SPACE
In Search of Alien Jupiters

EDUCATION
Building the 21st-Century Learner

NEUROSCIENCE
Hearing Loss from Everyday Noises

SCIENTIFIC AMERICAN

ScientificAmerican.com

HOW WE CONQUERED THE PLANET

Our species wielded the ultimate weapon: cooperation

0 74470 38529 5 08
$5.99 U.S.
AUGUST 2015

EVOLUTION

THE MOST INVASIVE SPECIES OF ALL

Many human species have inhabited the earth. But ours is the only one that colonized the entire planet. A new hypothesis explains why

By Curtis W. Marean

Illustration by Jon Foster

Curtis W. Marean is a professor at the School of Human Evolution and Social Change at Arizona State University and associate director of the university's Institute of Human Origins. Marean is also an honorary professor at Nelson Mandela Metropolitan University in South Africa. He is particularly interested in the origins of modern humans and the occupation of coastal ecosystems. His research is funded by the National Science Foundation and the Hyde Family Foundations.

SOMETIME AFTER 70,000 YEARS AGO OUR SPECIES, *HOMO SAPIENS,* LEFT AFRICA TO BEGIN its inexorable spread across the globe. Other human species had established themselves in Europe and Asia, but only our *H. sapiens* ancestors ultimately managed to push out into all the major continents and many island chains. Theirs was no ordinary dispersal. Everywhere *H. sapiens* went, massive ecological changes followed. The archaic humans they encountered went extinct, as did vast numbers of animal species. It was, without a doubt, the most consequential migration event in the history of our planet.

Paleoanthropologists have long debated how and why modern humans alone accomplished this astonishing feat of dissemination and dominion. Some experts argue that the evolution of a larger, more sophisticated brain allowed our ancestors to push into new lands and cope with the unfamiliar challenges they faced there. Others contend that novel technology drove the expansion of our species out of Africa by allowing early modern humans to hunt prey—and dispatch enemies—with unprecedented efficiency. A third scenario holds that climate change weakened the populations of Neandertals and other archaic human species that were occupying the territories outside Africa, allowing modern humans to get the upper hand and take over their turf. Yet none of these hypotheses provides a comprehensive theory that can explain the full extent of *H. sapiens*' reach. Indeed, these theories have mostly been proffered as explanations for records of *H. sapiens* activity in particular regions, such as western Europe. This piecemeal approach to studying *H. sapiens*' colonization of the earth has misled scientists. The great human diaspora was one event with several phases and therefore needs to be investigated as a single research question.

Excavations I have led at Pinnacle Point on the southern coast of South Africa over the past 16 years, combined with theoretical advances in the biological and social sciences, have recently led me to an alternative scenario for how *H. sapiens* conquered the globe. I think the diaspora occurred when a new social behavior evolved in our species: a genetically encoded penchant for cooperation with unrelated individuals. The joining of this unique proclivity to our ancestors' advanced cognitive abilities enabled them to nimbly adapt to new environments. It also fostered innovation, giving rise to a game-changing technology: advanced projectile weapons. Thus equipped, our ancestors set forth out of Africa, ready to bend the whole world to their will.

A DESIRE TO EXPAND

TO APPRECIATE JUST HOW extraordinary *H. sapiens*' colonization of the planet was, we must page back some 200,000 years to the dawning of our species in Africa. For tens of thousands of years, these anatomically modern humans—people who looked like us—stayed within the confines of the mother continent. Around 100,000 years ago one group of them made a brief foray into

IN BRIEF

Of all the human species that have lived on the earth, only *Homo sapiens* managed to colonize the entire globe.

Scientists have long puzzled over how our species alone managed to disperse so far and wide.

A new hypothesis holds that two innovations unique to *H. sapiens* primed it for world domination: a genetically determined propensity for cooperation with unrelated individuals and advanced projectile weapons.

the Middle East but was apparently unable to press onward. These humans needed an edge they did not yet have. Then, after 70,000 years ago, a small founder population broke out of Africa and began a more successful campaign into new lands. As these people expanded into Eurasia, they encountered other closely related human species: the Neandertals in western Europe and members of the recently discovered Denisovan lineage in Asia. Shortly after the moderns invaded, the archaics went extinct, although some of their DNA persists in people today as a result of occasional interbreeding between the groups.

