PERSPECTIVES: ARCHAEOLOGY

Blitzkrieg Against the Moas

Jared Diamond

Throughout areas of the world uninhabited by humans until 60,000 years ago, populations of naïve large animals might have been quickly exterminated in hunting "blitzkriegs" by the first arrivals (*1*, *2*). Animals that had never previously encountered humans did not have the opportunity to evolve or acquire fear of us, so that our hunter ancestors could just walk up to them and kill them. Documented victims in modern times include Steller's sea cow and subantarctic seals, and suggested prehistoric victims include big flightless birds, such as the moas of New Zealand, and most large mammals of the Americas and Australia. But it still taxes our credulity to imagine how just a few bands of prehistoric hunters could have killed enormous numbers of big animals in a very short time. On page 2250 of this issue, Holdaway and Jacomb (*3*) demonstrate that for New Zealand's moas it really did happen fast, and that the low reproductive rate of these long-lived birds made the moa blitzkrieg possible.

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Around a thousand years ago, New Zealand was settled by Polynesians, ancestors of modern Maoris. Some time thereafter, half of New Zealand's terrestrial vertebrates became extinct. Of these, the largest were a dozen species of giant flightless birds now known as moas (see the figure) (*4*). Identification of moa bones by zoologists in the 1830s triggered a still-continuing controversy over when and why the moas became extinct.

Earlier theories postulated that a drastic change in climate or the moas' supposed predisposition to extinction were the reasons they became extinct. These theories were shaken by discoveries that the earliest Maori sites contained the dismembered remains of thousands of moas of every species, and that late Maori sites contained no moa remains whatsoever. Nevertheless, anyone who has hiked over New Zealand's incredibly rugged terrain is staggered by the suggestion that a few Maoris could have quickly found and killed every single individual of those dozen moa species, with a total initial population estimated at 160,000 birds.

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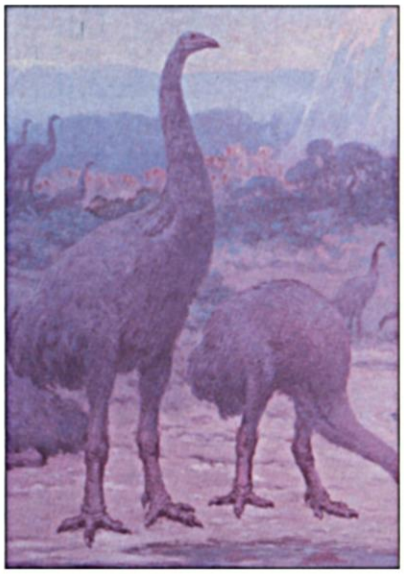
The usual response is that it took nearly a thousand years to do the job, with Maoris arriving in the first millennium A.D. and with the last moas surviving until around the time that the Europeans discovered New Zealand (1642 A.D.). Three findings now overturn this leisurely time scale of extinction: Maoris arrived later than assumed, moas vanished earlier than assumed, and moa demography made moas vulnerable.



Moas move over. New Zealand's moas were hunted to extinction.

Regarding the arrival date of the first Maoris in New Zealand, claims of an "earlier-than-previously-suspected date" in any field of archaeology tend to trigger a feeding frenzy of uncritical attention by the press. But reporters, and even many scientists, fail to realize that radiocarbon dating poses difficult technical problems and that radiocarbon dates cannot just be quoted at face value. Recently, Anderson *et al.* (*5*) "sanitized" Maori radiocarbon dates by excluding those based on unreliable materials or excavations, and by focusing on materials (such as charcoal from short-lived plants) that are the least susceptible to error. The earliest acceptable dates for the arrival of Maoris in New Zealand proved to be in the 13th century A.D., much later than previously assumed.

