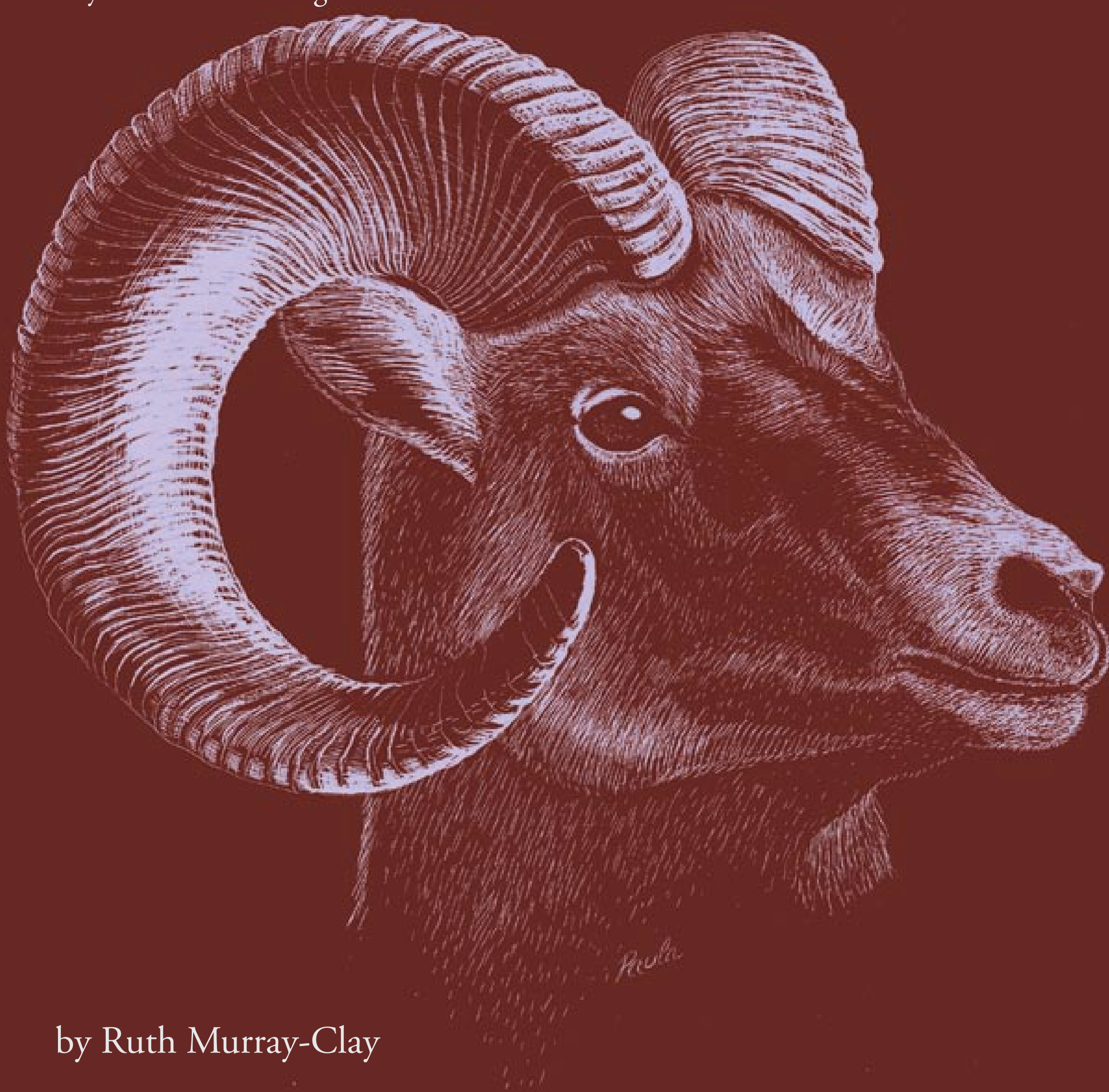
WHODUNNIT?

Mystery of the Missing Megafauna

Mastodons, saber-toothed cats, wooly mammoths and enormous ground sloths—these creatures and other giants roamed the earth for hundreds of thousands of years. Then, during the most recent ice age, they abruptly disappeared. Between ten and fifty thousand years ago, two thirds of the genera of large mammals alive on earth died. Now we may be in the midst of another great extinction, and biologists fear that our most charismatic creatures, species like the giant panda, the giraffe, and the African elephant, are about to meet the same fate. At Berkeley, researchers are working to unravel the root causes of large mammal extinctions, in hopes of learning how to protect currently threatened megafauna. One group is digging into the fossil record, investigating the origins of the late Pleistocene extinctions, while another is trying to understand the causes of present-day extinctions by looking in detail at a single species that roams the southwestern deserts, the California bighorn sheep. What these researchers find may help us mitigate the strains on today's "charismatic megafauna".