Once modern humans made it to the shores of Southeast Asia, they faced a seemingly limitless and landless sea. Yet they pushed on, undaunted. Like us, these people could envision and desire new lands to explore and conquer, so they built ocean-worthy vessels and set out across the sea, reaching Australia's shores by at least 45,000 years ago. The first human species to enter this part of the world, *H. sapiens* quickly filled the continent, sprinting across it with spear-throwers and fire. Many of the largest of the strange marsupials that had long ruled the land down under went extinct. By about 40,000 years ago the trailblazers found and crossed a land bridge to Tasmania, although the unforgiving waters of the southernmost oceans denied them passage to Antarctica.

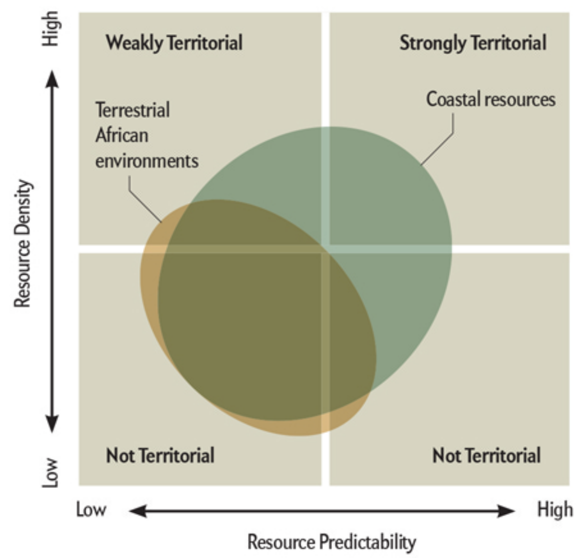
On the other side of the equator, a population of *H. sapiens* traveling northeast penetrated Siberia and radiated across the lands encircling the North Pole. Land ice and sea ice stymied their entry into the Americas for a time. Exactly when they finally crossed into the New World is a matter of fierce scientific debate, but researchers agree that by around 14,000 years ago they broke these barriers and swept into a continent whose wildlife had never seen human hunters before. Within just a few thousand years they reached southernmost South America, leaving a mass extinction of the New World's great Ice Age beasts, such as mastodons and giant sloths, in their wake.

Madagascar and many Pacific islands remained free of humans for another 10,000 years, but in a final push, mariners discovered and colonized nearly all these locales. Like the other places in which *H. sapiens* established itself, these islands suffered the hard hand of human occupation, with ecosystems burned, species exterminated and environments reshaped to our predecessors' purposes. Human colonization of Antarctica, for its part, was left for the industrial age.

THEORY

Worth Fighting For

A classic theory of biology holds that natural selection will favor aggressive defense of food sources (territoriality) when the benefits of exclusive access to these sources outweigh the costs of patrolling them. Among humans living in small societies, territoriality pays off when resources are dense and predictable. In Africa, certain coastal areas have dense and predictable food sources in the form of shellfish beds. Such environments probably triggered territoriality in early *H. sapiens* groups.



SOURCE: CURTIS W. MAREAN, AFTER "HUMAN TERRITORIALITY: AN ECOLOGICAL REASSESSMENT," BY RADA DYSON-HUDSON AND ERIC ALDEN SMITH, IN *AMERICAN ANTHROPOLOGIST*, VOL. 80, NO. 1; MARCH 1978

TEAM PLAYERS

SO HOW DID *H. SAPIENS* DO IT? How, after tens of thousands of years of confinement to the continent of their origin, did our ancestors finally break out and take over not just the regions that previous human species had colonized but the entire world? A useful theory for this diaspora must do two things: First, it must explain why the process commenced when it did and not before. Second, it must provide a mechanism for rapid dispersal across land and sea, which would have required the ability to adapt readily to new environments and to displace any archaic humans found in them. I propose that the emergence of traits that made us, on one hand, peerless collaborators and, on the other, ruthless competitors best explains *H. sapiens*' sudden rise to world domination. Modern humans had this unstoppable attribute; the Neandertals and our other extinct cousins did not. I think it was the last major addition to the suite of characteristics that constitute what anthropologist Kim Hill of Arizona State University has called "human uniqueness."

