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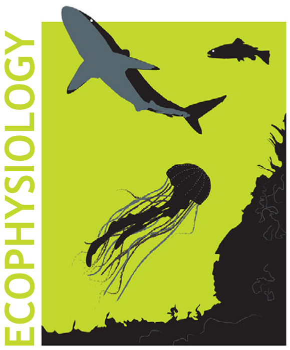
OUTSIDE JEB

Tuna keep their cool during heatwaves



Pacific bluefin tuna are majestic, torpedo-fast, super-sized apex marine predators. They're also delicious, according to sushi lovers around the world, which has led to a high-priced tuna fishery and a worrying decline in their numbers. Unlike most other fishes, tuna are warm-blooded and, just like humans, have a preferred temperature range at which the cost of keeping warm is lowest. Tuna occupy a vast interconnected habitat in the northern Pacific and migrate long distances to find patches of prey that are also on the move. Some marine predators survive by following rigid migration routes, a strategy that works well when conditions and prey are predictable. However, with climate change looming large, more flexible migrations might have benefits, by allowing predators to target prey as they become available. Surprisingly little is known about how tuna balance the needs for finding prey and staying warm, which is critical for protecting their vulnerable populations against overfishing and environmental change.

But how could one possibly track a wild torpedo-fast fish in the open ocean and measure its success at finding prey? Gemma Carroll at the University of California Santa Cruz, USA, with an international team of collaborators led by Barbara Block at Stanford University, USA, found a way. They caught tuna in California and surgically implanted high-tech bio-loggers into their bellies that recorded the fishes' location, depth and water temperature, before releasing the fish to continue with their migration. But best of all, the devices also measured the fishes' internal body temperature and the heat produced when digesting a meal, which revealed how much prey each fish consumed and where. The team repeated the procedure on hundreds of tuna over a staggering 15-year period, yielding a wealth of novel findings.

During this long-term experiment, ocean temperatures varied greatly between seasons and years. And yet, bluefin tuna managed to spend most of the time in waters that were within their thermal comfort zone. In warmer years, tuna shifted their migration pole-ward to colder waters; in cooler years, they headed south. This strategy even worked during the heatwave of 2015 when some tuna deviated from their usual routes by more than 1500 km and kept their cool by foraging in northern waters. This tremendous flexibility in migration patterns allows tuna to dampen the negative impacts of a warming and increasingly variable climate. But whether their prey follow suit is a different question.

Ocean heatwaves can disrupt entire food chains, first impacting primary producers, such as tiny algae, and then propagating the effects up to the apex predators. During the heatwave of 2015, tuna found less prey than they had in cooler years, but the northward shift in their migration route helped their foraging success. Therefore, tuna avoided the more devastating effects of the heatwave experienced by sea lions, grey whales and some seabirds, which are a more inflexible group of marine predators. To find scarce prey, tuna were even willing to leave their thermal comfort zone, spending more time hunting in northern waters that were colder than their usual preference. Being cold and miserable surely beats starvation.

Commercial fishery for Pacific bluefin tuna is seeing increasing catches, but that is not due to a recovery in their stocks, as their populations remain at an all-time low. Rather, it appears that changes in the temperature and prey landscape are pushing tuna into the fisher's nets, yielding record catches that, in the long run, are unsustainable. Exceptionally flexible migration patterns allow bluefin tuna to keep their cool during heatwaves, but may not protect them entirely from climate change at large. This is bad news for everyone: tuna, fishers and sushi lovers alike.

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Carroll, G., Brodie, S., Whitlock, R., Ganong, J., Bograd, S. J., Hazen, E. and Block, B. A. (2021). Flexible use of a dynamic energy landscape buffers a marine predator against extreme climate variability. *Proc. R. Soc. B. Biol. Sci.* **288**, 20210671. doi:10.1098/rspb.2021.0671

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Gliding geckos snap their tail to stick the landing

Geckos are well known for a gripping feat: the remarkable adhesiveness of their feet, which allows them to climb slippery surfaces like windows where other animals would struggle to get a foothold. But some geckos use other means for travel. They glide with the help of skin flaps that help to keep them airborne. When a team of researchers led by Robert Siddall and Ardian Jusufi from the Max Planck Institute for Intelligent Systems in Stuttgart, Germany, with colleagues from Siena College, USA, and the University of California Berkley, USA, filmed geckos crashing head-first into tree trunks in the rainforest in Singapore they were

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surprised to see such awkward landings and wanted to know how the geckos managed to remain in contact with the tree.

