Formica: strength in unity!

by Gervais Coulombe

Life sciences
Instructional project
Intermediate Age 15
Polyvalente de Matane
Eastern Quebec
Presented at the Science Fair in 1997

Project summary
At the Eastern Quebec Regional Science Fair, I will present a science project on ants, from their origins to their contribution to the world's biomass, including their social organization and homeostasis.

Project Report

Introduction

For more than 50 million years, ants have reigned over five continents, building empires and megalopolises with millions of inhabitants. They invented the concepts of society, state and people long before any developed primate appeared on Earth. When I began studying ants, I had no idea that I would discover such a paradoxical being: so small, yet so perfect. Before sharing the results of my research, I would like to extend my sincerest thanks to the following scientists: Laurent Keller, Institute of Zoology and Animal Ecology, University of Lausanne, Switzerland; Vincent Fourcassié and all the researchers at the Laboratory of Ethology and Animal Psychology, Paul Sabatier University, Toulouse, France; John T. Longino, Evergreen State College, Olympia, Washington, U.S.A.; Christian Peeters, Ecology Laboratory, Pierre et Marie Curie University, Paris, France; and André Francoeur, Director of the Biodiversity Documentation Centre, University of Quebec at Chicoutimi, Chicoutimi, Quebec. Without their invaluable contribution, this project on social homeostasis among ants would not have been possible.

Family

To date, myrmecologists from around the world have catalogued more than 20 000 different species of ants in the Earth's biosphere. They range in size from 0.7 mm to 40 mm and their bodies are divided into three distinct parts: the head, the thorax and the abdomen. Taxonomically speaking, Formicidae are Hymenoptera (suborder Aculeata). They are a natural phylogenetic group classified in a superfamily called Formicoidea and a family called Formicidae. The family is currently divided into 11 subfamilies classified into two major complexes: Myrmecioid and Poneroid.

Origins

Discovered by the famous American entomologist Edward O. Wilson, *Sphecomyrma freyi*, the oldest known ant fossil, is estimated at 80 million years old. Since then, the number of individuals and species has grown considerably. Some of them were giants. For example, species of the genus *Formicium* had forewings measuring between 25 mm and 65 mm, which makes them the largest known ants ever discovered. Today, there are some billion billion individual ants in the world, if not more. Their demographic

prowess is due to Formicidae's exceptional adaptive radiation since the end of the Mesozoic period. First, in order to defend themselves against predators, ants formed small societies of a few inhabitants. Then, gradually, some devoted their lives exclusively to reproduction. This was the origin of the three castes: a fertile queen, female workers and males. This morphological division of labour would not have been possible without a haplodiploid mating system. Ants could then begin forming the first group of eusocial predators, living and finding sustenance underground and in decomposing plant matter.

Castes

The queen is a functional female with wings that she will lose after mating. A very few queens are wingless. Physiologically speaking, the queen differs from the workers in a few obvious ways: large eyes, well-developed pterothorax, more highly developed brain and gonads. Hatched from a diploid egg, the queen possesses both paternal and maternal genes. In order to hatch in the larval state, a queen must have developed under optimal conditions. If the larva does not receive a special nectar, it will regress to the caste of worker. The queen's longevity and fertility, which can extend over 22.5 years, determines the survival and size of the colony.

Female workers hatch from fertilized eggs. They are usually sterile, small and wingless. During their three-year lifespan, they collect food, defend their territory, build and maintain the nest and take care of the young. Interestingly, workers are capable of extraordinary polymorphism, which results in the subdivision of the caste into several forms: huge soldiers, their abdomens filled with honeydew; scouts exploring unknown territory; etc.

Males devote their lives almost exclusively to mating. To produce a male, the queen must lay an unfertilized egg in a process known as arrhenotokous parthenogenesis. The male is haploid: it has only 16 maternal chromosomes. Black in colour, it does not possess a digestive system, but it has a pair of permanent wings, which it uses for its mating flight. It can be distinguished from the female by its small head, deformed by large eyes and ocelli, and often atrophied mandibles.

Society and communication

The most fascinating aspect of ant life is their perfect socialization. Sociobiology is based on the study of ant colonies, which demonstrate an extraordinary level of organization, comparable to that of humanoids. To sustain such a level of organization, these three-brained insects developed a complex glandular system that allows the citizens of a colony to communicate chemically. Thanks to pheromones, workers can transmit information to an entire colony, young reproductives can stimulate their partners erotically and a queen can communicate with her subjects. Essential to the survival of the colony, this language allows a worker returning from the hunt, for example, to indicate the location of a corpse, thereby stimulating the colony to send females to recover the spoils.

In addition to pheromones, ants secrete allomones in order to establish relationships with other organisms. Many other substances are produced by the different types of exocrine glands—metapleural, Dufour's, mandibular, labial, Pavan's, poison. Phenylacetic, 3-hydroxydecanoic and indoleacetic acids secreted by the metapleural glands of *Acromyrmex octospinosus* act as bactericides and fungicides, a plus for

cleaning the nest! Secretions from the Dufour's glands allow the colony to mark its territory.

Reproduction
Ants mate differently depending on where they live. They can mate in the air or on the ground. In species in which the queen is wingless and in cases where the queen has broken her fragile wings, mating takes place on the ground. The queen then lays her eggs inside the colony, provided that it is polygynous. The mating flight looks more like an aerial massacre than a mating ritual. First, young males and virgin females meet for the first time either on a launch pad or on the ground. Then, their glands secrete sexual pheromones that whip them into a mating frenzy and, in successive waves, their forewings and hindwings carry them higher into the air, where thousands of predators patiently await the feast. Of 1500 princesses taking wing, fewer than five will manage to reproduce. After mating, the male dies, and the future queen must found a new colony.

