requisite for observing a gravitational lens—is more common. Becker says the team has collected roughly 120 of these events, gathering statistics on how matter is distributed in the bulge and therefore on its shape.

Most of those brightenings follow a standard "light curve" of increasing and then decreasing brightness with time. Such a curve suggests that the degree of alignment—and of magnification—was slight, causing a modest jump in the star's apparent brightness, but not enough to resolve it beyond a point source. But in the case of the event called MACHO Alert 95-30, says Becker, deviations from that curve showed that the alignment was so perfect that "the lens passed across the face of the star," like a detective scanning a body with a magnifying glass.

As the brightness started increasing and MACHO issued the worldwide alert, says Bohdan Paczynski of Princeton University, a "spectacular and successful" coordination of telescopic observations came into play. Called the Global Microlensing Alert Network, or GMAN, the program, whose astronomers were co-authors on the paper, collected spectra and light curves (see graphic) of the days-long brightening almost 24 hours a day. The result was a kind of transect, indicating how the spectrum of the starlight—a clue to composition and structure—changed from point to point across the star, which had been identified as a bloated red giant.

In this case, the MACHO team found that although the orientation of the stars was nearly perfect, the lens's focus passed along a line closer to the edge than the center of the red giant's face. But that was enough to make the first-ever comparisons between the calculated structure of an old, bloated star and actual observations, says Dimitar Sasselov of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. Calculations by Sasselov and CfA's Abraham Loeb showed how the spectral signatures of stellar constituents like hydrogen and titanium oxide should vary from the center of the star to its visible edge, where the line of sight passes through more of the star's atmosphere, "and that's exactly what's observed," says Sasselov. Gravitational lensing, he says, "is giving us a fairly cheap and amazing way of studying the surfaces of distant stars"—and in greater detail than possible even for nearby stars with lengthy exposures on ordinary telescopes.

That kind of sleuthing could help firm up calculations of the age of the Milky Way's oldest stars, which seem to be paradoxically older than the universe itself. The MACHO group may eventually achieve its original goal of finding the galaxy's dark matter. Meanwhile, says Trimble, "it's impressive not only that the thing works, but that it's doing things it wasn't even designed for."

–**James Glanz**

WILDLIFE BIOLOGY

In Search of Africa's Forgotten Forest Elephant

Say "African elephant," and one pictures a vast savanna, where the largest land mammal mingles with lions, giraffes, gazelles, and zebras. In fact, about one-third of the continent's elephants live in its dark, often inaccessible rain forests, where the creatures are difficult for researchers to spot, let alone study. As biologist Claude Martin wrote in *The Rainforests of West Africa*, "Whoever is lucky enough to spy a forest elephant with his own eyes must satisfy himself with a few seconds of gray skin or a bit of white tusk shimmering behind the leaves."

But now a wealth of new studies is bringing these huge, elusive creatures out of the shadows. Scientists analyzing everything from elephant dung to DNA are piecing together the basics of forest elephant biology. With the forest elephant's rounder ears and thinner, straighter tusks, most taxonomists have long thought of it as a separate subspecies from its larger savanna cousin. But new analyses of mitochondrial DNA suggest that the two may be different species entirely (see sidebar). Studies of the forest elephant's diet suggest that the animal plays a crucial role in rain-forest ecology, dispersing the seeds of many fruiting trees. Ongoing research also is unraveling the secrets of their social behavior. Biologists have found, for instance, that unlike savanna elephants, the forest dwellers live in small groups. But like savanna elephants, they maintain dominance hierarchies and seem to mourn a family member's death, an event that scientists fear is becoming ever more common as an upsurge in commercial logging in Africa opens once-remote forests to poachers.

It's hard to blame scientists for overlooking the forest elephant. Why hike into an uncomfortably wet, hot habitat, when savanna elephants—one of the world's best studied mammals—can be easily observed from a jeep? The debate that preceded the 1990 ban on international ivory trade helped spark this new wave of research. Without knowing how many elephants were living in the forests of Africa, scientists found it hard to assess the overall impact of the trade. "Our ignorance of forest elephants was appalling," says Richard Barnes, a visiting scholar at the University of California, San Diego, and a member of the World Conservation Union's African Elephant Specialist Group.

Forest elephants range across more than a million square kilometers of dense forest and cannot be seen from airplanes, so estimating their numbers was a daunting task. But with support from the Bronx, New York–based Wildlife Conservation Society (WCS), Barnes and his wife, Karen Barnes, developed the first standardized method for gauging elephant populations by counting dung piles along transects and inserting the results into a mathematical formula that considers rates of defecation and dung decay.

