Bees are prevalent in the symbolism of many cultures throughout history. That is a testament to our fascination with these industrious insects.

Ancient Egyptians regarded bees as the embodied tears of the sun god Ra. In Hinduism, the deities Vishnu, Krishna, and Indra are referred to as Madhava, the “nectar-born ones.” They are sometimes depicted as bees resting on lotus petals. If Gro Amdam has her way, bees will be viewed as the symbol for social behavior evolution.

Amdam is a biology professor at Arizona State University’s School of Life Sciences. She began her bee research as a doctoral student at the Norwegian University of Life Sciences and continued it at University of California, Davis.

Amdam arrived at ASU in 2005. She is on a mission to cast the honeybee in a new light. She contends that bees should be seen as the prime model organism for scientists working to understand how social systems evolved in insects, animals, and possibly even humans. Amdam’s research was featured in the January 5, 2006 issue of the journal Nature.

“Usually, fruit flies and earthworms are used as models in research,” Amdam says. “But bees have an aspect of social biology. It is an advantage those organisms will never have.”

The Nature paper focuses on the puzzling evolutionary question of why some species of bees evolved to behave socially. According to Amdam, part of the answer lies in the reproductive traits of ancestral bees. These bees are known to have been solitary, not social.

Some species of modern bees, like carpenter bees, mirror those ancestors. They eschew social behavior in favor of a solitary lifestyle. Honeybees, however, live in highly complex communal societies. Divisions of labor exist among worker bees.

The workers are female bees with many jobs. Worker bees clean, maintain, and defend the hive. They also raise the young and forage for nectar and pollen. Interestingly—and somewhat counterintuitive to the ideas of natural selection—workers do not produce offspring.

“The exclusively female worker bees are considered to be ‘facultatively sterile.’ This means that when a queen is present, they do not lay eggs,” Amdam explains. “However, if the queen is removed, some of these females can develop their ovaries and produce males from unfertilized eggs.”

Why would a bee forego reproduction to support its hive? That is a perplexing question for biologists. Darwin himself had a big problem with it, Amdam says.

Most biologists accept an explanation known as “kinship theory.” When individuals in a group are very closely related, the theory says that traits can evolve that seem to benefit the group and not the individual. That is the case with honeybees. But kinship theory is only useful for understanding in a broad sense why this insect altruism can occur, Amdam says. Her research breaks new ground. The ASU scientist has identified how physiological and behavioral changes can provide a foundation that makes kinship theory—and sociality—possible.

“How social life emerges from a solitary lifestyle is a fundamental question,” Amdam says. “One theory is that social behavior is the result of new evolutionary inventions. In other words, new regulatory architecture pops up which leads to sociality. Another theory is that existing architecture is used as a foundation and then built upon to produce social characteristics. For bees, our research supports the latter theory.”
Busy as… Amdam began collaborating with Robert Page while working at UC Davis in 2003. Page is now a professor and director of ASU’s School of Life Sciences. Like Amdam, Page has a keen interest in the evolution of social behavior. With a strong background in entomology, Page realized bees were a natural fit for social evolution research.

“The history of beekeeping goes back to ancient Egypt,” Page says. “Modern beekeeping practices have been with us for well over a century. As a result, a lot is known about bees’ behavior and social organization. For more than 75 years, we’ve been able to control their mating and breed them for social traits.”

When he first met Amdam, Page was breeding strains of honeybees. The distinguishing trait between the strains was whether the workers were more likely to collect pollen or nectar. In addition to the differing foraging habits, each strain of bees also possessed other physiological and sense-related traits. But the researchers did not understand how these suites of traits were related or why they emerged in different strains.

Two years later, Amdam followed Page to ASU. Working together, they theorized that reproductive differences could have something to do with the diverging foraging behaviors in the two strains of bees.

Solitary species of bees exhibit different foraging behaviors depending on their reproductive physiology. That state changes throughout their lifetime. The ASU biologists found that a non-reproductive solitary bee mostly collects nectar as a food source. However, a reproductive bee of the same species will shift to hoarding pollen. Pollen is the necessary protein source for egg production and larval growth.

Amdam wondered if similar relationships were also present in social worker bees, even though their reproductive physiology was assumed to be inactivated by the presence of a queen.

