ESSAY

GLOBAL VOICES OF SCIENCE

Pleistocene Park: Return of the Mammoth's Ecosystem

Sergey A. Zimov

During the last ice age, the world's most extensive ecosystem stretched from France across the Bering Strait to Canada and from the arctic islands to northern China. It was at the very end of a more than million-year epoch, the Pleistocene, during which colossal ice sheets repeatedly advanced and retreated, plowing up much of northern Europe and America. At the same time, from a geological perspective, northeastern Siberia remained relatively unscathed. There, vast dust-covered plains and valleys dominated the landscape. Mammoths, woolly rhinoceroses, bison, horses, reindeer, musk oxen, elk, moose, saiga, and yaks grazed on grasslands under the predatory gaze of cave lions and wolves.

The ground, as in Siberia today, froze, contracted, and cracked each winter. In spring, water penetrated and froze in deep, narrow cracks, creating networks of ice wedges. Over time, because of the slow accumulation of dust, river silt, and ice, the northern lowlands of Siberia became covered with a thick sedimentary mantle of frozen loess. These frozen sediments are filled with rootlets of grasses, microbes, and animal bones, all of which have enabled scientists to chronicle the rise and fall of the region's Pleistocene ecosystem.

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About 10,000 years ago, at the beginning of the Holocene epoch, this vast system, which I refer to as the mammoth tundra-steppe, disappeared completely. In northern Siberia, mossy tundra and forest tundra replaced the mammoth ecosystem. The only herbivores to survive were reindeer that grazed on lichens and moose that fed on willows. The mammoths and their large animal companions, which had survived even the worst conditions the ice age could muster, disappeared during the Holocene warming.

It actually might not have been the climatic changes that killed off these great animals and their ecosystem, however. More consequential, perhaps, were shifts in ecological dynamics wrought by people who relied on increasingly efficient hunting practices, which decimated the very populations of grazing animals that maintained the tundra steppe. To test this possibility, my colleagues and I for the past decade have been working to reconstitute the mammoth ecosystem in one modest parcel of the northern Siberian region of Yakutia. We call our project Pleistocene Park. The primary scientific goal is to determine more precisely the role that Pleistocene animals played in maintaining their own ecosystem. However, we also suspect that by learning how to preserve and extend Pleistocene-like grasslands in the northern latitudes, we could subsequently develop means for mitigating both the progress and effects of global warming. The amount of carbon now sequestered in soils of the former mammoth ecosystem, and that could end up as greenhouse gases if released into the atmosphere by rising global temperatures, surpasses the total carbon content of all of the planet's rain forests.

The Vanishing of the Herbivores

Grassland ecosystems are evolutionarily the youngest of ecosystems. These ecosystems have the highest rates of biogeochemical cycling. Grasses use water resources more rapidly than their less productive competitors, such as cactuses and trees, rather than spending energy for making thorns and toxins to ward off enemies. When their numbers reach a level that can be sustained by the landscape, herbivores eat and trample all the grassland

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Sergey A. Zimov, director of the Northeast Science Station in Cherskii in the Republic of Sakha (Yakutia), received his academic training in geophysics at the Far East State University in Vladivostok, Russia. He subsequently did fieldwork in northern Siberia for the Pacific Institute for Geography, part of the Far East Branch of the Russian Academy of Sciences. In 1980, he organized the science station that he now directs. Research at the center includes studies of global carbon and methane budgets and animal extinctions that occurred in Siberia when the Pleistocene epoch gave way to the ongoing Holocene about 10,000 years ago. In 1989, Zimov initiated a long-term project known as "Pleistocene Park," which he now is pursuing with a number of partners. The goal of the project is to reconstitute the long-gone ecosystem of the Pleistocene epoch that supported vast populations of large animals including mammoths, horses, reindeer, bison, wolves, and other large predators. If the effort succeeds in the park, Zimov and his co-workers would like to see the ecosystem restored over much larger areas in an effort to stave off what otherwise could be a massive release of carbon that now is sequestered in the permafrost but that could be released into the atmosphere as global temperatures rise. His hunting of mammoth remains in the tundra and his bold vision of controlling and restoring ecosystems have earned him coverage in books, documentaries, and other media.

