combined greenhouse-aerosol effect, at least in summer and fall. That seasonal preference makes sense, says Santer, because those are the months when sunlight is most abundant in the Northern Hemisphere and the reflective haze would have the biggest effect. Santer and his colleagues believe their analysis "supports but does not prove that we have detected ... an anthropogenic climate-change signal."

There are plenty of uncertainties to prompt that tentative note. Taylor and Penner's model isn't state-of-the-art, incorporating only a simplistic ocean. The effects of aerosols on surface temperatures are still uncertain. And, says David Karoly of Monash University in Clayton, Australia, "you could still argue that there are other climate forcings [besides aerosols] that need to be included" in the models. But the biggest reason for caution, Santer and others say, is the possibility that natural variability might be producing a warming that mimics the greenhouse-plus-aerosol signature.

To test this possibility, Santer and his colleagues examined the patterns of temperature change generated by simulated natural variability in 1000-year runs of the GFDL model and an MPI model to see whether they could show the same trend of increasing similarity to the observed record. The comparisons revealed that, depending on the model, there was only a 1% to 3% chance that natural variability was behind the increasing similarity in the summer and fall and about a 6% chance that it was responsible for the similarity in annual temperature trends.

But Karoly says he has "serious concerns as to whether the natural variability [seen in the computer models] is realistic." Indeed, says Santer, doubts about the realism of computer climate models are the biggest hurdle facing both efforts to convict greenhouse warming. Like most climate models, for example, the models in both studies require sizable fudge factors to keep their simulated climates from drifting off into hothouse or deep-freeze conditions for no good reason (*Science*, 9 September 1994, p. 1528).

Uncertainties or no, these two studies do mark a turning point in the search for global warming's culprit. "This is where the debate is really starting," says Barnett. As Karoly puts it, "There's growing evidence [implicating the greenhouse], but it's not incontrovertible. That requires more than one or two studies. We will have to wait."

–Richard A. Kerr

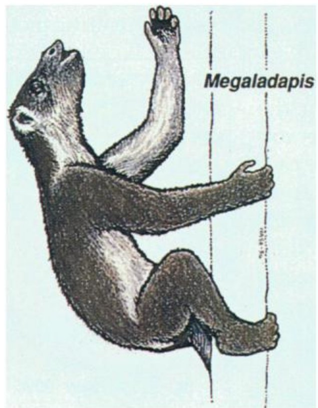
Additional Reading

B. D. Santer *et al.*, *Towards the Detection and Attribution of an Anthropogenic Effect on Climate* (Lawrence Livermore National Laboratory, PCMDI Report No. 21; available from NTIS, 5285 Port Royal Rd., Springfield, VA 22161).

CONSERVATION BIOLOGY

Many Suspects to Blame in Madagascar Extinctions

The tropical island of Madagascar is one of the world's treasure-troves of biodiversity. It's home to a spectacular array of primitive primates, more than half the Earth's species of chameleon, 10,000 kinds of plants, and some of the world's largest earthworms. Even so, the plants and animals of modern Madagascar are merely remnants of the astonishingly rich communities of the past. As recently as a few thousand years ago, the calls of gorilla-sized lemurs echoed through Malagasy forests, while 500-kilogram elephant birds and giant tortoises made a living in the island's complex mosaic of other habitats. By the 17th century, these creatures had all but vanished, creating a perplexing scientific whodunit: What—or who—pushed so many species, most of them large animals, to extinction?



In the past decade, this mystery has spurred droves of researchers to search Madagascar for clues to the culprit. Early this month, an interdisciplinary set of scientific sleuths gathered at The Field Museum in Chicago* to hash out the wealth of new evidence they've accumulated. Many scientists had long assumed that the extinctions were caused by early human populations who colonized Madagascar about 2000 years ago and may have hunted the animals and altered their habitats. But recently a new view has put the onus on a fickle climate, whose natural swings from wet to dry may have squeezed species to extinction.

The view that emerged from the meeting: All of the above were at fault. The new research indicates that natural and human-induced changes both contributed to the extinctions. Moreover, the meeting added yet another suspect to the list, as two researchers proposed the intriguing but unproven idea that humans ferried a lethal pathogen to vulnerable island communities. "It's like *Murder on the Orient Express*," says primatologist Alison Jolly of Princeton University. "The answer is they *all* did it."

