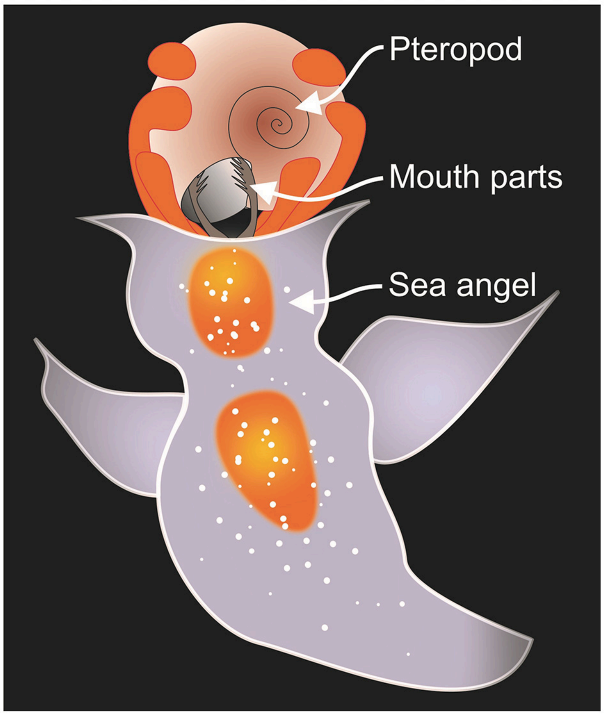


Figure 2

Figure 2

A sea angel preying on a sea butterfly. If the sea butterfly survives, tears to the protective coating of its shell will expose calcium carbonate to the ocean waters. If the waters are undersaturated, the exposed shell will dissolve [Figure adapted from Lalli and Gilmer [3]].

Wherever the protective coating has been damaged, calcium carbonate is exposed. The pteropod is unable to repair the protective coating, which means that any exposed calcium carbonate will always be vulnerable to **dissolution** when exposed to undersaturated water. Localized dissolution around a tear is common to sea butterflies living in the polar regions. However, localized dissolution is much more manageable than dissolution of the entire shell!

DISSOLUTION

This is the process by which something it broken down into its soluble component parts. In the case of calcium carbonate, dissolution caused by exposure to carbonic acid creates calcium ions (Ca^{2+}) and bicarbonate ions (HCO^{3-}).

CAN SEA BUTTERFLIES REPAIR THEIR SHELLS?

The second line of defense that sea butterflies have against ocean acidification is their ability to repair their shells. While studying sea butterflies with localized dissolution, we noticed something unexpected—it seemed that the damage was deeper than the thickness of an undamaged shell. To understand what was happening, we took 3D X-rays to get a better look at the tiny shells. We saw that an undamaged shell was $<10\,\mu m$ thick ($<1/100$ of a mm). Where there was dissolution, the shell could be up to three times thicker (Figure 3) [4]. This told us that, while pteropods are unable to repair their shells from the outside, they *can* make new calcium carbonate and patch themselves up from the inside! This ability to repair their shells is essential to maintaining their homes.

