wise. Nevertheless, the author should perhaps have questioned scientists about what more they expect from this fish. Its behaviour is barely known and, above all, its embryonic development is totally unknown. Knowing how the strangely articulated braincase or the fins of the coelacanth develop would be just as important as what we already know of its anatomy, in particular for understanding the early evolution of bony fishes and sarcopterygians. This is perhaps the next challenge for the forthcoming century.

Lay readers will certainly enjoy *A Fish Caught in Time*, but it can also be recommended to students and zoologists who are too young to have experienced this extraordinary zoological adventure. ■

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Pogo-centricity

Ants at Work: How an Insect Society is Organized

by Deborah Gordon

Free Press: 1999. 208 pp. \$25

Jürgen Heinze

It is certainly an odd sight in the early light of an Arizona desert morning to see a number of people digging themselves into the dry soil, crawling around with their noses close to the ground, hunting for something that is invisible from even a short distance. Still, the inhabitants of Paradise and Portal in southeasternmost Arizona are by now presumably quite used to it, because over the past decades the Chiricahua Mountains and adjacent San Simon Valley have become a favourite field site for researchers interested in the evolution, sociobiology and ecology of ants. One of them, Stanford professor Deborah Gordon, now writes about what she has discovered, in 17 years of observations, lab and field experiments and computer modelling, about *Pogonomyrmex* harvester ants.

Ants at Work is an entertaining mixture of personal travel report and popular science. And it is deliberately 'Pogo-centric', as the author herself says: it focuses almost exclusively on this genus, ignoring most other ants. It is also much more a private, 'Gordon-centric' *oeuvre* than a comprehensive and integrated treatise on ants, and three-quarters of the roughly 45 references in the appendix are by the author and her research team. Other research on *Pogonomyrmex*, including studies done just across the road from her own study site and a recently published book on harvester-ant biology, is left aside, as are other key publications, including several fundamental reviews on ant biology. These omissions might perhaps help a naive reader, whose knowledge does not go

Mating time: ants display enormous variability in reproductive tactics across the 300 ant genera.

much beyond the film *Antz*, to keep on track and not go astray among the fascinatingly complex universe of social insects.

Those ant novices will be initiated straight to *Pogonomyrmex*, their foraging strategies, their conflicts with neighbouring colonies and how they make decisions, without the detour to other ants with alternative ways of life. And they will also learn a lot about how all this information is gathered and how researchers cope with the manifold problems that generally make field studies on animal behaviour quite tricky — such as temporal changes in activity patterns or motivation. *Ants at Work* vividly involves the reader in several ingenious experiments especially designed to overcome these and many other difficulties.

Readers more familiar with ants, however, will occasionally feel somewhat uneasy. *Pogonomyrmex* is only one of about 300 ant genera and it has a rather specialized ecology and behaviour. Generalizations, such as those made in the introduction that workers of all ants are sterile and new reproductives fly off to mate, unduly oversimplify the enormous variability of reproductive tactics in ants, with wingless sexuals mating in the nest or workers laying both fertilized and unfertilized eggs.

Furthermore, some aspects of ant biology presented to the reader as amazing news have

for a long time and in much detail been known from other ants. It is common knowledge among social insect researchers, for example, that an ant colony operates without any central control, that workers can easily switch from one task to another, and that the meaning of signals used in communication is context-specific. That an ant queen is not in charge, claimed on the book jacket to be a revolution in our thinking on natural organization, is therefore trivial. On the other hand, the remark that no ant has power over another is somewhat puzzling, given the accumulating evidence for overt kin conflict and dominance hierarchies in some ant species.

One of the book's major themes is division of labour, a very acute problem that is being widely (and heatedly) discussed among social-insect researchers and has also elicited considerable interest in the artificial-intelligence community. Here, Gordon describes a series of experiments and observations which demonstrate that task allocation is highly flexible and that encounter rates between individuals may be important for task switching in *Pogonomyrmex*. She then uses this evidence to shatter the alternative hypothesis that an ant's task is innate, that is, that a worker does a single task throughout its life. However, to my knowledge, this latter viewpoint has never been

held seriously, not even by George F. Oster and Edward O. Wilson, to whom it is attributed. This looks to me like fighting a straw man. I would have preferred an up-to-date overview on the state-of-art in this field or a thorough analysis of how Gordon's encounter-rate model compares with temporal polyethism (which is mentioned elsewhere in the book) or the many other models of decentralized control and self-organized division of labour. Even readers less familiar with social insects would not have been overtaxed by a balanced treatment of this subject.

To conclude, *Ants at Work* offers a lot of information on harvester ants and introduces several new, and some not so new, interpretations of ant behaviour, including the concept of self-organization, to a broader audience. This is probably the author's main aim, and it is well achieved. It is doubtful, however, whether the book will satisfy the much farther-reaching aims listed on the dust-jacket. I enjoyed reading the book, but it did not really revolutionize my understanding of ants. ■

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An exobiologist's life search

Carl Sagan: A Life in the Cosmos

by William Poundstone
Holt: 1999. 560 pp. \$30

Carl Sagan: A Life

by Keay Davidson
Wiley: 1999. 540 pp. \$30

Christopher Chyba

The astronomer Carl Sagan died of pneumonia in December 1996, following a two-year struggle with the bone-marrow disease myelodysplasia.