Understanding the loss of the Malagasy megafauna may have implications beyond the island itself. The same debate rages about other extinctions, including the disappearance of large mammals in North America after the last Ice Age, and what is learned on Madagascar may shed light on controversies elsewhere, notes Jolly. On a more practical level, the new information provides a historical context for biologists trying to save endangered Malagasy species today, says conference co-organizer Steven Goodman, a Madagascar-based biologist from The Field Museum. "We have to distinguish between human and natural influences on the extinction process in order to understand how to ameliorate the human side," he says.

Any viable Malagasy extinction theory will have to explain the unusual pattern of species loss seen in some of the island's most famous inhabitants: the primitive primates known as lemurs, found almost nowhere else on Earth. Because Madagascar has been isolated from most of the rest of the world's biota for at least 100 million years, it's missing many common taxa, and groups such as lemurs and insectivores evolved into surprising new roles to fill the island's empty ecological niches. For example, some lemurs evolved slothlike adaptations, eating leaves and slowly swinging through trees; another species with huge feet and toes clambered through the trees "something like a giant koala," says William Jungers of the State University of New York, Stony Brook. A few thousand years ago, 49 known lemur species inhabited the island. Today, only 32 species survive.

Anthropologists have found a noteworthy difference between the living lemurs and those who died out: All the big animals—those weighing more than 10 kilograms—went extinct, says Laurie Godfrey of the University of Massachusetts, Amherst. She showed that the living species represent only a small, selected slice of the past ecological diversity. Living lemurs are mostly forest-dwelling agile leapers, while the giant extinct species tended to be slow-moving climbers. And although many modern lemurs are nocturnal, Godfrey and co-workers think most extinct lemurs were diurnal.

The selective extinction of large, slow, diurnal primates raises the obvious possibility that human hunters were the culprits, says primatologist Elwyn Simons of Duke Uni-

*The meeting, entitled "Natural and Human-Induced Change in Madagascar," was held from 2 to 4 June.

versity. Indeed, a decade ago, hunting topped the list of suspected causes of extinction, says anthropologist Robert Dewar of the University of Connecticut, Storrs. "It was thought that only the selective predation of humans could account for the pattern of large mammal extinctions," he says. "But now we are less convinced."

It's true that the few radiocarbon dates for the subfossil bones (the bones are so young that they haven't been replaced by minerals, as happens in true fossils) suggest that the animals vanished sometime after humans from Africa and Indonesia colonized the island. And the earliest evidence of a human presence on the island is 2000-year-old pygmy hippo bones with cutmarks showing that they were butchered by humans.

But even though archaeologists have scoured the island for more proof of the hunting hypothesis, they have found relatively little evidence. Dewar himself has unearthed the most convincing recent clues, excavating caves in which bones of extinct animals and human artifacts co-occur. But, he says, "The bones [of the megafauna] are few and fragmentary, with no obvious cutmarks." He and others, such as archaeologist Jean-Aimé Rakotoarisoa of the University of Antananarivo in Madagascar, think hunting alone cannot explain the extinctions. And a growing wealth of artifacts shows that early Malagasy were farmers, traders, and fishers, not hunter-gatherers, notes Rakotoarisoa.

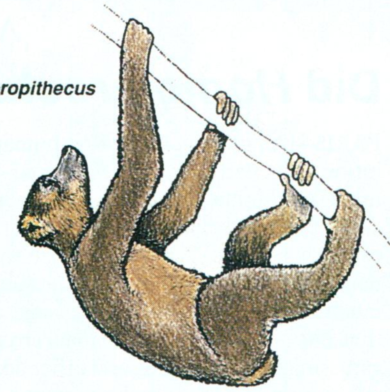
For mammalogist Ross MacPhee of the American Museum of Natural History in New York, frustration with the hunting theory, coupled with Richard Preston's articles about the Ebola virus in *The New Yorker* a few years ago, sparked a surprising new idea: Perhaps the megafauna perished from an emerging disease brought to the island by humans. Worldwide, megafaunal extinctions exhibit what MacPhee calls a "dreadful syncopation," in which humans make forays into new territory and then the large mammals vanish. In collaboration with virologist Preston Marx of the Aaron Diamond AIDS Research Center in New York, MacPhee proposed that such a pattern might be created by a lethal pathogen sweeping rapidly through native animals that had never been exposed to the disease before. Because illness hits young animals hardest and big species have fewer offspring, the megafauna would be more likely to be pushed to extinction, he says.

Also, those species that survived the pandemic would be resistant to future outbreaks, says Marx. Thus, the disease theory may explain why first contact with humans seems to be the deadliest. For example, although more than 70 species were wiped out in continental North America 10,000 to 12,000 years ago, no large mammals have gone extinct here since, says MacPhee.

