Moths tell us how organisms use resources

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A giant hawk moth is attached to the boom in the flight arena. This procedure is non-invasive and does not bother the animals. (Photo by Norma Jean Gargasz/UANews)

(PhysOrg.com) -- Using a one-of-its-kind flight arena, University of Arizona entomologist Goggy Davidowitz and his group study how giant hawk moths use energy resources for two of nature's most costly evolutionary traits: flight and reproduction.

A circular container about the size of a passenger car tire is sitting on top of a table. Behind the clear Plexiglas casing, a giant hawk moth is flying in circles, completing a round every second or so.

Rivaling a hummingbird in size, the magnificent insect is attached to a wire boom, causing it to spin on a hub at the center of the container. Tubes and cables snake in and out of the container and connect it to electronic recording devices.

"This setup was designed specifically for our lab," says Goggy Davidowitz, an assistant professor in the University of Arizona's department of entomology in the College of Agriculture and Life Sciences. "As far as we know, it is the only one of its kind that exists for insects."

The National Science Foundation has awarded Davidowitz a CAREER Award to tackle a fundamentally important question in evolutionary biology: What are the priority rules that govern how organisms use a continuously changing and limited set of resources? Just as there is no free lunch, nearly every evolutionary trait comes with a trade-off in energetic demands.

"For example, any organism that is growing, has to make a decision – physiologically speaking – where to allocate those resources," he explains. "You can allocate them to growth, to keeping yourself alive, to reproduction, locomotion and various behaviors like foraging and so on."

Some traits affect reproductive success more than others. For example, in some animals, larger body size can lead to higher mating success. Larger females can produce more eggs. A fast growth rate helps a vulnerable juvenile shorten the time it is exposed to predators and parasites.

"All these traits determine the reproductive success of an organism," Davidowitz says. "The trick is to find out which ones are the most important and how they trade-off with each other."

"What we still don't really know is how the history of an individual, from the very beginning of its life, influences the decision processes throughout its whole life and leads up to the final trait that an evolutionary biologist is interested in – reproductive success," he says.

To find answers to these questions, Davidowitz uses the giant hawk moth (Manduca sexta) as a model organism. The flight arena allows the researchers to precisely keep track of which resource an individual moth uses throughout its life, from the time it hatches from an egg as a caterpillar munching on its favorite host plant, Datura wrightii, also called jimson weed, to when it emerges from its pupa as a magnificent moth, about to embark on the final week of its life, most of which is spent searching for a mate, nectar sources and places to lay eggs.

The answers Davidowitz is hoping to find could also help solve questions that apply to a many living creatures, including humans.

"What we do is not specific to these insects. We still don't know how resource allocation changes as an individual grows and how the trade-offs shift over the course of a lifetime."

"Take athletes, for example," he says. "They invest a lot of nutrients into muscle mass and a lot less into reproduction, to the point where some female athletes no longer have a menstrual cycle. Reproduction requires a minimum amount of fat reserves. When those athletes no longer compete, they are able to develop those fat reserves and they can have babies."

Traditionally, evolutionary biology has taken a look at these processes at the level of whole populations and in the context of an end product, such as body size or number of offspring.

"But the current ability of an organism to function and reproduce is based on its past history, what kind of nutrients it has acquired and how much and so forth," Davidowitz says. "In addition, resource availability changes throughout its life. This is the first time we're able to study this on an individual level and not a population level. And we can do this in real time. We can see the changes in allocation as they happen."

While the moth turns its circles in the flight arena, Davidowitz and his co-workers measure the oxygen it takes in and the carbon dioxide it gives off. By analyzing the ratio of the two gases, the researchers can tell whether the moth is burning fat it stored from the plant material it ate as a caterpillar or carbohydrates it took in while sucking nectar from flowers.

"We can tell when they switch between carbohydrates and lipids," Davidowitz says. "This allows us to quantify how much energy they're using and from what source. The caterpillar eats and eats and eats, and then what does it do with what it's eating? Does it store it all for later use as an adult? Does it use everything up now to become as large as it can as fast as it can? It's things like these that we're after."

Using a carbon isotope gas analyzer, the team can distinguish between the carbon isotope signatures of the caterpillar and adult foods.

"We can tell whether they're burning nutrients we fed them when they were caterpillars or from when they were already adult moths."

Combining the flight arena and the isotope analyzer, the team studies two traits that are among the most energetically costly ever to evolve: flight and reproduction.

"Imagine a moth that uses nectar to fuel flight and provide carbohydrates to its developing eggs. Now imagine it emerges from the pupa and we make sure there is no nectar around. It would immediately start to use the fat stored when it was a caterpillar as flight fuel. But if we allow it to feed on nectar, it probably will shunt some of it to making eggs and some of it to power its flight. If more flowers are available, it probably will shunt most of the nectar to the eggs."

Giant hawk moths are powerful and enduring fliers. Davidowitz once observed a moth that flew circles in the flight arena for 50 miles (80 kilometers) non-stop.

"Insect flight muscle is considered to be the muscle system with the highest energy demand of anything," he says. "These hawk moths hover to suck nectar from flowers, and hovering is by far the most energy-intensive behavior. When they do that, their metabolic rate is about 100 times higher than when they're at rest."

The moths have to find nectar, find mates and a plant to lay the eggs on. These plants are dispersed so the moths have to fly considerable distances to find them. Fuel for flight comes from nectar initially but then the moth switches to lipids to fuel flight.

"After we fly the animals, we can look at the eggs and the flight muscle to see where the animal allocated the resources we fed them during their lives' history, and what they used them for."

In addition to a promising research proposal, a researcher must demonstrate a strong outreach and teaching component to land an NSF CAREER award.

"The idea behind this program is to develop scholar-teachers," says Davidowitz.

He helped design and launch the Insect Discovery project, a science outreach program reaching about 2,000 elementary school children in the Tucson area per year, most of which come from low economic or minority backgrounds.

As part of the project, UA undergraduate students training in science outreach go into classrooms or put on workshops at the UA, during which the school children get to engage in hands-on activities using live and preserved insects.

Says Davidowitz: "These workshops are hugely popular with the children and a very rewarding experience for us."

Provided by University of Arizona