When ants can

High in Panama's rainforest, a field biologist made a discovery that has opened up a new branch of science and a new understanding of the evolution of flight. By Kenneth Brower

On Barro Colorado Island in Panama, at the turn of the new millennium, Stephen Yanoviak had the first half of his epiphany. He was high in a rainforest tree, sharing a branch with workers of *Cephalotes atratus,* a large, dark, spiny, heavily armored ant. Yanoviak is an experienced and circumspect climber, but now and again, inevitably, his hand would come down on an ant. At the prick of the spines, he would brush the insect away. It would fall from the branch into the void.

"I was working on a project involving the ecology and behavior of ants," he said recently, over the office chatter of Peruvian colleagues in the jungle town of Iquitos, his base in the upper Amazon. "When I was up there, gathering data, there were long periods when there wasn't a lot to do. I

just had to sit around and watch ants eating different kinds of leaves. And like anybody who works up in high places, you get a kind of an obsession for the way things fall. And so I started dropping ants off the tree. And I noticed that some of them weren't falling all the way to the ground."

As a 10-year-old, in the suburbs of Philadelphia, Yanoviak was obsessed with insects, snakes, frogs, and anything else that hopped or crawled. He spent a great deal of time catching crayfish. "For as long as I can remember, I've liked being outside. I've always had a fascination for very small things and how they work and live, he says" This is common testimony from field biologists. Few can remember a pivotal episode. None can recall a time when they were not mesmerized by the natural world. The great E.O. Wilson, dean of the ant people, calls this predilection "biophilia," and Steve Yanoviak arrived with a congenital case of it. Chronologically he is now 37, but spiritually, by his own estimate, he remains about 17. He wears a ponytail; earlier in his exploration of the tropical canopy, he climbed his trees barefoot.

Yanoviak was excited by his observation of the non-random fall of ants, but he had no funding to prolong his stay in Panama, and he was deep in what he calls "Finish Dissertation Mode." The dissertation was on phytotelmata, "plant-held waters," in Panama's rainforest trees. He moved his observation on gliding ants to a back burner, where it cooled and then went cold.

Five years later, he found himself in the lowland rainforest of the Peruvian Amazon, managing the fieldwork for a National Institutes of Health virus study. Again he was investigating phytotelmata. In the tropical forest, rainwater

fly

fills hollows in trunks, branch crotches, basal leaves of bromeliads, bracts of heliconia, and the basins provided by the giant woody caps of fallen tropical nuts. Giant damselflies and poison-dart frogs hunt these microcosms, which are populated mainly by mosquito larvae. One mosquito common in the Peruvian canopy, *Haemogogus janthinomys,* is a vector of yellow fever. Many unsuccessful attempts have been made to breed the species in the laboratory. Yanoviak was collecting as many blood-fed females as possible to get a lab colony started. His technique was to offer the females the blood meal of himself.

One day in the forest a few kilometers outside of Iquitos, he selected a tree of the genus *Parkia,* which is widespread in Amazonia: a group of giant legumes, with broad, flattened crowns and big, black seedpods hanging at the ends of long peduncles. With a slingshot, Yanoviak fired a weighted fishing line over a high branch. He attached a clothesline to that leader, pulled the clothesline over the branch, and then followed the clothesline with a climbing rope. Clipping his Jumars to the rope, he ascended. One hundred feet above the ground, he reached his destination branch, which was pale, smooth-barked, and about 18 inches in diameter. He was immediately greeted by the residents.

"I ran into a colony of these same ants, *Cephalotes atratus.* This time they attacked me. They nest in hollow living branches of the tree, and I guess I was sitting right on top of their nest. Hundreds of them were running all over me and all over the branch I was sitting on. They don't sting, but they gnaw on you, and they become more or less unbearable. Basically I tried to give myself an ant-free place on the branch to put my hand down. I brushed a bunch of ants off, and watched them fall."

Several meters below the branch, the falling ants became a squadron and glided back into the trunk of the tree.

Yanoviak was transfixed. He instantly remembered the gliding ants of Panama. No one, to his knowledge, had ever written about wingless flight in insects. Here in Peru, with this second heavy hint from the tropical forest, he realized that he might be onto something.

