Gifford Miller collects fossil bird eggshells and marsupial teeth in the Australian Outback, hoping to learn about the Late Quaternary megafauna collapse.

Courtesy of Gifford Miller

ECOSYSTEM COLLAPSE IN PLEISTOCENE AUSTRALIA

Between 45,000 and 50,000 years ago, in the Late Quaternary, Australia suffered a major loss of its megafauna. Sixty taxa of mammals, predominantly large leaf- and twig-eating animals called browsers, went extinct, including all 19 species exceeding 100 kilograms, like the half-ton *Palorchestes azael*, a marsupial similar to a ground sloth, and the rhinoceros-sized *Diprotodon*. Also lost were more than half of species weighing between 10 and 100 kilograms, such as the giant koala, *Phascolarctos stirtoni*, as well as three large reptiles and a flightless bird, *Genyornis newtoni*.

Recent studies indicate that humans colonized the continent during that interval. Given this coincident timing and the lack of evidence for dramatic climate change during that period, a human cause for the extinction has long been inferred, but the extinction mechanism has never been resolved. Now Gifford Miller, a geologist at the University of Colorado at Boulder, and his colleagues think they have uncovered a potential mechanism for the megafauna's disappearance: a change in the ecosystem that made consistent food options no longer available.

The selective loss of large browsers suggested by Miller and his colleagues, including John Magee of the Australian National University in Canberra and Marilyn Fogel of the Carnegie Institution of Washington Geophysical Laboratory in Washington, D.C., indicates that an ecosystem change played an important role in the extinction. To test this hypothesis, Miller searched for proxies. Neither pollen, the most commonly used indicator for ecosystem changes, nor bones are typically preserved in Australia's arid interior. So, for nearly two decades, Miller has roamed the Outback, collecting fossil bird eggshells — the most common megafaunal remains in Australia's arid and semi-arid regions — and marsupial teeth. By analyzing the biominerals in these finds, the researchers have pieced together the ancient diets of three Australian animals: the extinct flightless

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At Gnaraloo (right) and Warroora (below) stations in Western Australia, winds have eroded several meters of sand, leaving behind heavier eggshells from the Late Quaternary. Miller and his colleagues detected these locations from high-resolution satellite images and then traveled to the locations to collect the eggshells.

Both: courtesy of Gifford Miller

bird *Genyornis*, along with the extant emu (another giant flightless bird) and the wombat (a small marsupial). They used these data to reconstruct the complex interactions between humans, vegetation, climate and megafauna in Australia over the last 140,000 years.

To reconstruct the creatures' diets, Miller and his colleagues first dated the remains by measuring the extent of amino acid racemization — the inversion of an amino acid from its protein configuration to its nonprotein mirror image, a process that proceeds slowly within the calcite crystals of the eggshell after it is laid — and converting these results to calendar ages using radiocarbon, uranium/thorium, and luminescence dating. They also analyzed the samples' carbon isotope composition, which is transferred from food to teeth, eggshells and bones, leaving behind a record of the animals' diet.

This 140,000-year record of dietary carbon, collected from three broadly separated regions, provides clear evidence for an abrupt ecological shift — and a permanent reduction in available food sources — about the time of human colonization, Miller says. Prior to 50,000 years ago, the emu eggshell carbon isotope values varied widely, exhibiting a pattern consistent with an opportunistic feeder living in an environment where moisture varied considerably, with some years wet enough for nutritious grasslands to grow abundantly and other, drier years dominated by shrubs and trees. From 50,000 to 45,000 years ago, the mean carbon isotope ratios in both emu shells and wombat teeth decreased, and it has remained low ever since. This isotopic shift documents an increased reliance by emus and wombats on shrubby plants and trees, he says. Being opportunistic eaters, emus adapted their diet to a large-scale change in vegetation that occurred around that time.

In contrast, dietary carbon data from *Genyornis* eggshells from 140,000 to 50,000 years ago indicate a more specialized feeding strategy for this heavier bird. The carbon isotopes indicate that *Genyornis* always included some grass sources, unlike the emu, which prefer grass but can tolerate a diet based entirely on shrubs and trees. Miller and his colleagues concluded in two studies, published in Science and Climate of the Past, that *Genyornis* consumed a more restricted diet that was no longer available after 50,000 years ago.

The team's findings of a dramatic upheaval at the base of the food chain are consistent with the hypothesis that systematic burning of the landscape by humans permanently converted the previous ecosystem from nutritious tree and shrub savanna (with frequent years of rich grasslands) to the modern desert scrub environment. Animals that could adapt survived; those that could not went extinct.

Eggshells from *Genyornis*, a large, flightless extinct bird (above left), and emus (above right and below) that Miller used to determine what happened to the megafauna.

All: courtesy of Gifford Miller

After collecting this evidence that ecosystem change played an important role in the megafauna's extinction, Miller and his colleagues decided to see if human burning permanently altered the ecosystem via feedbacks that reduced the delivery of monsoon moisture to the continent's interior. They used a general atmospheric circulation model to evaluate the sensitivity of monsoon precipitation to the continent's vegetation and soil characteristics, especially rainfall recycling through evapotranspiration.

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— Gilbert Price, University of Queensland

The initial results suggest that vegetation and soil characteristics play a significant role in determining the penetration of monsoon moisture into Australia's interior, with the model showing that a vegetation shift may cut interior monsoon rain by as much as half under conditions normally favoring strong monsoon flow. "If the vegetation is there, you'll get that feedback of recycling, and so the argument is that the vegetation changed, and that's what the isotopes in the emus tell us," Miller says. "What was lost were those elements that allowed the recycling of the water" and thus allowed moisture to penetrate into the interior.

"The dataset put together by Miller and colleagues is incredibly impressive and exactly what we need to be able to test the leading hypotheses concerning the extinction of Australia's Pleistocene megafauna," says Gilbert Price, a vertebrate paleoecologist at the University of Queensland in Australia who was not involved in the research. Price says he agrees that there appears to have been a shift in diet among the large flightless birds, but says he has concerns about the dates determined in the study: "How reliable is the existing age model? A well-dated record is critical for looking at the speed of extinction and allows us to determine whether the extinctions or diet shifts were rapid or sudden."

The concern, Price adds, is that more than 60 percent of the apparent ages of the *Genyornis* eggshells are "butting right up close to the radiocarbon dating window." Radiocarbon dating is most accurate up to about 50,000 years ago. "The Miller work is fantastic," Price says, "but I do think that their age model needs much further scrutiny before we accept the interpretation regarding the speed of extinction and diet shifts as gospel."

Terri Cook