PERSPECTIVES: PALEONTOLOGY

# Debating Extinction

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Over a century ago, Alfred Russell Wallace wrote that "we live in a zoologically impoverished world, from which all the hugest, and fiercest, and strangest forms have recently disappeared ..." (*1*, p. 150). Researchers seeking to explain this "marvelous fact," as Wallace called it, fall into two camps, one invoking global climatic change and the other human hunting as the cause. Over the past few decades, the debate has become deadlocked, in part because most researchers have focused their attention on the Americas and northern Eurasia, where the extinction of the huge, fierce, and strange creatures, such as mammoths and giant sloths, occurred between 12,500 and about 11,000 years ago. This was a time of rapid climatic change, but it was also when humans first arrived in these regions, making it difficult to discern causality. Australia provides the only separate, continent-sized natural laboratory in which dramatic Quaternary extinctions occurred. It is thus of exceptional importance as a testing ground for extinction theories, but until now problems with dating have limited its potential. As reported on page 205 of this issue, Miller *et al.* have now documented the extinction of the gigantic Australian bird *Genyornis* and so have broken new ground in dating megafaunal extinction in Australia (*2*). At the same time, these authors have broken the current deadlock in the great megafaunal extinction debate.

It has long been appreciated that the intensity of Quaternary extinctions varied greatly around the world. In the oceans, Africa, and southeast Asia, they were nonexistent or mild. Europe experienced moderate extinction rates, whereas the Americas, Australia, Madagascar, and many Oceanic islands suffered dramatic extinctions. North America lost 73% of all genera weighing more than 44 kg, but Australia suffered the most severely of all the continents, losing every terrestrial vertebrate species larger than a human, as well as many smaller mammals, reptiles, and flightless birds, the latter down to about a kilogram in weight. In all, about 60 vertebrate species were lost, including bizarre marsupials that resembled giant sloths and oversized capybaras, carnivorous kangaroos, a 7-m-long monitor lizard that was probably a top predator, and a terrestrial horned tortoise that approached the size of a Volkswagen Beetle car.

**Lunging for lunch.** Even if adult *Genyornis newtoni* were capable of escaping from the giant (up to 7 m long) varanid lizard, *Megalania prisca*, the bird's eggs would have enriched the predator's diet.

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Establishing just when this bizarre array of creatures last trod Australia's outback has been a torturous business, with many false leads and sites that are difficult to interpret. For decades, it was believed that the megafauna survived until close to the time of the glacial maximum, some 20,000 years ago, when temperatures were up to 9°C cooler than at present and the continent was extremely arid. Conditions were so extreme that trees virtually disappeared from the inland, and 40% of Australia was transformed into a vast active dune field. Even parts of Tasmania supported desert species.

Development of a widely accepted chronology for the arrival of humans has been equally difficult, and it was only with the development of optically stimulated luminescence dating that a human presence in Australia was confirmed at 53,000 to 60,000 years ago (*3*). Older dates for a human presence in Australia (*4*) have now been shown to be erroneous (*5*).

The importance of Australia as a separate natural laboratory in which to test extinction theories lies in the fact that humans arrived there much earlier than they arrived in the other continental areas (the Americas and northern Eurasia) that experienced substantial megafaunal extinction. What Miller *et al.* (*2*) have shown is that the extinction of *Genyornis* occurred simultaneously across southeastern Australia (indeed probably right across the continent) about 50,000 years ago. This is very close to the presently accepted time of arrival of humans in Australia. It was also a period of modest climate change, well before the dramatic climatic fluctuations of the terminal Pleistocene. The data of Miller *et al.* (*2*), therefore, support those who see human hunting rather than climate as causing the extinction of the megafauna.

*Genyornis* was a ponderous bird, around 80 to 100 kg in weight, about twice as heavy as the living emu and cassowary. It was an inhabitant of Australia's inland plains and some coastal regions, but its legs were relatively short and thick, suggesting that it was a slower runner than the emu. Proponents of human-caused extinction suggest that it is just such characteristics that made the megafauna vulnerable to human hunting.

The unique properties of bird eggshell make it an ideal candidate for amino acid racemization dating. The 1200 dates on emu and *Genyornis* eggshells provided by Miller *et al.* (*2*) from three very different regions in southeastern Australia provide a database that simply is not available for any other species of Australian megafauna, nor indeed for any extinct species anywhere in the world. Critics will doubtless quite justifiably question whether the extinction of *Genyornis* coincides with that of the rest of the Australian megafauna or whether just this one species went extinct at the time of human arrival. The answer to this vital question is entirely unknown at present, but what we can say is that there is currently no unequivocal evidence for the survival of any Australian megafauna after 40,000 years ago.

The eggshell data of Miller *et al.* (*2*) represent a serious challenge to the proponents

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of climatically caused megafaunal extinction. They must now posit a climatic phenomenon that could have devastated megafauna before the glacial maximum as well as just after it. They must also explain how climatic change could have extirpated the large, emulike *Genyornis* in Australia 50,000 years ago but left New Zealand's 11 species of Moa, living just across the Tasman Sea, entirely unaffected until just 800 years ago.