MacPhee and Marx hope to test their theory by searching for ancient genetic material from a pathogen in the bones or mummified tissue of megafauna. But at this stage, they have little evidence. At the meeting MacPhee's colleagues were intrigued but quite skeptical. "I never thought about disease before, but I'm going to think about it now," says anthropologist Henry Wright of the University of Michigan. But without more evidence, Simons, for one, isn't buying the disease hypothesis.

He and others think it unlikely that a pathogen would strike animals as dissimilar as giant lemurs and tortoises, while sparing small lemurs. And there's no evidence that the lemurs vanished all at once, as would presumably happen during an epidemic, says Simons. New, unpublished radiocarbon dates show that one giant lemur species, *Megaladipis*, survived until 600 years ago, more than 1000 years after humans first entered Madagascar. "On Madagascar, the megafauna didn't all disappear suddenly after the people came," Simons says. He believes that the tale of Madagascar's primates is "a long, sad, story," in which hunting and habitat loss first exterminated the giant lemurs and now take their toll on the surviving species.

If habitat loss did play a role, it might not all have been caused by human activity. Ten years ago there was little evidence for climate change, and many researchers still hewed to the mindset of the old French naturalists, envisioning the island as an unchanging forest paradise until humans came, says paleoecologist David Burney of Fordham University in New York. But in the last decade, Burney and co-workers have used ancient pollen to show that climate has cycled from wet to dry for tens of thousands of years on Madagascar. And between 1000 and 3000 years ago—when humans first arrived—the data show that forests and wetlands were shrinking in response to a drought. "Humans had such a devastating effect because they arrived in one of the driest periods in the last 40,000 years," says Burney.



Palaeopropithecus

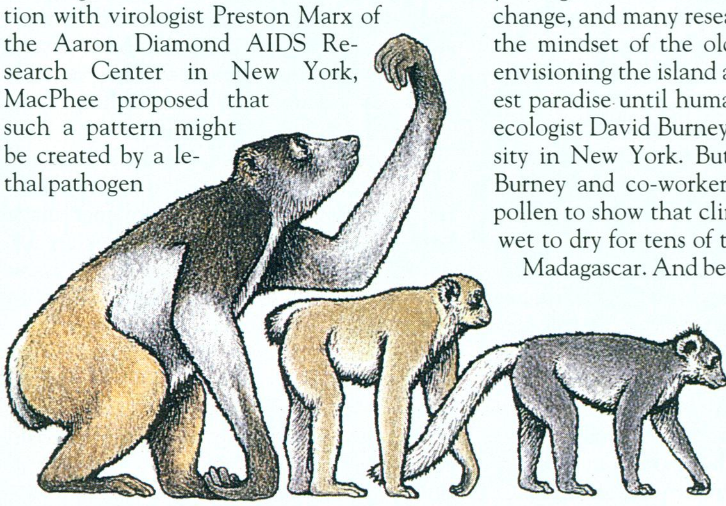
Such climatic shifts could have been fatal to some species, as shown by new data on birds, presented at the meeting by Goodman and Lucien Rakotozafy of the University of Antananarivo. By studying subfossil bones from sites around the island, they found that the now-arid southwest once contained lakes and marshes and supported extinct waterfowl as well as pygmy hippos. Today those sites are untouched by humans but are too dry or too salty to support freshwater communities, says Goodman. He concludes that in the southwest at least, natural climate change caused local extinction of aquatic birds.

Even so, he's not ready to let humans off the hook. On the steep central highlands of Madagascar, farms now occupy the flatter, wetter patches that were once wetlands, and Goodman has recovered subfossils of extinct aquatic birds from the area. "Yes, environmental change led to extinctions, but not solely," he says. "With the birds, you can see clearly that it was a combination of natural and human-induced factors." Agrees Burney: "A coalescence of several deleterious forces can have a synergy—that's what you see in the modern world."

All this helps explain why certain species are so rare, says Goodman. He cites the case of a Malagasy duck called Bernier's teal. Today only about 500 teals survive in a very restricted area, but his data show that the bird once ranged widely throughout the island. Its aquatic habitat was stolen over the past few thousand years by a combination of human and natural forces. "Given the history, it's abundantly clear that if we don't put some remaining aquatic habitat into a reserve, the teal and other biota will disappear," he says. In the case of the Malagasy extinctions, identifying the culprits is just the first step toward an even more difficult goal: trying to ensure that there are no more victims.

–Elizabeth Culotta

DRAWINGS BY STEPHEN NASH



Archaeoindris ***Hadropithecus*** ***Archaeolemur***

No more. The drawings show some of the extinct giant lemurs that once roamed Madagascar's forests.