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vegetation produced during the rainy season and return nutrients to the soil through their manure. On different continents, at different latitudes, grassland ecosystems have been, and are now, composed of different species, but they share a similar set of functional types or guilds. These include grasses, elephants, horses, rodents, dung-beetles, large cats, vultures, and so on. The greater the diversity within and among these functional types, the more active the biological cycles and the more successful and extensive the ecosystem can become.

In the Pleistocene, grassland ecosystems occupied about half of the world's land mass. *Homo* species emerged in these pasture ecosystems, where they left tools, weapons, cave paintings, and other signs of their presence. Starting with unpretentious ambitions to survive in a hostile environment, *Homo* ended up assuming the powerful role of ecosystem terminator. The mammoth ecosystem was the first large-scale victim, but the global destruction of grasslands only accelerated in the Holocene when people invented agriculture and began raising cattle.

Twenty years ago, scientists explained the disappearance of numerous animals in the northern grasslands very simply—the arid steppe climate changed into a humid one, and when the steppe vanished so did the steppe's animals. In short, the moist Holocene climate was a catastrophe for them. In the last few years, however, a growing accumulation of radiocarbon dates of animal remains has been suggesting a different story. It appears now that mammoths survived the Pleistocene-Holocene shift. For the first 7000 years of the Holocene, they persisted on Wrangell Island in the Arctic Ocean. Bison, horses, and musk oxen also lived in the north of Siberia in the Holocene. Horses and musk oxen lived there even up to historical times.

In Alaska, bison survived throughout the entire Holocene. They disappeared only in the historical period at the hands of human hunters. Alaskan native elders still tell stories that chronicle the taste of bison meat. Another indication that climate change has had little to do with the survival of bison is that in the past century, bison were brought back to Alaska, and they have been breeding there successfully. What's more, when musk oxen were reintroduced from the coldest, driest islands of the Canadian Arctic to Alaska in the 20th century, they immediately began to breed actively, even though the climate in Alaska was warmer and wetter. The same thing happened wherever musk oxen were reintroduced in Siberia. Even in the west Norwegian climate, musk oxen have prospered.

The recent history of horses bolsters the case against climate change as the factor that destroyed the mammoth ecosystem and its diversity of large animals. In the Republic of Yakutia in northern Siberia, the biomass of horses is greater than that of reindeer. Although horses are classified as domesticated animals, in practice most of them are wild, living without any aid from people. Evidently, they are suited to the present climate.

Yet, these great herbivores disappeared by the millions from northern Siberia and elsewhere. As has happened elsewhere and at other times, their vanishing coincides with the introduction by humans of new hunting technology. In Australia, 46,000 years ago, when people first arrived, 23 animal species vanished, all but one heavier than 45 kg (about 100 pounds). In America, 12,000 years ago, hunters began using small, sharp lances and arrowheads. After that, 70% of the large animal species vanished. By the time people started recording their own history, bison, aurochs, dziggetai (koulan), wild horses, saiga, and many other herbivores had already been exterminated from the steppes and prairies.

Horse sense. Grazing on a snow-covered tundra meadow in northern Siberia, rugged Yakutian horses like these could help reduce the effects of global warming by stabilizing vast expanses of grassland.

CREDIT: S. ZIMOV

Out to Pasture

Just as the great herbivore herds disappeared at the end of the Pleistocene, so did the northern grasslands that nurtured them. One possible explanation for this is simply that the cold, arid climate of the steppes changed into a humid one, turning the steppes into mossy tundra. However, the Holocene climate shift was not unique. Similar shifts occurred in previous interglacial periods, yet these did not cause catastrophic landscape reconstructions.