Having set up a platform perched 6.6 m above the ground and 3.8 m away from a tree trunk, the researchers used two cameras to film the geckos gliding to the tree from the platform; one that captured the entire glide from start to finish and a second that provided a zoomed view of the final portion as the geckos collided with the trunk. From these videos, the researchers could distinguish each stage of the landing manoeuvre and calculate how fast the geckos were gliding.

The videos showed that directly following impact with the tree, once all four feet were in contact with the trunk, the geckos curled their tail slightly inward to form a C-shape just as the forelimbs recoiled and they began to lose grip. Then, the lizard slapped its tail down onto the tree to act as a kickstand as its head and body pivoted backward. Eventually, the head and body recoiled so far back, bending the spine more than 90 deg to contort the lizard like the bullet-dodging characters from The Matrix action movie. In addition, the team recorded the small lizard's landing speed at a whopping 6 m s^{-1}, which is 140 body lengths per second – the equivalent of 238 m s^{-1} for a 1.70 m tall human – and the entire episode was over in 60 ms. The videos also revealed that the geckos didn't arrest their fall much with their gliding flaps: these only reduced their speed by 6% before impact, which is much lower than in other specialized gliding animals that can reduce speed by up to 60%. This illustrates that the gliding geckos' snappy tails make up for their lack of aerial agility.

To learn more about the importance of the tail for stabilizing landings, the team ran computer simulations of the foot and tail forces generated during an impact and built a robot gecko to investigate how tail length influences the gecko's ability to 'stick' the landing. The simulations showed that tail length helps to reduce the forces that the gecko's feet must generate to produce a foothold and the robot demonstrated that tails that are 25% shorter than their normal length doubled the amount of force required for the feet to get a grip. The model also incorporated a reflex that triggered the tail's stabilising 'call to action', which suggests that the gecko may also take advantage of a tail reflex to rapidly assume its kickstand pose.

Siddall and colleagues have shown how a whip of the gliding gecko's tail is important during head-first crash landings. The results may inform robot design by showing how a quick tail can provide controlled landings for robots on varied terrain and surfaces. However, crashlanding geckos are still likely to need to manage a sore head, unlike a robot. Fittingly, some species are better prepared for collisions, possessing a specialized skull that reduces the risk of injury; a clever adaptation for a head-banging gecko.

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Siddall, R., Byrnes, G., Full, R. J. and Jusufi, A. (2021). Tails stabilize landing of gliding geckos crashing head-first into tree trunks. *Commun. Biol.* **4**, 1020. doi:10.1038/s42003-021-02378-6

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Cockatoos know a thing or two about weight

Goffin's cockatoos – or blushing cockatoos as they are also known because of the salmon-pink coloured feathers between their eyes and beak – are not only adorable, but also smart. A casual YouTube search will soon convince you of their shrewdness. And these blushing beauties are excellent problem solvers. They can make and use tools from different materials, such as sticks and cardboard, to extract food from boxes in the lab. Assessing the weight of objects is also a critical skill displayed by these wise creatures: gauging the mass of a nut may help them to infer its nutritional value or decide whether they are strong enough to carry it, and determining the weight of an object such as a stick, could help them to optimise how they use it as a tool. But can cockatoos tell the difference between objects that appear to be identical, but are of different weights? Poppy Lambert, Alexandra Stiegler and colleagues from the Messerli Research Institute and the University of Vienna, Austria decided to find out. They predicted that the cockatoos might be able to distinguish visually identical objects that differ in weight.

To test this, the researchers first let eight cockatoos use their beaks to pick up and assess the weight of purple and blue coloured spheres made of modelling clay wrapped around a fishing weight or a cotton ball and, when an experimenter instructed, they had to place each sphere in a transparent dish to receive a sunflower seed reward. Then the researchers trained them to distinguish between the clay spheres by picking up the heavier (or the lighter) of the two and placing it in a black dish, in return for a cashew nut reward and some verbal praise. After that, the team made the task more difficult, by making both spheres grey and thus visually identical. If the birds could genuinely tell the clay spheres apart by weight alone, then they wouldn't find it difficult to still pick out the heavier of the two grey spheres.