The researchers first used the methodology in Gabon, where in 1993—after 2 years of hard, sweaty labor deep in the forest—they concluded that about 60,000 elephants lived.


A. K. TURKALO

Significant differences. Forest elephants are smaller and have rounder ears than their savanna relatives.

Over the next few years, WCS sponsored additional forest elephant surveys, and "today we have a pretty good idea where they live and of their relative abundance," says Richard Barnes. Of the continent's roughly half-a-million elephants, between a quarter and a third are forest elephants, the vast majority living in central Africa. The rest hang on in West Africa's very fragmented forests.

Elephant dung has also provided clues to what the animals eat and their role in forest ecology. Lee White, a WCS conservation scientist, says that unlike savanna elephants, which feed mostly on grass, forest elephants subsist on the leaves, twigs, bark, and fruit of rain-forest trees: "Their diet is much more like that of a gorilla than a savanna elephant." In Gabon's Lopé Reserve, White found that elephants eat 80 different kinds of fruit and will travel 50 kilometers or more to feed at a favored tree.

He and others contend that many fruiting trees depend on elephants to disperse their seeds. Seedlings of the makore (*Tieghemella heckelii*), for example—found only in Liberia, Côte d'Ivoire, and Ghana—were abundant along elephant trails in Ghana in the 1950s.

One Species or Two (or Three)?

The more researchers learn about the diet and social habits of Africa's forest elephant, the less it looks like its larger savanna cousin (see main text). Now, molecular genetics is adding to the differences: Recent studies of elephant DNA suggest that forest and savanna elephants, generally thought of as two distinct subspecies, may actually be entirely different species.

Nicholas Georgiadis, director of the Mpala Research Centre in Nanyuki, Kenya, used a dart gun to collect skin samples from elephants in nine countries across Africa. Collaborating with Alan Templeton of Washington University in St. Louis, he analyzed the elephants' mitochondrial DNA by cutting it up with so-called restriction enzymes and looking for the distinct cutting patterns that reflect differences in DNA sequences. According to Templeton, the results show that forest and savanna elephants "represent distinct genealogical lineages that diverged about 3.6 million years ago."

That's enough time for two populations to evolve into separate species. But more analysis is needed to determine whether the forest and savanna lineages really are different species. Templeton says the next step is to look at nuclear DNA, which is inherited from both parents, unlike mitochondrial DNA, which comes only from the mother. Still, asserts Templeton, "from a conservation point of view, whether savanna and forest elephants meet all species criteria is moot. The two animals are different enough that they cannot be managed the same [way]."

Georgiadis, meanwhile, is on the trail of a possible third species of African elephant. He recently returned to Kenya from Namibia, where he was collecting tissue samples from elephants that live in the desert. Like forest elephants, desert elephants look quite different from savanna dwellers—they are larger, for instance—and may represent yet another distinct evolutionary lineage. –L.T.

Botanists who returned to the same sites in the 1970s, however, found no young makore trees, and many believe that as the elephants were killed off by hunters, the tree could no longer disperse its seeds. White has identified a total of 25 species he believes rely exclusively on elephants for seed dispersal, and he estimates that in central African forests as a whole, there may be at least 50 such trees.

One example is *Omphalocarpum sp.*, whose fruit, says White, is "the size of a human head and as hard as a human skull—nothing but an elephant could break it open." Like many fruits consumed by elephants, this one is dull in color (elephants have poor vision), but it emits a strong, garlicky odor and makes a tremendous thud when it falls, appealing to an elephant's two most important senses. The animals gobble up virtually all *Omphalocarpum* fruit in Lopé, and a single dung pile may contain hundreds of intact or germinating seeds.

The patchy distribution of fruit trees in a forest may help explain differences in group sizes between forest and savanna elephants. Savanna elephants live in groups ranging in size from about eight to more than a hundred, but White and other researchers rarely see more than two or three elephants together in the forest. "A hundred elephants cannot feed under one rain-forest tree, but two to three easily can," says White.

More clues about the elephants' social behavior are emerging from the dense rain forests of southwestern Central African Republic. Since 1990, Andrea Turkalo, a research fellow with WCS, has been observing elephants at a 250- by 500-meter clearing, known as Dzanga Bai, which attracts large numbers of animals that come to eat the soil's rich mineral salts. Turkalo identifies individual forest elephants by physical features such as scars, ear markings, and tusk lengths and then records their comings and goings. Fully 40 to 100 animals appear daily, and as of September 1996, she had identified and collected data on 2300 individuals.