During the last glacial, when mammoths still roamed on the steppes that covered Europe, the annual precipitation there was 200 to 250 mm, and January temperatures were in the range of –25° to 35°C. Such climate conditions are similar to those of present-day northeastern Siberia. By many criteria, the present climate there is not humid, but rather is characteristic of an arid steppe. According to all weather stations of northeast Siberia, the annual radiation input is about twice what is necessary to evaporate the annual precipitation. This only adds to the mystery of why Siberia is no longer dominated by a grassy, steppe landscape.

The physiological traits associated with Holocene vegetation partially explain the vegetation changes that coincided with loss of the Pleistocene megafauna. Plant transpiration accounts for most of the water loss from landscapes, and high transpiration rates are associated with more productive plants. Rates of water loss must therefore have been high in the north when productive Pleistocene meadow and steppe vegetation prevailed. As a result, vast amounts of water were sucked up from the ground, resulting in dry conditions, while the plants themselves sequestered nutrients to drive their own productivity.

Holocene vegetation, in contrast, is dominated by unproductive moss and shrubs. This type of vegetation does not transpire enough moisture to dry out the soil. Moss does not even have roots. This leads to wet conditions conducive to the growth of mosses, which account for a substantial proportion of the northern Siberian biomass. Water-saturated soils inhibit decomposition of biomass and therefore the availability of nutrients to support plant growth. What's more, mosses insulate the ground efficiently—a 20-cm layer of moss prevents the underlying frozen soil from thawing. This also has the effect of sequestering nutrients and preventing their cycling through the ecosystem. All of these factors indicate that moss communities, once they are in place, create and sustain their own environment and do not depend so much on particular climate conditions.

They are quite vulnerable to physical disturbance, however, and this is where their ecological connection to herbivores comes in.

The Future of the Past

When mosses are destroyed on loess soils, the site becomes overgrown with grasses within 1 to 2 years. The grasses then dry out the soil through their high transpiration rates, creating a steppe-like ecosystem. But when herbivore populations are low, grass productivity begins to decrease within a few years, because grass litter accumulates on the soil surface, shading and insulating the soil. In turn, soil fertility declines. As a result, shrubs and mosses,

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which have lower nutrient requirements than grasses, ultimately become dominant.

In the mammoth ecosystem, the collective behavior of millions of competitive herbivores maintained the grasslands. In the winter, the animals ate the grasses that grew the previous summer. All the while they fueled plant productivity by fertilizing the soil with their manure, and they trampled down moss and shrubs, preventing these plants from gaining a foothold. It is my contention that the northern grasslands would have remained viable in the Holocene had the great herds of Pleistocene animals remained in place to maintain the landscape.

In the southern steppes, the situation is different. There, the warmer soil allows for more rapid decomposition of plant litter even in the absence of herbivores. In the north today, the soil is too cold to foster such decomposition, which means that the steppe ecosystem can be stable there only with the help of herbivores that decompose organic matter in their stomachs and that disturb mosses. Today's African savannas, in which trees and shrubs have supplanted grasses in much the same way that mossy tundra has supplanted grasses in Siberia, demonstrate this principle. These savannas would disappear without large herbivores, which are present there in large numbers. The large numbers of animals on African savannas amaze many people. However, similar animal densities exist in northern and middle latitudes. For example, at Elk Island National Park in Canada, about 60 bison browse on each square kilometer of grassland. The animal is much bigger than the gnus and zebra of Africa. Forests in the park are preserved only by strongly controlling the number of animals.

This is why I believe that the changing climate of the Holocene would have had little bearing on the survival of the mammoth ecosystem. In some places, such as sandy and stony ground, trees and shrubs would have appeared. And that might have caused changes in the relative proportions of horses and moose. But overall, if climate were the only controlling factor, the total pasture productivity and the number of herbivores should have increased in the Holocene. Support for this view comes from the climate history that is chronicled in the Greenland ice sheet. It shows a sharp warming and dramatic increase of precipitation ~14,700 years ago, leading to conditions that resemble the present climate. Even so, in the north of Siberia, mammoth populations soared at this time.

