OUTSIDE JEB

Fish get sunburn too but mom-made gadusol can help

Most life on earth depends on sunlight for energy. Flowers turn to face the morning sun; lizards bask to regulate their body temperatures; and humans rely on light therapy to cure their winter blues. Too much sun, however, can be harmful to animals, causing sunburn. We experience sunburn as pain, fatigue and red flaky skin, but biologically these are signs and symptoms of DNA damage from ultraviolet radiation. To combat these stresses, some animals such as cyanobacteria and sea urchins use natural sunscreen products produced by algae and microbes. A closely related transparent compound, gadusol, was discovered over 40 years ago in fish eggs, but where it came from and whether it worked to protect the fish from the sun's rays remained untested. This led Marlen Rice and colleagues from University of Utah, USA, to investigate gadusol's role as a maternally provided sunscreen in zebrafish.

First, to show that gadusol is produced by mother fish and can protect embryos effectively from sun damage, the researchers created mutant zebrafish by chopping out the *eevs* gene, which is essential for making gadusol. The embryos produced by the modified fish lacked maternally provided gadusol, and when the team measured the effect on swim bladder inflation – a hallmark of healthy development essential for survival – they found that all of the embryos that lacked gadusol failed to inflate their swim bladders at 5 days of age, and only 2% of larvae survived to 28 days. The fish lacking gadusol were extremely vulnerable to sun damage. The researchers next exposed the modified fish embryos to ultraviolet light and checked for the presence of damaged DNA. The embryos lacking gadusol suffered more DNA damage, further demonstrating gadusol's effectiveness as a sunscreen. Moreover, Rice and colleagues found that the embryos lacking gadusol had activated more genes that provide protection from stress than the embryos that had inherited sunscreen from their mothers.

Next, the team compared gadusol with other potential sunscreens, namely the skin pigment melanin and the nearly transparent shell of the zebrafish's egg, the chorion. To test the role melanin plays in providing protection from the sun, they created a mutant zebrafish by removing the *mitfa* gene, which disrupts a key step in melanin production. The fish without melanin still had far higher survival rates than those lacking gadusol. And by carefully removing the transparent shell of the egg using forceps, the researchers discovered it provided some UV protection, but the eggshell wasn't nearly as effective as gadusol, suggesting that gadusol is the primary, most effective sunscreen in early fish development.

However, natural sunscreens are not unique to zebrafish, so the researchers looked at the genomes of 136 fish species – including many species whose lifestyles protect them from sun damage – to see whether these fish had lost the genes involved in gadusol production. They concluded that gadusol production had been repeatedly lost in several species that live in habitats unpenetrated by sunlight such as caves and the deep-sea, as well as in fish that have live babies such as the greater pipefish and fish that use electroreception to navigate murky waters such as the electric eel. Fish moms make a natural sunscreen for their young that is very effective at preventing DNA damage, but evidently if you don't use it, you may lose it.

doi:10.1242/jeb.244998

Rice, M. C., Little, J. H., Forrister, D. L., Machado, J., Clark, N. L. and Gagnon, J. A. (2023). Gadusol is a maternally provided sunscreen that protects fish embryos from DNA damage. *bioRxiv*. doi:10.1101/2023.01.30.526370

Julie Jung (0000-0001-8319-3984)
University of Utah
julie.jung@utah.edu

Climate change leaves urchins on a rock in a hard place to live

The kelp forests off the West Coast of North America are often described as underwater rainforests – dense, beautiful and teeming with life. Unfortunately, climate change is altering seawater temperature, acidity and oxygen content in the forests, which could be highly stressful for the sea creatures that inhabit them. One of the most valuable players in the kelp forests are red sea urchins, which function as engineers, controlling how dense the forests are through their consumption of kelp. While urchins may be able to cope with changes in one of these stressors at a time, they might not be able to handle changes in all three simultaneously. Ultimately, urchin populations may collapse if they cannot endure this triple threat, leaving the future of the kelp forests uncertain. Emily Donham at the University of California, Santa Cruz, USA, worked with a team of researchers at Reef Check Foundation, USA, Monterey Bay Aquarium Research Institute, USA, and the University of

Outside JEB reports on the most exciting developments in experimental biology. The articles are written by a team of active research scientists highlighting the papers that JEB readers can't afford to miss.

California, Santa Cruz, to find out how resilient red urchins in California are to the environmental changes they face because of climate change.

