When it comes to collecting pollen, some bees are smarter than others.

ANIMAL BEHAVIOR

In the battle for fitness, being smart doesn't always pay

Studies of individual animals in the wild suggest that higher cognition has evolutionary trade-offs

By **Elizabeth Pennisi**, *in New York City*

A GPS navigation system is no match for a bumblebee's brain. Although it's the size of a grass seed, this clump of neurons processes information on the scent, color, and pattern of flowers, plots out the shortest route among them, and then adjusts that route on the fly to incorporate newly spotted flowers with even more nectar or pollen.

Some bumblebees are better than others at this challenging task. That's a surprise, given that bumblebees have been around for millions of years, seemingly long enough for all to have evolved great skill in retrieving nectar. "Why do we see so much variation?" asks bumblebee cognition expert Nigel Raine of the University of Guelph in Canada. In other words, why are some bees smarter than others?

At the 2014 International Society for Behavioral Ecology conference here this week, Raine and others tackled that question for bees and other animals. For example, researchers reported new data showing that individual differences in cognition influence reproductive success. A key challenge for this relatively new field is to come up with meaningful ways to measure cognitive abilities in the wild—what does it mean to be a "smart" bumblebee or grackle?

So far, researchers are finding that some aspects of cognition seem to be associated with other traits that have fitness drawbacks. "There are trade-offs to everything, and benefits may change over time," says behavioral ecologist Jason Keagy of Michigan State University in East Lansing.

In the past 2 decades, researchers have explored the cognitive abilities of many animals (*Science*, 23 June 2006, p. 1734). But most of those studies were done at the species or population level, with variation among individuals considered simply noise. Many comparative psychologists didn't think about cognition in terms of evolution, says Reuven Dukas, a behavioral ecologist at McMaster University in Hamilton, Canada. Now, as they explore how intelligence evolves, researchers need to "study individual variation in cognitive performance and its fitness consequences," Keagy says.

Raine has pioneered such studies, chiefly in bumblebees. In the lab, he tests how fast a bumblebee learns to associate different colors with nectar rewards. Some bees master each task in just a few tries, whereas others never quite get it. Colonies with the slowest learners collected 40% less nectar, he and his colleagues reported several years ago.

But by marking the tested bumblebees and allowing them free access to the outdoors, he and graduate student Lisa Evans discovered that in the wild there are trade-offs to being a fast learner. Bees that make errors in the color association test are also "more likely to assess new flower types," Raine says. In one experiment, these error-prone bees wound up collecting more sugar than their "smarter" sisters, the team reported at the meeting and online on 17 May in the *Journal of Comparative Physiology A*. Raine and Evans suggest that for bees, a mixed colony of fast and slow learners might be the most successful.

Similar trade-offs between learning and other factors seem to be at work in a common European songbird called the great tit, according to a talk by behavioral ecologist Julie Morand-Ferron of the University of Ottawa. In recent studies, she, Ella Cole of the University of Oxford, and their colleagues have discovered that these birds display individual variation when challenged to pull a lever out of a tube to gain access to food. The lab-tested birds belong to a monitored wild population, and the team reported in 2012 that "smarter" birds laid more eggs and were more efficient foragers. However, for unknown reasons, these birds are also more likely to abandon their nests, negating any reproductive advantage, the researchers noted. Thus, as in bees, a range of cognitive abilities persists among these birds, Morand-Ferron said.

Mountain chickadees offer a similar story. Those living at higher elevations, where longer winters require more caches of food, show better spatial memory for retrieving stored seeds than do their peers living lower down. But chickadees with better memories also abandon their nests more frequently, according to a talk by behavioral ecologist Vladimir Pravosudov of the University of Nevada, Reno. And as has been seen in other species, smarter chickadees wind up subordinates in their flocks.

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No one knows why these trade-offs exist, although researchers speculate that being smart correlates with other traits, such as being less aggressive socially.

Why might intelligence correlate with apparently negative traits? Simon Ducatez, a behavioral ecologist at the University of Sydney in Australia, proposes that cognition aligns with contrasting life history strategies or so-called pace-of-life syndromes. One strategy is to live fast—reproducing quickly, taking risks, and dying young. The other tactic is to develop more slowly, avoid risk, and live long. Each strategy has pluses and minuses, depending on the situation, and cognition may be part of these syndromes, he says.