Returning to the tree the next afternoon, he began painting the ants with white nail polish. He daubed the polish on different parts of the ants, so as to clarify whether they were falling belly up or belly down, head-first or tail-first. He dropped his subjects and videotaped them with a small digital camera.

"The second big epiphany for this project was when I saw white-painted ants walking past me on the same branches they were dropped from, a few minutes later. *They were doing this on purpose.* They were trying to get back home."

As Yanoviak's nail-polished ants, *Cephalotes atratus maybellinus,* marched by him on the branch he fell in behind, figuratively. The ants changed the direction of his career and they opened a new field of science: the study of flight in wingless arthropods.

"He just sits for hours up in the tree," mused Professor Robert Dudley, reflecting on Yanoviak. Dudley teaches at the Department of Integrative Biology at Berkeley, where he specializes in biomechanics and the evolution of animal flight. "That's why he's seeing a lot more than most people. Orangutans swinging by, everyone notices that, but Steve has got an eye for subtle things. He's a classical sort of field naturalist. He's at home in the canopy; very comfortable there." Dudley paused. "But it's hard to do it forever," added the professor, who was trying to lure his young colleague down from the treetops. "We're trying to get him here, as a three-year post-doc."

Dudley, himself afflicted by scientific wanderlust, chronic and irremediable, does his fieldwork at all latitudes and altitudes, yet one place he finds himself returning again and again is Barro Colorado Island, where Steve Yanoviak had his first brush with airborne ants. Dudley first heard of Yanoviak's ants there. After his second brush with the ants in Peru, Yanoviak conferred with an ant-ecologist colleague, Michael Kaspari, who suggested a collaboration with Dudley.

"Me, Mike Kaspari, and Steve Yanoviak, we were just hanging out in Panama," Dudley said, sitting in his office in Berkeley. "Mike said, 'What do you know about gliding ants?' I thought he was joking. There's no such thing. But then I talked with Steve and I thought, 'This is the most exciting thing since sliced bread.' We decided to start working on it as soon as possible. It has huge implications for the evolutionary origins of flight in insects."

The three men did their first joint fieldwork in Peru. In the treetops outside of Iquitos, they shanghaied workers of *Cephalotes atratus* and dolled them up with white nail polish. Gripping the ants in mid-thorax with forceps, they held them a few centimeters to the side of the branch, and dropped them, one after another. Each fall came in three distinct stages: first a vertical plunge, second a rapid directional adjustment and body alignment towards the tree, and third a steep but directed glide to the trunk. The flight path was J-shaped. Eighty-five percent of the ants never reached ground. By painting the gaster (the final body section) and hind legs white, the researchers determined that in the adjustment phase, the ants align their abdomens toward the trunk and sail in toward it, topside-up and tail-first. This was the first record of any macroscopic animal gliding backwards on purpose.

"We don't have many examples of backward locomotion," said Dudley. "Some eels go backward. But it's just not out there as a concept. Backwards locomotion. *We* are certainly not designed for it." Dudley smiled one of his fleeting smiles. The professor is a trim man, 45, with semi-curly hair of indeterminate color and features just beginning to weather from a life in

the field. He speaks rapidly, trying to keep pace with his thoughts, and sometimes the words run together.

"The ants glide in abdomen-first with their legs outstretched. Clearly, they're kind of doing what skydivers are doing—slight postural rotations." Sometimes the ant glides in to the near side of the tree, other times it sails around to the backside. Occasionally an ant will head—or tail, actually—toward a brightly lit patch of leaves, then realize its mistake, execute a sudden 180-degree turn, and glide back toward the pallor of the trunk. If spooked by a foreign object, an ant will voluntarily drop from the branch, casting its fate to the wind. Ten minutes later, it is back up on its branch.

The three researchers suspected that visual cues were guiding *Cephalotes* workers in their sail back to the trunks. To test this, they blinded ants by painting their eyes over with white enamel paint. These specimens, as expected, fared poorly. They then set out to identify the precise cues. From the railing of the canopy, they unfurled five velvet sheets, each one narrow and 10 meters long—an abstraction of a tree trunk—and each in a different color: red, black, blue, yellow, and white. In one experiment, they substituted green for blue, and in others they tried shades of gray. It was a beautiful convergence of science and art. "Cristo in the rainforest," Robert Dudley said of their rainbow curtains.