A protein called vitellogenin is a known marker of reproductive status among bees. Amdam noticed that vitellogenin was more common in the strain of Page’s pollen-foraging bees. She identified them as the high pollen-hoarding strain. But she found that low levels of the protein were associated with nectar-foragers, which she called the low pollen-hoarding strain.

Amdam and Page hypothesized that the high pollen-hoarding strain of worker bees, although facultatively sterile, represented the maternal, reproductive state of its solitary ancestors. Presumably, those bees foraged for pollen when reproducively active.

The ancestral reproductive states were no longer linked to reproductive activity. But Amdam predicted that the foraging behaviors would still reflect the influence of those states.

To test her hypothesis, Amdam set up a “race.” The race would determine which strain of worker bees would be the first to become reproductively active in the absence of a queen. If her hypothesis was correct, the high pollen-hoarders would win the race and develop ovaries sooner than the low pollen hoarders.

OFF TO THE RACES The experiment went on for several weeks. After only 10 to 21 days, almost 76 percent of the high pollen-hoarding strain had developed active ovaries. That compared to 42 percent that developed active ovaries in the low pollen-hoarding strain. Students working with Amdam also noticed that the winning strain of bees had larger ovaries. This seemed to strengthen the case that foraging behavior was tied to reproductive traits.

Amdam then put her results to a crucial test with wild-type bees. These were bees that had not been selected for a particular foraging behavior. The wild-type bees were captured after their first foraging flight. Amdam and her team measured the bees’ ovaries and compared the data to what the bees had brought back from their first forage.

The results were conclusive. The researchers found that pollen collection was primarily conducted by worker bees with larger ovaries. For Amdam, the finding cemented the connection between high pollen-hoarding strains and the reproductive state.

Amdam’s research results could prove more far-reaching than just the evolution of bee social behavior. Scientists might use the findings as a stepping stone for looking at the social evolution of other animals.

“Our findings identify a bridgehead between solitary and social behavior,” Amdam explains. “If we can understand the emergence of social behavior in one system, we can use this insight to create a more general model. Once we have a general model, we can build new hypotheses that outline how similar principles might apply to other animals.”

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This image appeared as the cover of the January 5, 2006 issue of Nature, an international science journal. A solitary bee forages for pollen. The pollen will serve as a protein source for her brood. Next to her is a sterile worker honey bee. The social biology of these two females is different, but the evolutionary origin of their behavior is identical. Photo courtesy Gro Amdam, Ph.D.
Gro Amdam’s fascination with honeybees grew out of her dissatisfaction with a foray into conservation biology while at the Norwegian University of Life Sciences. Controlling experiments and predicting the outcome is difficult in conservation biology. It is nearly impossible to design and tinker with isolated variables in complex ecosystems. Amdam is now an assistant professor with ASU’s School of Life Sciences. And an admitted control freak. She says that she needed more concrete answers from science. So she turned to bees. “With honeybees, I found it was possible to work with a very complex system and still have full control over the experiment,” Amdam says.

She received funding for her doctoral studies in 2000 and began designing simulation models. The models would depict the interplay between physiology and social behavior in bees.

During her work as a doctoral student, Amdam completed the first successful RNA interference knockdown in an adult honeybee. The knockdown is a modification to an organism’s genome that reduces the expression of one or more genes. Based on that success, Amdam realized that bees would make an ideal organism for studying the molecular aspect of social evolution. “Bees have been kept for honey and wax production for a very long time. People already know how to handle and work with them,” Amdam says. There also is a wealth of available information about bees, she adds. “People have been studying bees since the time of Aristotle.”

Amdam explains that there are several important steps to understanding the origins of sociality in bees. One of the most important is having a complete honeybee genome sequence. The latest version of that genome was published in May 2005 by the Human Genome Sequencing Center at the Baylor College of Medicine in Texas. The honeybee genome is only about one tenth the size of the human genome. Scientists use it to study a variety of health issues such as allergic reactions, longevity, and antibiotic resistance, as well as social behavior. “In 10 to 15 years, I want to be seen as a pioneer in establishing the bee as a model organism for the molecular foundations of social evolution,” Amdam says. “As our understanding of the evolutionary linkages between solitary and social behavior increases, our knowledge will be propelled to places it has never been before.”

And what about the bee stings? “I’ve only been stung a few times,” Amdam says with a laugh. “After a few stings, you really learn how to use the safety gear.”

Michael Price