A Mammoth Undertaking

Why extinct species buried in Siberia threaten global climate, and what scientists are doing to contain the damage.
As Siberia’s permafrost melts, billions of tons of carbon could escape and heat the planet. Do animals and plants hold a key to Earth’s thermostat?
IN SOVIET TIMES, Siberia’s Kolyma River basin was the destination of enemies of the state. Even today, the Kolyma highway is called the “Road of Bones,” because the life expectancy of a prisoner there was just one winter and the bones of the fallen were buried in the road itself. Now, oddly enough, the Kolyma is earning its place in the annals of world history for a mass killing that happened some 20,000 years earlier. When the prisoners scraped away moss to build the road, they were scraping away insulation keeping the permafrost frozen. In the past decade the underlying ice has vanished, leaving canyons as deep as the trucks that drove this vehicle from Vladivostok, some 2,000 roadless miles to the south, in the dead of winter. And now we are walking away from this scene, leaving the windows open and the keys in the ignition—Zimov is perhaps the only man in the history of Russian civilization to do that. He calls his son, Nikita, on the satellite phone to bring the other truck and rescue us. Nikita, 23, is the heir to an empire Sergei has built with his wife, Galina, whom he persuaded to settle at the mouth of the Kolyma about 30 years ago.

“From a spark, there ignites fire” is an aphorism attributed to V.I. Lenin, but it well describes life around what is officially the Northeast Science Station, a filial of the Vladivostok branch of the Russian Academy of Sciences. In practice the station is two families, the Zimovs and Sergei and Anya Davydov, who settled in this isolated hamlet of Cherskii more than two decades ago, slowly erecting a scientific powerhouse unmatched in its productivity of high-profile research in contemporary climate change, paleontology, soil science, hydrology, ecology and nearly every branch of the natural world.

In an era when the superabundance of scientific information has forced young scientists to delve into ever more peripheral investigations searching for some untouched territory, there is a place on Earth where two men and two women living in the wilderness have managed by virtue of their own skills at observation and analysis to make fundamental contributions to world science. And the most prominent among them has never touched a computer. Having walked every mile of this isolated landscape by the Arctic Ocean, picking up bones, throwing rocks in lakes, piecing together how this complex mosaic works, Sergei has at last settled on a plan to save civilization. He is building a preserve called Pleistocene Park, a menagerie devoted to the fauna predating civilization, in a bold effort to send us back to the icy epochs when humanity first thrived.

The big message from the final report of the Nobel-winning Intergovernmental Panel on Climate Change was the asymmetry between those who benefit from fossil fuel use (mostly those of us living in the temperate mid-latitudes) and those unintentionally impacted by the CO₂ that is emitted (mostly poor people in the tropics who live near the rising ocean or whose crops will yield less in a warmer climate). As a kind of corollary to this phenomenon, the CO₂ respired from soils at this very edge of the Arctic mixes through the rest of Earth’s
atmosphere within a year, incrementally warming the rest of us.

What brings me to Siberia is its place at the center of several contemporary scientific mysteries that have accompanied global warming; there is no substitute for going there and collecting data to put together the different pieces of the puzzle.

INNER SIBERIA (Yakutia) is the most hydrologically isolated territory on Earth. This means nearly all its rain comes from evaporation from land, so it is unusually sensitive to the ecophysiology of plants as they respond to drought, heat and cold stresses. Yakutia is also the coldest place on our planet; if your compass were a magnet of temperature, it would point to Verkhoyansk, the Pole of Cold in eastern Yakutia, which reached minus 90 F (minus 67.8 C) when explorers wintered there in 1885 and has stayed about that cold ever since. As a consequence this region is underlain almost entirely by frozen ground. This geographic peculiarity takes on significance in contemporary climate change, because eastern Siberia has experienced the greatest 20th-century warming on Earth.

Changes here have global consequences. The Arctic Ocean derives most of its fresh water from the giant Siberian rivers Ob, Yenisei, Lena (so great that Lenin named himself after it) and Kolyma. River gauge records that have recently come to light show a marked increase in runoff, the underlying cause of which is still somewhat murky. Because precipitation has not changed substantially in the region, greater runoff is likely to be linked to reductions in plant evaporation, perhaps a consequence of increased atmospheric CO2. Alternatively, Siberia’s forests may be evaporating less because the spring snowmelt is happening too fast for the water to infiltrate. The shift in timing of water availability affects plant productivity and may leave them drought-stressed in the late season, even though the annual supply of water hasn’t changed. (California’s farmers, dependent on a slow supply of snowmelt for irrigation water, are anticipating that similar changes there will accompany higher temperatures.)