To correct for any skewing effects in the method of launching of the ants, the team dropped the insects in different ways. In the Long John Silver Method, the ant was made to walk the plank—a stick projecting from the railing above the hanging sheets—its retreat discouraged by a barrier of toothpaste.

As predicted, the ants showed a strong preference for gliding toward white sheets, and after that, toward the lighter shades of gray, like the lichen-covered bark of rainforest trees. The red sheet performed poorly. It seems that *Cephalotes atratus,* like most insects, cannot see red.

"You don't need wings in order to fly," Dudley summarized. "Ants are derivative. They are very recent, relative to other insects—they don't turn up until the Cretaceous—so they're not the missing link, or anything. They just demonstrate feasibility. Or plausibility. It looks as if in insect evolution, controlled aerial behavior precedes the origin of wings."

The evolutionary implications are important, and Yanoviak and friends have given us a new fable, besides. As a rule, the parable of the social insects is told as a cautionary tale: The hive, the nest, the termite mound are evoked as warnings about the direction human society is headed. So it is cheering to learn that individual workers of *Cephalotes atratus* are not, after all, just expendable cogs in the machine. Their lives are regimented, surely, but not entirely bleak and Orwellian.

"Ant workers, even though they're reproductively sterile, are valuable," said Dudley. "There's something clever going on."

In other recent trips to Peru and Panama, the team of Yanoviak, Dudley, and Kaspari doggedly dropped small creatures from the trees. They discovered that *Cephalotes atratus* is not the only gliding ant. Most species of its tribe, the Cephalotini, seem to be gliders. The tribe has a number of pre-adaptations that facilitate gliding, among them long, flattened hind legs that seem to have a winglike function and a broad, flattened head, flaring toward the neck, that may serve as a rudder. "We're doing ablation experiments, removing some legs and other parts," Dudley said. "*Cephalotes* workers can do this—glide back to the tree—without the *abdomen,* which is really weird. It's 40 percent of their weight. They compensate with leg motions."

"Larval stick insects and larval mantids—praying mantises—are gliders, too," Dudley said. "We also dropped some larval grasshoppers, which look like adult grasshoppers but just don't have wings until the final molt. They're up there in the trees, and they can also do this gliding behavior. There are larval homopterans—aphid relatives—that do it, as well. And larval cockroaches. All the basal insect groups that we've looked at, thus far, have at least some representatives that do this. And spiders. There are some arboreal spiders that Steve's been working on in Panama. They're really flattened—they live under bark—and they're kind of crablike in shape, with these legs sticking off to side. You drop them, and they go headfirst at this beautiful 45-degree angle, whoosh, straight back into the tree trunk." He paused, considered. "*Scorpions* don't do it. Basically we're dropping everything."

The team removed different appendages of silverfish to test the effect on glide performance. Every amputation degraded performance somewhat, but some proved much more degrading than others. The removal of antennae seemed to have small effect. The progressive removal of the three long terminal filaments had a large effect, impairing glide performance in a dramatic way. It appears that silverfish are

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primarily ruddering with their tail streamers.

Who ever dreamed that silverfish, those primitive, slithery, soft-bodied, silver-gray habitués of book bindings and bathroom sinks might deploy their tail filaments to slip the surly bonds of earth and fly from the trees? It turns out that the myths of Icarus, Pegasus, Peter Pan, Superman, Dumbo the Elephant, Santa's reindeer, and the like, are more archetypical, even primordial, than we imagined. The dream of flight dates back at least 300 million years. The dream illuminated, in a dim-witted way, the tiny paired ganglia of the arthropod brain, on that great day late in the Paleozoic, 100 feet above ground, on the leaf-scarred trunk of a giant scale tree, when some Orville Wright of a silverfish looked down on the steamy coal-swamp forest below and asked itself, Why not?

FOR 15 YEARS, STEVE YANOVIAK HAS climbed trees everywhere he's gone. Over time, he has ruthlessly pared away all excess from the small lumbar pack he carries up into the trees with him. His first two digital cameras were casualties of the heights and he is now on his third. Occasionally he brings a video camera and small tripod. When he first started climbing trees, he wore hiking boots, but these provide poor traction in rain, when branches grow slippery. For a time he climbed barefoot, which gave him a better grip on the branch, and of late he has shifted to socks, for the modicum of protection they offer against bites and stings.