First, the researchers needed to find out what ocean conditions are like in California's urchin habitat. But California is a gigantic state, so the urchins living off the coast of northern California may be accustomed to different ocean conditions when compared with urchins from the south and, thus, have different vulnerabilities to climate change. So, the team placed sensors that measured seawater temperature, oxygen and water acidity in kelp forests along the length of the state. After determining the seawater conditions of the different populations, the team collected northern and southern urchins and brought them back to the lab. Then they held the urchins in seawater that mimicked the two regions and measured how much the urchins grew, ate and expended energy. They predicted that the urchins would thrive more in ocean conditions that mimicked their home environments.

As expected, the sea urchins performed better in the water that mirrored their own natural conditions, such that when the northern urchins were held in the southern-type water, they had lower survival rates and grew less than the southern urchins. The same thing could be said for the southern urchins, which outperformed the northern urchins across most tests, but did so to a much greater extent when held in the waters mimicking their own home southern water conditions.

The team also discovered that urchins in the north are used to experiencing simultaneous fluctuations in seawater temperature, acidity and oxygen levels, which makes these changes more predictable and therefore potentially easier for the urchins to react to. In contrast, the southern urchins appear to be accustomed to a more unpredictable environment. As climate change will make seawater conditions more erratic and variable, the team expected that the northern urchins would struggle more than the southern urchins when exposed to a climate change scenario.

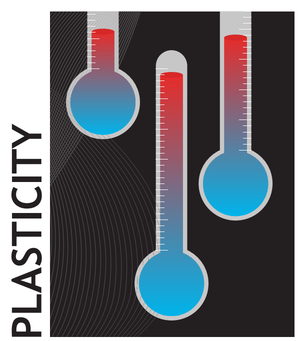
To test this, Donham and the team conducted a second study in which they exposed urchins from each population to conditions that simulated how climate change will affect their local environments. They found that climate change will harm urchins across California, as both populations grew and ate less in the future climate change conditions. But, surprisingly, the urchins in the north had a greater chance of surviving those troubling times. This is concerning news for urchins and kelp forests in the south but, hopefully, the populations will persist if enough urchins are able to withstand the coming changes. Ultimately, the best thing we can do for urchins is fight to keep climate change predictions from becoming reality.

doi:10.1242/jeb.245000

Donham, E. M., Flores, I., Hooper, A., Brien, E. O., Vylet, K., Takeshita, Y., Freiwald, J. and Kroeker, K. J. (2023). Population-specific vulnerability to ocean change in a multistressor environment. *Sci. Adv.* **9**, eade2365. doi:10.1126/sciadv.ade2365

Emily A. Hardison (0000-0002-3668-5035)
University of California, Santa Barbara
emilyhardison@ucsb.edu

Brook trout can handle some heat…given enough time



On average, the world is getting warmer, and heatwaves are becoming more common and unpredictable – especially in areas closer to the Earth's poles. Warming near the poles may be bad news for animals, such as brook trout, living in these areas. Luckily, many animals have evolved ways to deal with heat, which could give them a buffer against severe weather. Some animals can adjust how their bodies work when the environment gets warmer, which can help them better handle brief periods of extreme heat. But these internal adjustments take time and may depend on what temperatures the animal has experienced recently. Predicting how animals will handle temperature changes is hard, because the ability to modify body function varies across the animal kingdom, and often we do not know how long it takes to make these adjustments. Erin Stewart and Graham Raby at Trent University, Canada, and Chris Wilson and Vince Frasca at the Ontario Ministry of Natural Resources and Forestry, Canada, wanted to know whether living in warmer conditions helps brook trout to better tolerate extreme temperatures and, if so, how long it takes for their tolerance to develop.

To answer these questions, Stewart and colleagues used aquarium heaters and a slow, steady flow of water from a nearby creek to create three naturally fluctuating temperatures: unheated, warmed (+3°C) and warmer still (+6°C). All the water temperatures used in the experiment were within the 10–20°C range that brook trout typically survive best in. To find the hottest temperature that brook trout from each water temperature could stand before losing control of their body movements, Stewart slowly heated up an insulated tank of water containing a small number of trout until the fish reached the point where they began floating on their sides. After this, the trout were placed in a cool tank of water and monitored until they recovered. Almost all the trout survived this brush with extreme heat. To figure out whether the length of time a trout spent living in each creek water temperature (unheated or heated) influenced its heat tolerance, Stewart measured the heat tolerance of different fish from each group after 1, 4, 8, 16 and 30 days.

