Bending the Rules (p. 3273)

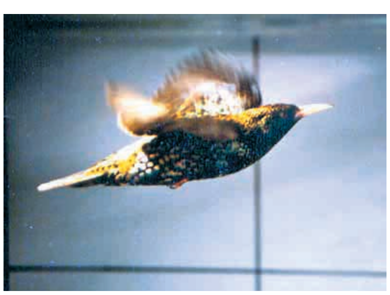
Jenifer Hurley explains that for most organisms metabolism is a continuum that starts with sleep and peaks at extreme exertion. But 60 years ago, P. F. Scholander measured the metabolism of mammals that he forced to dive, and found that their diving metabolic rate was even lower than when they were resting. Metabolic heresy! However, Hurley and her colleague Dan Costa might have laid this question to rest with diving data from California sea lions.

People had tried to reproduce Scholander's results using free diving animals, but with no success until Hurley tackled the problem with the help of four adult sea lions: Beaver, Hoover, Sake and Sushi. Hurley and Costa wanted to look at animals that were diving freely, so she had to train the animals to remain submerged until they reached their aerobic limit. This meant convincing them to sit at the bottom of a pool, and do absolutely nothing while they were down there. Which is quite difficult because sea lions are intelligent and very active, so they never want to sit still!

However, after a great deal of negotiating, the sea lions were ready for the test, and the four animals began diving to 3.1 m, where they held their breath and remained completely inactive, for up to 7 minutes. Hurley measured their resting metabolism before they left the surface and then recorded their respiration after they ascended from the bottom of the tank, while they repaid the oxygen debt from the dive.

They confirmed Scholander's results. When the sea lions dived, their metabolic rate dropped until it was even lower than that when they were resting at the surface. Costa says that he was pleased to see how clear the results were: 'it's not often that results are so unequivocal'. Both scientists agree that the sea lions could probably go lower, but not without a good reason, such as survival. Hypometabolism probably gives these animals the metabolic edge they need to function during long dives: liberating energy from non-vital functions and diverting it to life-support.

Since this set of experiments has finished, two of the seals have retired to an oceanarium where they now dive for pleasure. But they other two are still on a mission. One of their next challenges is to go head-to-head in a breath holding competition with the human champion breath holders, to see if humans can go hypometabolic too. Comparative biology doesn't get more comparative than that!



Metabolic Mathematics (p. 3311)

Estimating the metabolic cost of flight for birds isn't just a fancy academic trick, for some species it could mean the difference between survival and the doom of extinction. Imagine you're a migratory species that flies across a great ocean. That's fine, because most geological features don't suddenly change size. But if your migration takes you across an expanding desert, there could come a point when you can't store enough energy to cross in one go, and that would be fatal. So the energetic cost of bird flight has real ecological significance for the survival of some species.

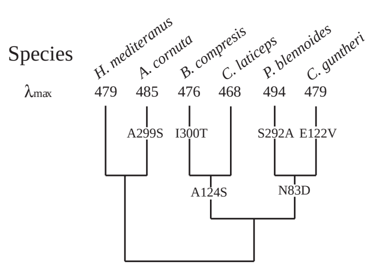
Aerodynamic models are one way to estimate the energetic cost of flight. They calculate the mechanical cost of flapping flight, but that isn't the same as the amount of energy consumed in flight, because muscle generates waste heat too. So the metabolic cost of flight is estimated by adjusting the mechanical cost with a fudge factor, called the flight muscle efficiency (0.23). John Speakman and colleagues wanted to check just how good this fudge factor is by comparing the calculated estimate with a metabolic rate measured from birds on the wing.

And that required some perseverance! Sally Ward had 14 tame starlings in an aviary in Scotland. They seemed like the ideal set of birds to try out the experiments, so she transported them to Germany where she taught them to fly in a wind tunnel. After they'd mastered the art of wind-tunnel-flight, she had to convince them to fly wearing a tiny mask, which is where the persistence came in, because when they decided they couldn't do it they just gave up and wouldn't fly at all.

Only two birds passed the final test and were able to fly wearing the respiration mask. Working with her colleagues in Germany, she filmed the birds as they flew with a facemask, so she could accurately calculate the muscle efficiency value. By collecting the kinematic and metabolic data simultaneously, she could compare the true muscle efficiency value with the value calculated from kinematic data alone.

It turned out that the established value for flight muscle efficiency wasn't quite right for starlings, 0.18 rather than 0.23. In fact, both birds that performed the experiments had slightly different values, suggesting that there isn't an ultimate number for an individual species. The old value that has been used up until now probably underestimated the bird's flight power by 15-25%!

But Speakman urges caution. We shouldn't all rush and throw the old value out. It could be perfectly accurate for some larger species, but it's probably better to use a range of values that take account of variations from bird to bird, let alone species to species. He believes that it's important to identify all the different elements that comprise the efficiency factor. That will produce direct measurements of muscle efficiencies for many different species. So in the future we'll be able to disregard the estimates, in favour of the hard won measurements. After all, it would be a waste not to use these values, which took a huge effort from an EU-wide team: let alone the starlings.



Seeing in the Sea (p. 3333)

Not much sunlight penetrates deep into the oceans, but that doesn't mean that there isn't light down there. Bioluminescence gives the depths a dim glow, so the creatures that live there have evolved photoreceptors with light sensitive pigments (opsins) that pickup wavelengths towards the blue/green (480 nm) end of the spectrum. David Hunt and his colleagues realised that every creature in this habitat were living under a strong selective pressure to optimise their vision to the dim habitat, so they wondered how each species had adjusted their opsin genes to get the best spectral down-tuning. Would all the opsin genes have the same set of specialised mutations, or would every gene be different?

Hunt and his team went trawling in the deep oceans and pulled-up 80 species from depths as great as 5000 m. Back in the lab, they sequenced 28 opsin genes that were already spectrally characterised. The first thing they noticed was that all the genes coded for rod-type opsins, and not cones. This wasn't surprising, as cones are adapted to bright light environments, and rods specialise in dimmer conditions. But rods are usually tuned to light around 500 nm, which doesn't penetrate more than 300 m into the sea, so these rod opsins have been modified relative to the surface proteins to pick up what little light there is down there.

Taking a closer look at the genes, they lined up the sequences to see if there was a set of conserved substitutions that gave the fish blue/green vision. There wasn't. Realising that the story was more complicated, they grouped the genes by species and a pattern began to emerge. The mutations that have shifted the opsin's sensitivity to blue/green wavelengths occur at nine key positions in the gene sequence. From the structure of the related bovine rhodopsin protein, Hunt knew that these amino acids were involved in interactions with the chromophore, but had these deep sea species used a common amino acid tuning code?

Genes from closely related fish were either identical or only differed by one or two residues at the nine key sites. More distantly related fish showed more divergence, but still share many common substitutions. The take home message is that there isn't a single tuning code, so it'll be tricky to predict spectral tuning on the basis of gene sequence alone. However, Hunt has mapped the mutations onto a standard phylogenetic tree. From this perspective he has predicted the sequence of the ancestral deep-sea opsin, which he believes probably had a maximum absorbance at 480 nm.

Still intrigued by deep-sea vision, Hunt is moving on to look at fish that have multiple visual pigments. Some of these fish are also bioluminescent at these longer wavelengths. He points out that this could be very handy if you're a predator because 'if you can see your prey, but they can't see you, that's a huge advantage.'

Kathryn Phillips
Kathryn@biologists.com

Glendinning, J. I., Domdom, S. and Long, E. (2001). Selective adaptation to noxious foods by a herbivorous insect. *J. Exp. Biol.* **204**, 3355–3367.