Swarm Savvy

How bees, ants and other animals avoid dumb collective decisions

By Susan Milius

This is a phone conversation, so if Tom Seeley rolls his eyes, that's his business. He's a distinguished behavioral biologist, full professor at Cornell University, member of the American Academy of Arts & Sciences and so on. Yet he takes it pretty well when asked whether honeybees could have had a real estate crisis and crashed their banking system.

Seeley, at least voice-wise, stays polite and treats this as a serious question. Which it is.

Of course honeybees don't have a banking system, but they do exhibit collective behavior. The queen bee doesn't decide what the colony needs to do. Instead, each colony member does her or his bee thing, and out of hundreds or thousands of interactions, a collective decision emerges. Seeley's next book, due out in 2010, will be called *Honeybee Democracy*.

Bees, ants, locusts and plenty of other animals collectively make life-or-death choices. The biologists studying animal groups are finding strange lab fellows these days in economists, social scientists, even money market specialists. They are trading tales of humans and of nonhuman animals to understand collective behavior and what makes it go right or wrong.

"There is a new excitement in this whole field of decision making these days," says ant biologist Nigel Franks of the University of Bristol in England. Franks and Seeley organized a multidisciplinary conference on collective decision making held in January at the Santa Fe Institute in New Mexico. And both biologists contributed to a special issue of *Philosophical Transactions of the Royal Society B* (March 27) on the same topic. The issue considers insects as well as the European Parliament.

Even compared with gatherings of diplomats in bespoke suits, bee nests and ant colonies have plenty to contribute to the field. "The really lovely thing is that we can take these things apart and put them back together again, and we can challenge them with different problems," Franks says. Seeley notes that studying honeybees has taught him a lot about how to run faculty meetings.

All but the darkest view of university professors credits them with more cognitive power than can be found in the minuscule brains (sorry, bees) of insects. So one might wonder how well collective wisdom works for nonhuman animals.

That question is what makes the research so intriguing. Bee colonies have been making collective decisions for about 30 million years, Seeley says, "so they've had lots of chances for failing systems to get pruned out by natural selec-

FROM TOP: T. SEELEY; DEJAN750/ISTOCKPHOTO; ARCHITECT OF THE CAPITOL

Rock ants (magnified, top), dabbed with paint so researchers can track who does what, have evolved a quorum system to cope with the challenges of collectively choosing a home. Other forms of this handy way of balancing the need for independent observation with the logistics of moving or leading in a group have also evolved in fish and primates (middle, bottom).

tion." Bees have unique needs of course, but when it comes to real estate (alas, humans), bees almost always get it right.

The human hive

To be fair, today's research on these successful insects draws from studies of the first animal to be analyzed in detail for collective wisdom: *Homo sapiens*.

In the 18th century, Marie-Jean-Antoine-Nicolas de Caritat, marquis de Condorcet, welcomed the French Revolution and used mathematical probabilities to argue for the virtues of shared decision making. Known today as Condorcet's jury theorem, his work describes conditions in which members of a group voting by majority rule are more likely to render a correct choice between two alternatives than is any individual in the group. One of the critical conditions for a happy outcome, the Marquis contended, was that each group member vote independently rather than copy another (possibly mistaken) juror.

Human groups deciding as a whole have scored spooky triumphs. "Nearly everybody is miles out, but when you take the average of these guesses, they're usually very, very accurate," says Ashley Ward, a fish behaviorist at the University of Sydney in Australia, whose work is cited in the special *Transactions* issue. The idea goes by the name "many wrongs," as in many wrongs make a right.

A classic example appeared in *Nature* in 1907. Two reports looked at 787 contestants competing to guess the weight of a particular ox after butchering. Collectively, guessers came within 10 pounds (looking at the median of guesses) or just a pound short (looking at the mean) of the correct weight of 1,198 pounds.

Examples appear in abundance in business writer James Surowiecki's best-seller *The Wisdom of Crowds* (2004). What enthusiasts of crowd wisdom (though not Surowiecki) tend to overlook is that the accuracy is in the arrangements. Those perfect systems of independent deciders who evaluate their own information are tricky to create in the busy real world. And human crowds can go so very, very wrong.

Smart swarms

Honeybees do real estate well. But only in the last decade has a technical breakthrough let Seeley and his colleagues figure out how. Now he has used recent biological insights to work with a scholar from the London School of Economics and Political Science and a mathematician to analyze how bees balance independence and going along with the crowd.

When a robust colony splits, the queen and some two-thirds of the workers move out to search for a new home. Bees swarm out to a temporary perch such as a branch, where they cling to each other in a dangling clump. Having no protection from predators or weather and no food stores, the swarm needs a new home, and fast.