Warming is also implicated in the strong increase in Siberian forest fires that make the air quality in some years worse than Los Angeles. Fires send carbon that is stored in wood into the atmosphere and also reduce the ability of the ecosystem to remove CO2 from the atmosphere by photosynthesis. Fire weather is a concept used by foresters to combine the effects of temperature, precipitation, humidity and wind into a single metric of “dryness.” As a warming Siberia experiences more frequent and intense fire weather, we may see a gradual erosion of the boreal forest carbon storage sink.

The real wild card in Siberia’s response to warming is its permafrost, which shapes every facet of the climate, hydrology and ecology. As sophisticated as permafrost science has become in the past century, its models are fundamentally small-scale and purely physical. The important news from Siberia is that the key role of the organic matter locked up in permafrost, which threatens to become a “carbon bomb” as the soils warm and start to decay. (See sidebar, page 68.)

Only recently have scientists begun to decipher the key role of plants and ecological processes in the global warming equation. Climatologist Mikhail Budyko first conceptualized an important regulatory role of vegetation in the earth system in the 1960s, but the major models for understanding the aggregate behavior of entire continents of plants have come in the past three decades from the work of plant ecologists Joe Berry and Chris Field of the Carnegie Institution, and Stanford biology professor Hal Mooney.
measures the turbulent eddies that carry heat, water and trace gases. While it is conceptually simple, it is practically challenging. Terry Chapin, who earned his PhD in biological sciences in 1973 under the direction of Mooney, was among the first Western scientists to establish experiments in Russia to directly monitor the interactions between plants and the atmosphere in Siberia’s unique larch-tundra ecosystem.

These experiments have been maintained by Sergei Zimov for nearly a decade by diesel and willpower, and they have the potential to break open our understanding of ecosystem-level responses to climate change in the far north. However, the data have been collected from a half dozen sensors on three meteorological towers at 10 times per second for that entire time and have accumulated on a stack of CD-ROMs nearly a yard tall.

This is the firehose of data that I have come to Siberia to sip. You would think it would be easier to send CDs back to the United States to be analyzed, but we hear rumors that Russian customs officials have been confiscating CDs and laptops, causing the loss of untold time and money, not to mention enthusiasm and goodwill. And a bicycle is probably faster than file transfer protocol in Siberia. The best approach to rescuing this data is probably the most sustainable for continued research; I am here to teach micrometeorology to Sergei’s son, Nikita, a mathematician trained at Akademgorodok, Russia’s brain trust for the physical sciences.

The secret to the station’s success is lots of walking and seven months of winter to think about it. Sergei will take you to a lake a short hike from his house and persuade Nikita to trudge around in the brackish water, dislodging bubbles as if from a carbonated pond. Nikita shuffles backward with a washbasin upside-down to catch the fizz he has stirred up, until Sergei asks him to hold still for a moment. Producing a lighter, Sergei starts a torch of methane from the washbasin that lasts more than a minute. We are dumbstruck, until we cheer for more. This is the science you could imagine Calvin and Hobbes conducting, but the methane from this very lake was the topic of widely distributed. The abundance of grasses led to the evolution of herbivores, among them the woolly mammoth, creating an ecological mutual admiration society: the Mammoth Steppe ecosystem.

About 10,000 years ago, there came a time when no more mammoths walked the Earth. The demise of that society marks the beginning of the Holocene period, which persists today. Hardly any animals walk here, and in the place of steppe grasses are only larch, moss, blueberry and other flora of the taiga, the vast Eurasian boreal forest.

If you follow the discussion on what possible trajectories global warming might take, the crucial ingredients are: first, how much CO2 from fossil fuels we are releasing; next, how much the atmosphere will heat from that; and finally, how the land and ocean will react to mitigate or amplify the warming. Few scientists argue that grazing animals make any mark on the global climate, perhaps in deference to a longstanding idea in ecology known as the Green World hypothesis, which notes that despite ravenous insects, burrowing prairie dogs, leaf-eating koalas and trampling elephants, the landscape remains largely green. This suggests that in the timeless struggle between herbivore and herb, the plants have the upper hand, and therefore it is plants that shape terrestrial weather, not animals.

But isolation from computers means isolation from scientific consensus and groupthink. Sergei looks at the bones buried everywhere under this landscape and proposes that those mammoths would have crushed nearly every tree in Beringia, leaving an extensive grassland. Much as we watch with alarm as Arctic sea ice melts and reveals a dark ocean to absorb the sun’s rays, the loss of mammoths and consequent northward expansion of forests would have an unambiguous warm-
ing effect. In springtime, while grasses lie dormant under a thin blanket of snow, black trunks of trees tower above the surface and absorb the sun's light as it emerges from polar winter. The difference between energy absorbed by trees or energy reflected by snow in those first weeks of spring is what determines the accretion or thaw of permafrost. This is a major reason why land in high latitudes is warming faster than any other place on Earth. Just as many authors argue that the northward advance of forests is accelerating warming today, Sergei reasonably suggests the corollary: mammoths and other herbivores kept the climate of their day cool. The mass extinction of the fauna of the Mammoth Steppe—mammoths, bison, horses, rhinos, cave lions, beavers, reindeer, elk, deer and many others—is still a source of active debate between two camps: those who argue that the animals died out and others who argue that human settlers in Beringia slaughtered the animals en masse on their way to North America. Sergei is unreservedly in the latter group: “In America, 500 men with guns killed 50 million buffalo in five years. In Australia, the 23 largest herbivores were extinct in the first century.

