OUTSIDE JEB

Polar bears in action!

What's in a name? For polar bears, a lot. While their common name identifies the extreme habitat they live in, their Latin name – *Ursus maritimus* – reminds us that unlike all other bears, these giant white carnivores rely on a marine diet. Adult seals are a perfect meal for the meat-loving bears because they are chock-full of calorie-rich blubber and polar bears are well adapted for hunting this prey, voyaging onto sea ice and lurking by air holes, ready to ambush a seal when it surfaces to breathe. Unfortunately, the sea ice is now thinner, sparser and breaks up sooner in the spring due to climate change, and the rapidly declining polar bear populations are thought to be a direct consequence of these changes to their hunting grounds. Although this explanation for population decline is certainly logical, so far the only data to support these claims are from captive animals or are extrapolated from other carnivorous species. No one actually knows how active polar bears are on sea ice, how much energy they expend navigating the ice flows and whether they actually catch enough seals to satisfy their energy needs. So, scientists from the US Geological Survey, University of California Santa Cruz and San Diego Zoo Global teamed up to learn more about what it takes to be a top Arctic predator when your world is melting away.

The team captured and tranquilized nine adult female polar bears on the Alaskan coast, then weighed each bear and collected a blood sample. Next, the researchers injected each bear with modified water that was made of unique hydrogen and oxygen ions that distinguish it from regular water. The researchers planned to quantify how many of these unique ions remained in the bears at the end of their study and to use these numbers to calculate how much energy each bear spent on the sea ice. Finally, the researchers attached a video GPS collar to each bear to record the location and activities of the charismatic beasts throughout the study period before releasing them.

After about 10 days, the bears were located on the sea ice and recaptured. The researchers re-weighed the bears and collected more blood, removed the collars and freed the bears before heading back to the lab to analyse their data. After reviewing the GPS and video footage and analysing the blood, the researchers discovered that polar bears move around a lot on the sea ice, burning thousands of calories as they go. In fact, the team learned that polar bears have a higher metabolic rate than previously estimated and that each bear needed to eat one fat adult seal every 10 days just to meet its basic energy needs, let alone have enough fuel left over to gain weight, reproduce or raise cubs! Yet few of the bears in their study managed to catch adult seals, or any other food for that matter, and they lost weight as a result. As sea ice continues to dwindle, catching that fatty meal will become even harder for these Arctic predators.

This study is the first to bring us out onto the ice with the polar bears; to live and hunt and breathe alongside them; to understand their world and the challenges they face. The numbers are solid – the ice is not.

10.1242/jeb.169987

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Mantis shrimp are the key to smashing new materials

As ambush predators, mantis shrimp excel at lying in wait for their prey before striking from the shadows with specialised feeding appendages, but the form and function of these appendages has divided mantis shrimp species into two evolutionarily distinct groups. There are 'spearers', which use sharp harpoon-like appendages to slash and stab at soft-bodied prey, and 'smashers', which use blunt hammer-like appendages to break into hard-shelled crustaceans. These bulbous smashing appendages, known as dactyl clubs, are capable of accelerating at 100,000 m s^{-2} (similar to a small-calibre bullet) and applying crippling forces equal to 2500 times the body weight of the mantis shrimp. Wielding such powerful weapons makes the mantis shrimp a formidable predator, but how are they able to apply such devastating blows and remain undamaged after constant use?

The answer to this cracking question lies in the complex regional microstructures of the mantis shrimp feeding apparatus. A team led by Lessa Kay Grunenfelder, from the University of California, Riverside, USA, built on previous work investigating the structural regions of these feeding appendages and focused on examining the structure and evolutionary history of the previously unexamined 'striated region'. Using both optical and electron microscopy, the team carefully examined and compared cross-sections taken from the appendages of the

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.

'smashing' peacock mantis shrimp, *Odontodactylus scyllarus*, and the 'spearing' zebra mantis shrimp, *Lysiosquillina maculata*, in order to learn more about the role of this region.

Their findings, published in *Advanced Materials*, reveal that the striated region of the smasher *O. scyllarus* is composed largely of tightly packed sheets of mineralised chitin, compared with the organic components of the surrounding regions. They also found that this region of toughened chitin wraps all around the club, leading the authors to compare its role with that of the hand-wrap used by boxers, condensing the fist into a tight ball and preventing catastrophic injury upon impact. This region was also found to contain a network of pore channels that allow for ion transport and give the region its striated appearance, but may also hold the potential for self-healing following particularly devastating impacts.