In the 1940s, biologist Martin Lindauer noticed that some bees on the outer layer of a swarm waggle-danced. He knew that foraging bees danced to report flower locations, but these waggling bees looked as if they had picked up soot from a chimney or grit from construction debris. He realized these bees had been scouting for new nest cavities and were dancing about the possibilities.

In his later years Lindauer told Seeley about running through the rubble of war torn Munich trying to keep flying bees in sight. What finally made decisive tests possible (and easier) were affordable, high-quality video cameras, Seeley says. In the 1990s, he and his coworkers filmed and analyzed the intel that scouts waggle to each other on swarm surfaces.

Out of a swarm of 10,000 bees, some 300 to 500 females buzz off to scout possible nest sites. Important features include enough room for storing honey and a small entrance to minimize winter drafts. "Every scout we've seen is an elderly bee that has a lot of experience going around the countryside," Seeley says.

Elderly bees still manage to check out the possibilities over some 30 square kilometers. A good cavity is hard to find, though. Seeley reports that only a few of the scouts, maybe 25, come across something worth reporting to their sisters.

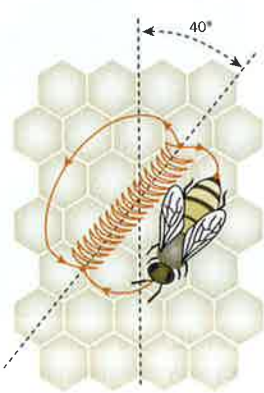
At first scouts dance for a wide variety of sites, perhaps 20 or 30. The dance

GRAPHICS ADAPTED FROM T. SEELEY/*AMERICAN SCIENTIST*, 2006

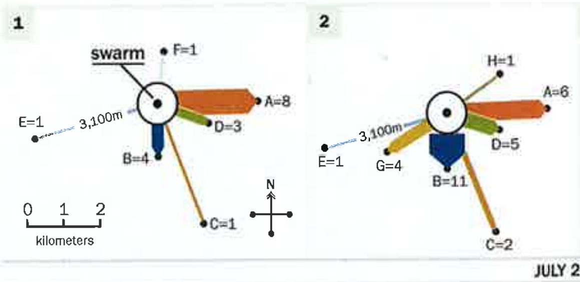
How a honeybee swarm decides

When thousands of honeybees swarm off to find a new home, the emigrants first cluster at a temporary spot while some of the experienced foragers scout sites. Back at the swarm, scouts dance to communicate promising locations, giving other scouts incentive to go look for themselves.

Anatomy of a bee dance
Scouts reporting on a possible nest site use the basic rules of the waggle dance foragers use to describe flower locations. The slant of the dance's main axis indicates a site's direction relative to the sun. How long a bee waggles along the axis indicates how far to fly. The more repetitions, or waggle runs, the more enthusiastic the scout is about the site's quality.



Debate and decide
This schematic shows scouts in a honeybee debate about 11 possible nest sites that ends with all scouts finally favoring location G (possible sites are A through K). Each panel tallies scouts going to and from the swarm (center). Arrow thickness indicates the number of bees dancing in favor of a site. The scouts "decide" when enough meet at a site, but all scouts must dance for the same site at the end for the swarm to stay united.



	1	2
Time:	11:00–13:00	13:00–15:00
Scout bees:	18	30
Dances:	68	70
Waggle runs:	547	2,376
	Site A has eight scouts.	Site B has 11 scouts.

encodes the direction and distance to the cavity, and the more enthusiastic a scout is, the more times she repeats her waggle report. Her dance may inspire her sister scouts to take off and check it out for themselves. They in turn come back to the swarm and dance their opinion.

This recruitment step is critical to the success of the process, Seeley says. Other scouts will look for themselves. As Seeley puts it, "Scouts search autonomously, report freely and argue."

Human groups can falter at this step, Seeley says. They tend to rush to a decision when they could benefit from exploring more options. And a rush to judgment was what went wrong for the bees the one time Seeley saw a swarm fumble a decision in the wild. Support had been building for a nest site that was sort of OK when a scout discovered a superior cavity in an old tree and returned to the swarm to report. "She danced like fury," Seeley says, but she failed to redirect a decision that was already solidifying.

Scouts also go back to a site multiple times, returning to the swarm between trips to dance about it again. For all sites, great to dubious, a scout dances to the swarm with fewer repetitions, perhaps 15 fewer than the time before. Eventually she stops. "It's a clever thing," Seeley says. "They allow their enthusiasm to decay."

Repeat dances for all sites dwindle, but the ho-hum possibilities, first reported with a small number of repetitions, disappear from the dance floor faster than primo sites. The decaying interest makes the decision possible. "We've all been in committee meetings where agreement was never reached because nobody would ever give up," Seeley says.

As the search goes on, scouts dance about fewer and fewer sites. By the time the swarm takes off, scouts are almost always unanimous in dancing about a single site. And that's where they go.