Sitting high above the clearing on a wooden platform, Turkalo has found that while forests elephants typically travel in smaller groups, they love to socialize. The animals enter the clearing in twos and threes, but they quickly disperse to greet and interact with others.

Like savanna elephants, the forest males seem to be governed by a strict dominance hierarchy, and Turkalo believes that Dzanga Bai may be an important place for establishing and maintaining that hierarchy. "If a dominant male comes up to a water hole, a smaller one will get out of the way fast," she says. In contrast to savanna elephant males, which form small bachelor groups, however, forest elephant males tend to be loners. Also, young males leave their mothers sooner in the forest. Turkalo attributes this difference to the presence of large predators in the savanna, such as lions, which may make solitary life dangerous for young males.

Turkalo and others raise the provocative possibility that forest elephants, despite appearances, form large social groups whose members keep in touch over long distances through low-frequency sounds. Support for this notion comes from Turkalo's observations that some small elephant groups always seem to arrive at the clearing at the same time—apparently coordinating their movements—and from new research on elephant infrasound vocalizations. Previous studies in east Africa have revealed that infrasound is an important form of communication among savanna elephants. And recently, Steve Gulick, a WCS researcher based in northern Congo, recorded a forest elephant call with a very low frequency of 5 hertz. "It is possible that forest elephants rely on low-frequency sounds even more than do savanna elephants," he says.

Turkalo also says that, like their savanna cousins, forest elephants seem to form strong attachments. Mothers are very protective of their calves. And, last year, Turkalo saw one young female standing over the body of a dead male, "stroking him with her trunk," for the better part of a day. The male had been shot.

Death has been a rare event at Dzanga, but Turkalo counts the vulnerability of the elephants to poachers as a serious threat to the long-term success of her study. Thus far, a shortage of firearms locally, and perhaps her own presence, has kept poaching at Dzanga to a minimum. But just across the border in Congo, Turkalo's husband, WCS researcher Michael Fay, found 300 carcasses of illegally slaughtered forest elephants near a national park last September.

A. K. TURKALO

Meet and greet. Forest elephants come to Dzanga Bai to socialize and ingest mineral-rich soil.

Conservationists say a recent upsurge in commercial logging in central Africa also poses a serious danger to forest elephants. According to a report released this week by the Washington, D.C.–based environmental organization World Resources Institute, logging endangers 79% of Africa's large, intact forests. In West Africa, 90% of the rain forests have already been destroyed, and elephants there are confined to small, isolated populations that are vulnerable to inbreeding and to natural disasters such as drought and disease. According to Richard Barnes, these small populations would also be at risk should countries fall prey to civil unrest.

Logging not only destroys forest habitat, however; it opens up once-remote areas to farmers and miners. And when this occurs, elephants can run into trouble with their neighbors. Throughout Africa, "crop raiding" has turned elephants into feared and hated pests. Last July, for example, 13 village chiefs from around Ghana's Kakum National Park marched on the nation's capital to protest park-dwelling, forest elephants that foraged in nearby fields.

Efforts to find solutions are bringing together unusual allies. At a meeting last fall in Washington, D.C., at Conservation International, an environmental group, Ben Asamoah-Boateng, director of Kakum, met with Richard Barnes and Jack Birochak of the Pennsylvania-based Counter Assault Tactical Systems, a company specializing in personal safety devices. Birochak has designed a special capsicum pepper spray—a larger version of what city dwellers carry to deter muggers—that will be tested on the park's crop-raiding elephants.

Some researchers contend that, in certain areas, crop-raiding claims may be exaggerated. In Gabon, cane rats and porcupines cause far more damage, White says, but are not nearly so hated by farmers. The difference, he says, is psychological. "An elephant may have raided your farm [only] once 10 years ago, but you never forget an elephant."

–Laura Tangley

Laura Tangley is a science writer in Washington, D.C.