Interestingly, when the team looked at the appendages of the spearer, *L. maculata*, they found a similar striated region, even though this species is subjected to very different pressures during a feeding strike. In contrast, the fibres in the spear are aligned in a position more suited for longer appendages, which may help to reduce deformation of the stabbing appendage when connecting with prey. As the spearers evolved prior to the appearance of the smashers, the team believe that this microstructural feature may have been instrumental in the evolution of the first club-wielding mantis shrimps as a response to the appearance of hard-shelled crustaceans. Finally, the team identified the characteristics of a similar striated structure in the limbs of a praying mantis, *Stagomantis limbata*, revealing that terrestrial arthropods may also have convergently evolved similar structures for their own hunting needs.

With the aim of applying this knowledge for humanity's benefit, the team go on to describe how the microstructures of these weaponised feeding appendages could be used to influence the biomimetic design of new materials. The authors highlight their particular interest in the aerospace and sports industries with the goal of creating more durable aerofoils for aircraft, as well as bicycle helmets and golf clubs that maximise speed and strength without sacrificing structural safety. In these turbulent times, it is refreshing to see that scientists are hoping to turn one of nature's deadliest and most durable 'swords' into ploughshares.

10.1242/jeb.169953

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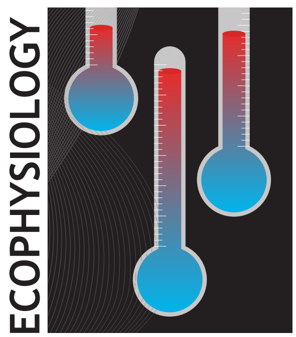
Redband trout thrive in a hot desert stream



Extreme environments select for performance and tolerance traits that are vital for population fitness. Biologists have always been fascinated by how animals perform in their natural environment and how this relates to physiological mechanisms, with the hope that knowledge gleaned from such studies will help us to protect endangered species and maintain biodiversity in this era of global climate change. With a view to understanding how environments select physiological traits and the associated molecular and genomic mechanisms, Zhongqi Chen and colleagues from the University of British Columbia, Canada, and the Columbia River Inter-Tribal Fish Commission, USA, studied how the redband trout, a subspecies of rainbow trout, adapts to a desert stream and explored the evolutionary limit of the fish's thermal adaptation.

The researchers first collected newly emerged (3 months old) redband trout fry from Little Jack Creek (hot desert climate), Keithley Creek (cool mountain climate) and Fawn Creek (cold mountain climate) in southern Idaho, USA. Having allowed the fish to adapt to their new lab home for at least 6 weeks, the team measured their physiological performance over a range of acclimation temperatures (12–24°C). The researchers discovered that the desert population had the best thermal tolerance, the highest maximum heart rate during acute warming and maintained aerobic capacity above 24°C. However, the difference between maximum and minimum aerobic metabolism (known as the aerobic scope) – which is the maximum amount of oxygen available for any aerobic activity above basic maintenance needs – of the two mountain populations collapsed by nearly 50% beyond 24°C. Therefore, the ability of the cardiovascular system to deliver oxygen to tissues appears to be crucial for redband trout when living in a desert stream.

The team then explored which molecular mechanisms responded to an acute warming and contributed to the outstanding physiological function of the desert redband trout population. Collecting samples of the heart tissue at 15°C, 20°C and the temperature at which the heart began to fail (24–25°C), and minute clips from the fins to identify genes that responded to the higher temperatures, the team discovered that the expression of genes associated with cardiac function, energy production pathways and protection from stress were upregulated. To determine whether these candidate genes contributed to the desert fish's ability to tolerate heat, the researchers calculated upper thermal tolerance values, based on the gene expression patterns that they had measured in the desert trout, and found that they were very similar to the measured values. Thus, these genes likely contribute to the sustained cardiac function and aerobic capacity that support the fish's upper thermal tolerance, which is essential for the population to thrive in a hot desert stream.

Biologists are definitely in an exciting time now that they can reveal the molecular mechanisms of thermal adaption. This study by Chen and colleagues demonstrates one survival strategy used by the Little Jack Creek redband trout population in a desert stream: they maintain cardiac function and aerobic capacity in a high temperature environment. However, it is likely that there are many other species out there with their own unique responses to their particular conditions awaiting the attention of intrigued biologists.

10.1242/jeb.178590

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In rough waters, sea bass should stick together

Schooling behaviour in fishes reduces the energetic costs of swimming for the school's members by essentially allowing each fish to 'draft' off of others in the group. This phenomenon has been thoroughly studied in laboratory settings under conditions of laminar flow – that is, steady, unidirectional flow with minimal turbulence. However, in the natural environment, water flow can often be turbulent owing to weather, underwater structures, water current dynamics and other factors, which could make it difficult for fish in schools to maintain optimal positions relative to their fellow group members (and thus to reap energetic rewards). Lewis Halsey, of the University of Roehampton in the UK, along with colleagues from the Centre for the Environment and the University of Glasgow, wanted to determine whether schooling behaviour remains energetically advantageous in turbulent conditions. The group further wanted to test whether the size of a school is important in conferring energy cost savings.