We modern humans cooperate to an extraordinary degree. We engage in highly complex coordinated group activities with people who are not kin to us and who may even be complete strangers. Imagine, in a scenario suggested by anthropologist Sarah Blaffer Hrdy of the University of California, Davis, in her 2009 book *Mothers and Others,* a couple of hundred chimps lining up, getting on a plane, sitting for hours extremely passively and then exiting like robots on cue. It would be unthinkable—they would battle one another nonstop. But our cooperative nature cuts both ways. The same species that leaps to the defense of a persecuted stranger will also team up with unrelated individuals to wage war on another group and show no mercy to the competition. Many of my colleagues and I think that this proclivity for collaboration—what I call hyperprosociality—is not a learned tendency but instead a genetically encoded trait found only in *H. sapiens*. Some other animals may show glimmers of it, but what modern humans possess is different in kind.

The question of how we came to have this genetic predisposition toward our extreme brand of cooperation is a tricky one. But mathematical modeling of social evolution has yielded some valuable clues. Sam Bowles, an economist at the Santa Fe Institute, has shown that an optimal condition under which

Graphic by Jen Christiansen

genetically encoded hyperprosociality can propagate is, paradoxically, when groups are in conflict. Groups that have higher numbers of prosocial people will work together more effectively and thus outcompete others and pass their genes for this behavior to the next generation, resulting in the spread of hyperprosociality. Work by biologist Pete Richerson of U.C. Davis and anthropologist Rob Boyd of Arizona State additionally indicates that such behavior spreads best when it begins in a subpopulation and competition between groups is intense and when overall population sizes are small, like the original population of *H. sapiens* in Africa from which all modern-day people are descended.

Hunter-gatherers tend to live in bands of about 25 individuals, marry outside the group and cluster into "tribes" tied together by mate exchange, gifting, and common language and traditions. They also sometimes fight other tribes. They take great risks in doing so, however, which raises the question of what triggers this willingness to engage in risky combat.

Insights into when it pays to fight have come from the classic "economic defendability" theory advanced in 1964 by Jerram Brown, now at the University at Albany, to explain variation in aggressiveness among birds. Brown argued that individuals act aggressively to attain certain goals that will maximize their survival and reproduction. Natural selection will favor fighting when it facilitates these goals. One major goal of all organisms is to secure a food supply, so if food can be defended, then it follows that aggressive behavior in its defense should be selected for. If the food cannot be defended or is too costly to patrol, then aggressive behavior is counterproductive.

With the joining of projectile weapons to hyperprosocial behavior, a spectacular new creature was born.

In a classic paper published in 1978, Rada Dyson-Hudson and Eric Alden Smith, both then at Cornell University, applied economic defendability to humans living in small societies. Their work showed that resource defense makes sense when resources are dense and predictable. I would add that the resources in question must be crucial to the organism—no organism will defend a resource it does not need. This principle still holds today: ethnic groups and nation-states fight viciously over dense, predictable and valued resources such as oil, water and productive agricultural land. An implication of this territoriality theory is that the environments that would have fostered intergroup conflict, and thus the cooperative behaviors that would have enabled such fighting, were not universal in early *H sapiens*' world. They were restricted to those locales where high-quality resources were dense and predictable. In Africa, terrestrial resources are, for the most part, sparse and unpredictable, which explains why most of the hunter-gatherers there who have been studied invest little time and energy in defending boundaries. But there are exceptions to this rule. Certain coastal areas have very rich, dense and predictable foods in the form of shellfish beds. And the ethnographic and archaeological records of hunter-gatherer warfare worldwide show that the highest levels of conflict have occurred among groups who used coastal resources, such as those in coastal Pacific North America.