As the researchers predicted, the cockatoos correctly picked out the heavier of the two clay spheres with their beaks and placed them in a box that an experimenter presented, irrespective of whether the spheres differed in colour. If a cockatoo chose wrongly, the experimenter said, 'nein' (no) and the bird had to wait for 30 seconds before attempting another trial. Remarkably, the cockatoos could learn to differentiate objects based on weight after only 60 trials, faster than primates, which can take around 895 trials to learn a similar task. This is probably because birds need to be more sensitive to weight; flight is an energy-demanding task and so the animals need to be sure whether they have enough power to take off with a heavy burden.

Thanks to Lambert, Stiegler and colleagues, cockatoos now join the ranks of animals, including monkeys and chimpanzees, that can learn to discriminate quickly between visually identical objects based on weight alone; and they do so despite their dramatically

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different lifestyles. The research highlights that the phrase 'birdbrained' is not as insulting as some people might think.

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Lambert, P. J., Stiegler, A., Rössler, T., Lambert, M. L. and Auersperg, A. M. I. (2021). Goffin's cockatoos discriminate objects based on weight alone. *Biol. Lett.* **17**, 20210250. doi:10.1098/rsbl.2021.0250

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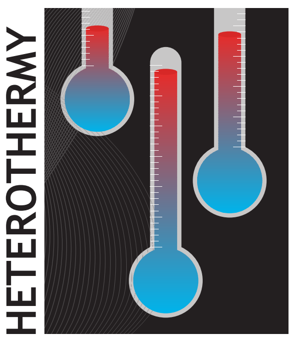
Tenrecs: freaks we can all learn from



Tenrecs, hedgehog-like mammals more closely related to elephants than hedgehogs, are freaks of nature when it comes to body temperature regulation. Most mammals that vary their body temperature (heterotherms) are not active at low body temperatures and instead become torpid – a state where their metabolic rate is reduced and they either become immobile, as in an extreme form of sleep, or very lethargic. Tenrecs, on the other hand, can remain active with body temperatures as low as ∼14°C and they can become torpid at relatively warm ambient and body temperatures of 28°C. A group of researchers, led by Frank van Breukelen at the University of Nevada, USA, and Jane Khudyakov at the University of the Pacific, USA, sought to further understand the underlying physiology behind the common tenrec's (*Tenrec ecaudatus*) extraordinary abilities by looking at the proteins expressed in the animal's liver.

van Breukelen and his colleagues kept the tenrecs either at a cool (12°C) or warm (28°C) temperature in their captive colony at the University of Nevada Las Vegas, USA. Then, the researchers collected liver samples from three tenrecs that remained active in the warm conditions with a body temperature of 33.5°C and three that had slipped into torpor with body temperatures ∼27.7°C. Of the tenrecs housed at the cool temperature, the researchers took samples from three tenrecs that had become torpid with body temperatures of 12.8°C, three active tenrecs with cool body temperatures (14.5°C) and three active tenrecs with warm 30.2°C body temperatures. In this way, the researchers were able to not only compare active and torpid animals, but also body temperature with activity state. This experimental design is almost impossible to do with most other hibernators, as most mammals are not able to be active at such low body temperatures or become torpid at such high body temperatures.

Of the 768 liver proteins that the team could identify, 51% were different between the torpid and active animals, which is almost unheard of; hibernating ground squirrels change the expression of only 15.5% of their proteins when they switch off for their long winter slumber. These differences in protein abundance were mostly connected to protein turnover, coordinating the processes that build proteins (anabolism) and those that break them down (catabolism). Additionally, they found nine proteins that were present more in the chillier temperatures, which may identify part of the liver's response to cold. 72.2% of the proteins that were upregulated in the cold tenrecs that remained active, compared with the warm active animals, were also upregulated in the tenrecs that had slipped into torpor at 28°C. This suggests that being at a cooler environmental temperature and being active at a low body temperature may hinder the animals' ability to maintain a stable set of proteins. Overall, many of the 768 proteins identified overlapped with proteins found in other hibernating species, suggesting that even across distantly related species, the core metabolic pathways dealing with torpor are conserved.

By researching the common tenrec – one of the most heterothermic mammal species, which retains many of the same physical characteristics as the first mammal – we can get a better understanding of how the ability to maintain a stable body temperature, homeothermy, may have evolved from heterothermy. van Breukelen and his colleagues predict that the evolution of homeothermy likely came about from the better coordination of protein destruction and production, resulting in a more balanced set of proteins matched to the thermal sensitivities of metabolic pathways.