SHEEP PORTRAIT COURTESY OF PAULA DISANTO BENSADOUN

by Ruth Murray-Clay

Anthony Barnosky, a paleobiologist in Berkeley's Integrative Biology department, studies the Pleistocene, which lasted from 10,000 to 1.8 million years ago, in an effort to understand the mystery of the large mammal extinctions. This epoch of geologic history was characterized by hugely unstable climate, as the planet oscillated between frigid "ice ages" and warmer "interglacial" climates more than twenty times. Many of the plants and animals living in the Pleistocene were similar to those inhabiting the planet today, but the epoch's large mammal diversity was notably greater: mammoths and mastodons, saber-toothed cats and dire wolves, giant beavers and armadillos, and many others roamed the globe.

Most of these behemoths persisted through the climate swings from one ice age to the next. But during the most recent ice age, between 10,000 and 50,000 years ago, the large mammals went extinct in record numbers. At least 97 of the world's approximately 150 genera containing animals weighing more than 44 kilograms disappeared, with the most striking losses concentrated in the Americas and Australia. What killed them? The unusual severity of these extinctions is the subject of a heated debate between those who believe that climate change caused the losses and those who think that humans were primarily responsible.

The late Pleistocene extinctions began with the onset of the latest ice age and lasted until the transition to the current interglacial period. In northern high and mid-latitudes (in Europe, Siberia, and Alaska), two pulses of extinctions occurred. As the planet cooled between 20,000 and 45,000 years ago, warm-adapted species were lost, and as the planet warmed between 9,000 and 12,000 years ago, cold-adapted species disappeared. These correlations suggest a causal role for climate change in the extinctions.

However, climate change alone cannot account for their severity. During at least some of the major heating and cooling events of the earlier Pleistocene, the number of small, medium, and large animals found in North America remained roughly constant, and none of the earlier ice ages caused the widespread extinctions characterizing the most recent ice age. Global oxygen isotope records show that the rapid deglaciation at the end of the late Pleistocene was neither faster nor more extreme than other similar events over the past 700,000 years.

Another major change was occurring on Earth during the last glacial period that differentiated it from prior ice ages: humans were dispersing far from Africa. In North America, the first humans to reach the continent, the Clovis-style hunters, arrived within 1500 years of the majority of the extinctions in the area. In Africa, where humans evolved with large animals rather than invading as fully developed hunters, extinction rates were lowest, affecting 18 percent of mammalian megafauna genera. Europe lost 36 percent, and North and South America, where the first human inhabitants were already skilled hunters, lost 72 and 83 percent respectively. In the Americas, Eurasia, Australia, and Madagascar, most large, slow-breeding animals that did survive occupied territories inconvenient for humans—they were nocturnal or they lived in the deep forest, in trees, or on tall mountains. Finally, the extinction affected large, slow-breeding species preferentially, rather than hitting small animals first and indirectly affecting large animals through their food supply, as would be expected if climate change were the primary culprit. For many scientists, these data suggests that humans were a significant factor in the late Pleistocene extinctions.

Barnosky and his collaborators

LEFT: Male "Irish elk"' (*Megaloceros giganteus*), skeleton on display in the Geology Department at Trinity College, Dublin. This Eurasian megafaunal species took three thousand years to dwindle to extinction.

RIGHT: The Smilodon, or "saber-toothed tiger", is the California state fossil. These predators were not quite as long as modern-day lions, but weighed about twice as much. Fossils have been found all over North America and Europe; they went extinct about 10,000 years ago.

SMILODON COURTESY UC MUSEUM OF PALEONTOLOGY/ IRISH ELK COURTESY OF TRINITY COLLEGE, DUBLIN

Robert Feranec and Alan Shabel from Berkeley, Paul Koch from UC Santa Cruz, and Scott Wing from the Smithsonian Museum of Natural History, summarize these arguments in an October 2004 review in *Science*. They suggest, however, that the conclusion pegging humans as the cause of the late Pleistocene is too simplistic. They argue that a closer look at extinction events worldwide suggests that while human impacts generated the extinctions, climate change played a vital role in determining their regional differences, timing, and perhaps extent.

In their paper, the authors review the evidence for causal factors producing extinction on a region-by-region basis. For instance, they note that in Australia, extinctions of animals like the marsupial lion occurred after humans arrived during a period of little climate change, while in Alaska, mammoths died out during periods of climate change when very few humans were present. In Eurasia, the evidence increasingly suggests that Pleistocene climate change caused large mammals to shift their ranges, contributing to their extinction. Eurasian extinctions also coincide with the spread and then an increase in population sizes of modern humans. These populations may have impacted megafauna as early as 30,000 years ago.