In his studies with Carib grackles, Ducatez finds that "smart," quick-acting problem solvers—potential fast-livers—may be less accurate. If so, then slower, more accurate problem solvers will sometimes do better. "It's not a matter of being smart or not smart," he says. In one of his studies, for example, Ducatez offers grackles a plastic tube in which the nearest end is sealed. Birds that are slower to try to retrieve food from this tube are actually quicker to figure out that they must walk around to the far end to get the reward; birds that immediately start pecking at the closed end take longer to get the food.

To see if slower reacting birds may have a more leisurely pace of life, Ducatez is correlating the birds' cognitive differences with variation in growth and immune function. Preliminary results show that slow responders have better immune responses—a prudent investment for animals invested in a long life, he said.

Despite this progress, critics complain that field studies often lack the rigor to unravel detailed cognitive mechanisms, whereas lab tests may be biased by stress or other factors. At the meeting, Morand-Ferron introduced an outdoor testing box that could address some of these problems. Different-colored buttons on the outside of this weatherproof box can be programmed to release a treat when a great tit pecks the correct button. The birds carry radio frequency ID tags like those used in pets, so the machine can track each bird's performance and adjust the buttons accordingly. Birds that were good problem solvers in the lab proved to be equally adept at the outdoor test, she reported.

"It's a really strong attempt to systematically study what's going on in the field," says Luc-Alain Giraldeau, a behavioral ecologist from the University of Quebec, Montreal. He predicts that such studies may help the field come to grips with the complexities of cognition and its evolution. ■

CHEMISTRY

New recipe produces ammonia from air, water, and sunlight

Catalytic approach could eliminate CO_2 emissions from the key step in making fertilizer

By **Robert F. Service**

The ability to turn the nitrogen in air into fertilizer has enabled farmers to feed billions more people than our planet could otherwise support. But it's costly. The massive chemical plants that produce ammonia—the starting material for fertilizer—consume up to 5% of the world's natural gas and belch out hundreds of millions of tonnes of carbon dioxide (CO_2) annually. Now, chemists have come up with an alternative approach drawing on renewable energy. On page 637, they report using heat and electricity produced from sunlight to stitch together nitrogen from the air and hydrogen from water to make ammonia, all without emitting a molecule of CO_2.

"It's an important scientific advance," says Morris Bullock, a chemist at the Pacific Northwest National Laboratory in Richland, Washington. Still, says Ellen Stechel, a chemical physicist at Arizona State University, Tempe, the question is whether the process's "very respectable" efficiency in the lab can be scaled up to compete with the current ammonia industry.

Nitrogen molecules in air are inert, held together by triple bonds that aren't easily broken. In the early 1900s, the German chemists Fritz Haber and Carl Bosch figured out how to make nitrogen more biologically reactive. They used high pressures and temperatures to sever those bonds and weld nitrogen atoms to hydrogen to make ammonia, NH_3. Today, that reaction produces hundreds of millions of tons of ammonia each year.

Yet the large amounts of energy required for this reaction have prompted a number of researchers to look for alternatives. One popular approach has been to search for catalysts that break nitrogen's triple bonds and make ammonia when fed electricity. So far, however, even the best such catalysts harness only about 1% of the electrons for forming ammonia's bonds.

Stuart Licht, a chemist at George Washington University in Washington, D.C., tackled the problem from the opposite direction. He spotted work on fuel cells that break down ammonia into nitrogen and hydrogen, generating electricity in the process. A new electrolyte, which helps charged ions move in the device, improved the efficiency of the fuel cell.

Licht and colleagues tried using the same electrolyte—a molten mixture of potassium and sodium hydroxide—in reverse to synthesize ammonia. It worked. In their reactor, they combined the electrolyte with catalytic nanoparticles made from iron oxide, then fed in water, air, heat, and electricity. The reactor split water, snapped nitrogen's strong bonds, and welded the components into ammonia and molecular hydrogen (H_2)—itself a fuel. All told, 65% of the electricity wound up stored in chemical bonds: 35% in ammonia and 30% in H_2 molecules.

Though impressive, the result "still has a long way to go" to replace the Haber-Bosch process, says James Miller, a chemist at Sandia National Laboratories in Albuquerque, New Mexico, who specializes in using solar energy to make chemical fuels. The reactor is most efficient when fed only a trickle of electricity. Licht and his team will need to boost the current 50-fold to match related industrial processes, Stechel says. Still, Miller adds, "he's on the right track." ■

A vital chemical with major costs

120

Millions of tons of N_2 extracted from air annually to produce ammonia for fertilizer

2

Percentage of world energy used for ammonia production

102

Billion dollars, the estimated market for ammonia in 2019

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