

cates are undaunted, citing their access to better software and powerful new analytical methods. "The branches are slowly but steadily taking shape," insists Michael Lee, who studies turtles and other reptiles at the University of Queensland in Australia. According to reports from earlier workshops, the number of phylogenetic analyses is doubling every 5 years. "For many, many years to come, there will be legitimate hand-wringing and unresolved issues," Donoghue explains. "But I think the data speak loud enough to say" that a consensus will eventually develop.

Progress has been slow so far. Since the days of Darwin, taxonomists have grouped organisms based on morphological characters such as the number of legs and body shape. But in the past 2 decades, phylogenetic biologists have introduced other classification methods. For example, most now assess relatedness of species according to the degree of similarity in equivalent stretches of DNA. Sometimes the morphological and molecular data clash, although Lee says that, "on the whole, morphological and molecular data have been in broad agreement."

Researchers have found that the more data they collect, the more confident they can be about the lines of a species, and this has encouraged many to incorporate several kinds of data in their analyses. Those who rely mainly on molecular data also take stock of morphological analyses and the fossil record. Fitting all the pieces together will remain a challenge, though. The sequencing of microbial genomes has flooded systematists with new genomes, but it also has revealed extensive gene transfer among microbial species. Thus microbial trees no longer consist simply of bifurcating branches; they look more like tangled brambles.

Plant and bacterial species can be very tricky to sort out. For example, there are about 1000 proteins in *Arabidopsis* that are clearly cyanobacterial in origin, most of them expressed in photosynthesizing components of plant cells called chloroplasts but some expressed elsewhere in the cell. And the origins of some algae can be hard to pin down, according to Delwiche. They appear to have two chloroplasts, at least one of which was acquired when the algae's ancestor ate another photosynthetic eukaryote. What resulted "is like a Russian doll, with a eukaryote inside a eukaryote inside a eukaryote," he explains. Who is to say which is the true ancestor?

Resolving these problems and building a tree of life will require a big-science approach involving "a lot of money, a lot of people, and a lot of effort," says Terry Yates, a systematic biologist at the University of New Mexico in Albuquerque. Indeed, "a human genome-scale effort would be marvelous," adds Tim Littlewood, a systematist at the Natural History Museum in London.

The first task, argue Hillis and Donoghue, should be to develop the computational tools needed to collect lots of data rapidly and to compute ever-larger trees. They call this new field "phyloinformatics." "If we can dramatically increase the rate of discovery about the tree of life, it will pay off enormously in the long run," Hillis insists.

Although a tree-of-life project might sound expensive, advocates say it would make systematics more efficient by encouraging greater coordination. "Currently," says

Littlewood, the field "is rather like a cottage industry with key groups around the world working in isolation." Evolutionary biologists aren't the only ones who might gain: DNA sequencers might use the tree to set priorities. "We don't need to sequence entire genomes for every bit of life on Earth," Yates notes. A tree of life can clarify which organisms would yield the most insights. Given the huge costs of sequencing, he argues, building a tree of life might be well worth the money.

—ELIZABETH PENNISI

PALEOANTHROPOLOGY

What—or Who—Did In the Neandertals?

Was it a changing climate, competition with modern humans, or both? Experts who debated the topic at a high-level meeting couldn't agree

GIBRALTAR—About 100 experts in human evolution paused atop the Rock of Gibraltar to admire the view: Stretched out below were the golden shores of southern Spain, and on a clear day the mountainous coast of Morocco is visible some 30 kilometers away across the blue straits. A moment later, the group began a dizzying descent down 300 stone steps cut into the sheer limestone cliffs to the rocky beach below. Their destination: two sandy caves that were occupied by Neandertals at least 90,000 years ago. Recent excavations in these caves have turned up important new evidence that Neandertals butchered marine mammals, including seals and possibly dolphins, and exploited a much wider range of animal resources than they are often given credit for.

This field trip capped a high-level gathering* at which researchers sought answers to some pivotal questions about the rela-

tionship between Neandertals and modern humans, who coexisted in Eurasia for several thousand years before the Neandertals finally went extinct about 25,000 years ago. How much interaction was there between the two groups? Was competition with modern humans responsible for Neandertal extinction?

In recent years, Neandertals, once viewed as subhuman brutes, have increasingly earned respect, even if most experts today relegate them to a different species from our own. There is a growing consensus among researchers that the Neandertals were not easily shoved aside when *Homo sapiens* ventured into their territory and possibly even continued to advance culturally and technologically (*Science*, 2 March, p. 1725). But whereas some researchers argued at the meeting that there may have been no competition at all between the two groups, others saw the appearance of modern humans as the ultimate death knell for the Neandertals. The participants also got their first detailed look at the evidence behind a controversial claim that the skeleton of a 4-year-old child—first reported in early 1999 from Portugal—was the result of interbreeding between Neandertals and modern humans.

No contest?

The meeting kicked off with biologist Clive Finlayson,



At home in the Rock. Neandertals butchered marine mammals at Gorham's Cave (left) and Vanguard Cave.

* Neandertals and Modern Humans in Late Pleistocene Eurasia, Gibraltar, 16–19 August.

director of the Gibraltar Museum, who threw down the gauntlet: He stated flatly that there was no basis for believing that modern humans caused the extinction of the Neandertals. Indeed, he argued, during their coexistence the population density of each group was too low to trigger serious competition between them. Finlayson proposed that Neandertals went extinct because they were less well adapted to the rapidly fluctuating climate changes that dominated Europe and Western Asia between 60,000 and 25,000 years ago.