This view means that the present Holocene climate of northern Siberia, particularly near the present tree line, is likely just now to be optimal for the mammoth ecosystem. If we accept the argument that the pasture landscapes were destroyed because herbivore populations were decimated by human hunting, then it stands to reason that those landscapes can be reconstituted by the judicious return of appropriate herbivore communities.

In northern Siberia, mainly in the Republic of Yakutia, plains that once were covered by tens of meters of mammoth steppe soils now occupy a million square kilometers. The climate of the territory is near optimal for northern grassland ecosystems. Thus, in principle, the ancient mammoth ecosystem could be restored there.

Pleistocene Park. This territory in the Republic of Yakutia is roughly an even split of meadow, larch forest, and willow shrubland. This Siberian region could become the venue for a reconstituted ecosystem that vanished 10,000 years ago.

In Yakutia, we are trying to do just that. The government has adopted a program to restore the republic's former biodiversity. One thrust of this effort has been through the nonprofit organization of Pleistocene Park—of which I am a founding member—on 160 km^2 of Kolyma lowland. One-third of the territory is meadow, one-third is forest, and one-third is willow shrubland. Today, many of the animals of the mammoth ecosystem and grasses remain in northern Yakutia.

Reindeer, moose, Yakutian horses, recently reintroduced musk oxen, hares, marmots, and ground squirrels forage for vegetation, and predators, including wolves, bears, lynxes, wolverines, foxes, polar foxes, and sables, prey on the herbivores. However, strong hunting pressure has kept the overall number of animals low. Therefore, their influence on vegetation is small. The first step for Pleistocene Park, which we are just now initiating, is to gather the surviving megafauna of the mammoth ecosystem (initially without predators) within the part of the parkland that is rich in grassland. The second step will be to increase the herbivore density sufficiently to influence the vegetation and soil. As animal densities increase, the fenced boundary will be expanded.

The most important phase of the program will be the reintroduction of bison from Canada and subsequently, when the herbivores are sufficiently abundant, the acclimatization of Siberian tigers. In many regions of the Amur River basin, where this formidable predator survives, January temperature is as low as –25° to –30°C. The tigers' survival there is limited more by poaching and herbivore density than by climate. Scientifically, Pleistocene Park is important because it directly tests the role of large herbivores in creating and maintaining grassland ecosystems, something that can only be surmised but not proven from the paleorecord.

There is more than just scientific discovery at stake here. Northern Siberia will influence the character of global climate change. If greenhouse gas–induced warming continues, the permafrost will melt. At present, the frozen soils lock up a vast store of organic carbon. With an average carbon content of 2.5%, the soil of the mammoth ecosystem harbors about 500 gigatons of carbon, 2.5 times that of all rainforests combined. Moreover, this carbon is the relatively labile product of plant roots that were incorporated from productive steppe vegetation during the Pleistocene. As soon as the ice melts and the soil thaws, microbes will begin converting this long-sequestered soil carbon into carbon dioxide under aerobic conditions or into methane under anaerobic conditions. The release of these gases will only exacerbate and accelerate the greenhouse effect.

Preventing this scenario from happening could be facilitated by restoring Pleistocene-like conditions in which grasses and their root systems stabilize the soil. The albedo—or ability to reflect incoming sunlight skyward—of such ecosystems is high, so warming from solar radiation also is reduced. And with lots of herbivores present, much of the wintertime snow would be trampled, exposing the ground to colder temperatures that prevent ice from melting. All of this suggests that reconstructed grassland ecosystems, such as the ones we are working on in Pleistocene Park, could prevent permafrost from thawing and thereby mitigate some negative consequences of climate warming.

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