Susanne Foitzik & Olaf Fritsche
THE SIX-LEGGED SUPERPOWER: THE HIDDEN LIVES OF ANTS

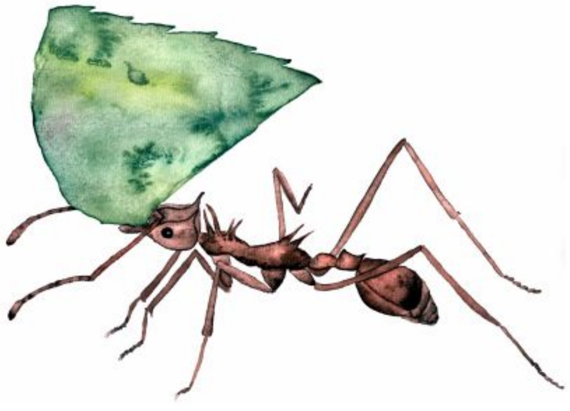
Rowohlt
October 2019
320 pages

On workers, soldiers and slavemakers.

Fascinating yet commonplace animals, ants have certain similarities to humans. They have developed forms of communication, social organisation and ways of dividing labour. They establish gardens and cultivate fungi, keep aphids as work animals that they protect against rustlers. They keep stores and move from one abode to another, wage wars and turn other ants into slaves, who in turn attempt to break free. They develop defences against pathogens, including vaccines. Many of their colonies are the size of an acorn, but some are thousands of kilometres across. After bees, ants are probably the most astoundingly complex of all insects.

Evolutionary biologist Susanne Foitzik, a world authority on ants, and biophysicist Olaf Fritsche have written a fascinating and informative book that tells us everything we need to know about ants. It offers deep insights into their social forms and explains their evolutionary development. Yet this richly illustrated book also describes the work of scientists. How do researchers study the behaviour of animals only a few millimetres in size? And what happens if you want to take an ant hill you've just excavated in Utah through customs? Readers of this book will never see ants the same way again.

- **Richly illustrated with 14 aquarelles and over 50 photographs.**



Susanne Foitzik is an evolutionary biologist and behavioural scientist. Her PhD focused on the evolution and behaviour of ants. After research stays in USA, she taught at LMU in Munich and is currently a professor at Johannes Gutenberg University in Mainz. She investigates coevolution between slaveholding ants and their hosts as well as behavioural manipulation through parasites. She also studies the evolution of aging and work roles in insect states. The results of her work have been published in over 100 scientific papers.

Olaf Fritsche is a biophysicist and science writer with a PhD in biology. After completing his studies, he joined the staff of *Spektrum der Wissenschaft*. He later became a freelance science journalist published in many newspapers, magazines and online publications, writing about the latest scientific research. Olaf Fritsche also writes university-level biology and medical textbooks. Rowohlt has published several of his non-fiction works.

Susanne Foitzik, Olaf Fritsche
WELTMACHT AUF SECHS BEINEN

The Six-Legged Superpower
The Hidden Lives of Ants

Contents

Small but powerful

They say that, from a great height, humans look like ants.
I lean forward slightly in my seat and look out of the window. The plane to Peru hasn't reached its travel height yet. Below us, streets, houses and fields are visible, cows on a meadow, villages every once in a while, further away a city. The comparison isn't bad at all, I think. Everything that I can make out from here, I've also seen in the ant world: solid paths, impressive constructions, agriculture, livestock farming. I sink back into my soft seat again. If you think about it some more, the parallels go much further. Like humans, ants live in states. In times of peace, they carry out their tasks based on a division of labour. Every ant has its job, from the nurses in the crèche, to the architects, construction workers and housekeepers in the nest, to the hunters and gatherers who ensure that everyone is fed. But even in the ant world, peace doesn't last forever. Neighbours get into arguments about where territorial boundaries lie and wage fierce wars with each other. Invaders swamp unsuspecting colonies. The weak are displaced and enslaved. Entire empires develop and decay.

Just like in our human world.