When did humans first adopt dense and predictable resources as a cornerstone of their diet? For millions of years our ancient ancestors foraged for terrestrial plants and animals, as well as some inland aquatic foods on occasion. All these comestibles occur at low densities, and most are unpredictable. For this reason, our predecessors lived in highly dispersed groups that were constantly traveling in search of their next meal. But as human cognition grew increasingly complex, one population figured out how to make a living on the coast by eating shellfish. My team's excavations at the Pinnacle Point sites indicate that this shift began by 160,000 years ago on the southern shores of Africa. There, for the first time in the history of humankind, people started targeting a dense, predictable and highly valued resource—a development that would lead to major social change.

Genetic and archaeological evidence suggests that *H. sapiens* underwent a population decline shortly after it originated, thanks to a global cooling phase that lasted from around 195,000 to 125,000 years ago. Seaside environments provided a dietary refuge for *H. sapiens* during the harsh glacial cycles that made edible plants and animals hard to find in inland ecosystems and were thus crucial to the survival of our species. These marine coastal resources also provided a reason for war. Recent experiments on the southern coast of Africa, led by Jan De Vynck of Nelson Mandela Metropolitan University in South Africa, show that shellfish beds can be extremely productive, yielding up to 4,500 calories per hour of foraging. My hypothesis, in essence, is that coastal foods were a dense, predictable and valuable food resource. As such, they triggered high levels of territoriality among humans, and that territoriality led to intergroup conflict. This regular fighting between groups provided conditions that selected for prosocial behaviors within groups—working together to defend the shellfish beds and thereby maintain exclusive access to this precious resource—which subsequently spread throughout the population.

WEAPON OF WAR

WITH THE ABILITY to operate in groups of unrelated individuals, *H. sapiens* was well on its way to becoming an unstoppable force. But, I surmise, it needed a new technology—projectile weaponry—to reach its full potential for conquest. This invention was a long time in the making. Technologies are additive: they build on prior experiments and knowledge and become increasingly complex. The development of projectile weapons would have followed the same trajectory, most likely evolving from stabbing stick, to hand-cast spear, to leverage-assisted casting spear (atlatl), to bow and arrow, and finally to all the wildly inventive ways contemporary humans have come up with to launch deadly objects.

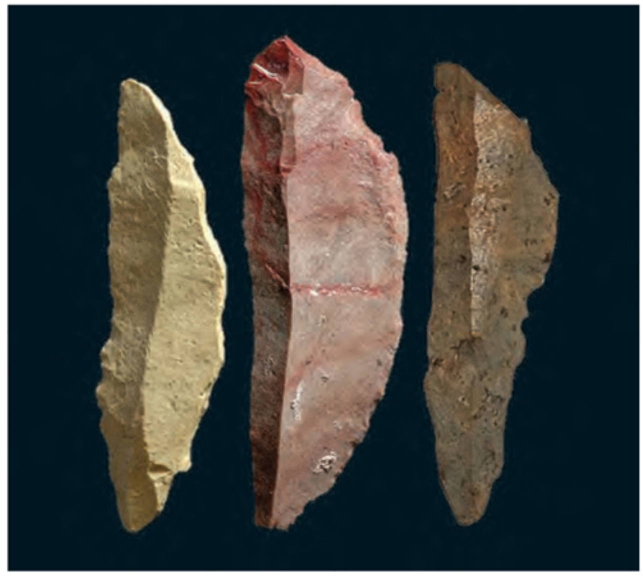
With each new iteration, the technology became more lethal. Simple wood spears with shaved points tend to produce a puncture wound, but such an injury has limited impact because it does not bleed the animal quickly. Tipping the spear with a sharpened stone increases the trauma of the wound. This elaboration requires several connected technologies, however: one must be able to shape a tool into a point that will penetrate an animal and shape a base that can be attached to a spear. It also requires some type of connecting technology to secure the stone point to the wood shaft—either glue or a tying material, sometimes both. Jayne Wilkins, now at the University of Cape Town in South Africa, and her colleagues have shown that stone tools from a site in South Africa called Kathu Pan 1 were used as spearpoints some 500,000 years ago.

The antiquity of the Kathu Pan 1 find implies that it is the handiwork of the last common ancestor of Neandertals and modern humans, and later remains from 200,000 years ago show that, as one might expect, both descendant species made these kinds of tools, too. This shared technology means that, for a time, there was a balance of power between Neandertals and early *H. sapiens*. But that situation was about to change.