A new school of thought has recently established itself in the extinction debate. It advocates the idea that a combination of human impact and climate change was responsible for the extinction of the world's megafauna. The new *Genyornis* data (*2*) also weaken that argument, for the following reason. Fifty thousand years ago, Australia was experiencing mild cooling; 11,000 to 12,000 years ago, the Americas were experiencing rapid warming. These disparate climatic conditions, all coincident with megafaunal extinction, suggest that whatever was happening with climate, it was bad for the big animals. Under these conditions, the hybrid model becomes indistinguishable from the human-caused extinction model, for the influence of climate becomes extremely weak, and only the arrival of humans is important in predicting extinction.

**References**

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PERSPECTIVES: CLIMATE CHANGE

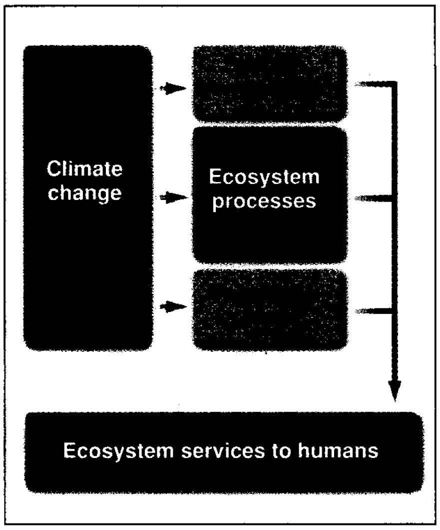
# Warm, Warm on the Range

**Jerry M. Melillo**

The climate of Earth is changing. Climatologists are confident that over the past century, the global average surface temperature has increased by about half a degree Celsius (*1*). This warming is thought to be at least partly the result of human activities, such as the burning of fossil fuels and the clearing of forests for agriculture. As the global population grows and national economies expand, the global average temperature is expected to continue increasing by an additional 1.0 to 3.5°C by the year 2100 (*1*).

Climate change is one of the most important environmental issues facing humankind. Understanding the potential impacts of climate change for natural ecosystems is essential if we are going to manage our environment to minimize the negative consequences of climate change and maximize the opportunities that it may offer. Because natural ecosystems are complex, nonlinear systems, it follows that their responses to climate change are likely to be complex. Climate change may affect natural ecosystems in a variety of ways (see figure). In the short term, climate change can alter the mix of plant species in land ecosystems such as grasslands. In the long term, climate change has the potential to dramatically alter the geographic distribution of major vegetation types—savannas, forests, and tundra. Climate change can also potentially alter global ecosystem processes, including the cycling of carbon, nitrogen, phosphorus, and sulfur. Moreover, changes in these ecosystem processes can affect and be affected by changes in the plant species of the ecosystem and vegetation type. All of the climate change–induced alterations of natural ecosystems affect the services that these ecosystems provide to humans.

The global average surface temperature increase of half a degree Celsius observed over the past century has been in part due to differential changes in daily maximum and minimum temperatures, resulting in a narrowing of the diurnal temperature range. Decreases in the diurnal temperature range were first identified in the United States, where large-area trends showed that maximum temperatures have remained constant or increased only slightly, whereas minimum temperatures ($T_{MIN}$) have increased at a faster rate (*2*). On page 229 of this issue, Alward *et al.* (*3*) report on the different sensitivities of rangeland plants to $T_{MIN}$ increases.




**Interrelations of global climate change and Earth's ecosystems.**

On the basis of a decade of measurements at the National Science Foundation's (NSF) Long-Term Ecological Research site in the short-grass steppe in northeastern Colorado, Alward *et al.* concluded that increased spring $T_{MIN}$ was correlated with a reduction in the abundance of buffalo grass, *Bouteloua gracilis*, and an increase in native and exotic forbs. This alteration in species composition of the rangeland affects its ability to provide an ecosystem service that ranchers have come to rely on—the availability of a productive, palatable, drought-resistant grass, buffalo grass, which is important to livestock production in the region.

From their work at the Toolik Lake site in the Alaskan arctic (another NSF Long-Term Ecological Research site), Chapin *et al.* have also reported that climate change can alter plant species composition (*4*). Over a 9-year period, they increased the mean daily air temperature above the vegetation by 3.5°C at a tussock tundra site by placing clear plastic tents over the vegetation. One of the major effects of the warming was to increase the availability of nitrogen to plants by speeding up its release from decaying organic matter. The enhanced nitrogen availability increased the dominance of the four plant species that were initially most abundant and decreased abundance of (or eliminated) plants that were initially least abundant, including forbs and lichens. Forbs in the tundra are nutritionally important and selectively grazed by caribou during lactation, whereas lichens are critical to the over-winter nutrition of caribou. The loss of forbs and lichens from the tundra as a result of climate change could lead to reductions in the caribou herds that are important to the lives of Alaska's native peoples.

Over decades to centuries, climate change may cause large-scale alterations in the distribution of major vegetation types such as grasslands and forests. Global-scale simulations (the new dynamic global vegetation models, for example)

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