As for the date of moa extinction, consider Monck's Cave, a site whose artifacts reveal that it must have been occupied after the earliest phase of Maori colonization but before the so-called Classic (post-moa) phase. The site's radiocarbon dates cluster around 1370 to 1420 A.D., about a century after the Maoris reached New Zealand (*3*). But there is no evidence of moa consumption at Monck's Cave, although moa hunters had lived earlier at nearby sites. Evidently, moas were already locally extinct when the cave was occupied.

Similar conclusions emerged from a recent re-analysis (*6*) of the largest of all moa-hunter sites, Shag River Mouth. Here, there was a base village for moa hunting used by the first Maoris to reach this part of New Zealand. The quantity of moa bones at this site translates into several hundred tons of moa meat. But radiocarbon dates show that the village was occupied for at most a few decades, in the 14th century. Early in that occupation, villagers were eating the largest moa species, plus easy-to-kill seals and penguins. Within a decade or two, bone remains of those prey became scarce as villagers shifted to eating small moas, dogs, songbirds, fish, and shellfish. In another decade or two, the village was abandoned, probably because there were no more moas and seals anywhere nearby.

How could the descendants of a few boatloads of Maori colonists have wiped out 160,000 moas within a few decades? The answer lies in the moas' life cycle. Preserved nests show that moas laid clutches of only one or two eggs. By comparison with other large birds (such as albatrosses) on remote islands with few natural predators, moas were surely long-lived and slow to mature. Such comparisons suggest that moas did not begin to breed until 5 years of age, did not reach their reproductive peak until 12 years of age, and even then could rear barely one chick per year. If adult moas were killed at even a low rate, their low reproductive output would not be able to keep pace with adult death rates.

Holdaway and Jacomb make some conservative calculations, assuming that the first colonists numbered only 100 people, that their numbers increased at only 1% per year, that they abstained from eating moa eggs or destroying moa habitat, and that they killed only one female moa per week per 20 people. With those assumptions, their model shows that moas would have been extinct throughout New Zealand within 160 years. But the human population probably grew by at least 2 to 3% per year, and might have initially numbered over 100. The first colonists surely did eat moa eggs and did destroy moa habitat, and they probably killed far more moas than one per week. Most parts of the moa carcass were discarded except for the upper legs, and moas were also fed to dogs. Modeling

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based on more realistic assumptions yields extinction of moas within a few decades. If you doubt it, think of the tameness of Galapagos birds even today, and think of Steller's accounts of how his men "hunted" sea cows. (Men paddled up to it, jabbed a hook into it, and pulled the unresisting beast ashore).

This study yields two conclusions specifically about New Zealand. First and foremost: yes, this was a blitzkrieg; yes, a few people could and did kill every moa. At a time when all moas had been eliminated from 270,000 km^2 of some of the world's most rugged territory, the Maori population probably still numbered under 1000. As for how they could have found every moa, it was easy: Within a generation, they had also found all sources of stones in New Zealand that were useful for toolmaking.

Second, it is often asserted that the colonization of New Zealand must have preceded the earliest known radiocarbon-dated sites by centuries, because the chances of finding the actual first sites are supposedly negligible. On the contrary, the conclusion is now that the first sites were the ones with the greatest archaeological visibility because of their piles of moa bones. What we see is everything that was there then; there wasn't an earlier, archaeologically invisible human population.

Where should we seek evidence for other blitzkriegs? Almost anywhere, except on the Eurasian and African mainlands, long inhabited by humans. Candidate victims include Cyprus's pygmy hippo, Hawaii's flightless geese, the Caribbean's bear-sized rat, Fiji's land-lubber crocodile—and, of course, all of the large animals that disappeared in Australia, North America, and South America around the time of human arrival (*2*).