Experts agree that the appearance of miniaturized stone tools in the archaeological record signals the advent of true projectile technology, for which lightness and ballistics are crucial. Such tools are too small to wield by hand. Instead they must have been mounted in slots grooved into bone or wood to create weapons capable of being launched at high speed and long distance. The oldest known examples of this so-called microlithic technology come from none other than Pinnacle Point. There, in a rock shelter known simply as PP5-6, my team found a long record of human occupation. Using a technique called optically stimulated luminescence dating, geochronologist Zenobia Jacobs of the University of Wollongong in Australia determined that the archaeological sequence in PP5-6 spans the time from 90,000 to 50,000 years ago. The oldest microlithic tools at the site date to around 71,000 years ago.

The timing hints that climate change may have precipitated the invention of this new technology. Before 71,000 years ago, the inhabitants of PP5-6 were making large stone points and blades from a type of rock called quartzite. Back then, as team member Erich Fisher of Arizona State has shown, the coastline was close to Pinnacle Point. And reconstructions of the climate and environment by Mira Bar-Matthews of the Geological Survey of Israel and Kerstin Braun, now a postdoctoral researcher at Arizona State, indicate that conditions were similar to the ones that prevail in the area today, with strong winter rains and shrubby vegetation. But around 74,000 years ago the world's climate began shifting to glacial conditions. The sea level dropped, exposing a coastal plain; summer rains increased, resulting in the spread of highly nutritious grasses and woodlands dominated by acacia trees. We think a large migration ecosystem in which grazing animals traveled east in the summer and west in the winter, tracking the rainfall and hence the fresh grass, developed on the formerly submerged coast.

Exactly why the denizens of PP5-6 began making small, light armaments after the climate shifted is unclear. But perhaps it was to pick off animals as they migrated across the new plain. Whatever the reason, the people there developed an ingenious means of making their tiny tools: turning to a new raw material—a rock called silcrete—they heated it with fire to make it easier to shape into small, sharp points. Only with the shift in climate that occurred could these early modern humans have had access to a sufficiently steady supply of firewood from the spreading acacia trees to make the manufacture of these heat-treated microlithic tools into an enduring tradition.



TINY STONE BLADES, **or microliths, from Pinnacle Point in South Africa (*top*) show that humans invented projectile weapons by 71,000 years ago. They attached the microliths to wood shafts to form arrows or darts like those reconstructed here (*bottom*).**

COURTESY OF SIMEN OESTMO (*top*); COURTESY OF BENJAMIN SCHOVILLE (*bottom*)

We do not yet know what kind of projectile technology these microliths were used for. My colleague Marlize Lombard of the University of Johannesburg in South Africa has studied somewhat later examples from other sites and argues that they represent the origin of the bow and arrow, given that damage patterns on them resemble those seen on known arrow tips. I am not totally convinced, because her study did not test the damage created by atlatls. Whether at Pinnacle Point or elsewhere, I think the simpler atlatl preceded the more complex bow and arrow.

I also suspect that like recent hunter-gatherers in Africa, whose lives were documented in ethnographic accounts, early *H. sapiens* would have discovered the effectiveness of poison and used it to increase the killing power of projectiles. The final killing moments of a spear hunt are chaos—pounding heart, heaving lungs, dust and blood, and the stink of sweat and urine. Danger abounds. An animal run to ground, fallen to its knees through exhaustion and blood loss, has one last trick: instinct screams for the beast to lurch to its feet one final time, close the gap and bury its horns in your guts. The short lives and broken bodies of Neandertals indicate that they suffered the consequences of hunting large animals at close range with handheld spears. Now consider the advantages of a projectile launched from afar and tipped with poison that paralyzes that animal, allowing the hunter to walk up and end the chase with little threat. This weapon was a breakthrough innovation.