Seeley and his colleagues have established that a decision doesn't occur at the swarm at all. It's what happens at the candidate nest sites that matters. It's all about quorum.

As the better site builds a bigger fan base, more and more scouts shuttle between it and the swarm. When some 15 or so scouts meet outside the nest site — with probably another 30 to 50 bees inside — bingo, that's the new home. Some of the scouts do continue dancing. But while dancers finish their convergence, scouts start motivating the swarm to fly.

Seeley and his colleagues' new model of this process appears in the *Transactions* issue. The model shows that changing the values can crash the system. Requiring that bees in the model act more independently of each other than they actually do in nature, for example, can keep them from making a decision at all. Yet too little independence can easily lead to stupid decisions as bees too readily copy a misguided nest mate. In the real world, honeybees "balance interdependence and independence," Seeley says.

Ants do it

Handy idea, that quorum. Rock ants have evolved one too.

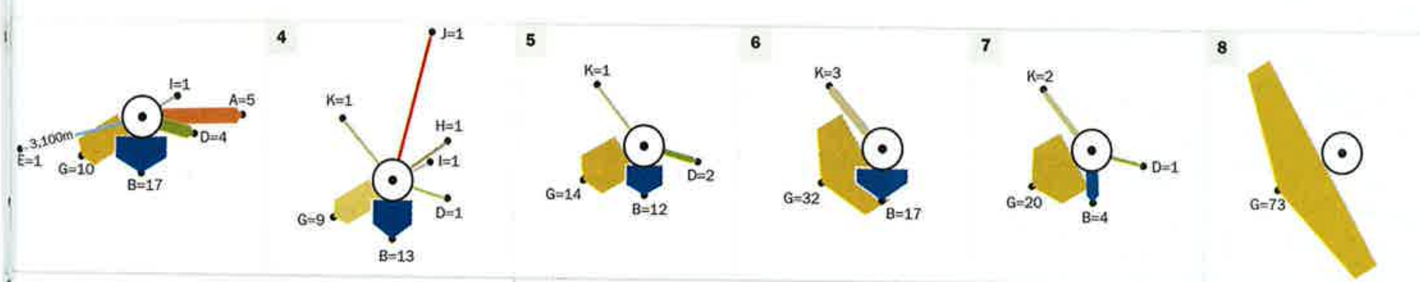
Only a few millimeters long, rock ants (*Temnothorax albipennis*) prove difficult to track in the wild but excellent for the tabletop world of the laboratory.

When something terrible happens to a rock ant home, such as a researcher lifting off the roof, the majority of ants cluster in the ruins. A quarter to a third of the colony scurries out looking for new possibilities.

"I think of the ants as a sort of search engine," Franks says. In one set of tests, he and his students disrupted a nest and watched to see what the ants would make of a series of new possibilities that improved with distance. The best nest was almost three meters distant, nine times as far from the original home as a nearby but less appealing choice. "It was just such fun doing this experiment because the ants won," Franks says.

In spite of the epic distances, the ants typically found and agreed to move into the best nest. "They're fantastic at it," Franks says.

Franks and Elva Robinson, also of the University of Bristol, monitored rock ants by fitting them with radio-frequency identification tags. The data suggest that each scout follows a simpler rule than



		JULY 21			JULY 22
15:00–17:00	**17:00–19:00**	**07:00–09:00**	**09:00–11:00**	**11:00–11:54**	**09:00–11:58**
Scout bees: 38	Scout bees: 27	Scout bees: 29	Scout bees: 52	Scout bees: 27	Scout bees: 73
Dances: 66	Dances: 45	Dances: 53	Dances: 99	Dances: 43	Dances: 352
Waggle runs: 2,400	Waggle runs: 1,877	Waggle runs: 868	Waggle runs: 1,697	Waggle runs: 713	Waggle runs: 3,100
Site B has 17 scouts.	Site B has 13 scouts.	Site G has 14 scouts.	Site G has 32 scouts.	Site G has 20 scouts.	Site G has 73 scouts.

previously thought, Robinson, Franks and their colleagues report online April 22 in *Proceedings of the Royal Society B*.

Instead of making direct comparisons between sites, a scout follows a threshold rule. If she finds a poor site, she keeps searching. When she finds a site that exceeds her "good enough" threshold, she returns to the original nest.

Next, previous work shows, the scout recruits a new scout to join her on a trek to the good site. She dashes around tapping her antennae on other ants and releasing a pheromone from her sting gland, explains Stephen Pratt of Arizona State University in Tempe. Usually she finds a volunteer within a minute or so, and the two set off tandem running.