In North America, where dating is most robust, the case for an interaction between both climate and human impacts is clear. Within 1500 years of the arrival of the Clovis hunters, who traveled from Asia across the Bering land bridge to North America roughly 14,000 years ago, at least 15 species of megafauna went extinct in the region, including mammoths, mastodons, rhinos, saber-toothed tigers, and giant ground sloths. The arrival of humans and their practice of overkill coincided with a major climate change event, and Barnosky argues that if first contact had been significantly earlier or later, the extinction event would have been much less dramatic. "What made the big extinction event was putting together the two causes," Barnosky says.

A bighorn ewe in the Old Woman mountains approaches a water hole on a day when temperatures reached 110 deg F. Bighorns depend on springs, tinajas, and water catchments to survive the long hot summers in the Mojave.

COURTESY OF JULIA PERKINS

Barnosky and the members of his lab have been contributing to the extinction debate by studying the effect of climate change on ecosystems and evolution. In a paper published in the *Proceedings of the National Academy of Science* in June of 2004, Barnosky, Shabel, and collaborators including former graduate student Christopher Bell use fossil evidence gathered at Porcupine Cave in Colorado to study the effect on mammal populations of glacial-interglacial transitions from 600,000 to 1,000,000 years ago in the mid-Pleistocene, long before humans arrived. Mid-Pleistocene sites are less common than those representing the late Pleistocene, and the differences between them can help separate the effects of climate from the effects of humans. The group used the sediments in a sequence of mid-Pleistocene fossils to identify glacial and interglacial conditions, and followed the area's species composition and richness over transitions in the Pleistocene, comparing their results with species composition in historical and modern times. The group found that the mammal community near Porcupine Cave was structurally and functionally stable over the long periods of time preceding the historical period. The species present in the region changed, but the species richness and functional relationships in the ecosystem remained the same, with only minor adjustments during periods of climate change. In addition, they found that the "fine-tuning" of the ecosystem generated by these minor adjustments occurred by affecting species of smaller size and at lower trophic levels. These findings differ markedly from the changes seen in the area during the 19th and 20th centuries. Human hunting has targeted large animals and carnivores, changing the ecosystem from the top down, causing the preferential loss of large mammals, as was also observed in the late Pleistocene.

What caused the double punch of humans and climate change to be so effective? Barnosky's research suggests that humans directly affect large animals through hunting or some other mechanism, while climate change affects small animals first through their plant food supplies. To better understand how these mechanisms work in our current world, Clint Epps, a recent graduate of the department of Environmental Science, Policy and Management, has focused on megafauna currently living in California: the desert bighorn sheep.

Desert bighorn sheep (*Ovis canadensis nelsoni*) live in small populations, usually fewer than 100 individuals, in the arid mountain ranges of the Mojave, Sonoran, and Great Basin deserts of the southwestern United States. Brown with white highlights on the nose and rump, the sheep range in length from 150 to 180 cm (5 to 6 feet) , and are armed with spectacular thick, curved horns. Though they weigh up to 127 kg (280 lbs), the sheep jump and climb with enviable dexterity up steep mountain slopes, protecting themselves from predators such as the mountain lion. The estimated 56 populations of desert bighorn sheep in California occupy many small, isolated mountain ranges, separated by uninhabitable desert.

While each population on its own has a low chance of long-term survival in this harsh environment, the metapopulation, or system of small populations, is more stable if there is good connectivity between the individual groups. If one population dies out, individuals from neighboring populations can recolonize the emptied habitat, ensuring the continuity of the species in the region.

Epps, a lifelong outdoorsman and self-described "hillbilly," spends his summers camping in the sheep-occupied mountain ranges of the Mojave Desert. Despite daytime temperatures that can reach 125° F (52° C), frequent vehicular breakdowns, and extreme isolation, the desert can be rewarding during the hot months. As Epps explains: "Summer is the best time to find sheep in the Mojave. The hotter the better—when they cluster near water, it's much easier to collect data on the sheep."

In a paper published in the journal *Conservation Biology* in February 2004, Epps and his colleagues, including his advisor, professor Dale McCullough, examined current and historic sheep populations. Using data from the last 60 years, they found that thirty of the eighty populations of sheep known to live in southern Californian mountain ranges over that period are now extinct. To determine the primary causes of these extinctions, the researchers looked at each mountain range hosting a current or historic sheep populations, and considered factors like annual precipitation, temperature, and human-related characteristics such as proximity to towns and cities, poaching, mining, and contact with livestock that may have carried disease.