FORCE OF NATURE

WITH THE JOINING of projectile weapons to hyperprosocial behavior, a spectacular new kind of creature was born, one whose

NEW SCENARIO

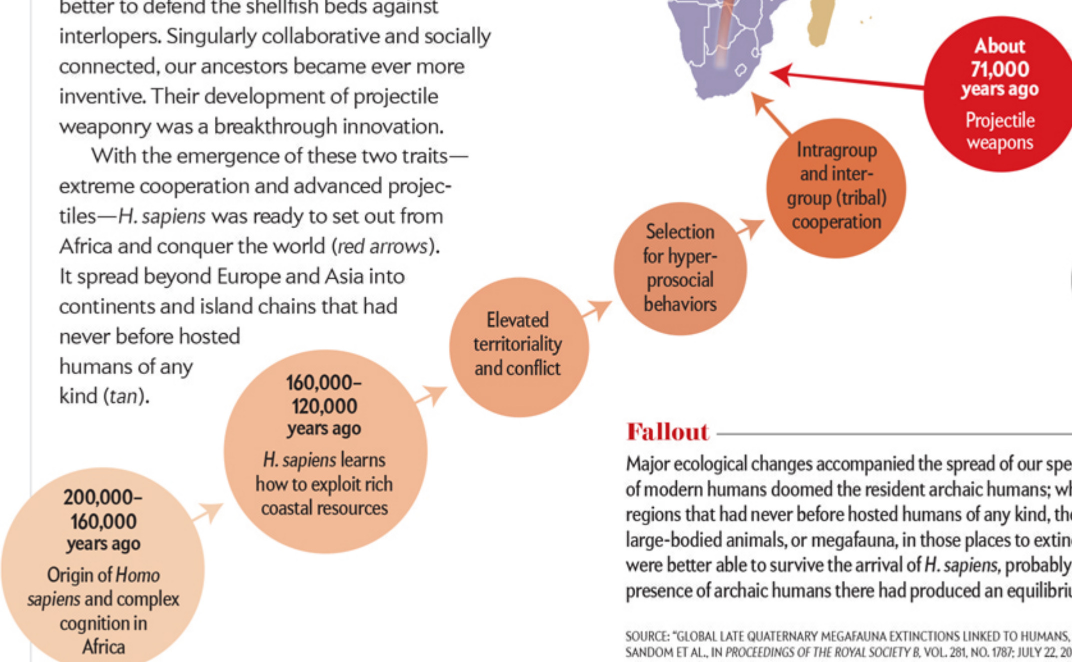
Ultimate Invader

Homo sapiens did not merely follow in the footsteps of its predecessors. It blazed trails into entirely new lands—and transformed ecosystems wherever it went.

After the debut of our genus, *Homo*, in Africa (*purple*), some early human ancestors began to disperse from the motherland starting around two million years ago. They pushed into various regions of Eurasia and eventually evolved into *Homo erectus*, Neandertals and Denisovans (*green*).

By 200,000 years ago, anatomically modern *H. sapiens* had evolved. When climate conditions deteriorated around 160,000 years ago, leaving much of inland Africa uninhabitable, some members of this species sought refuge on the southern coast and learned how to exploit the rich shellfish beds there for food. The author proposes that this lifestyle shift led to the evolution of a genetically encoded proclivity for cooperation with unrelated individuals—the better to defend the shellfish beds against interlopers. Singularly collaborative and socially connected, our ancestors became ever more inventive. Their development of projectile weaponry was a breakthrough innovation.

With the emergence of these two traits—extreme cooperation and advanced projectiles—*H. sapiens* was ready to set out from Africa and conquer the world (*red arrows*). It spread beyond Europe and Asia into continents and island chains that had never before hosted humans of any kind (*tan*).



Fallout

Major ecological changes accompanied the spread of our species. In Europe and Asia, the arrival of modern humans doomed the resident archaic humans; when these modern people entered regions that had never before hosted humans of any kind, they quickly hunted many of the large-bodied animals, or megafauna, in those places to extinction. (The megafauna in Eurasia were better able to survive the arrival of *H. sapiens*, probably because the long-standing presence of archaic humans there had produced an equilibrium between predator and prey.)

