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Reef Sharks Return
Nature's Original Bombshells
Science Meets Art in *From the Depths*

Bombardier Beetles

These well-armed beetles aren't just beauties, they're bombshells.

Photo by David R. Maddison

Seven years ago, Wendy Moore pulled out a drawer of beetles in the Academy's entomology collection and fell in love. At the time she was a graduate student at the University of Arizona, and she had traveled to the Academy—home of the most extensive and well-curated beetle collection in any museum, she says—to nail down the focus of her Ph.D. dissertation. It was during this visit that she first laid eyes on a paussine, or flanged bombardier beetle.

"What initially caught my eye was the mind-boggling diversity of shapes and structures in this group," Moore says. "I had never seen beetles like that before. I'll never forget seeing the first specimen under the microscope. I couldn't tell exactly what I was looking at—not even the standard beetle body parts were readily discernable. But what really

astounded me was that every specimen I examined was just as odd, and yet totally different from the previous specimen, and that happened time and time again!"

Later, back in her hotel room, she spent the night engrossed in a 95-page paper on paussines, written in 1950 by entomologist Philip Darlington. The list of bizarre traits grew longer and longer . . . and Moore was hooked. Over the next several years, her pursuit of live paussine specimens would take her to Africa, Central and South America, and Australia.

Today, Moore is one of the world's experts on paussines, and she has returned to the Academy as a post-doctoral fellow to continue her research. Though she has learned and published much about the beetles since her

first sighting of them, there are still many questions to explore. And to the paussine novice, Moore loves pointing out the unusual features that attracted her to them in the first place. Her enthusiasm for paussines is contagious, and listening to her, one can't help being drawn into their bizarre world.

Bombs Away

"Bombardier" is an antiquated term for a person who fires cannons, and bombardier beetles are so named because of their explosive abilities. When threatened, adult beetles fire a hot, caustic liquid from their rear ends. The liquid can reach temperatures of up to 100°C and creates an audible *pop!* when discharged. Charles Darwin, an ardent collector of insects, once put a bombardier beetle in his mouth and was quickly "bombed." He spit it out and the beetle escaped.



Left: Dr. Wendy Moore with her paussine beetles. Center: Paussine larvae have a distinctive “terminal disk.” Right: Ants surround a paussine and feed on its chemicals.



The mechanism behind bombing is a marvel of evolution. Inside the beetle, a special gland produces a mixture of hydroquinones and hydrogen peroxide, which travels down a long duct and accumulates inside a reservoir chamber. When the beetle wishes to deliver a bomb, the chemicals are forced through a one-way valve into a reaction chamber, where they come in contact with enzymes that induce an explosive, exothermic reaction. The end products are benzoquinone (the caustic agent), oxygen (which provides the propelling force), water, and heat. They emerge from an exit pore at high velocity. Each beetle is equipped with two of these systems, side by side.

The Coanda Effect

There are two groups of bombardier beetles, the Paussinae and the Brachininae. While brachinines can swivel the tip of their abdomen to spray in any direction, paussines are not as flexible, but can still aim their spray forward thanks to a phenomenon known as the Coanda effect.

Anyone who has ever poured milk from a jug and watched it dribble onto the tablecloth has witnessed the Coanda effect—it is the tendency of moving fluids to stream along a curved surface rather than follow a straight

path. Paussine beetles harness the Coanda effect with a slight protrusion, or “flange,” on each side of their body. When attacked from the front, they align their exit pore with the flange; the stream of chemicals that bursts out follows the curve of the flange toward the front of the body. When they want to spray in a direction other than forward, they simply disengage the flange by moving the exit pore out of alignment.

The effect is named after Henri Coanda, a Romanian engineer who almost died because he put flanges on an aircraft that he thought would direct the jet exhaust outward. Instead, the exhaust streamed along the flanges back toward the aircraft. Had he been acquainted with the paussine beetle, he might have avoided the accident. Nevertheless, entomologists acknowledge the beetle’s inventive use of his fluid dynamic principle by naming its little protrusion “the Flange of Coanda.”