PALEONTOLOGY

How Reptiles Took Wing

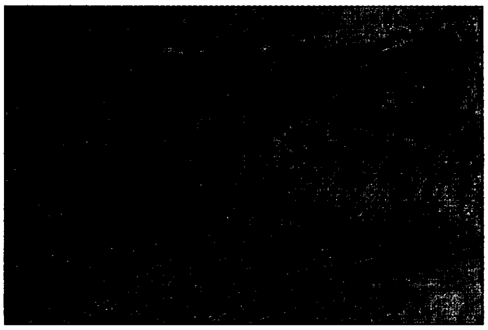
In 1910, a copper miner in central Germany picked up a nearly flawless fossil: an unusual reptile with a winglike fan of bones spreading from each shoulder. When he sold the specimen to Otto Jaekel, the premier German paleontologist, the miner labeled it "Flying Reptile." But Jaekel thought the animal too improbable and removed the bones of the wings, believing they were the fin rays of a fish superimposed on the reptile. In later years, it turned out that the miner was right and the expert wrong. Now, a report in this issue of *Science* (p. 1450) makes clear just how bizarre a beast *Coelurosauravus jaekeli*—the earliest known flying vertebrate—really was.

By examining several new, exquisitely preserved specimens collected by amateur fossil hunters, Eberhard Frey and Wolfgang Munk of the State Museum of Natural History in Karlsruhe, Germany, and Hans-Dieter Sues of the Royal Ontario Museum in Toronto, show that this 250-million-year-old animal glided on a unique set of wings, unlike any others known in living or extinct animals. The long, hollow bones that strengthened these wings formed directly in the skin itself. "*Coelurosauravus* is totally bizarre because in every other animal that flies, wing support draws on the normal skeleton," says Sues. For example, the wing bones of birds and bats are converted forelimbs.

Strange as *Coelurosauravus*'s wings are, they teach an important evolutionary lesson, says vertebrate paleontologist Robert Carroll of McGill University in Montreal: "We typically think of evolution as taking an existing structure and making some new function of it, but this animal has taken the capacity to produce bone and elaborated it in a completely unique way."

Carroll was the first paleontologist to identify *C. jaekeli* as a flying reptile, back in 1978. Based on the partial fossils then available, he interpreted the reptile's wing rods to be extensions of its ribs, like the wing struts of the modern gliding lizard *Draco*. Later, researchers suggested that the animal had hinged, two-part ribs. But in the early 1990s, Sues and Frey began to question this assumption. They reasoned that such a reconstruction required *C. jaekeli* to have a rib and a vertebra for each of its 24 to 28 wing rods, creating an animal with an implausibly long, flat trunk, stretched into a kind of "reptilian pancake."

Looking for a more plausible picture, they examined several beautifully preserved specimens, most of them owned or discovered by private collectors. Two partial skeletons showed that "the [wing] rods had nothing to do with the ribs," Sues says. A nearly complete skeleton sold by an amateur collector to the museum in Karlsruhe offered the final proof. This fossil had only 13 vertebrae, but 22 rods on each side, which splayed out in bundles and were unattached to any other skeletal elements.



E. FREY

Winging it. *Coelurosauravus*'s wings were supported by new bones that formed in the skin, rather than by modifications of existing bones.

Thus, the wings of this precocious flyer opened like an old Japanese fan, explains Sues. The bundles of bony rods formed directly in the skin and radiated from the shoulder area. When spread, the bundles extended to form two curved wings that could carry *Coelurosauravus* tens of meters. The long tail, which made up half of the 30-centimeter body length, may have added stability in flight.

Carroll himself is now persuaded of this unusual wing structure. "The new German material is good enough that it should settle most of the arguments," he says. "This demonstrates how early flight, even if not active, flapping flight, was achieved by vertebrates." And the new understanding of *C. jaekeli* could also spur new insights into the mechanics and evolution of flight in other animals, adds Kevin Padian, a paleontologist and pterosaur expert at the University of California, Berkeley: "It may now prove interesting to take another look at later flying vertebrates that evolved independently."

Frey and his colleagues owe their close look at *C. jaekeli* to the work of several amateur fossil hunters, including a German house painter and a baker. They are among the hundreds who pore over the spoils of abandoned copper mines in central Germany's Kupfershiefer formation every weekend, splitting open blocks of copper-shale and noting their finds in detail. Because most of the fossils from this region are already well described, no professional paleontologists work these mines, says Sues, and amateurs have gathered almost all the known *Coelurosauravus* specimens. "Paleontology, unlike particle physics, is something an amateur can make important contributions to," says Sues.

Of course, relations between amateurs and professionals are not always so cordial. For example, given the surprising results on *C. jaekeli*, paleontologists would like to see what else may be learned from little-known groups such as the kuehneosaurs, rare, 225-million-year-old reptiles whose wings are thought to be adaptations of ribs. But researchers say that the best specimen, once held by the American Museum of Natural History, is now back in private hands—and unavailable for scientific study.

–Bernice Wuethrich

Bernice Wuethrich is a science writer in Washington, D.C.