SOURCE: "GLOBAL LATE QUATERNARY MEGAFAUNA EXTINCTIONS LINKED TO HUMANS, NOT CLIMATE CHANGE," BY CHRISTOPHER SANDOM ET AL., IN *PROCEEDINGS OF THE ROYAL SOCIETY B*, VOL. 281, NO. 1787; JULY 22, 2014 (*hominin ranges and megafauna extinction map*)

SCIENTIFIC AMERICAN ONLINE View a slide show of images from the Pinnacle Point excavations at ScientificAmerican.com/aug2015/marean

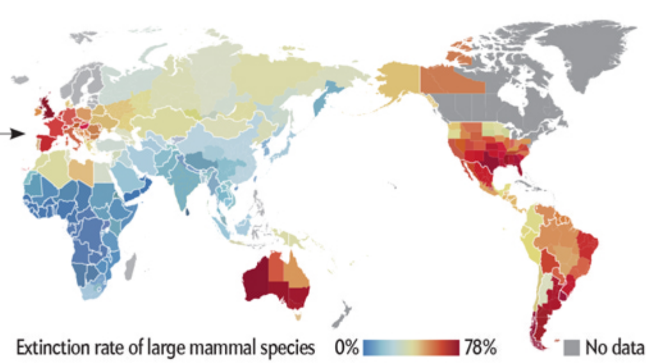
members formed teams that each operated as a single, indomitable predator. No prey—or human foe—was safe. Availed of this potent combination of traits, six men speaking six languages can put back to oar and pull in unison, riding 10-meter swells so the harpooner can rise to the prow at the headsman's order and fling lethal iron into the heaving body of a leviathan, an animal that should see humans as nothing more than minnows. In the same way, a tribe of 500 people dispersed in 20 networked bands can field a small army to exact retribution on a neighboring tribe for a territorial incursion.

The emergence of this strange brew of killer and cooperator may well explain why, when glacial conditions returned between 74,000 and 60,000 years ago, once again rendering large swathes of Africa inhospitable, modern human populations did not contract as they had before. In fact, they expanded in South Africa, flourishing with a wide diversity of advanced tools. The difference was that this time modern humans were equipped to respond to any environmental crisis with flexible social connections and technology. They became the alpha predators on land and, eventually, sea. This ability to master any environment was the key that finally opened the door out of Africa and into the rest of the world.

Archaic human groups that could not join together and hurl weapons did not stand a chance against this new breed. Scientists have long debated why our cousins the Neandertals went extinct. I think the most disturbing explanation is also the most likely one: Neandertals were perceived as a competitor and threat, and invading modern humans exterminated them. It is what they evolved to do.

Sometimes I think about how that fateful encounter between modern humans and Neandertals played out. I imagine the boasting tales Neandertals might have told around their campfires of titanic battles against impossibly huge cave bears and mammoths, fought under the gray skies of glacial Europe, barefoot on ice slick with the blood of prey and brother. Then, one day, the tradition took a dark turn; the regaling turned fearful. Neandertal raconteurs spoke of new people coming into the land—fast, clever people who hurled their spears impossible distances, with dreadful accuracy. These strangers even came at night in large groups, slaughtering men and children and taking the women.

The sad story of those first victims of modern human ingenuity and cooperation, the Neandertals, helps to explain why horrific acts of genocide and xenocide crop up in the world today. When resources and land get sparse, we designate those who do not look or speak like us as "the others," and then we use those differences to justify exterminating or expelling them to eliminate competition. Science has revealed the stimuli that trigger our hardwired proclivities to classify people as "other" and treat them horrifically. But just because *H. sapiens* evolved to react to scarcity in this ruthless way does not mean we are locked into this response. Culture can override even the strongest biological instincts. I hope that recognition of why we instinctively turn on one another in lean times will allow us to rise above our malevolent urges and heed one of our most important cultural directives: "Never again." ■



MORE TO EXPLORE

An Early and Enduring Advanced Technology Originating 71,000 Years Ago in South Africa. Kyle S. Brown et al. in *Nature,* Vol. 491, pages 590–593; November 22, 2012.

The Origins and Significance of Coastal Resource Use in Africa and Western Eurasia. Curtis W. Marean in *Journal of Human Evolution,* Vol. 77, pages 17–40; December 2014.

FROM OUR ARCHIVES

When the Sea Saved Humanity. Curtis Marean; August 2010.

scientificamerican.com/magazine/sa

Maps by Terra Carta