This might seem counterintuitive, because the Neandertals—who were braving the European ice ages many thousands of years before modern humans arrived on the continent—were more robust and cold adapted than their more slender cousins, whom most researchers consider to be relatively recent arrivals from Africa. But the key difference between the two species, Finlayson suggested, was that modern humans had more “complex social networks” and thus were better at dispersing across the landscape. Neandertals, on the other hand, tended to stay in one locale; the raw materials for their stone tools, for example, appear to come from sources much closer than those used by modern humans.

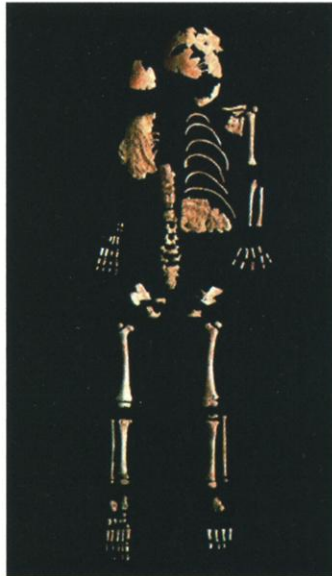
As a result, Finlayson suggested, Neandertals were more vulnerable to alternating episodes of population growth and population decline—and sometimes local extinction—as temperatures rose and fell. The cumulative effect of such local extinctions led to the demise of the species, despite its sometimes superior local adaptability. Ian Tattersall of the American Museum of Natural History in New York City agreed that too much local adaptation can mean death for a species. “Adaptation to specific conditions is a passport to extinction,” Tattersall said. The ones who do best, he concluded, are those most able to adopt new strategies.

Some researchers thought they saw evidence in the fossil record for such severe population fluctuations among the Neandertals. Paleoanthropologist Erik Trinkaus of Washington University in St. Louis cited recent studies of Neandertal fossils showing a significant underrepresentation of adult skeletons over 40 years of age. “If you model populations that build up and crash repeatedly, you get a population profile with a dearth of older individuals,” Trinkaus said.

But other scientists argued that, whatever the other pressures on Neandertals, competition with modern humans couldn’t be ruled out. Once modern humans arrived on the scene, noted New York University archaeologist Randall White, “you no longer had the same ecological or cultural landscape.” Chris Stringer of the Natural History Museum in London agrees: “If it was just climatic changes, we have to ask why Neandertals did not go extinct sooner.”

Mary Stiner, a zooarchaeologist at the University of Arizona in Tucson, argued that the archaeological record contains hints

that modern humans made more efficient use of food resources, making them better overall competitors for resources. For example, she said, during the Upper Paleolithic period—



Paleolithic love child? Some researchers believe this skeleton is a hybrid of Neandertals and modern humans, as evidenced by its Neandertal-like incisors (right).



which corresponds to the arrival of modern humans—archaeological sites begin to show signs that humans were boiling animal bones in water to extract fats rather than simply breaking them apart. “This method can probably double the amount of fat you can get out of the bones,” Stiner said. This greater efficiency at gaining nutrition could have led to faster population growth by modern humans that “could swamp other populations.” Other scientists noted, however, that the findings from the Gibraltar caves—much of which is unpublished—indicate that the Neandertals were also using more varied food sources, including marine mammals, at least on a local level.

A divisive discovery

Whether or not the advent of modern humans led to the Neandertals’ demise, most researchers assume that the two groups did not interbreed. But that assumption was rudely challenged by the discovery in late

1998 of the skeleton of a 4-year-old at Lagar Velho in Portugal. The team studying the skeleton, which includes Trinkaus and João Zilhão, director of the Portuguese Institute of Archaeology in Lisbon, claimed that the 24,500-year-old skeleton was a hybrid or “admixture” resulting from interbreeding between Neandertals and modern humans, but other researchers concluded that the child was actually a modern human (*Science*, 30 April 1999, p. 737).

The debate continued in Gibraltar, where Trinkaus and Zilhão gave their most detailed presentations yet of the skeleton. Showing a long series of unpublished slides of the fossils, Trinkaus pointed out that the leg bones show much greater “robusticity” than that seen in modern humans and that the back of the child’s incisors show an indented “shoveling” pattern typical of Neandertals. Another Neandertal-like feature is the claimed existence of a suprainiac fossa, a depression at the back of the skull often used to distinguish the species. Other features of the skeleton, however, resemble modern humans. “This is not just a funny-looking early human,” Trinkaus concluded.

Yet many researchers at the meeting remained skeptical. Yoel Rak, a paleoanthropologist at Tel Aviv University in Israel, argued that if the child was really a hybrid, the Neandertal and modern human features should be more blended. “If you look at a mule, you don’t have the front end looking like a donkey and the back end looking like a horse,” Rak said. And Tattersall, who was one of the first to challenge the hybrid theory, told *Science* that he saw nothing in this more detailed view to change his mind. “The skull is typically modern human in most of its characteristics,” Tattersall says, adding that the features found in its burial—including a pierced shell and red ochre—were “typical” of early modern human funeral practices.

A less dismissive view was offered by Stringer, who had earlier argued that the child’s robustness might be an example of short-term adaptation by modern humans to cold conditions in Iberia. “I would take the suprainiac fossa very seriously if it is there,” Stringer said, “because that is considered diagnostic of Neandertals.”

Thus the debate over just how up close and personal the relations between Neandertals and modern humans really were shows no indications of ending soon. By the time researchers return to Gibraltar for the next meeting, 3 years from now, there may be more answers—perhaps even from those sandy caves at the bottom of the Rock.

—MICHAEL BALTER