Not all queens are equal

Of course, these parallels don't imply that ants and humans are the same, or even that ants are a better kind of humans. Anyone who thinks that is mistaken. Many apparent similarities have even been brought into existence just because we imposed concepts from our human social order onto the organizational structures of ants. The queen ant, for example, has almost nothing in common with our monarchies' queens. Or do you happen to know of a queen who's literally the mother of all her subjects? We wouldn't be able to find the typical worker ant in our factories either. Still, we use the same terms in both cases because we don't have better words, and there's no need to complicate everything with new technical terms. Moreover, in the end the expressions do describe many of the ants' properties surprisingly well. We should just keep in mind that they aren't completely identical to their meaning in human societies.

Indeed, there's no denying the parallels between humans and ants. These similarities have usually come about in different ways - in the case of ants, because of natural selection, in the case of us humans, also due to the influence of civilization, technology and a moral value system - but often they are based on similar problems: How can many individuals live together in relatively small areas? How do groups compete for resources? How do we hold our ground in an environment fraught with danger?

Similarities and differences - perhaps precisely that combination makes ants so fascinating to us humans.

Enormously tiny

The most striking difference between ants and humans is certainly their size: ants are so much smaller than us. The largest specimens reach the size of May bugs, while the smallest aren't even as big as the dot on the i on this page. A tiny pharaoh ant, the Monomorium pharaonis, could easily enjoy a stroll on the head of the giant forest ant Camponotus gigas - a size ratio like between a mouse and a human.

Regarding the ants' states, we encounter size ratios similar to, for instance, the one between San Marino and China. The colonies of the slender ant Temnothorax, for example, only contain a few dozen animals and fit entirely into an acorn. The colonies of leafcutter ants, by contrast, can accommodate up to three million animals who live in underground nests the size of a house. Fully equipped with extensive rooms, corridors, ventilation systems, humidity control, waste disposal and climatic chambers to cultivate mushrooms in. A huge city with millions of inhabitants like Berlin, really, only completely underground. Would we humans also be able to not just create such a subterranean world, but also keep it alive?

In all these comparisons, we of course shouldn't forget that when referring to humans, we only ever speak about one species, the Homo Sapiens, whereas with ants, we're dealing with thousands of different species, with sometimes very distinct lifestyles. That's why exceptions and variants exist to almost all of the behaviours we will encounter in this book, or why these only occur in a few species at all. But in some respects, (almost) all ant species are alike. Thanks to these similarities, ants occupy such an unique position on this earth.

The secret to success

The secret to the ants' success lies largely in their outlook on life: "Don't ask what your people can do for you! Ask what you can do for your people!" A single ant would indeed be completely lost without its colony, and it is always willing to sacrifice itself for its people. Even the mighty workers of the tropical "bullet ants" or Paraponera clavata, who grow as big as hornets and whose sting is so painful that it can drive a person mad, die within just a few days if they can't find their way back to the colony. If ants act as a group, however, almost nothing can stop them. That's why even humans leave their huts when a convoy of tropical army ants passes through a farmhouse or village on a raid. Woe the poor pet that, because the inhabitants forgot, is kept on a leash or left locked up.

Another part of the ants' secret to success lies in their sheer number. Nobody knows how many ants there really are in the world. Some scientists estimate that there might be around ten quadrillion. If that's true, then there are one million ants out there for each human. If we assume that they are on average one centimeter long, then together they could form a chain which would stretch the distance from the earth to the sun and back 334 times. That's about ten times further than Pluto, which used to be classified as the solar system's outermost planet. These numerical games hint at how the tiniest contribution of a single ant can become a significant factor, due to the ants' enormous number. A single ant might not eat much, but all ants in the world combined kill countless tons of other insects every year. And although a single animal might just shift a few grains of sand, together they move entire mountains in the end. Moreover, this has been happening since ants came into being at least 100 million years ago, when dinosaurs still ruled the world.

