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How fire ant architects connect to build balls

A network of fire ants. Photo credit: Tim Nowack.

For red fire ants (*Solenopsis invicta*), rain gently drumming on the ground is the trigger for a mass exodus. Streaming from their nest as the water levels rise, the ants rapidly assemble and grip onto their nearest neighbours, forming a raft to carry them to safety. What is more miraculous is that each individual ant is denser than water and in danger of sinking if submerged. However, the ants don't just draw the line at constructing rafts: they routinely form bivouacs, assemble towers and even coalesce into droplets when swished in a cup. 'You can consider them as both a fluid and a solid', explains David Hu from the Georgia Institute of Technology, USA, who is most interested in the ants because they are large enough for him to begin to find out how they interact to pull off these remarkable engineering feats. Hu teamed up with Paul Foster and Nathan Mlot to investigate how balls of living fire ants self-assemble (p. 2089).

Gently swirling 110 ants in a beaker to form a sphere, the team then swiftly froze the structure in liquid nitrogen and coated it in Super Glue™ vapour to preserve the minute contacts within, ready for Angela Lin to visualise the structures in a CT scanner. 'With the CT scan we can focus on individual ants and see how they are connected to their neighbours', explains Hu, who adds that processing the images could only be partially automated because it is hard to tell where one ant ends and another begins.

However, after months of painstaking scrutiny, Foster and Hu discovered that on average, each ant participated in 14 contacts – reaching out with all six legs to grip neighbours and receiving eight contacts back to its body – although large ants participated in as many as 20 contacts and the smallest ants participating in only eight. 'It turns out that 99% of the legs are connected to another ant and there are no free loaders', says Hu, who admits that he was impressed by the high degree of connectivity.

Next Foster digitally removed all of the limb connections so that he could take a closer look at the ways that the ants' bodies packed together, and he was amazed to see that instead of clustering together in parallel, like grains of rice in a jar, the ants had actively oriented their bodies perpendicular to each other. 'They have to be alive to do that,' says Hu, adding, 'It requires some intelligence, and suggests that somehow they sense their relative orientation.' The duo also analysed how closely the ants' bodies packed together and realized that the smaller ants were packing in to fill the gaps between the larger ants to increase the number of contacts. They also noticed that the ants were actively pushing on each other, using their legs like tiny jacks to increase the distance between neighbours and reduce the density of the ball. Hu explains that by introducing air pockets between their bodies, the ants increase their water repellency and buoyancy, which is why their rafts are so effective.

Finally, Hu and Foster took a closer look at the contacts made by individual ants with a scanning electron microscope and saw that the insects rarely used their mandibles to grip on to other ants. Instead they mainly used their legs, holding on with hooks on their feet and the sticky pads that allow them to walk on vertical surfaces.

So, having discovered how fire ants self-assemble to form light but stable structures, Hu is keen to know how they react to reinforce weak points in structures where ant architecture could fail.

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Foster, P. C., Mlot, N. J., Lin, A. and Hu, D. L. (2014). Fire ants actively control spacing and orientation within self-assemblages. *J. Exp. Biol.* **217**, 2089-2100.

Kathryn Knight

Motherhood is no picnic for sea otter mums

Southern sea otter mum and pup. Photo credit: J. Tomoleoni.

Sea otters have voracious appetites, and for good reason. As the smallest marine mammals, they face unprecedented metabolic challenges just to stay warm, consuming a quarter of their own body mass each day. And there are times when the metabolic demands of sea otter females rocket even further. Nicole Thometz, from the University of California at Santa Cruz, USA, explains that in addition to the extra cost of lactation, the mums must also expend additional energy while foraging to sustain themselves and their dependents. However, no one knew the true magnitude of the metabolic burden placed on sea otter mothers: 'neither the energetic demands of immature sea otters nor the cost of lactation for adult females have been quantified', says Thometz. Fortunately, Thometz and her colleagues had access to the world's most successful sea otter pup rehabilitation program at the Monterey Bay Aquarium in California, where they could measure the metabolic rates of wild sea otter pups while they grew, prior to their return to the ocean, to begin to find out how much of a burden motherhood is for sea otter females (p. 2053).

Measuring the metabolic rates of sea otter youngsters (ranging from tiny pre-moult pups to juveniles) as they participated in a range of activities from resting to swimming and foraging, the team discovered that their daily metabolic demands rose from 2.29 MJ day^{-1} during the first few weeks after birth to 7.41 MJ day^{-1} when the youngsters were about to begin foraging for themselves;

even when the animals were beginning to fend for themselves they continued returning to mum to supplement their diet. It is only after weaning at 6 months that the mothers are truly free of their obligation.

Tallying up the metabolic data, the team calculated that to supply a pup with a staggering total of 930 MJ of energy through to independence, the female's daily metabolic rate has to escalate by an extraordinary 96%. And when the team converted this colossal energy expenditure into the amount of energy reserves that a sea otter female would use if unable to increase foraging, they realised that she would consume almost 133% of her own body mass. The only way that sea otters have to make up this gigantic metabolic shortfall is to increase foraging at a time when they are already running near their metabolic limits, stretching an even tighter energy budget still further.

