Molding the Planet

Human Niche Construction at Work

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Foreword

Sometime in 2011, my colleague and friend, archaeologist Tony Wilkinson, introduced me to the concept of human niche construction (HNC). I had met him in 2008, when I organized a workshop on irrigation in archaeology for students from Leiden University. The HNC concept appealed to Tony as it seemed to offer a potential model of the development of early water systems, particularly—but not exclusively—for Mesopotamia. In 2011, after an initial workshop in Durham in which the HNC concept was linked to imperial water systems in Iran, Tony and I succeeded in securing a grant under the AHRC-NWO Humanities Research Networking and Exchange Scheme of the Dutch Science Foundation and the UK Arts and Humanities Research Council.

The resulting workshop was held in April 2013 in Delft. We had a rather broad scope of water-related topics and presentations, including a comparison of the ancient West and East, skiing in the modern Austrian Alps, and communities interacting with their surrounding landscapes in the central Netherlands over the last 220,000 years. This allowed us to consider and tackle multiple dimensions of HNC in relation to ancient water management—including the material environment modified by human agency, social arrangements when modifying the environment and responding to changes, and genetic structures of the human group as a result of modifications. The workshop made clear that in the field of land and water studies, it is not yet possible to easily include genetic changes in the analysis—perhaps the link is simply too broad and, as such, might become obscured by other influences. Another conclusion of the workshop was that HNC is not only specific to small-scale systems—there is no reason to assume that larger-scale systems cannot also be studied as niches. The results of the workshop were published in *Water History* in December 2015 (volume 7, issue 4), one year after Tony had passed away.

With the conclusion of the Delft workshop, I set off for Munich to begin my fellowship at the Rachel Carson Center. I decided to organize an informal discussion on HNC that resulted in quite animated, but also confusing, discussions; participants acknowledged that the concepts of HNC and environmental history (EH) potentially challenge the notion of anthropogenic influence as a recent phenomenon—which is not the same as suggesting that the concept of niche construction itself is/was completely accepted. An especially positive aspect of the discussion was the focus on the importance of human agency in transforming humanity's own environment and the consequent feedbacks, which opened up several avenues for debate. The potential of HNC to draw renewed attention to human-induced change prompted me to suggest a formal workshop at the Rachel Carson Center on human niche construction. The essays in this volume are the result of that workshop, which took place in Munich on 16 and 17 October 2015.

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Not all of the papers that were discussed at this workshop could be included in this volume, but we would like to thank everybody who submitted papers or took part in the original workshop as a discussant, including in particular Giorgia Aquilar, Gregory Cushman, Sandra Junier, Michael Just, and Smiti Nathan. We are grateful to the University of Delft for their support of the workshop, and to colleagues at the Rachel Carson Center for organizing it. However, our biggest thank you goes to the editors at the RCC, in particular Samantha Rothbart, who dedicated considerable time and energy to this project and helped to see it through production.

Maurits W. Ertsen, Christof Mauch, and Edmund Russell

Introduction

I

Since the 1980s the theory of *niche construction* or *ecosystem engineering* has become an increasingly accepted way to explain how plant and animal species have been able to adapt, evolve, and survive over centuries and millennia. How might this approach inform our understanding of the relationship between *Homo sapiens* and environments?

The idea of niche construction is a recent elaboration on an old and malleable concept in ecology. Charles Elton equated a species's niche with its occupation. A badger had to perform a set of behaviors to survive in the same way that a vicar had to perform a set of behaviors to earn his living. Seeing species as jobholders implied that they interacted with each other in much the same way that holders of human occupations interacted with one another. Not coincidentally, a common term for *ecology* was "nature's economy."

G. Evelyn Hutchinson offered another definition of *niche*. Instead of seeing niches as species-specific packages of behaviors, he saw niches as species-specific packages of resources. Each species, he suggested, needed certain things from their surroundings—such as food, water, and shelter—to survive. If one listed all the resources used by badgers, one described the badger's niche. A niche was not a physical space, nor a job description, but rather a grocery list.