A garden for millions of ants

When I was doing my PhD, I had a special encounter one morning. I was the first to arrive at the institute, and immediately noticed a procession of red ants making its way through the corridor in a long line. The workers each held a small, semicircular piece of rubber mat high in their jaws as they marched from the genetics laboratory to the climate chamber where their nests were located. Obviously, our leafcutter ants had escaped overnight and had started gathering new material for their colony at once. Since we had no potted plants, they had had no choice but to find a substitute that apparently at least reminded them remotely of leaves. I couldn't yet imagine what they had chosen. Only when I unlocked the door to the lab, following the industrious transport worker ants' trail, did I see a group of their sisters, charged with cutting material up, who had scaled the gel dryer and were busily carving the rubber mat loose from its cover, neatly transforming it into easy-to-handle pieces.

They simply dropped the cut pieces to the ground, where they were picked up and dragged away by the other workers. Just like leaf cutters do in the wild with real leaves. However, I had to interrupt our laboratory ants' work as quickly as possible, catch them and bring them back to the climate chamber. Fortunately, the damage they had caused wasn't too great. Still, for several years afterwards, we had to seal the holes in the gel dryer's cover in makeshift ways when using it. From then on, we double- and triple-checked whether the ants' nest chambers were really closed tight in the evening.

The flower children amongst the ants

When leafcutter ants aren't busy taking apart a German laboratory, they live in the American tropics and subtropics. The northernmost of the 47 species we know of so far is found in the warm US states of Louisiana and Texas, and the southernmost in Argentinian Patagonia. In Europe, they don't exist in the wild, but many zoos don't pass up the golden opportunity to showcase this crawling attraction and keep a colony with workers marching through transparent plastic tubes, holding their leaf flags up high as big and especially small visitors watch in amazement. Even the stores of a large outdoor outfitter use leaf cutters to attract customers who appreciate the ants' inspiring crawl when buying a sleeping bag and rain jacket. There's no doubt about it: Together with the driver ants, leaf cutters are the pop stars of myrmecology.

Both taxonomic groups also share the fact that indigenous tribes used the ant soldiers' sting to treat open wounds in the past, and that they are still on the menu of some tribes today. In Mexico and Colombia, the leafcutter ants' roasted queens are considered a delicacy, called Hormigas culonas, as well as an aphrodisiac - a somewhat strange honour for an animal species that only has sex on one day of its entire life. Curious to know how such a royal snack tastes? Crispy, salty, a little nutty and a little earthy. A doctoral student from South America once brought along a sample of red-black animals without their heads, legs and antennae. Not my taste, perhaps also because I silently regretted the fact that these leafcutter queens would definitely no longer form an ant colony.

In other respects, driver and leafcutter ants actually represent two opposite poles of the rich ant repertoire. While driving ants are pure carnivores without a long-term home, leafcutter ants are vegans who live in gigantic, permanent nests.

And what dwellings those are! But even a metropolis with millions of inhabitants starts off very small one day.

The birth of a megacity

The young leafcutter ant queens found their colonies the traditional way. During their wedding flight, they mate with at least five males, filling their sperm sac with about 300 millions of sperm cells. They then break off their wings and look for a suitable place for a new colony on foot. They prefer open terrain with little vegetation, as can for example be found on the edges of country roads. Here, the future mother digs herself about 30 centimeters into the earth and excavates a small chamber. On her last walk outside, meant to bring a mouthful of earth in front of the door, she catches some daylight for the very last time in her life. But she doesn't have the time to appreciate this moment, because there's a great deal of work waiting for her in the chamber. Not only does the young queen have to lay the eggs for the first generation of workers in the coming days and weeks, but she also has another task to complete, which is at least as important for the fate of the colony: she has to do some gardening.

In a special pouch in her mouth cavity, the queen has brought some fungal mycelium from her old nest as a souvenir. Not just from any fungus, but from a very specific type, around which all the work of leafcutter ants' work revolves, as we will see in a moment. If this fungus dies, the queen can save herself all further trouble, because no leafcutter ant colony can exist without it. Without the fungus, both the queen and her first workers would actually starve to death quickly. That's why she carefully places the fungal threads on the ground and fertilises them with a little liquid excrement - a dirty but extremely efficient method that has been boosting fungal growth for millions of years now. Only then does the queen lay her first eggs, a little further away.