The helicopter ride to Cherskii affords a schematic view of a battlefield where earth, air, water and fire (and fire’s inverse, photosynthesis) struggle for supremacy. The field is churned, scarred, pitted—no wonder the study of landforms there has reached its apotheosis. This is a landscape for connoisseurs of form: line, dimension and color and their arrangement with each other all have meaning and give insight into the battle between the elements, both contemporary and ancient. On the horizon is a collection of lakes, thousands of them, all triangular and pointed in the same direction. Below us, adjacent to the Kolyma River, defunct channels form long, narrow oxbow lakes. These eventually drain and give way to long stripes of mosses or trees that reveal the pace of the river’s meander. The river itself is the least interesting part of the braided skein.

Most bizarre are the polygons. Like the storming of a citadel, water finds a small chink in the armor of the earth and exploits this crack, expanding it as it freezes so as to allow more water to penetrate after the next year’s thaw. This process is amplified over years until the soil becomes filled with ice wedges and it is unfair to still call it soil; it is now an ice-complex, or yedoma. From above, this can look like polygons—quadrangular, hexagonal, with straight sides and distinct corners.

It would appear ice rules this landscape. But no: enter fire. As it burns off the insulating layer of moss, the black soil warms, melting the ice below. In a couple of summers the ground will collapse, one meter, two meters, 10 meters. What was once a tranquil, tussocky but flat landscape is shattered into giant mounds and pits owing to the now-absent ice. Like walking on the beach, any violation of the tranquil surface leaves a wet depression. The wetness absorbs the sun, and warms. The puddle now makes a small pond, now a lake, as the ground below it collapses, and it collects more and more runoff from the surrounding landscape.

As the lake expands and grows deeper, the surrounding landscape starts to melt, collapse into the lake and slide to the bottom. The yedoma sediments are particularly high in organic matter, containing not just soil humus but frozen roots, leaves and bones from tens of thousands of years ago. Once they settle at the bottom of the lake, there is a small family of microbes that makes its meager living exploiting the stored energy in this matter, creating methane in the process. This methane bubbles up from the lake bottom and into the atmosphere, where it is invisible but very effective at trapping the long-wave radiation emitted from Earth. The greenhouse effect heats the world atmosphere. One theory holds that the methane from these lakes is partly responsible for the runaway warming that happens at the end of an ice age, accelerating the melting of permafrost.

From MAMMOTHs to METHANE

The helicopter ride to Cherskii affords a schematic view of a battlefield where earth, air, water and fire (and fire’s inverse, photosynthesis) struggle for supremacy. The field is churned, scarred, pitted—no wonder the study of landforms there has reached its apotheosis. This is a landscape for connoisseurs of form: line, dimension and color and their arrangement with each other all have meaning and give insight into the battle between the elements, both contemporary and ancient. On the horizon is a collection of lakes, thousands of them, all triangular and pointed in the same direction. Below us, adjacent to the Kolyma River, defunct channels form long, narrow oxbow lakes. These eventually drain and give way to long stripes of mosses or trees that reveal the pace of the river’s meander. The river itself is the least interesting part of the braided skein.

Most bizarre are the polygons. Like the storming of a citadel, water finds a small chink in the armor of the earth and exploits this crack, expanding it as it freezes so as to allow more water to penetrate after the next year’s thaw. This process is amplified over years until the soil becomes filled with ice wedges and it is unfair to still call it soil; it is now an ice-complex, or yedoma. From above, this can look like polygons—quadrangular, hexagonal, with straight sides and distinct corners.

It would appear ice rules this landscape. But no: enter fire. As it burns off the insulating layer of moss, the black soil warms, melting the ice below. In a couple of summers the ground will collapse, one meter, two meters, 10 meters. What was once a tranquil, tussocky but flat landscape is shattered into giant mounds and pits owing to the now-absent ice. Like walking on the beach, any violation of the tranquil surface leaves a wet depression. The wetness absorbs the sun, and warms. The puddle now makes a small pond, now a lake, as the ground below it collapses, and it collects more and more runoff from the surrounding landscape.