A Rear Door and More

What first attracted Moore to paussine beetles was their mind-boggling diversity of physical attributes. The larvae, for example, have a two-part, fan-shaped disk on their rear ends, fringed with bristles and antler-like projections. They use this disk as a door, plugging the entrance of their burrows

and waiting for unsuspecting insects to approach. When an insect stimulates sensors on the disk, its two halves slam shut and capture the prey.

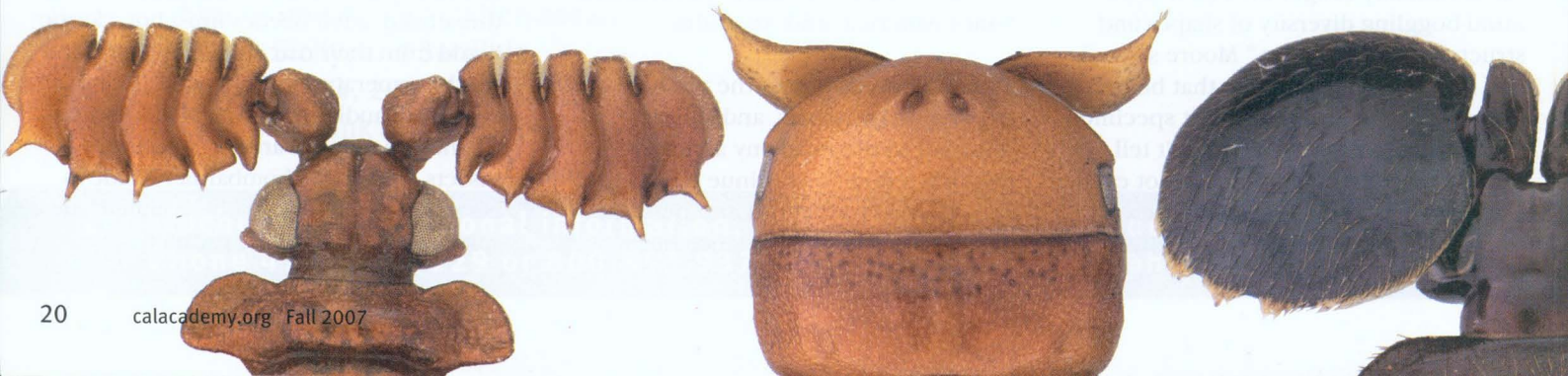
“In effect,” Moore says, “these larvae wield a Venus fly trap on their rear ends.”

The adults also have their share of odd appendages. Most noticeable are the antennae, which can take on a variety of shapes: flat, slender, ribbed, ovoid, pointed, spoon-shaped, and more. Examination under a microscope reveals other curious traits, such as strangely modified mouthparts, pits in the head, deep clefts in the thorax, tiny chemical-dispersing hairs all over the body, and legs that range from wide and flat to long and thin.

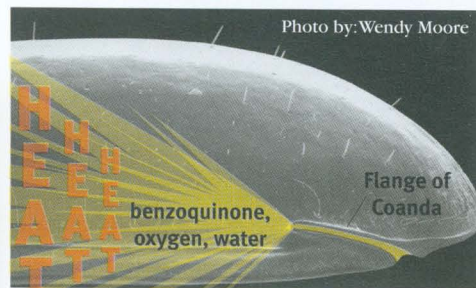
What is the driving force behind this wild anatomical diversity? They are adaptations for living with some of the most ferocious predators in the world—ants!