Colonies
Depending on her species, the new queen will lay her eggs in one of two types of societies: monogynous or polygynous. In a monogynous society the queen will found a veritable metropolis, which will develop over future generations. *Formica rufa* is one example. Polygynous colonies may have up to a hundred queens capable of laying eggs.

Queenless colonies were discovered in the early 1980s. How can a colony grow without a reproducing queen? Workers possess the same genes as queens, and can reproduce. While most workers become sterile, some colonies of 10 to 300 workers lost their queen in the evolutionary process. They are part of the subfamily Ponerinae and represent only one percent of all ants. The different roles are based on behavioural regulation: the dominant workers control reproduction and the others become sterile. To form such a hierarchy in a society, several dominant-submissive relationships will be established. Behavioural changes in the losers prevent ongoing conflict. Only young workers participate in the hierarchical struggle, the older ones preferring to go out hunting.

Finally, some parasitic species no longer have a worker caste, such as *Myrmica lampa* in Quebec. These Formicidae cannot found immense empires of hundreds of sister colonies like *Formica rufa*, which create long paths connecting their various states. Some of the colonies adapt to a specific task (e.g. raising aphids, hunting, waging war), increasing the level of socialization and equilibrium among individuals.

Power and sex ratio
So who has the power in an anthill? In some monogynous *Iridomyrmex humilis* colonies, power is genetic. Fatherless males possess only one series of chromosomes and all their spermatozoa are identical. Female workers and queens possess two series of chromosomes. Therefore, in a monogynous colony, workers are true sisters. They possess the entire paternal genome and, on average, half of the maternal genes. This explains why workers are sterile: they share ¾ of their genes with their sisters, and only half with eventual daughters. Thus, they favour the development of their sisters over that of their offspring, which makes it possible to maintain a balance between egg layers and workers in the nest. Males share only ¼ of their genes with the females in the colony. A Japanese team has demonstrated that the amount of energy workers of a local species of ant invest in raising males is directly proportional to the number of genes they share. Workers spend three times as much time raising their sisters as they do raising males.

French researchers compared the proportion of male eggs laid by the queen (primary sex ratio) with the proportion of males who reach adulthood (operational sex ratio) in *Iridomyrmex humilis*. The conclusion they reached is striking: the operational sex ratio is lower than the primary sex ratio. Workers therefore eliminate a certain number of useless males, while keeping a few in case the queen should die. Power in the anthill is clearly a women's issue!

From the nursery to the great outdoors
The evolution of young ants barely out of the nymph stage can be compared to daily life in a metropolis. Ants are born in the nursery, in the upper storeys of the anthill, warmed by the sun's rays. Until they are 10 days old, they look after the queen in her quarters, which are closely guarded by huge soldiers with terrible mandibles. Then, between the ages of 11 and 20 days, workers see to the cocoons in the nursery, before tending and feeding the freshly emerged larvae. From age 30 to 40 days, they are in charge of domestic tasks and roadwork, then earn the privilege of raising aphids outdoors. At the age of 50 days, they go out hunting and exploring. At the age of 11 days, young reproductives remain in their cells until it is time for their mating flight.

A made-to-measure army
Defence is very important for an ant colony. Recent research has shown that, if the colony feels threatened, it will substantially increase the number of soldiers. Soldiers are huge workers with gigantic mandibles. Some ants employ mercenaries to fight their wars. Others enslave their enemies! If a small bird is unfortunate enough to dig too deeply into an anthill, the army will attack it with streams of formic acid and invade its orifices all the way to its internal organs.

Collective spatiotemporal intelligence
A number of researchers throughout the world are amazed by ant intelligence, including those at Paul Sabatier University in France, who have proven experimentally that Formicidae possess spatiotemporal intelligence, which tells them when and where the scientists will be feeding them. One hypothesis has it that, in addition to time and space, temperature is an important factor for these social insects. Since they are cold-blooded invertebrates, time for them passes more quickly at 20°C than at 15°C. Finally, the colony's intellectual strength is a function of its unity. If a worker is faced with a complex problem, she will secrete pheromones and her fellows will rack their brains until they find a solution.

Food
In order to eat, ants must hunt daily. Their prey includes beetles, caterpillars and dragonflies. An average colony easily disposes of a hundred thousand insects a day, or the equivalent of half a tonne a year. They also consume any dead insects they find. The commensalism they have developed with aphids provides them with an unlimited supply of honeydew, their favourite food. Hunters eat their prey on site, transforming the food into a liquid, which they carry home in a pouch called a social stomach. Then, adopting a solicitation posture, famished workers claim their part of the harvest and the food makes its way to the lower storeys where each individual awaits his or her turn. This mouth-to-mouth feeding is known as trophallaxis.

Contribution to the world's biomass
Did you know that 10 to 15 percent of the world's animal biomass is made up of ants? Ants act as a catalyst, accelerating the decomposition of millions of corpses. In the

forests of the Amazon, one third of the terrestrial animal biomass is made up of ants and termites. On average, there are eight million Formicidae and one million termites per hectare! In many environments, they move as much if not more soil than earthworms and enrich it by burying arthropod corpses and plant parts. Ants are found everywhere on the planet, except in Antarctica, Greenland and Iceland and at the North Pole, which have no indigenous species. They also do not venture between the tree lines and the poles. Ants have not yet given up all of their secrets. There are a number of sibling species, genetically isolated but very difficult to differentiate morphologically. It is sometimes necessary to resort to caryogram analysis or allozyme electrophoresis.

A promising future

In conclusion, ants' key to the future lies in their incredible capacity for adaptation. They have managed to survive the radiation resulting from nuclear testing. Insecticides don't work for very long. The future belongs to ants and Aesop would be surprised to learn just how long the toiling ant will continue to amaze us.