The team suspects that this extreme exertion could account for the poor condition of many sea otter mums and their relatively high mortality rates at the end of lactation. It could also account for the relatively high numbers of abandoned pups. Thometz says, 'Female sea otters are thought to utilize a "bet-hedging" strategy, either keeping or abandoning a pup post-partum [after birth] depending upon physiological factors.' She explains that females that are in poor condition and unlikely to be able to provide for their young are more likely to abandon their pups after birth to give themselves a better chance of successfully raising a pup during the following breeding attempt. 'The optimal decision may be to "cut losses"', says Thometz. And she adds that sea otter mothers may also choose to wean their young sooner to preserve their health, rather than risk their own survival and subsequent breeding attempts by investing too heavily in the present pup, although this strategy places youngsters that were weaned early at a greater risk of mortality after independence.

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Thometz, N. M., Tinker, M. T., Staedler, M. M., Mayer, K. A. and Williams, T. M. (2014). Energetic demands of immature sea otters from birth to weaning: implications for maternal costs, reproductive behavior and population-level trends. *J. Exp. Biol.* **217**, 2053-2061.

Kathryn Knight

Tree ant family tree reveals swimming evolution

Pachycondyla sp., a tropical swimming ant. Photo credit: Stephen P. Yanoviak.

Life in the forest canopy is precarious: lose your footing and you could rule yourself out of the evolutionary arms race. Yet this hazard has not deterred many tropical ants from making their homes amongst the branches. In response to the risk of taking a tumble, many have developed the ability to glide to safety, although not all are lucky enough to land on another tree. Steve Yanoviak, from the University of Louisville, USA, explains that many plummet into water when the rivers below flood. However, when Yanoviak tried dropping tropical ants into water to find out what happened, he was amazed to see some species scuttle across the surface with ease. Intrigued, Yanoviak suggested that his Master's student, Dana Frederick, find out how widespread this swimming ability is and which swimming techniques, if any, the ants favour (p. 2163).

Fortunately, both Yanoviak and Frederick had heads for heights and were unfazed dangling from climbing ropes in the forest canopy as they collected ants from the branches. 'Some individual trees may have 20 or more ant species, so collecting workers of several species was not a major obstacle', recalls Yanoviak, who was also adept at distinguishing between harmless species and ants that could give a painful sting.

Having collected 35 species – ranging from minute *Wasmannia rochai* to gargantuan *Paraponera clavata* – the duo returned to the ground and tried gently dropping the ants from a bridge over a flooded region of the forest to see how they fared. 'Over half (57%) of the tested species exhibited some swimming ability', says Yanoviak, adding that the rest fell helplessly into the water. Of the swimmers, 10 proved to be elite athletes – with *Gigantiops destructor* notching up top speeds of over 16 cm s^{-1} – while the weakest 10 species eventually lumbered to safety after slow starts. The duo also analysed the ants' swimming prowess in terms of an ant family tree, discovering that the insects have evolved the ability to swim on four different occasions. And when the duo compared the ants' swimming abilities against their ability to glide, they found that the best gliders tended to be the weakest swimmers.

Next the duo focused on the swimming techniques of three of the larger species (*Odontomachus bauri*, *Pachychondyla foetida* and *P. villosa*), filming the insects with a high-speed camera at 240 frames s^{-1} as they zipped across water in a shallow rectangular pan. 'Recording high-speed videos of swimming ants in the lab was technically the most challenging part of the work', recalls Yanoviak, adding that the ants would invariably stop performing when the filming conditions were perfect. However, after painstaking analysis, Frederick could see that the swimmers were alternately moving one and then the other tripod of legs; pulling the front two legs from each tripod through the water to propel themselves forward, while using the rear leg from each tripod to provide stability.

Yanoviak and Frederick also wondered whether the immersed insects could locate and swim toward dark objects, such as trees, that they could climb to escape. Placing a 3.8 cm diameter black tube at one of the four compass bearings around a child's play pool, Frederick then dropped *O. bauri* ants into the water and waited to see which direction they aimed for. Amazingly, 87% of the ants successfully escaped the water by scaling the dark pipe, while only 23% of the ants successfully located a white pipe. Yanoviak admits that he was surprised by the strength of the ants' attraction to the dark object, known as scototaxis, and adds that he is now keen to understand how predatory fish respond to swimmers and non-swimmers that land in the water.

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Yanoviak, S. P. and Frederick, D. N. (2014). Water surface locomotion in tropical canopy ants. *J. Exp. Biol.* **217**, 2163-2170.