After that, she divides her attention between the fungus and her offspring. The fungus soon forms a dense lawn, but eating it is still forbidden, both for the queen herself, who is living off her now useless wing muscles and her fat reserves, and for the larvae, who are fed eggs instead. Only after the workers have hatched, they are allowed to snack on the fungus. In exchange, however, they have to help with the gardening. They dig their way out through the closed entrance and start collecting leaves, which they chew up and carry into the chamber as a substrate for the fungus. Only two to three out of a hundred queens manage to get to this point at which they can transfer the day-to-day business to their daughters, so that they can concentrate fully on laying eggs.

For now, however, the queen's lonely home isn't anything more than a small family yet. Still, the goal is to form a gigantic nation that functions like a superorganism.

1000 rooms, three million residents

During its first year, the new colony struggles to survive. Its growth does not take off until the second year. Not just regarding the number of its members, but also regarding these members' size and the workers' total size. While the first generations were all still rather puny, gradually the larvae grow into more impressive ants, until four worker subcastes emerge in the end: the tiny minors, who stay in the nest their entire lives, cultivating the fungus, between whose threads they can scurry thanks to their minuscule dimensions; the slightly larger minors and the median workers, who are the most common in terms of numbers and who carry out almost all routine jobs, from collecting leaves to warding off enemy ants; and finally, the majors or soldiers, whose rearing and care require so many resources that only colonies with over 100 000 animals can afford these giants with the big heads. Despite the exorbitant costs, the investment is worth it, because majors can cut up leather with their jaws and can also easily bite through human skin, as countless ant researchers can confirm from their own painful experience. I must admit, however, that in such cases it's the human's own fault. Normally, leafcutter ants are extremely peaceful, but you shouldn't start digging up their nest.

In a fully developed colony, all workers live together in a nest that, regarding its population size, is so enormous that it would be like burying not only Stuttgart's railway station, but also two or three times its entire population, underground. Scientists like the Brazilian Luiz Forti used a drastic method to find out what exactly such a metropolis looks like: they cast entire nests in cement and excavated the resulting sculpture. Although it's easy now to write or read about what the researchers did, in reality it was incredibly difficult to accomplish. Firstly, they probably had a hard time trying to convince a construction company to deliver 6.3 tonnes of cement and 2000 litres of water to the middle of nowhere. And then everything had to be mixed into a paste so thin that it would flow through the fine passages rather than clog them. When the nest's structure was finally filled to the brim, they had to wait for the cement to set. For three solid weeks. Then, the delicate shovelling work began. An excavator would have been far too brutal and would certainly have destroyed part of the nest, so that all the effort would have been in vain.

Thus, like archaeologists, the researchers had to dig out by hand what was once a thriving civilisation. After many litres of sweat, it however became increasingly clear that their efforts were worth it. To such extent, even, that the researchers didn't just dig up that one nest, but gradually started digging up others too.

The casting of cement for scientific purposes has provided us with a fairly accurate picture of how a leafcutter ant colony is structured. The central part occupies about 50 square metres, which corresponds to about eight parking spots. That might not seem like much, but the ants apply the same principle with which New York fits some of its inhabitants into the tranquil area of Manhattan: They use the third dimension. Their corridors and chambers stretch up to eight metres into the earth. Usually, a nest consists of 1000 to 2000 chambers, but the record is 7864 cavities, ranging in size from a tennis ball to a football. In about one third of the chambers, researchers found ants or fungal gardens, while others served as waste dumps.

Yet these rooms are just one part of the ants' fascinating world. The infrastructure, which consists of different types of special tunnels, is at least as amazing. The passageways leading to the fungal chambers, for example, rise slightly, keeping them free from water during heavy downpours. But that alone isn't enough to keep the animals and the fungus alive. After all, both species consume oxygen through their respiration and emit carbon dioxide. Without a sophisticated ventilation system, all underground inhabitants would suffocate horribly. And indeed, the nest is surrounded by a circle of steep canals that arc from the lowest point to the surface, where they end in proper chimneys that provide an adequate ventilation. All together, several kilometers of corridors pass through the earth, and some of these tunnels lead to exits and satellite chambers at distances of almost 100 metres. If we include these outposts, large nests reach the size of several football fields.