Clint Epps, recent graduate of the Department of Environmental Science, Policy and Management, uses a spotting scope to pick bighorn sheep out from their surroundings.

COURTESY OF LAUREN GWIN

The researchers were surprised to find that sheep extinctions were most closely correlated with local climate conditions. According to climate records for the southwestern desert region, the mean annual temperature rose 1 degree Celsius (1.8 degrees Fahrenheit) from 1901 to 1987, while, over the past century, annual precipitation dropped by about 20%. Those places where the climate was warmest and driest suffered the greatest number of sheep extinctions. Future changes are predicted to be more severe.

Desert bighorn sheep numbers decline in response to decreased rainfall because desert ecosystem productivity is limited by available water. In general, the more it rains, the more desert plants will grow. Temperature increase, however, can help or hurt sheep survival, depending on timing. Warmer springs and summers lead to lowered diet quality as plants wither in the heat, while warmer winters lead to earlier plant growth and higher diet quality in the spring, a critical time for the survival of bighorn lambs.

The sensitivity of sheep populations to climate change may result from their geographical distribution. While other large mammals may gradually shift their territories north in response to global warming, bighorn sheep have a limited ability to move to new environments. Often, potential new ranges are uninhabited for good reasons (like higher temperatures and lower rainfall).

Complicating the situation, Epps and his colleagues found another significant obstacle for sheep survival. In their quest to find new mountain range habitat, sheep must cross the broad and bleak desert flatlands, which offer a suite of other threats. In addition to increased exposure to predators, dispersing bighorn sheep may encounter human-made barriers such as interstate highways that are difficult or impossible to cross. In addition to analyzing population extinction and the effects of climate on diet quality, Epps collected pellets for analysis of fecal DNA. After an analysis of the genetic diversity of 27 populations of desert bighorn sheep, the group concluded that new highways and other human-made barriers effectively isolated sheep populations, halting gene flow across the barriers and significantly reducing the genetic diversity of the groups in only 40 years.

The California bighorn sheep case illustrates what may happen to other large mammal species. As global temperatures change, a species' habitat may shift from one place to another. To survive, the animal must move with its habitat. But human settlements and barriers can be as difficult to cross as the forbidding desert, and many animals will be deprived of a way to follow their preferred environments. As a result, many animals face extinction from climate change. This situation is particularly acute for desert species, which often live in naturally fragmented habitats: in addition to the desert sheep, the huge desert tortoises are also having difficulty.

Barnosky emphasizes this point. “Animals respond to ‘normal’ climate change,” he explains, “by tracking their climate across the landscape. In order for that to work, their life history has to be such that they can move with their climate. There has to be habitat to pass through.” But habitat destruction and fragmentation challenge nearly all of today’s large animals as human development spreads into remote corners of the globe. Large animals are particularly sensitive to habitat fragmentation because individuals often require broad territories of continuous land. Their habitat is often the same land that people prefer, and for similar reasons: like us, they need access to water and food.

Today, both climate change and direct human impacts such as habitat fragmentation are occurring at rates unprecedented in recorded history, leading Barnosky and his collaborators to warn that climate change should be considered a serious threat to large animal populations. If the late Pleistocene may be taken as a guide, the combination of direct human impacts and climate change is particularly dangerous and could catalyze extinctions massive enough to destabilize global ecosystems.

In his studies of bighorn sheep, Barnosky says, Epps could easily be observing today processes similar to those that led to the late Pleistocene extinction. So how are California’s bighorn sheep doing? They still have a chance—“for the moment,” says Epps, “they’re holding their own. Some populations are going up, and some populations are going down. There’s lots of variation in the system.” Over the years covered by the Berkeley group’s study, a couple of the areas hosting extinction events were recolonized, but these areas were not isolated by roads or human settlements. Whether or not the bighorn sheep in California ultimately survive, both studies clearly warn that the dual pressures of climate change and direct human impact may be too much for today’s megafauna to bear.

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Want to know more?

Check out “Assessing the causes of Late Pleistocene extinctions on the continents”: Barnosky et al, . *Science* **306**:70-75 (2004).

“Exceptional record of mid-Pleistocene vertebrates helps differentiate climatic from anthropogenic ecosystem perturbations”: Barnosky, A. D. *Proceedings of The National Academy of Sciences* USA **101**:9297-9302 (2004).

“Effects of Climate Change on Population Persistence of Desert-Dwelling Mountain Sheep in California”: Epps et al. *Conservation Biology* **18** (1): 102-113 (2004).