Scout A, who knows the way, runs back toward the nest while her follower, B, jogs closely enough to tap antennae against the leader. Should A sprint a little too fast and dash beyond antennae range, she slows until her partner catches up. Periodically the two ants stop, and the newbie looks around as if learning landmarks. It's a slow way to get to the site, and Franks argues that it qualifies as animal teaching.

When the ants do reach the possible site, the recruit explores it and, depending on her assessment, returns to recruit yet another scout.

As with the bees, it's the quorum of scouts at the sites that matters. When enough of them gather at a particular place to encounter each other at a sufficiently high rate, they've got a decision.

Once scouts reach that decision, their behavior changes. Each scout dashes back to the nest, but instead of coaxing a nest mate for a tour, she just grabs somebody. She uses a mouthpart hook, an over-the-shoulder throw, and off she goes with the passive nest mate curled on her back in an ant version of the fetal position. Carrying takes about a third as long as leading would, and scouts can haul the rest of the colony to a new home within hours. The ants shift from the independent info gathering of scouts to group implementation of the quorum's decision.

Rock ants' willingness to thrive in the lab allows experiments on finer points of collective decision making, Pratt says. For example, forcing a crisis among the ants demonstrates that they will, in a pinch, trade accuracy for speed. When researchers destroy an old nest so that ants are completely exposed, the ants scope and relocate within hours. Other experiments that just offer the ants a better nest but don't ruin their current one can result in days of deliberation. Speed has its costs, and ants in a hurry now and then make mistakes, such as splitting the colony between two nests. Slower moves prove more accurate.

Ants and bees may run the best-studied decision quorums, but Pratt sees evidence for similar doings in other animals. Studies of cockroaches choosing between hiding places find that a crevice already full of roach buddies attracts more recruits. That phenomenon alone wouldn't qualify as a quorum, Pratt says in an article in the *Transactions* issue. Yet the roaches don't pay a lot of attention to a few lurkers, finding larger numbers quite attractive. Now that, Pratt says, looks like a quorum.

One of the best examples of quorum behavior in a vertebrate other than a human comes from three-spined stickleback fish. In a lab setup, the fish readily swim toward shadowy nooks to hang around. But choosing which nook can depend on the choices made by other fish, Ward and his colleagues reported in *Proceedings of the National Academy of Sciences* in 2008.

To test fish decision making, researchers offered two inviting corners of a tank, each with a path rigged for towing along fake sticklebacks of painted resin. When researchers let two or more real fish watch a single fake "swimming" to one of the corners, the real fish ignored the singleton. Released to choose a corner, the live fish swam off in their own direction regardless of where the fake fish went. However, when researchers towed two artificial fish to a particular corner, the real fish paid attention and proved more likely to favor the same corner.

"They wouldn't take one fish's word for it, but they would take two fish's word for it," Ward says. Going from one fish to two may not seem like a big deal, but Ward argues that it should reduce risk. If one fish, for example, has a 1 in 20 chance of making a stupid choice, the chance of two fish making the same dumb mistake would drop to 1 in 400, Ward notes. Requiring even a small fish quorum, he says, becomes "a really nice simple mechanism of reducing the chance of completely going wrong and following an idiot."

A real fish all by itself, possibly desperate in its isolation, didn't bother with the quorum. Towing even one fake fish to a particular corner influenced the loner to choose that direction.

When a fake predator, a plastic perch, moved along one path, a loner still tended to swim along that route if researchers offered just one fake stickleback for company. The experiment "shows the possibility that isolated social animals, and that includes human beings, can easily be misled by a mendacious leader," Ward says.

Tricking a whole group of live fish proved much more difficult.

The quorum system could be widespread in group behavior in nature, Pratt says. Overall it's a beautiful tool, allowing for carefully balanced independence plus some shortcut speed. Yet the system "has a dark side," he acknowledges. Once individuals have made their independent assessments and then a quorum has reached agreement, fellows copy the quorum behavior. The chances are low that the whole quorum will reach the same wrong decision. But flukes can happen. In most uses of a quorum, "it's going to make a decision more accurate," he says, "but it also slightly increases the incidence of these rare events when you get it really spectacularly wrong."

S.PRATT

A rock ant leads a second scout in a slow tandem run to a possible nest site (top). Once they reach a quorum, scouts stop leading nest mates and just carry them (bottom).

Bees and ants don't mess up that often, but they have been making fewer kinds of decisions, about nest sites for example, and for millions of years. For humans, "there's a lot more creativity going on in the kinds of problems we solve," Pratt says. Our inventive species has to cope with ever-changing structures, societies and other challenges without millions of years for natural selection to hone the systems.

Pratt sounds wistful in remarking that ants don't have a stock market. "If they did," he says, "we could rely on them to have figured the whole thing out."

Explore more

- Iain D. Couzin. "Collective cognition in animal groups." *Trends in Cognitive Sciences*. January 2009.