The entire construction is so complex and ingenious that one would instinctively assume an experienced architect to be behind it, yet the ants built it all without a plan or complicated computer simulations. With nothing but their small brains, the sensitive sensors on their antennae, and several dozens of millions of years of evolution.

Two to three million ants live in these subterranean megacities. For the species Atta sexdens, scientists even calculated about eight million animals once. And all of them are all dependent on one single fungus.

The fungal issue

Leafcutter ants experience a problem that many vegetarians have to deal with: they can't digest cellulose. Unfortunately, however, plants are made up for a large part of precisely that cellulose, and vegetarians would starve if they couldn't somehow delegate the job to someone else. Hence, rabbits, cows and to a lesser extent even we humans harbour microorganisms in our intestines. They easily decompose cellulose into other substances, which we then absorb. Alternatively, we just digest the whole microbes at once. For this, leafcutter ants, with their short intestines, have joined forces with a relative of the mushrooms that belongs to the genus which scientists call Leucoagaricus. They regularly supply their fungus with fresh plant substrate, keeping it moist and clean. In return, the ants can harvest the nutrient-rich swellings, called gongylidia, at the ends of the fungal filaments. Especially the larvae are completely dependent on this protein-rich diet, while the workers can make do with the sap of the leaves if need be.

That's how the deal works, but the ants have to work hard to put it into practice. First, they send out scouts to look for suitable shrubs and trees close to the nest. In doing so, they ignore plants that are poisonous to the fungus, and instead search for juicy leaves or, at times, colourful flowers. How the scouts know what exactly the fungus needs is still an unsolved mystery. After all, they have practically nothing to do with its care and therefore can't see to which plant the fungus reacts in what way. Nevertheless, they discover the ideal stuff for fertilisation with dreamlike certainty, and make a scent track from there back to the nest.

The work crew thus knows where to go, and a chain of finely tuned work steps, that can't be found anywhere else in the animal kingdom, is set into motion. The leaf cutters start off the process. They climb the plant that needs to be harvested and break off large pieces from the leaves with their mighty jaws. Their approach is less like the cutting of scissors than like the use of a Japanese saw. Their one jaw supports itself on the leaf, like our free hand would on the cutting board, while the other jaw cuts through the greenery from bottom to top. If the worker judges the leaf to be particularly suitable, she beckons more sisters to join her on the sheet by making knocking noises with her abdomen. The cutters often simply drop the cut pieces to the ground, where the transporters are already waiting for them.

The next step is the popular relay race with leaf flags to the nest. Raised high above its head, the average transport worker carries a piece of leaf that's similar to a human carrying a weight of about 300 kilograms. At a speed that, in the human world, would do a world-class marathon runner proud, it runs along a carefully cleared stretch towards the nest. If the way is long, it hands the relay flag over to a colleague, who covers the next section with it, until the last runner finally deposits the leaf at the nest's entrance. There, minors set to work on it, biting it into smaller pieces which are subsequently reduced further in several stages. Eventually, minors chew the shreds into a pulp, with which they look after the fungal threads.

According to scientists, it takes up to 29 work steps to harvest the leaf pieces. An enormously time-consuming task, considering that though some of the workers ingest some plant sap during their work, the leafcutter ants don't actually subsist directly off the leaves, but rather take care of their fungal gardens with it. The well-being and suffering of all the millions of colony members depends on this fungus. It thus isn't surprising to find an army of small specialists looking after the gardens day and night. Ironically, the smallest subcaste shoulders the responsibility for the colony's survival.

Advanced gardening

It's no coincidence that the minors are tiny - they have to be that small. As the colony's gardeners, they have to be able to crawl into even the most hidden corner of the fungal network. With its interwoven threads, that network forms a real cave system similar to the one we know from natural bath sponges. The minors scuttle through the tunnels, checking the condition of the fungus. They feed it the chewed leaves, lay the foundation for new cultivation areas, and again use liquid manure as a fertilizer. From time to time, the gardeners nibble the tuberous gongylidia at the fungal threads' ends and distribute them to the larvae and their sisters. It's a process of giving and taking which benefits both sides.