Elton and Hutchinson, like Charles Darwin before them, focused on ways in which organisms adapted to environments. To them, environments were relatively fixed.

But, ecologists have recently stressed, organisms do not just respond to fixed environments. Sometimes they adapt environments to themselves.

A classic example is beavers. These remarkable creatures do not just adapt to streams as they find them. They topple trees, build dams, create ponds, and control the flow of water. Beavers do not bed down in whatever patch of earth they happen upon. They erect complex lodges, complete with slides for entering and leaving, that offer snug quarters.

Ecologists use the term *niche construction* to refer to the process by which organisms adapt environments to themselves. *Ecosystem engineering* expresses much the same idea. Once introduced to the concept of niche construction, it is easy to see examples everywhere. Walk into a forest and you will see birds that adapt trees to themselves by building nests. Look under your feet, and you will see ants that adapt soil to themselves by digging tunnels. Look under eaves, and you will see wasps that adapt houses to themselves by building nests.

To see the most extreme example of niche construction, look at that strange animal known as *Homo sapiens*: houses, offices, water and sewer pipes, streets, railroads, carpeting, and. . .well, the list of ways we adapt environments to ourselves is endless. We have gone hog wild for niche construction.

When we build niches for ourselves, we often build niches for other species. We consciously build niches for domestic plants and animals. Watering, fertilizing, feeding, and building barns are all ways of constructing niches for other species deliberately. We also construct niches for other species accidentally. In the United States, house sparrows (aka English sparrows) and rock doves (pigeons) live in or near towns or cities. People do not build stores to attract sparrows and pigeons, but birds do not care why people do something—they capitalize on what people offer them. In response, store owners add spikes to ledges to prevent pigeons from landing. People deconstruct, as well as construct, niches for other species.

This is nothing new. To be human is to construct niches. The controlled use of fire, for instance, and the burning of woody plants helped our ancestors tens of thousands of years ago to scare away wild animals, to eat things other than plants and insects, to kill bacteria, to live on the ground (instead of in trees), and to create and maintain a variety of new ecosystems. One of the results of ecosystem management through fire was the transformation of "untouched" nature into cultivated land, which, in turn, initiated sustained evolutionary change. It allowed for a higher concentration of the human population, a decrease in infanticide and starvation, the domestication of animals (for food and manure), and complex processes of ecological and social change: with rising populations and the tendency towards cultivating high-yield varieties, plant and livestock varieties were irreversibly lost and at an increasing rate. Growing intensive monocultures also typically entailed the use of herbicides and pesticides, which affect (and often destroy) much of the other plant and animal organisms in agricultural ecosystems. Altogether, engineering the environment and constructing niches has helped humans to make the world a more livable place for themselves—or so many thought, as human activities have often produced unintended consequences. Creating human niches has led to the destruction and creation of niches for other species as well.

II

Niche construction shapes evolution as well as ecology. Evolution means change in the frequency of traits in populations. When a population constructs its niche, it changes the forces that might select for and against certain traits. In human history, one of the best examples is lactase persistence (also known as lactose tolerance). All mammals, including humans, drink milk as infants. They produce enzymes, including lactase, to break down and use the nutrients in milk. Once mammals are weaned, the gene coding for lactase usually shuts down. If most people in the world drink milk as adults, they experience gastric upset.

A few human populations are exceptions. In northern Europeans and north Africans, the lactase gene continues to operate after weaning. Adults in these populations, and their descendants elsewhere, guzzle milk without a problem. These populations have a long history of raising cattle, which modified the niche in which people lived. Our very genes, not to mention the dairy sections of supermarkets, record our history of niche construction.