Sagan had directed the Laboratory for Planetary Studies at Cornell University, where his research group pursued questions related to the organic chemistry of the outer

Solar System, the origins of life on Earth and the search for life elsewhere.

Always optimistic about the prospects for extraterrestrial life and intelligence, Sagan's early scientific contributions nevertheless considerably diminished hopes for life on Venus and Mars. His subsequent work on the "early faint Sun paradox" set the stage for decades of research trying to reconcile the evolution of the Sun with the early terrestrial greenhouse atmosphere.

Throughout his career, he played a leading role in Solar System exploration, including the Viking and Voyager missions. Sagan's popular book *Cosmos* (Abacus, 1983), based on his award-winning television series, was the best-selling science book ever published in the English language. At the time of his death, he was undoubtedly the most famous scientist in the United States. He was a vocal enthusiast for the scientific search for extraterrestrial life, a public sceptic about claims for the paranormal and UFO visitations, and had played a prominent public role in the 'nuclear winter' debate, warning of the possible effects that the fires resulting from nuclear war would have on climate. This was a remarkable brew, and guaranteed that his life would prove of unusual interest. His first two biographies have just been published.

Carl Sagan: A Life in the Cosmos is by William Poundstone. His previous book, *Prisoner's Dilemma* (Doubleday, 1993), was part biography of the mathematician John von Neumann, part popular explanation of game theory and part cold-war history. As a result, Poundstone brings to Sagan's life a feeling for science combined with an intuition for politics and bureaucracy.

Poundstone understands the psychological free-for-all at work when scientists choose which problems to pursue: "These decisions are necessarily intuitive and idiosyncratic, based on incomplete information and personal value judgments. A prime example of this is Sagan and the exobiologists' belief that, of all the possible things we might learn about the universe, the detection of extraterrestrial life would hold unique significance." But he also understands Karl Popper's distinction between this personal realm of hypothesis formation and the intersubjective, though tricky, realm of hypothesis testing. This gives Poundstone's accounts of both exobiology and the nuclear winter controversy some sophistication. About nuclear winter, he writes, "the TTAPS [Richard Turco, O. Brian Toon, Thomas Ackerman, James Pollack and Sagan] group was qualitatively right and quantitatively wrong in their first publication — and then they revised as new data became available. What makes nuclear winter different is that the error-correcting mechanism of science was played out in the political arena."

The second new biography is *Carl Sagan: A Life*, written by Keay Davidson, a science writer for the *San Francisco Examiner* newspaper. Both biographies contain a great deal that is unflattering to the young Sagan. Each particularly criticizes Sagan's behaviour in his first marriage to Lynn Alexander (now Lynn Margulis, the biologist). Sagan was 22 and Alexander 19 when they married. Clearly, the union was premature. "The divorce was probably a greater success than the marriage," Poundstone comments dryly.

Neither biographer can be blamed for quoting a divorced spouse, a bitter child of a first marriage or even a long-time friend who chooses to reveal old confidences. Poundstone is interested in Sagan's personal life, but lets those he quotes speak for themselves. Davidson's biography, by contrast, is replete with attributions of motive and unsubstantiated accusations that go well beyond the evidence.

Consider Davidson's description of the teenage Sagan at the University of Chicago (Sagan went to university at 16): "He apparently did not show special favors to women — did not talk down to them, as if they were children — which, one surmises, at least some of them found strange but alluring, like being seduced by someone eager to ravage a previously unravaged part of their bodies: their brains."

"Whether he ravaged anything else is unclear; Sagan left virtually no reminiscences about his college dating habits, and what he did recall was typically self-centered, concerned less with the girl than with how he thought she perceived him."

It is hard to know what to make of this disturbing passage. Quite apart from his strange "surmises" about women, Davidson criticizes Sagan for leaving no reminiscences about his romances with the "girls" he met. No honourable explanation is entertained, such as simple respect for the young women's privacy.

More serious is Davidson's accusation that the young Sagan wilfully and illegally revealed classified information in order to further his chances of winning a Miller Institute graduate fellowship to Berkeley. This is a serious and specific legal allegation which Davidson does not substantiate. Instead, we learn that Sagan was nominated for the Miller fellowship by Nobel laureate Joshua Lederberg, that the Nobel laureate H. J. Muller wrote in support that Sagan "stood head and shoulders above" other students of his age and that he had recommendations from the future Nobel laureate Melvin Calvin and the chair of Berkeley's astronomy department. Yet Davidson claims that these alone were "probably not good enough to ensure his victory" in the fellowship competition. Therefore, he asserts, Sagan revealed the classified information to "make the Miller judges sit up and take notice".

From inner to outer space: Sagan in 1959 holding his and Lynn Margulis' son, Dorion.