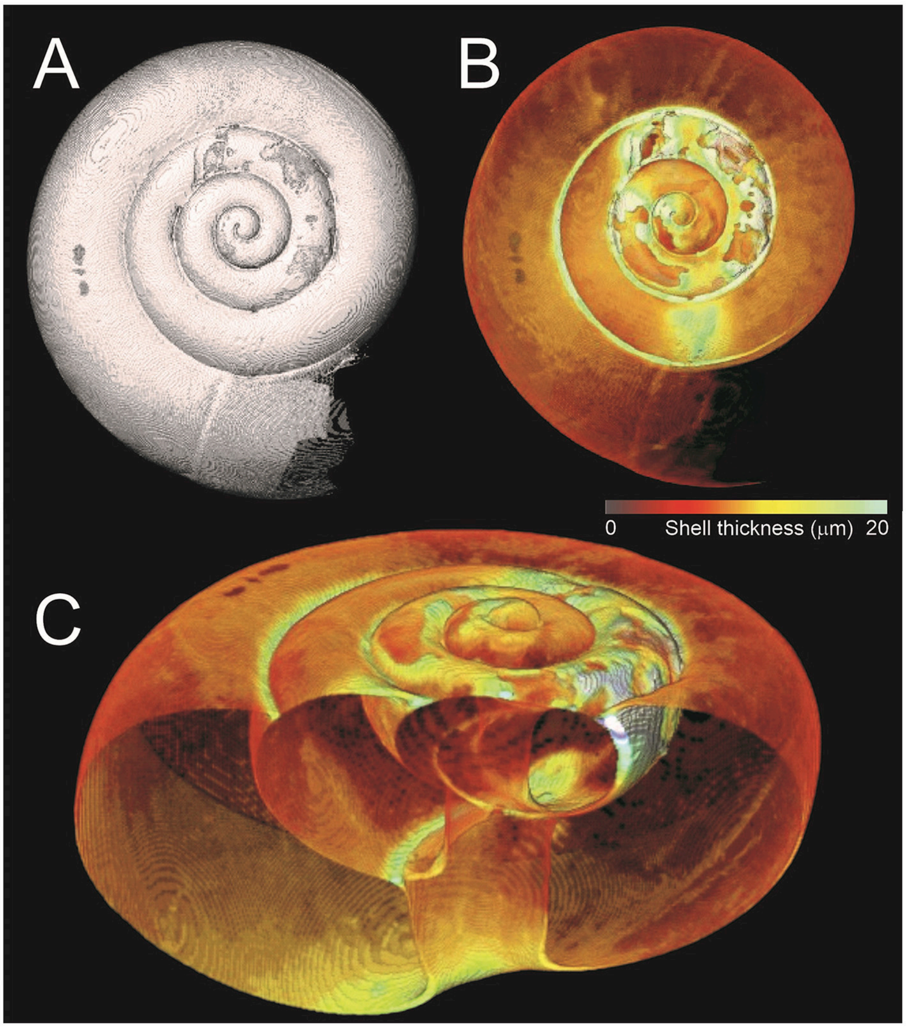


Figure 3

Figure 3

Images of a damaged pteropod shell. **(A)** The outer surface of the shell. Note areas of deep damage in the inner whorls. **(B)** A color map showing the thickness of the shell. **(C)** The shell from **(B)** in 3D, showing the inside. Note that the undamaged shell has a uniform thickness (<10 μm). In areas of damage, the shell can be more than 20 μm thick. These are the areas where the pteropod has repaired itself from the inside.

THE FUTURE OF SEA BUTTERFLIES

Their protective coating and ability to patch themselves up from the inside means pteropods are more resilient to ocean acidification than we originally thought. However, the amount of energy they must invest into maintaining their damaged shells comes at a cost—after fixing their shells, some pteropods may not have enough energy for anything else. For example, reproduction may become too much of an effort. It is also important not to think of ocean acidification as happening on its own, because it usually happens along with ocean warming, sea-ice loss, and pollution—all of which could affect ocean animals like pteropods. So, while pteropods may be doing better than expected so far, the true test for these sea butterflies is yet to come.

ACKNOWLEDGMENTS

We are grateful for funding support from NERC, DEFRA, and DECC to the pelagic consortium of the UK Ocean Acidification Programme (Grant no. NE/H 17348/1*).

ORIGINAL SOURCE ARTICLE

Peck, V. L., Oakes, R. L., Harper, E. M., Manno, C., and Tarling, G. A. 2018. Pteropods counter mechanical damage and dissolution through extensive shell repair. *Nat. Commun.* 9:264. doi: 10.1038/s41467-017-02692-w

REFERENCES

1. Bednaršek, N., Tarling, G. A., Bakker, D. C. E., Fielding, S., Jones, E. M., Venables, H. J., et al. 2012. Extensive dissolution of live pteropods in the Southern Ocean. *Nat. Geosci.* 5:881–5. doi: 10.1038/ngeo1635
2. Peck, V. L., Tarling, G. A., Manno, C., Harper, E. M., and Tynan, E. 2016. Outer organic layer and internal repair mechanism protects pteropod *Limacina helicina* from ocean acidification. *Deep Res. II Top. Stud. Oceanogr.* 127:41–52. doi: 10.1016/j.dsr2.2015.12.005
3. Lalli, C. M., and Gilmer, R. W. 1989. *Pelagic Snails*. Stanford, CA: Stanford University Press.
4. Peck, V. L., Oakes, R. L., Harper, E. M., Manno, C., and Tarling, G. A. 2018. Pteropods counter mechanical damage and dissolution through extensive shell repair. *Nat. Commun.* 9:264. doi: 10.1038/s41467-017-02692-w

SUBMITTED: 07 October 2022; **ACCEPTED:** 10 August 2023;
PUBLISHED ONLINE: 25 August 2023.

EDITOR: Nicholas R. Golledge, Victoria University of Wellington, New Zealand

SCIENCE MENTORS: Arthee R. and Manuel Esperon-Rodriguez

CITATION: Peck VL and Manno C (2023) Sea Butterflies Defend Their Homes Against an Acidic Ocean. Front. Young Minds 11:1064102. doi: 10.3389/frym.2023.1064102

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

JOSEPHINE, AGE: 11

My name is Josephine, I am 11 years old and I am in 6th grade. I live with my mom and dad, my four parakeets and a husky. My favorite color is neon-orange, I figure skate, swim, and play golf. I like to read and watch shows about animals, dragons, and mythology. I love animals, but I do not have a favorite since all have different skills and features. I enjoyed working on the article and I hope to do another one.

PARITHI, AGE: 10

I like insects and lizards. I also like to keep on learning about the physics of ecosystems.

AUTHORS

VICTORIA LOUISE PECK

Vicky Peck started her career as a geologist. She specialized in looking at microscopic fossils found in mud from the seafloor, using them to understand how the oceans have changed over 100's of 1,000's of years. Ten years ago, when we first became aware of ocean acidification, she took the opportunity to study the animals that produced these fossils while they were still alive and fell in love with sea butterflies! Vicky enjoys scuba diving and one time was lucky enough to come face to face with a pteropod underwater. *vlp@bas.ac.uk

CLARA MANNO

Clara Manno dreamed of traveling the word and explore the nature since she was a child. She worked in Italy, France, Norway, and UK as Biological Oceanographer. Clara studies how tine marine organisms (including Sea Butterfly!) supports the health of our planet by transporting part of human-produced atmospheric CO_2 in the deep oceanic sediments. In the free time, Clara enjoys hiking and climbing mountains with her two daughters Aurora and Morgana.