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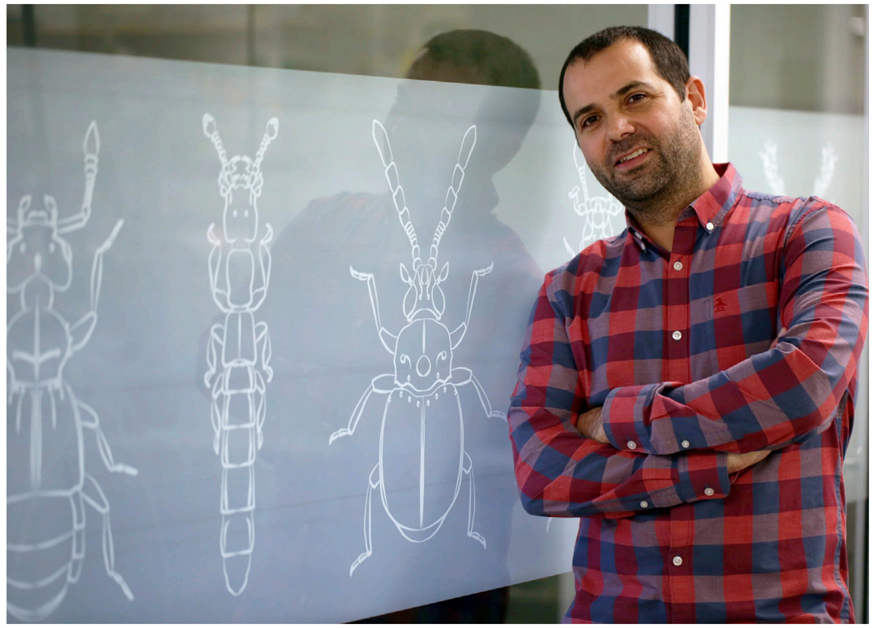
Q & A

Joe Parker



Joe Parker is an Assistant Professor of Biology and Biological Engineering at California Institute of Technology in Pasadena, USA. He studies rove beetles and their interactions with social insects to understand how relationships between species emerge during evolution.

Your lab studies rove beetles, but your insect fixation is more ancient. How did it start? I can pinpoint the moment: walking with my dad through the National Museum of Wales in Cardiff when I was seven. There was a display of all the insect orders, example specimens accompanying each one, with details about morphology and lifestyles — a wonderfully rich exhibit of the old school kind where the specimens take center stage (too rare in modern museums). One insect shook me: a gigantic cicada, three inches long with big, membranous wings. The absolute otherworldliness of this thing — equal parts mechanical, grotesque, and… beautiful?! In my seven years I hadn't encountered anything so mesmerizing, and I had to know more. But one of the first things that you learn as a cicada fan growing up in Swansea, South Wales, is that they are not to be found in the UK. In the late 1980s, our one native species, *Cicadetta montana*, was already almost extinct. So, the cicada obsession gave way to an interest in arthropods closer to home, plus tropical stuff that I could keep in my bedroom — stick insects, katydids, scorpions, and a tarantula, kept warm with half a dozen tungsten light bulbs.

How did the leap to rove beetles happen? Looking back, one of the best things I did was to join the UK Amateur Entomologists' Society (AES). In the early 1990s, the AES junior section was run by Darren Mann, now at Oxford University Museum of Natural History. Darren led field trips for junior members, and these were brilliant — a bunch of unruly kids with nets and pooters crammed on a minibus, careening to field sites to dutifully search for cool insects. I can't stress how formative these trips were. I was mentored by Darren as well as other entomologists and learned masses, including how to do fieldwork properly, the taxonomy of challenging groups such as rove beetles, and the basics of systematics and ecology, all while being exposed to museum collections and the research going on inside them. I was a bit unengaged in school and more interested in blasting Public Enemy and doing graffiti, but this alternative, entomological education held real meaning for me. I'm forever grateful to Darren and am but one of his AES progeny with similar stories. I gravitated toward beetles, which were omnipresent, diverse, and beautiful. Eventually, I focused on Staphylinidae — the rove beetles.