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Khudyakov, J. I., Treat, M. D., Shanafelt, M. C., Deyarmin, J. S., Neely, B. A., van Breukelen, F. (2021). The liver proteome response to torpor in a basoendothermic mammal, *Tenrec ecaudatus*, provides insights into evolution of homeothermy. *Am. J. Physiol. Regul.* doi:10.1152/ajpregu.00150.2021

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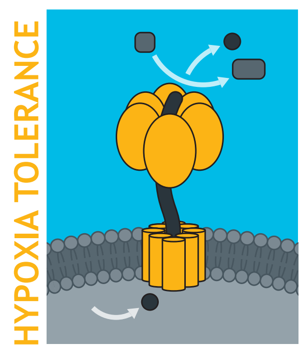
Hypoxic hagfish gills binge calcium



Slimy, tentacle-faced hagfish look like aliens and, accordingly, possess several PhD theses' worth of unusual traits. Their body fluids have a similar number of dissolved salts to seawater, although because hagfish control the levels of some ions like calcium in their blood, the mix of salts is slightly different. Hagfish are also famously tolerant of low oxygen conditions (hypoxia), which comes in handy when they burrow inside rotting whales to dine. In some fishes, hypoxia disrupts how they manage the delicate balance between their internal salts and the salts in their surroundings as they cut back on the energy-intensive process of ion movement to save energy. But what about hagfish with their unusual balance of salts? And what happens when oxygen is scarce? Chris Glover of Athabasca University, Canada, and Greg Goss of the University of Alberta, Canada, decided to find out.

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Glover and Goss hypothesized that their slimy beasts would do the same as other fish when oxygen was in short supply: decreasing calcium uptake and accumulation. They tested this idea by placing hagfish in air-tight jars and tracking the movement of mildly radioactive calcium into their tissues as they used up the available oxygen.

Unlike the hagfish in open jars, the hagfish in sealed jars moved calcium quickly into most of their tissues, including skin, liver, muscle, heart, plasma and brain. Low oxygen levels also bumped up the rates of calcium build-up in their gut and especially their gills; the guts of the fish in the low oxygen conditions had nearly 4 times more calcium than the guts of the fish in oxygen-rich conditions after adjusting for calcium contained in the blood flowing through the tissue. Since hagfish have no bones to leech calcium from, these results meant that, contrary to expectations, hagfish responded to hypoxia by importing more calcium into their bodies.

When an animal does something you don't expect, the next questions are usually: how and why? Tackling the first question, Glover and Goss focused on how calcium moved across hagfish skin and gut tissue when it was isolated from the rest of the body with the goal of understanding the role each tissue played in the hypoxic fish's calcium binge.

They discovered that low oxygen in the environment reduced calcium uptake by the skin, but only when the experiment was performed in unnaturally low calcium conditions, so this was unlikely to be a major mechanism of calcium accumulation in living animals. However, the results in the gut tissue were more puzzling. Despite surging calcium levels in the gut under hypoxia, there were no differences in the calcium uptake rates between the guts of the hagfish that had been kept in normal levels of oxygen and those that were oxygen starved. The authors mused that perhaps the sealed-in hagfish had gulped down seawater as a reaction to the stress, accidently flushing the tissue with calcium in the process. With the skin and gut ruled out as major importers of calcium into the body, the researchers determined that the gills were the source of the calcium detected in the closed-jar hagfish, which squares with the impressive rate of calcium accumulation observed in this tissue.

Hagfish are peculiar creatures, so it's perhaps unsurprising that they respond so differently from most other earthbound fishes. As for why hypoxic hagfish pull in so much calcium through their gills, that remains a mystery. Calcium could possibly aid in coping with low oxygen conditions by constricting blood vessels or protecting brains cells. Alternatively, the calcium accumulation might not be a strategy at all and could simply be a result of hagfish moving more water – and consequently calcium – through their gills; but that's a study for another time.

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Glover, C. N. and Goss, G. G. (2021). Hypoxia modifies calcium handling in the Pacific hagfish, *Eptatretus stoutii*. *Comp. Biochem. Physiol. A. Mol. Integ. Physiol.* **261**, 111042. doi:10.1016/j.cbpa.2021.111042

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