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CONVERSATION

Extraordinary creatures: *Tenrec ecaudatus* (the common tenrec)

Tenrec ecaudatus (the common tenrec) is a small mammal (250 g–2 kg) that is native to Madagascar and has been introduced to other islands in the Indian Ocean. Tenrecs dine on insects, small reptiles, amphibians and mammals in the wild, but also consume fruit and vegetation and are thought to hibernate for up to 8 months. However, unlike other hibernators, which periodically arouse from torpor during hibernation, tenrecs do not and are notoriously difficult to keep in captivity. Frank van Breukelen, custodian of the only known colony of captive tenrecs, tells Journal of Experimental Biology about these extraordinary creatures and the challenges that he has faced learning about their unconventional physiology and how to care for them.

Four-month-old tenrecs drinking at a water bowl. Photo credit: Gilbecca Smith.

Frank van Breukelen, why are tenrecs so fascinating?

Tenrecs are bizarre animals with numerous physical features that likely appeared in the most ancient ancestor of all placental mammals. They have cloacas (which are rarely found in placental mammals), internal testes and the smallest relative brain size of all living mammals, including monotremes and marsupials. In addition, *T. ecaudatus* appears to lack a functional corpus callosum, a region of the brain that is only found in placental mammals, and although the neocortex comprises more than 40% of most mammal brains, it only contributes 8% of tenrec brains. These anatomical features are accompanied by remarkable plasticity – the ability to produce different phenotypes in response to different environmental conditions – such as the ability to grow indeterminately (they can grow as adults) and they can carry two independently timed litters at a time. Metabolically, tenrecs can walk around with body temperatures of 12°C or hibernate at 28°C, which is extraordinary, because most mammals can only survive and be active over a narrow (∼2°C) temperature range and most hibernators allow their body temperature to fall to near ambient. Even when active, a tenrec maintained at 12°C can have a 25-fold variation in resting oxygen consumption rate.

Can you tell us about the natural environment where these animals are found?

They are endemic to Madagascar, which is about the size of California, Oregon and part of Washington State. Madagascar is enormous and hypervariable, but now, wherever a road has been built, the environment has been completely disturbed. Tenrecs have, however, been quite successful at colonizing the disturbed areas and this is why they have survived. The species that we work with is found throughout the island, which has mangroves with crocodiles on the eastern side, and in the south there is a spiny, dry desert, which is where the biggest tenrecs live. They're even found in Andringitra National Park, a high-altitude area where the summer nighttime lows get down to 12°C and it can snow in the winter.

What structures do they live in?

In the wild, they dig themselves into a burrow about a meter deep and then they close it and take an extended nap for 8 months or so. Everyone used to think that they hibernated singly, but I was exploring YouTube one day and I found a video that showed a hunter pulling 13 of them out of a burrow. That was the first indication that they hibernate socially. In our 2018 JEB paper (Treat et al., 2018), there's a link to the YouTube video. Very little is known about them and when people say that they hibernate for 8 months, it's just because they don't see them as frequently; it could just be that they're less active.

How did you become interested in tenrecs?

I was introduced to them by Barry Lovegrove in 2012 when I heard him give a talk. He had put iButtons – temperature sensors – in the tenrecs' abdomens in the wild to monitor their hibernation and discovered that they did not do an interbout arousal, where they periodically warm up and are briefly active during hibernation. I had put together a model of how hibernation works, which absolutely depended upon the interbout arousal to allow normal hibernators to reset the body's homeostatic processes – processes that maintain the body's internal physiological balance. An animal that did not need to arouse was going to cause problems for my model. But then I realized that it is hot in Madagascar where tenrecs are from, so I thought, what if we brought them into the lab and cooled them down, maybe they'd have to do an interbout arousal. That was the whole rationale for getting the tenrecs.

Have you been to Madagascar to see tenrecs in the wild?