As the lake expands and grows deeper, the surrounding landscape starts to melt, collapse into the lake and slide to the bottom. The yedoma sediments are particularly high in organic matter, containing not just soil humus but frozen roots, leaves and bones from tens of thousands of years ago. Once they settle at the bottom of the lake, there is a small family of microbes that makes its meager living exploiting the stored energy in this matter, creating methane in the process. This methane bubbles up from the lake bottom and into the atmosphere, where it is invisible but very effective at trapping the long-wave radiation emitted from Earth. The greenhouse effect heats the world atmosphere. One theory holds that the methane from these lakes is partly responsible for the runaway warming that happens at the end of an ice age, accelerating the melting of permafrost.

LOSING GROUND:
Wedges of soil along the banks of the Kolyma are all that remain after the ice melts from the yedoma formation. This soil is rich with bones of Pleistocene fauna, as well as vast stores of frozen carbon.
Siberia’s ‘CARBON BOMB’

Microbial decomposition generates its own heat, a phenomenon Sergei Zimov and colleagues explored in permafrost soils in a 2001 Russian publication. Dmitry Khvorostyanov and Philippe Ciais of the Laboratoire des Sciences du Climat et de l’Environnement (LSCE) in Paris recently incorporated this microbial heating effect into a model of the carbon and heat budget of yedoma soils. They found that atmospheric warming can kick-start a microbial engine that thaws the entire frozen soil column tens of meters deep, seen in the left panel as a transition from cool colors to warm colors around model year 30 (the time period represented by the horizontal axis is arbitrary). The heating is fueled by the decomposition of the organic matter in the process, seen in the right panel where soils transition from high soil carbon (black) to low soil carbon (white). Once the organic matter that fuels the microbes is exhausted, the soils freeze again, but with only a fraction of the carbon left. The whole process takes only about 100 years to complete and begins when just 10 percent of the organic matter has decomposed.
physiology of the park, he points to the wrecked underbrush strewn about the path. “Three mammoths came through here, two female mammoths, one child,” he announces. I am bewildered, unable to imagine what it is like to walk around in the present, all the time aware of ghosts of the deep past. He continues: “But today we have no mammoths, so I use a tank.”

Among the assorted vans, Jeeps, boats, ATV, motorcycle, barge, float plane and hovercraft at the station there is a tank. A real tank, with Caterpillar treads. Sergei bought it new in Yakutsk a decade ago and drove it to Cherskii himself, several hundred miles in the dead of winter by dirt road (and, as necessary, overland). It is easy to see where this tank has been: in place of the shrubs and larch surrounding us everywhere there is a trail of succulent brome grass, spontaneously emerging and continuing to thrive several years later. Only after seeing the tank does it begin to dawn on me what life here used to be. Mammoths were the tanks of the former world.

Sergei has a personal collection of mammoth tusks in his home, but even sitting in their shadow around the kitchen table, he makes a strong effort to divert one’s attention from the allure of bones to the layers of grime accumulated around them. The real goldmine, he says, is not the bones, but the black yedoma soil unique to this region. When most of the world was covered in ice at the peak of the Wisconsinan glaciation, eastern Siberia was cold and dry but free of glaciers, permitting the existence of the flora and fauna of the Mammoth Steppe ecosystem. Pollen records and carbon dating testify to the presence of grasses, birch trees and other plant life more characteristic of southern Russia in the present day. These grazing fields supported the wildlife whose bones are found everywhere.

The animals had to endure a harsh, continuous wind, because continent-sized glaciers wreak havoc on atmospheric circulation, causing a dramatic increase in the power of cyclones bringing heat north to quell the polar cold. The aftermath of these Pleistocene storms is seen everywhere in the world, from the Palouse hills in eastern Washington state to the extensive loess deposits of Manchuria and Inner Mongolia. In eastern Siberia, the dust settled slowly on top of the grasses, gradually adding millimeters to the surface while being chased by the formation of permafrost a foot below. Tens of thousands of years later the plain is elevated 150 feet or more, a great stockpile of roots and bones frozen in time.

While in some sense Pleistocene Park is an attempt to understand the Mammoth Steppe ecosystem before the age of man, the real mission may as well be to see how restoration of that ecosystem can prevent the runaway warming mankind has never experienced. In the same can-do style that keeps diesel motors running here far beyond their stated longevity, Sergei calculates that 5,000 head of bison shipped from Canada would be enough breeding stock to start a continental-scale effort to restore the Mammoth Steppe and keep 500 billion tons of Pleistocene carbon frozen in permafrost.

At the kitchen table, Sergei considers the current price of CO₂—around $5 per ton at the low end—and reckons his yedoma is worth about $9 trillion on the world market. His greatest asset is that he knows how to keep this carbon locked up: with a tank and some bison.

Adam Wolf, a doctoral candidate in biology, is a scientist at the Carnegie Institution’s Department of Global Ecology on campus.