The team found that living in warmer water improved the ability of the brook trout to handle hotter temperatures, but that it took time for the fish to adjust. Trout from the warmest treatment (+6°C) showed a marked increase in heat tolerance after only a single day of living in these warmer conditions. In contrast, trout from the warm group (+3°C) took about 8 days before they showed an improvement in survival over fish living in unheated creek water. Stewart and colleagues also found that the heat tolerance of both warmed groups continued to improve throughout the 30 days of living in the different creek water temperatures.

These results suggest that brook trout can adjust to warming environments, within reasonable limits. More importantly, this study highlights an often-overlooked factor that applies to the study of heat tolerance for all animals, not just fish: how long these adjustments take. With climates changing faster than ever in history, many scientists are turning their attention to studying the heat sensitivity of animals. But, if we, as researchers and conservationists, want to use our finite time and resources wisely, we need to account for the fact that biological adjustments to warming temperatures take time.

doi:10.1242/jeb.245001

Stewart, E. M. C., Frasca, V. R., Wilson, C. C. and Raby, G. D. (2023). Short-term acclimation dynamics in a coldwater fish. *J. Therm. Biol.* **112**, 103482. doi:10.1016/j.jtherbio.2023.103482

Jordan R. Glass (0000-0001-7521-2698)
Arizona State University
jrglass@asu.edu

Lamprey eyes change across time

Lampreys are jawless fishes known for their parasitic lifestyles. Young lampreys move from freshwater streams to find a host to latch onto in the ocean. After more than a year of feeding on a host, the lampreys move back to freshwater streams to breed and eventually die. These very different phases of their lifestyle come with major differences in their environments, moving from saltwater to freshwater, and going from eating continuously to living off energy reserves in the body. It is not surprising that these big differences in the environment might result in changes to the lamprey's body, including how they sense the world around them. Previous work has suggested that the sizes of different parts of the brain responsible for the senses change with age. So how might vision change when a lamprey moves from a well-fed state in a marine environment to starving in a freshwater stream? Hermann Collin from the University of New South Wales, Australia, and colleagues from La Trobe University, Australia, and the University of Western Australia studied lamprey eye anatomy in the early and late stages of the life cycle to understand how vision might change across time.

The researchers collected Australian lampreys (*Mordacia mordax*) from several streams in New South Wales, Australia, at two points in the animals' life cycle – the early phase when they were younger and smaller, moving downstream towards the sea; and the late phase, when they were older, larger and moving upstream away from the sea and back to their freshwater breeding grounds. The researchers used powerful microscopes to compare the anatomy of the eyes, including the cornea (the clear part of the eye that allows light in) at the two different life stages.

They discovered that there were several differences between the eyes of lampreys in the early life phase and those in the late phase. The outer layers of the cornea were thicker in the late life stage lampreys than the younger lampreys that were headed out to sea. These thicker layers of the cornea in older lampreys have a similar refractive index to sea water, so they do not bend light as it enters the eye, giving the fish a clear view; the cornea is optimized for vision in the saltwater that the older lampreys migrated from. The team also investigated the mucoid layer of the cornea, which is responsible for keeping the eye moist. They discovered that it is attached to the tissue that surrounds the iris in the late phase of the lamprey's life, but is detached in the young lampreys, which may allow extra room for the eye to grow when fish are young, similar to how human babies are born with unfused skulls to allow for brain growth. The young lampreys also had less organized collagen bundles in the center of the cornea compared with the older lampreys. As the lamprey grows, these collagen bundles likely become more organized to keep the cornea as transparent as possible, which helps the lamprey to see which fishes may serve as their next buffet.

While lampreys aren't particularly charismatic, they offer some amazing insights into the eyes and vision of some of the earliest vertebrate ancestors, as they are so closely related to these ancient animals. Understanding how their vision works and how it changes when exposed to different environments can help us to uncover how modern vertebrate vision originated and how vision may be affected by aging or the environment. This knowledge can help researchers to better understand how perception may have evolved and how senses such as vision can respond to changes in challenging environments.

doi:10.1242/jeb.244999

Collin, H. B., Ratcliffe, J. and Collin, S. P. (2023). The functional anatomy of the cornea of the shorthead lamprey, *Mordacia mordax* (Mordaciidae, Agnatha): a comparison between downstream and upstream migrants. *J. Morphology* **284**, e21552. doi:10.1002/jmor.21552

Amanda Palecek (0000-0002-9908-3103)
Clemson University
apalece@g.clemson.edu