Is archaeology a useless discipline, irrelevant to the present, and deserving of the late Senator Proxmire's Golden Fleece Award for wasted research money? Think of all those long-lived plants and animals still being harvested today at unsustainable rates. As Santayana said, those who do not remember the past are condemned to repeat it. Then, there were no more moas; soon, there will be no more Chilean sea bass, Atlantic swordfish, and tuna. I wonder what the Maori who killed the last moa said. Perhaps the Polynesian equivalent of "Your ecological models are untested, so conservation measures would be premature"? No, he probably just said, "Jobs, not birds," as he delivered the fatal blow.

References

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PERSPECTIVES: ASTRONOMY

How Flat Is the Universe?

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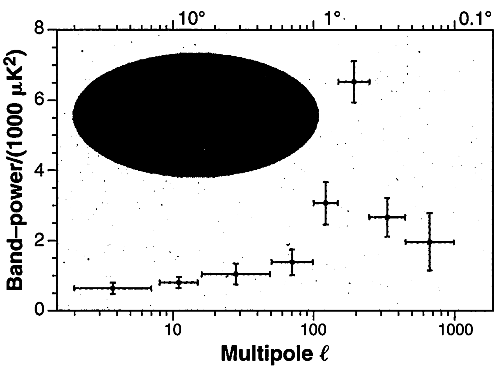
The discovery of the cosmic microwave background (CMB) in 1965 (*1*) provided key evidence supporting the hot Big Bang model for the evolution of the universe. Tiny temperature variations in the CMB discovered in 1992 (*2*)—of just the right size for gravity to have created the observed large-scale structures over the age of the universe—established gravitational instability as the mechanism of structure formation. These first measurements of CMB anisotropy on an angular scale of tens of degrees have been followed by many experiments concentrating on smaller scales. Already in 1995 (*3*), indications for enhanced temperature variations on a scale of 0.5° were reported. Here we combine all existing observational data to show that the temperature variations decrease again below 0.5°. This observation has profound implications for the origin of structure in the universe and the global curvature of space.

The CMB sky is conventionally expanded into a set of functions labeled by a multipole number ℓ. Functions with higher ℓ probe smaller angular scales. The squares of the expansion coefficient amplitudes, as a function of ℓ or inverse angle, are referred to as the "anisotropy power spectrum" (*4*), which statistically describes how the temperature variations depend on angle—a high power spectrum at some ℓ means large variations in temperature on a scale $\theta = 1/\ell$. This power spectrum is easy to compute theoretically for model universes and contains essentially all of the cosmological information in the CMB. What remains to be done, however, is to obtain this power spectrum experimentally. Until now, individual experiments have had limited angular range, and each has provided only a small piece of the puzzle. Different CMB experiments can, however, be combined to provide an essentially model-independent estimate of the power spectrum (*5*). This estimate, provided that it is carefully calculated, can then be used to constrain models.



The power spectrum of cosmic microwave background anisotropies. This plot of temperature variations versus multipole ℓ, which is equivalent to an inverse angle, is a binned spectrum from all currently available data. A prominent peak is centered just below 1°. Top left: Map showing CMB fluctuations from the COBE satellite (*21*). This map only represents the first two points in the power spectrum.

We used a maximum likelihood technique to obtain a power spectrum encompassing the knowledge gained from all currently available observational data of which we are aware. The data comprise those collected in (*6*), together with the more recent results of the QMAP (*7*), MAT (*8*), Viper (*9*), and BOOM97 (*10*) experiments, as summarized in the RADPACK package (*11*), with some minor corrections. We divided the range from $\ell = 2$ to $\ell = 1000$ into eight bins spaced at roughly equal logarithmic intervals, with slight adjustments to allow for regions where data are scarce (*12*). The power spectrum was approximated as a piecewise constant, and the values of that constant were fitted within each bin to the combined data, taking into account nonsymmetric error bars and calibration uncertainties in a manner similar to (*13*). We maximized the likelihood function for the eight parameters (plus 17 calibrations) using a simulated annealing technique (*14*). From the maximum likelihood position, we then used Monte Carlo integration to calculate the covariance matrix of the parameters. The final result is a power spectrum (see

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