Why the inordinate fondness for staphylinids? Haldane could have been referring to *just* staphylinids when he noted the Creator's "inordinate fondness for beetles". Rove beetles are an evolutionary phenomenon: there are 64,000 species of these (mostly) tiny, predatory insects, and these are just the ones we know about. The true number could be 10 times higher — suffice to say, there are *a lot* of rove beetles, and they've squeezed into every terrestrial niche imaginable (plus some transiently submerged coral reefs!). But, from my point of view, the most interesting aspect of rove beetles — and the reason why I stuck with them, ultimately building a research program around this family — is that many species are myrmecophiles.

What-ofiles? Myrmecophiles — "ant lovers" — are symbiotic organisms that live inside ant colonies. This lifestyle has arisen perhaps hundreds of times across Staphylinidae. To me, myrmecophiles are wonders of nature: supremely specialized organisms capable of inserting themselves into the social fabric of nests that are otherwise fiercely policed against intruders. They gain their unknowing hosts' acceptance with remarkable (and often convergent) traits for chemical and behavioral deception, and many species are jaw-droppingly strange to look at: ant-like body shapes, fusions of segments, losses of eyes and wings, and glands springing up everywhere. I would open a drawer of staphylinids in an insect collection, or turn a page in a book, and one specimen would catch my eye — the rare and enigmatic myrmecophile, alone by itself, the odd one out. You cannot help but ponder these creatures and their morphological deformations. How is *that* possible? What turn of events happened in the history of *that* thing's lineage? On learning what's known of their behaviors, the rest of the biological world sort of fell away for me. The idea that evolution could produce these obscurities, and that what I was looking at in these beetles' anatomies was actually biological stealth technology, was miraculous; I felt like there were few more interesting things out there.

Wait, wasn't your PhD thesis about fruit fly embryos? It was! To get where you want to be, you sometimes need to take a detour, and I took a pretty big one: from rove beetles to flies and back again. This happened on realizing that, to do something meaningful with rove beetles, I needed better knowledge of genetics and model organisms. I was a zoology undergraduate at Imperial College, around the corner from London's Natural History Museum (NHM) where Alfried Vogler leads a group focused on beetle molecular systematics. Alfried was very generous in allowing me to try reconstructing the phylogeny of a major clade of rove beetles, the subfamily Pselaphinae. I would run to the NHM between lectures, setting up PCRs and running gels, and made early ribosomal DNA trees of this massive group. These did a not-too-bad job of resolving relationships. Moreover, they revealed a pattern, where the myrmecophiles were dispersed across the tree. The beetles had evolved this lifestyle, with its behaviors and morphologies, convergently.

This was fascinating to me. I started to wonder how it might happen mechanistically. The morphology in particular was so immediately alluring, a lot of it down to changes in sizes and shapes of segments as well as limbs. What were the mechanisms on which evolution had acted to remodel the rove beetle body into a myrmecophile? I read a review by Peter Lawrence, then at the MRC Laboratory of Molecular Biology in Cambridge, arguing how organ size might be controlled by morphogen gradients but that the mechanisms were a real mystery. I was thinking about potential PhD projects and seemed to have hit upon a 'big question'. I e-mailed Peter, explaining how I'd wandered into this problem by studying rove beetles. Peter is an incredibly thoughtful and perceptive scientist, with a biological intuition of which I am envious. I was very naïve about genetics and development, but Peter gave the sense that these inadequacies were secondary, and that finding a biological problem — one with real mileage — was far more important. Pursuing this problem in *Drosophila* was perhaps the path forward. Plus, I could gain expertise in genetics and molecular biology with an eye to returning to rove beetles when the time was right. So, I went to Peter's lab and worked on how abdominal segment size is controlled during fly embryogenesis (leading to my thesis paper, published in this very journal).