My grad student, Michael Treat, and I spent 3 weeks in Madagascar. It's good because the stuff that we see the animals doing in the lab is not necessarily what they do in the wild. When we got our wild animals from Mauritius, their mass was often 250 g, but they can grow up to 2 kg in south Madagascar. Usually, the animals in the wild are skinny and they hibernate very deeply, but they also die frequently. When the animals first arrived with us, they wouldn't

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A torpid tenrec. Photo credit: Daylin Sigler.

arouse; in fact, I thought they were dead when we took them out of the shipping crates. They were in deep hibernation, but they were floppy, which is unusual, because most hibernating animals are stiff. However, after a bit they started moving a little and we realized that they were okay, they were all alive. Now our captive tenrecs are a bit plumper and when they hibernate at 25°C, they are quite disturbable. They can get up, even though they are still torpid – metabolically depressed – and their heart rates are 30 beats min^{-1} and they are able to walk around in a zombie-like state. They did this much less when they were skinny.

How did you obtain the founder members of your tenrec colony?

Barry Lovegrove helped me tremendously. At the time there were none in the USA; nine zoos in Africa and Europe had them, but they only had one or two individuals, so I contacted the Malagasy government, but they told me that I could only have two. Then Barry came across a friend, Owen Griffith, in Mauritius, where the tenrecs had been introduced for food. Owen captured 40 of them in live traps in May 2014, when they were about to go into hibernation, and they were transported to Las Vegas, USA, in the following June.

What was the biggest challenge that you faced when the tenrecs arrived?

There really hadn't been much done work done on them, so we didn't know what they needed to thrive. I didn't know if they would be fierce, but it turns out that they're really nice to each other, except for during the mating season. Also, they weigh 250 g, unless they get a lot of food, then they get to 1.5 kg. We didn't know what temperature and humidity they prefer and we didn't know what they needed to eat, so we had to explore different foods. Initially, we lost five animals, because they were so small and skinny and they often die in the wild during hibernation. But we learned lessons from hibernating ground squirrels and began monitoring the tenrecs' weights. We found that if we had a small animal and it started to lose weight quickly (normal hibernators lose weight very slowly), we had to give it lactated Ringer's solution, which is the liquid in intravenous drips. Then they got through hibernation successfully. During the first year of the colony, we probably saved 12 animals that way. Now we don't have to worry so much because our tenrecs are bigger, they hibernate well and they survive, so we rarely have to intervene.

Have the tenrecs shifted their body clocks to hibernate in the northern hemisphere winter?

They are still on a modified southern hemisphere pattern, and when they are small and skinny they have a longer hibernation season. But when they're big and robust, their hibernation season is shortened. The lowest point of hibernation – when they're most torpid – seems still to be about June, which is the southern winter. Now the first animals are born in October, but in the first year they were born in December, and it looks like monsoons trigger when these guys come up out of hibernation. Las Vegas usually gets monsoons in August, but years ago we had heavy rain on 5 June and then, all of a sudden, every tenrec came out of hibernation. We thought we were in big trouble because June is the best month for hibernation, so we were concerned about our data collection, but 5 days later they all went back into hibernation. We think that seasonality of rains is a big trigger for their hibernation. We also know that social cues are significant. When we have a tenrec that is reluctant to go into hibernation, we put it in with a bunch of animals that are torpid and it drops in. The same thing happens on the way out; if an animal is lagging behind everybody else, we drop it in with active animals and within a day or two it's up. These guys are driven by responses to their sense of smell and I'm convinced everything revolves around their breeding season.

How big is the colony currently?

I think it's about 70 at the moment. We could make it much bigger, but it costs a fortune to maintain, and it could be smaller, but if it became too small, we would probably have problems breeding. At the moment, we have a very successful breeding program, but the females are terrible mothers – they eat their babies – so we hand rear a tremendous number of them. My students and postdocs are fantastic, they come in every hour, on the hour, to hand rear babies. In the wild, people have documented 32 pups in a litter, and a typical litter in Madagascar is 16 to 20, but the biggest litter we've had was 19, and we regularly get much smaller litters. Typically, they weigh about 12 g at birth, but some have been 70 g, and we've had some that were born in late November that were over 1 kg mass by late January. That's close to the growth rate of a seal, but seals put on fat; our guys gain muscle, fat and bone as they grow. One of my students is documenting their growth, she has done thousands of micro-CT scans, and she sees that their bones grow differently from other animals'.