To address these questions, the researchers placed European sea bass in a special swim flume individually or in groups of three or six fish. Three propellers at one end of the flume allowed the scientists to subject each fish or group of fish to three different water flow rates (20 min at each rate) which, because of the flume design, corresponded to three different levels of turbulence. Using video footage of each trial, the team recorded the three-dimensional position of each fish within the flume, analysed how much (or little) it maintained its position, and determined its tail beat frequency at each flow rate and level of turbulence. After the experiments, to more precisely quantify the turbulence experienced by each fish, the team used a velocimeter to measure the rate and direction of water flow at many different locations within the flume under the three experimental conditions.

Halsey and his colleagues found that mean flow rate did not affect tail beat frequency in fish swimming alone or in groups of three. In groups of six fish, tail beat frequency decreased with increasing flow rates, which could reflect more effective drafting among fish in larger schools. Increases in turbulence increased the tail beat frequency in all group sizes, suggesting that swimming generally becomes costlier as flow becomes more uneven. However, fish in larger groups had lower tail beat frequencies in turbulent conditions than fish swimming alone or in smaller groups, indicating that schooling did help conserve energy as it does under laminar flow conditions. Notably, though, the energy cost savings afforded by schooling behaviour in turbulent flow were much lower than those estimated in past studies with laminar flow.

Overall, the researchers found that swimming in schools is energetically advantageous for sea bass in dynamic water conditions. However, the metabolic advantage of schooling appears to be smaller in turbulent conditions than in ideal conditions. In addition, the size of a school affects the degree to which changes in water flow rates and patterns influence the energy expenditure of fish within a school. Although more research is needed to better understand the energetic costs and benefits of group swimming in nature, this study shows that when the going gets rough, sea bass should probably stay in school.

10.1242/jeb.169979

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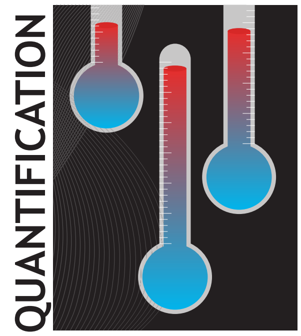
What eyes can tell



While all of us know that an increase in our body temperature above 38°C means that we are experiencing a feverish immune response, most people don't know that body temperature can also show variations linked to how much we eat or how much stress we are experiencing. Fasting individuals, for example, produce less body heat than individuals that have unlimited access to food, and during stress, blood is redirected from the body surface, causing cold hands or feet. Although information about an animal's physiology, such as whether they are stressed or coping well, is interesting for researchers, obtaining physiological data from free-ranging animals is difficult and often puts additional stress on the animals. Animals often have to be captured multiple times to measure their body temperature and draw blood or collect faeces, which can be used to look at stress hormones in the animal's system.

In the search for other ways to obtain those data, a team of international researchers led by Paul Jerem, from the University of Glasgow, UK, made use of thermal imaging to measure body temperature. Thermal imaging cameras take a picture of the heat lost by an animal through its surface, which is higher when an animal is warmer and a lot of warm blood is allowed to flow close to the skin. In particular, the team wanted to know whether the non-invasive measurement of variations in the eye temperature of blue tits can give an indication of the bird's body condition; that is, how well fed and how stressed the birds are.

For their study, Jerem and colleagues measured the eye temperature of blue tits over a winter and the following breeding season. During the winter, they lured the birds with food into a trap and filmed the animals with thermal cameras while feeding. They then closed the trap and took blood samples and weighed the birds. In the breeding season – when it is important not to disturb the birds too much – they mounted thermal cameras inside nest boxes to continue monitoring their eye temperature and captured the birds once to weigh them.

As hoped, the team found that eye temperature reflected the bird's physiological state. Breeding birds, which were under stress, had higher eye temperatures than birds in the winter and the birds that had better body condition (weighed more) had higher eye temperatures during both seasons. And, when they looked at the amount of stress hormones in the blood of the birds during winter, they found that the birds with higher stress levels also had lower eye temperatures.

The study suggests that measuring body surface temperature via thermal imaging cameras can be used to draw conclusions about an animal's condition, whether it is stressed or how it is coping with seasonal food availability, providing new opportunities to study free-ranging animals noninvasively in the wild.

10.1242/jeb.169961

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