III

Trying to understand human niche construction is both fascinating and challenging because of the capacity of humans to change the environment in complex and varied ways—ecological and evolutionary as well as social and cultural. Humans do not create just one type of niche. Niches take on different shapes in different parts of the globe and at different times in history. They are produced on multiple scales in time and space: from hunter-gatherer settlements to contemporary architecture, from open fields to indoor biomes. Niche construction is related to important concerns about equality and distribution of effects, as some niches may have been created with unequal power relations and/or more far-reaching consequences for those farther away. Despite these inequalities within the species as a whole, humans can indeed be described as "the ultimate ecosystem engineers" (Smith 2007b). What sets our species apart is perhaps what Smith calls the "potential for open-ended expansion and ever-increasing returns."

The concept of human niche construction challenges the dichotomy between nature and culture in a unique way. It suggests that we are not separate from our environment: even as we manipulate and manage our environment we are also coproduced by our ecological and material surroundings and by our fellow humans. Obviously, human niche construction is only one of several theories that try to explain how humans have evolved on the planet. As we realize the enormous impact of human activity, including our role in global warming, we have introduced several concepts that describe human relationships with the environment and over a longue durée period. Recently the concept of the Anthropocene has gained particular currency. This concept expresses the thesis that recent human activity in the natural world has affected the Earth's crust as significantly as volcanic eruptions, tsunamis, and earthquakes. It helps us understand the enormous impact of agriculture and mining, energy consumption and industry, travel, and the manufacture of synthetic products. In many respects, the idea of human niche construction goes beyond the Anthropocene. The concept focuses on the construction of our environment. The results of anthropogenic change are obviously relevant in human niche construction theory, but HNC also emphasizes the processes and mechanisms of change over time. It helps us explain not just *what* has changed but rather *why* and *how* humans have become a major force on the planet.

IV

Each of the essays in this volume addresses a *how* or *why* question. Each of them helps us to understand developments over time that cannot be understood by genetic determinism or by cultural factors alone. Between them, they study different time periods, different types of niches, and different regions on the globe. And while all the authors explain the theoretical basis of their research (often by contrasting or combining human niche construction with other theories), they each showcase concrete examples of human niche construction. The application of niche construction theory to individual research fields gives readers an idea of the wealth of disciplines, time periods, and research areas in which the theory of human niche construction can be fruitfully applied—even if these essays offer only a first taste of this.

The essays in this volume are written by scholars from different disciplines including environmental history and the history of technology, ecology and environmental sciences, botany and geography, archaeology and soil science, cultural anthropology and aesthetic theory. And while the authors are experts in a particular discipline, they all grapple with and transcend the confines of their respective disciplines to come up with a new understanding of human nature over time.

In his essay on human-cattle niches in Texas, environmental historian Timothy J. LeCain discovers a great affinity between human niche construction theory and neo-materialist theory. He explains that, long before humans began to shape the material world, it was already shaping us. The ranchers and "Cattle Kings" in Texas did not create their world alone; they relied on the intelligence of longhorn cattle to establish and maintain an ecological niche in which they could survive and thrive. The power and wealth of Texas ranchers was thus an outcome of multiple factors, including the genetic evolution of cattle over millennia and the human ability to consume beef and dairy products.

David A. Bello, an expert on Chinese history, turns our attention from cocreation of niches to competition. He explains how Chinese farmers during the Qing dynasty created "agri-niches" that would feed the country with cereals and reduce survival pressures. Interestingly, grasshoppers—originally "non-farming insects"—were attracted to these niches, and within a short time period, they underwent behavioral and physiological changes that allowed them to feed on cereals in vast numbers. From a niche construction perspective, humans and grasshoppers cocreated a niche; from a human perspective, the grasshoppers destroyed human livelihoods. As a result, a historic struggle began between humans and grasshoppers for the occupation of agri-niche turf in China.