But even the best cannot garden in peace if evil weeds have different plans. The fungal gardener's worst enemy is the sac fungus Escovopsis, which always lies in wait for an opportunity to infest the fungal culture and thus to spoil it for the ants. In young leafcutter colonies, about every fifteenth fungal culture is already infected, and the parasite spreads so rapidly that after one to two years more than half of the fungal cultures are affected. In really bad cases, the infestation can be so severe that the ant colony has to leave its entire nest, in which it has invested many years of hard work, and start all over again.

To make sure that doesn’t happen, the minors remove all spores and threads of foreign fungi on their patrols through the network. The workers, who might be carrying various pathogens on their cuticles because of their travels outside the nest, aren’t allowed to enter the fungal gardens at all. And dead ants end up in special waste chambers, just like leaf remains and parts of the fungal network that have died off. Old workers make sure that the waste is disposed of, and they also turn the decaying material around more often, so that it decomposes more quickly. Like in our human world, they receive little thanks for this important task: the garbage disposers are shunned by their sisters and are no longer free to move through the nest, to avoid the spreading of Escovopsis spores. Still, these preventive measures alone wouldn’t be enough to keep the parasites away from the fungal monoculture. The ants have another trick up their sleeve for this - and a special kind of ally.

Like true chemistry experts, leafcutter ants regularly wield their chemical clubs in their gardens. The minors of the Acromyrmex octospinosus species use their metapleural gland, which is located at the back of their breast, to produce a secretion with more than 20 components that they distribute on the fungi. Among the substances is the growth hormone indoleacetic acid, which stimulates the fungus to grow as fast and as densely as possible. In addition, there are antibiotics and antimycotics, which the ants can’t synthesise on their own at all. Indeed, the true producers are symbiotic bacteria that live on different parts of the insects' bodies, depending on the ant species, and feed on glandular secretions. In the leaf cutters’ gardens, a wrestling fight thus takes place between four parties, a fight that probably exists nowhere else in the animal realm: the ants take care of a fungus, which is threatened by another fungus, which the insects fight off with determination, helped by bacteria. This battle has been going on for over 50 million years. Back then, the ants probably cultivated the first fungi, starting a growth so successful that neither the leafcutter ants nor the fungus could still exist on their own today. And almost right from the start, both the parasitic fungus and the bacteria must have been part of this never-ending game, in which one side invents new tricks and the other side counters. A tightly connected co-evolution with an exceptionally high number of participants.

Inside swank, outside rank

The leafcutter ants thus ensure that their underground gardening is a success through dedication, chemistry and allies. But how does their above-ground agriculture look?

Two words: pretty bad! Inspired by the motto "there’s only room for one gardener", leafcutter ants ruthlessly defoliate entire fields of fruit trees, citrus fruits, cocoa, cotton, coconut palms and many other agricultural crops. To trim a lemon tree down to its bare structure, a colony only needs 24 hours, consuming as much greenery as a cow along the way. In the Brazilian state of São Paulo alone, the insects cause damages of 130 million dollars a year that way. And there's almost no way to stop them. The only thing that helps is a protective circle of waste from the ant nest’s waste chamber. The fear of dragging the parasitic fungus into their own garden prevents the leaf cutters from entering the protected area for about a month. But you can't order this miracle cure online: you’d first have to dig your way to a waste chamber.

Plantation owners therefore have little positive to say about leafcutter ants, and cattle breeders too are scared of them. In some areas of South America, species have specialized in blades of grass as a substrate for their fungi. To avoid being eaten as bycatch by grazing cattle during the harvest, these ants have pointed thorns on their backs. Biting into such a walking cactus obviously causes pain to the lips and tongue, which is why the cattle avoid fields with leaf cutters.

Understandably, the leafcutter ants aren't very popular with farmers. In the natural world, however, they play an important role despite their uncompromising harvesting practices. Like all ants that live in nests in the earth, they air the soil with their tunnels and bring in, thanks to their leaves and fungi, numerous nutrients that would otherwise only be found close to the surface. This makes the jungle soil up to ten times more fertile. Ants are hence very useful to the ecosystem - you just shouldn't get in their way.