How do you care for the tenrecs?

I started off housing them in closed reptile cages, because I thought they were going to climb out, but then we realized that they weren't, so now we use restaurant food tubs and cattle troughs for pens. We've tried peat moss, corn cob, shredded newspaper and sometimes cloth towels as substrate for them to live on. They also have weird health issues, so more than 20 undergraduates come in each day during four shifts to keep them alive. For example, the tenrecs get a lot of dry flaky skin on their feet, and now we use a moisturizing dairy cow udder treatment and Chapstick to treat their skin. The tenrecs also like to be held, so my staff are really good at interacting with them, holding them even when they are doing other tasks. The tenrecs also like social interactions with one another, but they do not do toys; we've tried. They usually get along fine although they fight sometimes, especially during the breeding season, and during the hibernation season they make a big heap of tenrec bodies.

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What challenges have you encountered while keeping the tenrecs healthy?

Their lymphatic system is enormous and their blood perfusion – blood flow through the capillaries – is really bad when they are torpid. Basically, they take the fluid component of their blood and stick it into their abdomen to reduce the blood volume when they lower their metabolism. As a result, every once in a while, they get a blockage in their lymphatic system and their arm swells, so we massage them and use Epsom salts to reduce the swelling. Also, the males' penises are 70% of their body length. More than 10 males have died because they accidentally tied their penis in a knot and their bladders filled with urine. We tried to cannulate the penis to unblock it, but it is super thin at the end and we couldn't, so, sadly, we have to euthanize the animal when this happens.

They can also go into rigor mortis spontaneously when they're alive. They become stiff as a board, but they are definitely alive. The first time an animal went into rigor mortis, a vet was there. He thought it was dead, but I did not. We kept testing its reflexes and 25 min later it started to relax. Eventually it started walking. This has happened more than 10 times. Usually, the animal is somewhat torpid, we scare it somehow and then I think they try to contract their muscles without any available ATP, so they go into rigor mortis. It lasts for about 30 min and then the animal recovers with no issue.

Another time, we had wanted to see how low their body temperature could go. An undergrad was cooling a tenrec and when it got down to 6°C, he called me because he hadn't recorded a heartbeat for an hour. I called my technician, Lori Scholer, who lived in North Las Vegas. She drove to the lab, started giving heart compressions to the animal and 2 h later it recovered and was walking around. Tenrecs are remarkably plastic animals, but they die frequently because they make physiological mistakes, like accidentally going into rigor mortis.

What do they eat and what is their favorite food?

We don't give them their favorite foods because we are very careful about their weight. When we first got them, they grew and grew, so I put them on a diet, but we got down to where we were feeding a 1 kg tenrec 3–5 g of food per day (a 30 g mouse eats 15 g of food a day) and they wouldn't lose weight, they just dropped their metabolism. Now they are weighed a couple of times a week and we constantly change their food in order to maintain their body mass. They get a lot of Mazuri® Insectivore Diet and dry or wet dog food. We have given them crickets once in a while and they get really excited, but after half an hour, they get bored, so then I have insects running all over the place. They drink a lot of water, but they also like to play with it, so they spill it and we have to clean their bedding twice a day, otherwise they get foot issues.

What are you hoping to learn about tenrecs next?

We're trying to get a grant because I think that they are reminiscent of an early mammal: tenrecs have a lot of plesiomorphic (ancestral) physical traits. We think that they can repair their heart as an adult, or survive extended periods without kidney function, because they are constantly turning off physiological processes; they can have low body temperatures, experience low metabolism, have really low heart rates and turn off kidney function. They probably incur damage all the time, but maybe they can fix it. Modern mammals have lost the ability to repair some damaged tissue, but fish and salamanders can repair their hearts and maybe tenrecs can too.

Frank van Breukelen was interviewed by Kathryn Knight. The interview has been edited and condensed with the interviewee's approval.

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