In their essay on Scandinavian landscapes, evolutionary plant ecologists Ove Eriksson and Matilda Arnell turn to history and archaeology to explain the origins and development of the so-called "infield system," introduced during the early Scandinavian Iron Age. Infields were fenced-in areas that allowed farmers to produce crops and to make hay close to the farm, while at the same time keeping livestock and herbivores out. These human-made niches were maintained for approximately 1,500 years. Though intended to guarantee the survival of farmers over centuries, they likely also triggered cultural concepts such as land ownership in Scandinavia, and inadvertently created ecological niches with ideal conditions for certain plants and animals—which have become extinct elsewhere—to thrive.

Focusing on aesthetic inheritance, philosopher Mariagrazia Portera suggests that the human appreciation of landscapes and environments coevolved with our appreciation of the arts over the centuries. Portera follows scholars who maintain that the emergence of artistic practices and aesthetic sensibility may well be linked to the evolution of the human brain. Standards of beauty, Portera argues, are neither part of our genetic makeup nor given at birth, but tend to evolve through cultural niche construction behavior and biological evolution.

Historian and ecologist Laura Jane Martin looks at the coexistence of humans and other creatures—plants and animals—within human dwellings. Although we typically try to fight back against what we consider pests that have become adapted to living in our own homes, we are in fact unknowingly surrounded by and "collaborating" with tens of thousands of bacteria and microbes. Martin maintains that an understanding of the organisms which cocreate our indoor living spaces can lead to a novel, and less anthropocentric, understanding of human evolution, history, and ecological future.

Like Laura Martin, geoarchaeologist Sjoerd J. Kluiving and his colleague Arthur Hamel claim that research on the Anthropocene should be complemented by theories of human niche construction. Kluiving defines human niche construction as the ability of humans to transform the environment "to such an extent that anthropogenic cycles change, or even replace, natural cycles." He distinguishes between "inceptive" and "counteractive" niche construction, with the latter being an adaptive and ongoing response to an already altered environment. Kluiving and Hamel claim that the beginning of the Anthropocene coincides with the "tipping point from inceptive to counteractive changes" and they suggest that future research should focus on early human-induced activity that triggered escalating environmental change.

In the last essay of this volume, geographer Erle C. Ellis explains why he began to integrate social and cultural developments into his understanding of evolutionary developments. According to Ellis, the "ultrasocial" character of behaviorally modern humans provides the key to answering why humans have changed the planet's ecology more profoundly and in more varied ways than any other creature. He challenges the notion of the human niche and even suggests replacing it with "sociocultural niches." Because cultural traits have evolved more rapidly than biological traits, they have caused "runaway processes" of evolution that "lock societies into long-term cycles of adaptation in their sociocultural niche." Ellis warns us of a return to "balance of nature" concepts. There is no safe haven in nature, he says, and humans have always been more than "destroyers of nature."

In their understanding of the complex and specific role of humans on this planet, the essays in this volume raise new questions: How should we care for nature if we are an intrinsic, yet peculiar, part of it? What does "conservation" mean in a world that is cocreated by animals, plants, and humans? What should the future of environmental science look like if cultural traits play a prominent role in human species evolution? How should historians talk about flora and fauna, and about the small organisms that constitute most of our niches? We do not have answers to these questions yet. The complexity, and indeed the mystery, of the Earth's transformation defies anything but preliminary comprehension—and perhaps fortunately so. Altogether, we would like to see our volume as a progress report. We hope that it will trigger more case studies and an ever deeper understanding of human niches over time and into the future.

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Timothy J. LeCain

How Did Cows Construct the American Cowboy?