Yanoviak has never had a serious fall from the trees. "Mostly just what rock-climbers call 'whippers,'" he said. One time, in the Costa Rican cloud forest, he climbed in very dry weather into the canopy, worked happily for a while, and then was ambushed by a tropical downpour. He was wearing a sweatshirt and jacket against the cool of the cloud forest. As these garments became waterlogged and grew heavier, so, too, did the leaves of the branches supporting his rope. The branches broke, sending him on the first 20 feet of a death plunge before secondary branches arrested him. On another occasion in Costa Rica he went off the end of a branch, plummeted, was arrested by his security rope, and pendulumed through mid-story crowns safely back to the trunk.

"I love it here," he said of the upper Amazon. "It's challenging, culturally, to be transplanted to the tropics, because I grew up in the States. I've been down here for nearly 15 years, but it's still a different lifestyle. I miss my family. But I love what I do. This is where I'm happiest."

Today Yanoviak, on the verge of a new life in the halls of ivy of the Northern Hemisphere, faces an irony common in the careers of outdoors professionals. Naturalists enter the National Park Service or Forest Service or Bureau of Land Management or become rangers in the state parks, because where they are happiest is out under the sky; yet to advance in their calling, to earn salary enough for a mortgage or to send a kid to college, they must soon move behind a desk. "I had opportunities to go the normal route," Yanoviak said. "Instead of doing that, I went to Costa Rica to work in the canopy. I really felt that I wanted to be in the tropics."

Occasionally he has encounters with monkeys in the treetops. One came in the course of mosquito work in Panama, research for which he built a number of fake phytotelmata—sections of bamboo filled with water and leaf litter—and hung them high in the trees. Spider monkeys, which follow regular routes through the canopy, integrated these little oases into their daily itinerary. "They were drinking out of my water holes," he said. "I didn't know." He was tending his phytotelmata one day when a troop of spider monkeys came through.

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A mother and her baby passed to either side of him, and the mother, seeing Yanoviak between, panicked and bluffed a charge. Compared to a spider monkey, Yanoviak is slow-moving, lacks a prehensile tail, and is undefended by prominent canine teeth. At the same time, he is from a line of big Old World apes and was doubtless terrifying to the spider monkey. She broke off her attack, collected her offspring, and swung off with the troop through the trees.

Life is exciting in the canopy, but a career can dead-end in a place like Iquitos, Robert Dudley pointed out. "It's not like being in Central America, where there are a lot of gringos and good universities and institutes, Iquitos is a great place for biology, but ..." Falling in love with the tropics is risky, Dudley said.

"Which is why we're trying to get him back here. He's already had a couple of interviews last year in the North. So he'll get a good academic job. It's going to be a hard transition. He's been five years in Iquitos, and you really change."

When pressed on the matter, Yanoviak admits that he has far more friends on the equator than he does in the States. He admitted that the move North will be difficult. "Sure," he said. "Anytime you go through that kind of change, it's hard. But I also am comfortable with it. If I stay in Iquitos, it would almost guarantee the end of my academic possibilities, because I've been down here long enough that I'm no longer competitive."

A window of competitiveness has opened now since the publication, with his colleagues Robert Dudley and Mike Kaspari, of an influential *Nature* paper on *Cephalotes atratus,* and there are other good canopy papers in the pipeline. Yanoviak is poised to glide away to academe on the backs of his flying arthropods.

"There are a lot of other things involved," he said. "You get tired of not having a home. One thing that has been tough about living in Iquitos, and other places I've lived, is that the moment I set foot in a house, I know it's not permanent. That limits how much you invest in a place. I never bought a motorcycle in Iquitos. It's *crazy* to live here that long and not have your own form of transportation. There are a lot of little things like that, things I never do, because I figure, 'Well, I may pull up stakes here soon.' It wears on your psyche after a while. I really feel I've reached a point where it would be good to have a permanent home in the States."

No doubt it is a good decision. A 37-year-old cannot feel 17 forever. The time arrives when he must get his head out of the canopy and come down to earth. Let us hope it is the right thing. Once he casts off from the treetops, Steve Yanoviak, unlike his ants, is not configured to glide back home to the trunks again.

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