How did you return to rove beetles? The *Drosophila* detour was intentional, but I was naïve about how long it would last. I joined Gary Struhl's lab at Columbia University as a postdoc and continued working on growth and size control in flies. Gary — who incidentally was another of Peter's students — is the most ingenious experimentalist. He attacks problems relentlessly, and from multiple directions, deducing mechanisms for which all possibilities of generating counterevidence have been exhausted. It was hugely influential to work with him, experiencing his tireless creativity and high bar of proof. During this period I set up a microscope in my NYC apartment and began working with increased intensity on rove beetles again, mostly on their phylogenetics and fossil record, the latter partly in collaboration with David Grimaldi at the American Museum of Natural History. It became a sort of double life — flies by day, rove beetles by night — and I'd ruminate about how I might move fully back into staphylinids in a satisfying way. By this point, questions beyond just morphology had taken hold. What was happening in the brains of these beetles to enable them socially to interact with ants? How did their glands and chemistries evolve, permitting them to communicate with and deceive their hosts?

It started to dawn on me that rove beetles might embody something more fundamental. I think that, for many biologists, why a question or an organism or a clade is truly interesting crystallizes long after that first, instinctive rush of intrigue. It happens when one considers what that question/organism/clade really encapsulates (subconsciously, it's probably the very same thing that prompted the initial fascination). And it was only while I was a postdoc (in a fly lab!) that I recognized how rove beetles — beyond the intrinsically captivating myrmecophiles — represent something more general. As a clade, they do something exceptionally well, which is to interact and forge relationships with other animal species, and to evolve new means of doing so. And, it serendipitously turns out, they do these things in ways that lend these beetles to powerful experimental approaches and deep evolutionary inferences. When it comes to understanding how animals ecologically interact with each other, carving out existences in living landscapes full of other species, rove beetles are a hard clade to beat. They are the animal kingdom's virtuoso interactors.

All of this is to say… what exactly? That there was a larger point to studying them. They were a model system hiding in plain sight, with a trove of questions impossible to address in current model organisms. And, eventually, a way back to them found me. I discovered that several biological control companies had started to sell a species of rove beetle, *Dalotia coriaria*: a ravenous predator of greenhouse pests, such as fungus gnats and thrips. Buy a tub of 10,000 *Dalotia*, bye-bye pests. This was a revelation to me for two reasons. First because *Dalotia* is free-living but sits within a clade — Aleocharinae — that has sprung more lineages of myrmecophile than any other group of Staphylinidae. This extreme convergence points to an underlying predisposition — a potentiation — in the genomes, brains, and various dimensions of the phenotype of free-living aleocharines like *Dalotia*, poising them to evolve into symbionts. In all ways that matter, *Dalotia* embodies the evolutionary starting conditions to transform into a myrmecophile. It held the secrets that I was searching for. Second, if this beetle was being sold commercially, I must surely be able to grow it too…

A rove beetle* Drosophila*!? Close enough. I got hold of some and, lo and behold, it was easy to keep, laid lots of eggs, had a small genome, and — as we now know — is tractable genetically. I'm not sure how things would have panned out had it not been for this creature. Such is the importance of luck throughout one's scientific career. My postdoctoral side-hustle with staphylinids became my job talk, and a lot of projects in my lab now involve *Dalotia.* One of our goals is to understand the molecular, cellular, and phenotypic predispositions that

Current Biology
Magazine

underlie the convergent transition to myrmecophily. Our work is comparative, and *Dalotia* is a free-living template used in conjunction with myrmecophilous counterparts that we both collect in nature and culture in the lab. A major focus is on behavior and neurobiology. For example, how does *Dalotia* detect ants and evaluate them as threats, releasing chemical defense behavior? How have myrmecophiles undergone this dramatic reversal where they are now attracted to ants and socially interact with them? Both free-living and symbiotic staphylinids are brilliant behavioral subjects, executing stereotyped interactions with ants so readily that they can be studied quantitatively and in high throughput — the closest one can get to animal partnerships in petri dishes. In parallel, we study these beetles' chemistries, from the evolution of novel secretory cell types and glands to the compounds they produce and their impacts on ant behavior. The two things complement each other — our understanding of chemistry informing behavioral experiments and yielding tools to manipulate the interaction.

