NATURAL HISTORY

Beyond the Chimpanzee Genome: The Threat of Extinction

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I have had the privilege of watching chimpanzees for many hours in their natural habitat in Africa and in a variety of zoo settings. They are magnificent animals. Watching them is unlike watching any other nonhuman creature. When a chimp looks back at you, your soul has been penetrated. You feel as though your inquisitiveness has been volleyed back, no words or actions exchanged.

The unveiling of the chimpanzee genome (*1*) presents a unique opportunity to systematically explore how and why we diverged from our closest living relatives. Perhaps, once and for all, we can begin to figure out the meaning of the tiny differences in DNA between our respective species. Perhaps we will learn how small differences in the code of life enabled us—but not chimpanzees—to cook soufflés, create symphonies, translate our own voyages into maps, build ever more complicated artifacts, and write plays that reflect the social intricacies of our lives. But none of this will have any meaning unless we understand what it is like to be a chimpanzee. Humans are unique, and so too is every other species on this planet. But characterizations of uniqueness only make sense in light of a comparative record, one that documents the anatomy, physiology, and behavior of other species.

A map of the genome provides one layer of description. It is a meaningless layer without equally rich descriptions of how genes enable each species to make a living, escape predators, fend off competitors, build allies, and produce babies. In this sense, my greediness to understand extends beyond the chimpanzee genome to that of its closest genetic relative, the bonobo. Although remarkably similar on many levels, bonobos differ from chimpanzees—and resemble humans—in important parts of their skeletal anatomy, brain physiology, sexual behavior, and temperament. In many ways we are "chimpobos," a hybrid ape.

Thanks to the pioneering work of Jane Goodall [see the figure; (*2*)] and the many primatologists who have enriched her work since, we now have a detailed description of chimpanzee life. The general public's impression of this life is, however, highly colored by the documentaries presented on television. These focus on the brutality of their hunting and intercommunity killings, or on their exceptional talents with tools. But if you take a snapshot of chimpanzee life at a random moment, here's what you see: eating, sleeping, or grooming.

Watching a chimpanzee eat may not be the most exhilarating experience for even the most die-hard field biologist, but by documenting what these animals eat, when, how, and for how long, scientists have unlocked some extraordinary mysteries. When chimpanzees are infected with certain pathogens, such as the nematodes that attack them in the Mahale Mountains of Tanzania, they consume plants that act as either chemical or physical defenses. For other ailments, including constipation, lethargy, and lack of hunger, they eat the bitter pith of a plant; this same plant is used across Africa as a local cure for humans infected with bilharzia and malaria. These discoveries, made possible by painstaking observations, have ignited an entire field of inquiry: searching for new remedies in the plant life that surrounds us (*3*).

Detailed observations of their eating habits also reveal an exceptionally diverse tool technology (*4*). On the basis of studies spanning the natural range of chimpanzees in eastern and western Africa, we now know that different populations use different tools to gain access to their local resources. Some use sticks to extract termites, others use rocks to crack open hard nuts, and yet others use tree bark as sandals to climb over the thorny needles of trees that hold a delectable fruit. The variation among populations is not due to genes, but rather to the capacity for social learning that the genes have built. What we see when we watch a chimpanzee population is a microculture—one that has developed its own unique signature, evidenced by distinctive tool technologies and, in many cases, equally distinctive social gestures (*5*).

When chimpanzees eat, sometimes they do so in the midst of several other community members, and sometimes they do so alone. Here, sex differences emerge. Males live in their natal groups for life, whereas females leave once they reach reproductive maturity. When you watch chimpanzees in the wild, it is not uncommon to find an adult female, either alone or with her offspring. Seeing a male alone is rare. Many of the males in a community are brothers. They hunt together, cooperate to form alliances against other members of the community, and often go off on patrols to defend their turf against often violent neighbors. Like our own species, but unlike their close relative the bonobo, chimpanzee males are extremely aggressive toward their neighbors. If members of one community have outnumbered a foe, they will attack and kill a member of another community who has wandered too far from home (*6*, *7*); some of the calculations used in making such group decisions may be carried out with the chimps' exquisite mathematical prowess (*5*, *8*). Watching such kills is chilling. It is too close for comfort.

When chimpanzees cluster into social groups, the political strategizing that goes on reflects planning, power, and peace offerings (*9*). Studies in the wild and in cap-

Understanding our relatives. Jane Goodall observes a family of chimpanzees.