Ant Lovers

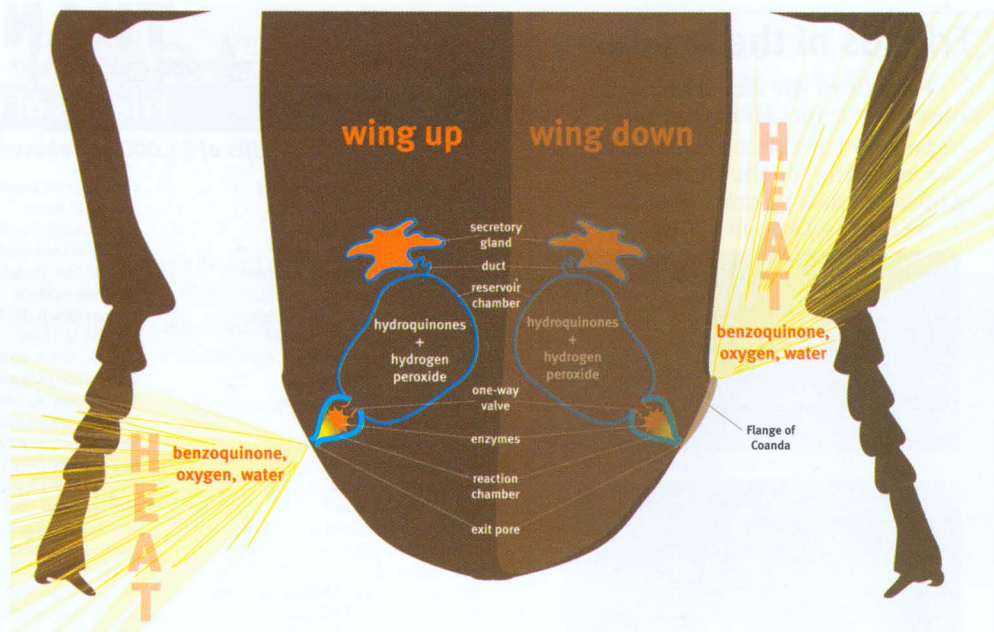
Ants will usually dismember any foreigner that attempts to enter their nest. Some insects, however, have cracked the code of getting inside. These interlopers are called myrmecophiles, or “ant lovers.”



Right: Glands of the bombardier beetle. Chemicals produced by the gland are stored in a reservoir chamber. When forced into the reaction chamber, they undergo an explosive chemical reaction and blast out the exit pore at up to 100°C.



The Flange of Coanda directs defensive chemicals toward the front of the body.



Many species of paussine beetles are myrmecophiles, and they employ two strategies to gain entry into ant nests. The “defiant” type tucks in its legs and hunkers down like a miniature tank, withstanding the barrage of ant attacks with its thick exoskeleton. The “symphilic” type is more cunning: ants will actually surround it and drag it inside the nest. The paussine, for its part, will flail its legs in apparent show of resistance. Moore suspects, however, that this behavior allows the beetle to pick up the scent of the ants, masking its own odor.

“The trick is in the chemistry,” Moore says. “Ants perceive the world chemically through touch, so if the beetle smells like an ant, the ants are none the wiser. What’s more, these paussines secrete chemicals from specialized glands in their antennae and in the deep clefts and pits—these chemicals seem to act as food or drug to the ants, inducing the ants to drag the beetles into their home.”

Once inside the nest, the paussines

feed on the very ants that dragged them inside, as well as the most precious resource in the ants’ nest—their eggs and larvae. Furthermore, paussines lay their own eggs in the nest. Moore explains, “By cracking the chemical code of the ant colony, paussines simultaneously solve two of the great challenges in the living world—finding a reliable source of food and providing safe shelter for their young.”

The ants appear to get nothing out of the relationship, besides the satisfaction of the paussine’s mysterious chemicals. Because of their Trojan horse tactics and feats of chemical deception, Moore considers paussines to be “the ultimate myrmecophiles.”

Moore is working on two projects at the Academy. First, she is investigating how paussines from Madagascar fit into the larger scheme of paussine evolution and biogeography. Having sorted through 70 insect traps that the Academy maintains in Madagascar, she estimates that they contain about 25 new species and

several new genera. Second, Moore is researching the systematics of the Bay Area’s own paussine species, *Metrius contractus*. It lives along the West Coast from Monterey up to British Columbia, as well as in the high Sierras. It is a primitive member of the group, lacking both flanges and myrmecophilous behavior.

Although her work on paussines is already broad, Moore has a host of other questions that she eventually wants to tackle. How do they manufacture hydroquinones and hydrogen peroxide? How closely related are brachinines and paussines? What exactly is the mystery chemical that ants love? Do ants feed the paussine larvae that hatch in their nests? High on Moore’s wish list is to rear a live ant colony with paussines and observe their interaction first-hand. She would also like to collect paussines from India and Southeast Asia, the two major gaps in her data set.

“This could take several lifetimes of work,” she says. “Luckily, I think working on bombardier beetles is a blast.”