What is it about species interactions that you find so intriguing? It's not controversial to say that interactions are a major driver of evolution, shaping organisms all the way down to the subcellular level. Microbiologists know this very well — studying interactions is front and center in their discipline — but it's a much more universal truth. It's in the context of species interactions that animals have engineered new chemistries, reconfigured nervous systems, built entirely new organs, and invented ways to subjugate other species. But animals in general — even species we don't think of as symbiotic or exhibiting some kind of specialized relationship — are impressive in somehow being able to recognize and interact with the myriad other species they encounter in their daily lives (and not necessarily species with which they have coevolved).

This ability to effortlessly navigate the living world is so routine that it's almost taken for granted, but it's a hallmark of a metazoan existence that we know stunningly little about. Coexistence within highly species-dense animal communities, such as leaf litter or coral reefs, is striking and implies that interactions have molded many dimensions of animal phenotypes. And, of course, it's from this condition that nascent interactions of a more intimate nature arise. One of the biggest mysteries to me is comprehending how pre-existing attributes predispose organisms to fall into relationships with other species, and then, after that happens, how their genomes and phenotypes bias subsequent evolution, leading to the more blatant, obligate interactions we observe. Rove beetles are valuable in that they've traveled along this road many times, from highly competent generalists to profoundly specialized symbionts, following somewhat parallel paths of exaptation and adaptation (and I suspect drift — likely pronounced in the numerous obligate myrmecophiles with seemingly very small populations).

You went from working on a classical model system to trying to develop a new one. How can biology become more accommodating of organismal diversity? Virtually everything we study in my lab stems from scattered behavioral observations and evolutionary insights by earlier staphylinid workers, most of whom were taxonomists. Without these fragments, we'd have nothing to go on. I think that biology, as a field, would benefit from an increased connection with natural history. Otherwise, we risk being confined to knowing about a narrow slice of the biological world, and hence missing out on a huge potential for human understanding. The last decade has seen an uptick in new model systems, but funding is still problematic when the framework for justification remains so anthropocentric. It's certainly also the case that getting a new model system off the ground takes luck — you may be fighting against the biology of a species that won't obey — but there need to be greater incentives for even trying. More problematic still is our failure to invest in taxonomy and natural history themselves — the two preconditions for working on new organisms and questions. Without them, we're in the dark about what an organism is and what it might do. Nobody would get to study killifish aging, deer mouse behavior or *Aplysia* LTP without some prior inkling about these organisms, as well as of what even constitutes a species of killifish, deer mouse or *Aplysia*. Taxonomy and natural history are foundational for branching out into new systems, but this knowledge is now held largely in the minds of a dwindling number of experts, with few mechanisms for its generational transmission. We undervalue these disciplines, but a rich synergism could come from integrating them into modern training in both molecular and computational biology.

What does the future hold for your own symbiotic relationship with rove beetles? Rove beetles are ecological dark matter — a megadiverse, massively abundant group of which we know embarrassingly little. But it's telling that these insects have exploded in modern, ant-dominated ecosystems and evolved to infiltrate colonies many times over. As fascinating as ant social behavior undeniably is, its consequences for all the other organisms in the biosphere are just as profound, and rove beetles are a compelling success story — a clade seemingly outfitted for ant coexistence. I would say that a long-term challenge is to connect what we find in the lab about mechanisms with how these interactions play out in nature. We are just starting to move into field-based studies of ants and their organismal interactions in Southern California. One motivation is an acceptance that we don't understand the functional relevance of these relationships. Reports of insect declines are distressing, and ants are so integral to modern ecosystems that gauging the importance of species with which they interact is critical. The diversity of such taxa implies that, in totality, they are likely significant. No doubt many interactions are sensitive to disturbance. Selfishly, to lose any one of them would make for a less interesting planet on which to live.

Lastly, outside of insect-related activities, what can you most often be found doing? Teaching my three boys — Jonah (6), Eden (4), and Oscar (2) — how to beatbox (hyped up by my wife, Heidi). If, for some reason, the science doesn't work out, managing this talented hip-hop act is a possible back-up plan.

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