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tivity, especially the latter, have revealed that individuals both compete and cooperate by making inferences about what others know and intend (*10*, *11*). These studies have revolutionized our understanding of what chimpanzees think and feel, raising profound philosophical questions about the nature of thought without language, as well as ethical questions concerning the rights and welfare of these animals (*12*).

Constraining our continued understanding of this wonderful animal is one annoying hurdle: our own species. In the very near future, we may ironically face the possibility of having a detailed map of the chimpanzee genome, but no individuals to study. Illegal hunting, the bushmeat trade, and deforestation are destroying chimpanzee populations (see, for example, www.chimpcollaboratory.org). If the same amount of effort that is going into genetic analyses went into chimpanzee conservation and behavioral biology, not only would we save this species from extinction, but we would write the most detailed story of our past—as rich as the Bible, but grounded in science.

References and Notes

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GENOMICS

Thoughts on the Future of Great Ape Research

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When the Human Genome Project was established in 1991, the planners wisely included sequencing the genomes of model organisms in the project's goals. At that time, the only nonhuman mammalian genome scheduled for sequencing was that of the laboratory mouse. Although the relevance of the mouse genome for interpreting the human sequence was beyond dispute, some biologists were disappointed that no nonhuman primate genome had been included. The remarkable similarity of the chimpanzee genome to that of humans was already predicted from overall DNA comparisons, and it seemed clear that questions about the genetic basis for human uniqueness would eventually require detailed comparisons with the genomes of great apes (*1*), our closest evolutionary relatives. A formal presentation of the need for sequencing the chimpanzee genome was published in 1997 (*2*). Soon thereafter it was pointed out (*3*) that there should also be a project to increase our knowledge of the great ape "phenome" (the complete body of information about an organism's phenotype under various environmental conditions), about which very little is known. Scientists from a variety of disciplines rallied in support of sequencing the chimpanzee genome, also citing biomedical reasons and the potential importance for proper care and conservation of great apes (*4*, *5*).

We now have a draft sequence of the common chimpanzee genome (*Pan troglodytes*) and a detailed comparison with the human genome (*6*). The results include extensive information on comparative genomics, such as the number of single base pair and insertion/deletion differences and transposable elements unique to either human or chimpanzee. The report clarifies much previously conflicting or confusing information in existing human nucleotide sequence databanks and addresses several important questions about genomic and population evolution mechanisms. It also adopts a rational orthologous chromosomal numbering system to facilitate comparisons of human and ape genomic organization (*7*).

Can we now provide a DNA-based answer to the fascinating and fundamental question, "What makes us human?" Not at all! Comparison of the human and chimpanzee genomes has not yet offered any major insights into the genetic elements that underlie bipedal locomotion, a big brain, linguistic abilities, elaborated abstract thought, or any other unique aspect of the human phenome. This state of affairs may seem disappointing, but it is merely the latest example of a generalization that genomics research has already established—interpretation of DNA sequences requires functional information from the organism that cannot be deduced from sequence alone. Functional genomics investigations must determine where a gene is expressed within an organism, when it is expressed during development and life history, and what the level of expression is at various times. Furthermore, these data must be integrated with information about the related phenotypes, as well as critical environmental influences under which the genotype generates the phenotype (see the figure).

There are three general reasons for substantially increasing research on chimpanzees (and the other great apes—bonobos, gorillas, and orangutans): First, to understand the contribution of genomic DNA to human and great ape evolution; second, to improve our understanding of human and ape phenomes (at all levels, from molecular to behavioral to states of diseases); and third, to help preserve populations of these important human relatives. These goals must be pursued in the face of challenging ethical issues that still need to be resolved by open debate.

Understanding the genetic basis of uniquely human traits will require increasing the accuracy and completeness of the currently available chimpanzee genome sequence, as well as sequencing other primate genomes as out-groups. The genomes of the orangutan and the rhesus macaque are currently being sequenced, but other genomes are needed to obtain a complete picture. Among other benefits, such multispecies comparisons are essential for identifying human-specific coding and regulatory regions.

A parallel requirement is the comparison of human gene expression with those of chimpanzees and other primates. There are formidable obstacles to achieving this goal, the most obvious of which is obtaining experimental material from great apes. It is not ethically acceptable to sacrifice a great ape simply to obtain tissue samples.

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