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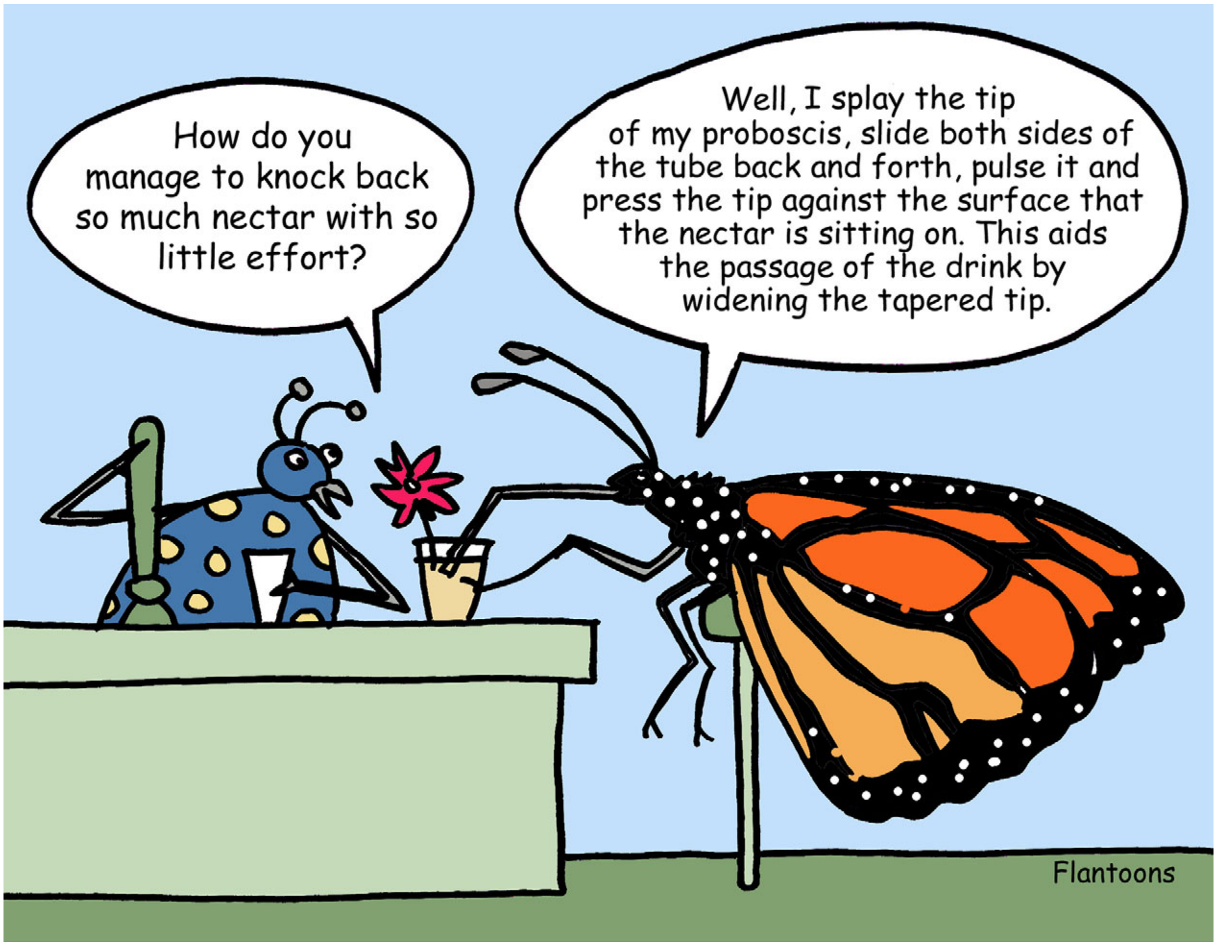
Butterflies manipulate proboscis to suck



Elegantly sipping from drops of nectar, most butterflies have no idea of the mystery surrounding their drinking technique. Konstantin Kornev, from Clemson University, USA, explains that although the delicately tapered proboscis looks like an elaborate drinking straw, calculations show that the insect would paradoxically have to produce sucking pressures of more than 1 atmosphere to draw sugary fluids through the structure. Kornev and his colleagues wondered whether the insects were overcoming these challenges by flexing and moving the proboscis to alleviate the constriction and reduce the pressures required. Teaming up with Chen-Chih Tsai, Daria Monaenkova, Charles Beard and Peter Adler, Kornev began characterising how monarch butterflies use their proboscises for sipping (p. 2130).

After filming how the proboscis moved while the butterflies sucked, the team saw that the insects use a combination of four strategies: they splay the tip of the proboscis, slide both sides of the tube back and forth, pulse the proboscis and press the tip against the surface that the droplet is sitting on. The team suspects that these factors aid the passage of fluid through the proboscis by widening the tapered tip, altering the way in which the meniscus travels along the structure and augmenting the suction power of the cibarial pump to reduce the suction required to pull fluid through the proboscis.

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Tsai, C.-C., Monaenkova, D., Beard, C. E., Adler, P. H. and Kornev, K. G. (2014). Paradox of the drinking-straw model of the butterfly proboscis. *J. Exp. Biol.* **217**, 2130-2138.

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