My interest in human niche construction emerged over the past few years from a growing dissatisfaction with the ways in which historians and other humanists typically understand the material world. Environmental historians problematized the concept of "nature" some years ago, yet the seemingly more scientific term "environment" often continues to be used without any equally rigorous analysis. Our concept of the environment has expanded to encompass the human-built world of cities and technologies, yet there is still a tendency to understand humans as fundamentally separate from their environment, interacting with it only through discrete pathways or influences. We tend to think of humans as being *in* an environment rather than emerging *from* their environment. The concept of niche construction suggests a more useful approach in its assumption that all organisms, humans included, are better understood as emerging from an ongoing process of creating a "niche" around them. Rather than adapting to a largely fixed and preexisting environment, organisms shape the very environments to which they adapt. When applied to humans with the concept of human niche construction, the theory further challenges conventional distinctions between "natural" and anthropic environments, suggesting instead that it is in the nature of humans, like all other organisms, to alter their material surroundings. This human niche construction thus closes the gap between the human and the material, suggesting that humans should at some level be understood as coextensive with their environment.

Recently, Kevin Laland (2014) and other supporters of niche construction have begun to call for an even broader paradigm called the extended evolutionary synthesis (EES), which moves away from the once dominant gene-centered approach in evolutionary biology to emphasize the many ways in which these niches shape the actual growth of an organism. "We hold that organisms are constructed in development," Laland notes in a recent article, "not simply 'programmed' to develop by genes." Advocates of EES embrace the possibility of extragenetic inheritance through epigenetic factors, social transmission, and the structures and changes in the environment that endure to become part of the niches that their descendants will develop within. This developmental approach not only suggests that "external" environmental niches play a role in creating organisms that is of equal importance to that of “internal” genes, but that these environmental influences are also heritable over multiple generations in a variety of different ways.

While the theory of niche construction has its origins in the biological sciences, when applied to humans it has some striking affinities with the recent development of neo-materialist theory in several humanistic disciplines. With the waning influence of postmodern theories that stressed idealist social constructivist models of historical change, scholars have taken a renewed interest in the power of material environments and things to shape or constitute humans and their societies. Neo-materialist scholars reject any simplistic material determinism, yet they argue that previously dominant constructivist theories neglected the many ways in which humans emerge as biological and cultural creatures through their engagement with a dynamic and creative material environment. Put simply, neo-materialist theory stresses that before humans could socially construct their material environment, that material environment had in many cases already constructed *them*, often profoundly so.

Obviously there is a tremendous opportunity here to bring human niche construction together with neo-materialism, particularly given that the latter focuses its efforts on the complex sociocultural means through which humans shape, and are shaped by, their material environment—the very “extragenetic” developmental processes that Laland and his colleagues also emphasize. Here, I want to offer four brief and (to varying degrees) somewhat speculative examples of how the strengths of these two theories might be usefully combined in an analysis of late-nineteenth-century open-range cattle ranching in the American northern Rocky Mountain state of Montana.

It is well understood that the introduction of Texas longhorn and other Euro-American cattle breeds had a profound effect on the grasslands of the western United States. Clearly, humans engaged in a type of niche construction as they attempted to use these western ecosystems for their own ends. However, western ranchers did not construct this niche on their own; rather, they worked in close cooperation with another intelligent social species: domesticated cattle. In this, it is also critical to bear in mind that western ranchers had already been shaped by a long coevolutionary history with cattle. When Euro-American settlers like the German-born Conrad Kohrs first brought cattle up into the western Montana territory in the 1860s, they unwittingly sought to benefit from a human-animal partnership that had its origins in the Neolithic. The ability of cattle to digest the complex cellulose in grasses and turn it into muscle and milk provided early humans with a powerful new source of highly concentrated caloric energy, helping them to thrive. Indeed, while Kohrs raised his cattle almost exclusively for their meat, as a northern European he probably possessed the genetic mutation that allowed him to drink cow's milk into adulthood, a trait shared by only that 25 percent of humans on the planet whose ancestors coevolved in close cooperation with cattle. Years before he became a rancher, even before he had laid eyes on a living cow or steer, Kohrs's own body had been shaped by cattle. In sum, cattle had constructed Kohrs and many of the other ranchers and their families in Montana, not to mention the tens of thousands of Americans who would eventually eat the muscle of the animals he raised. In this sense, Kohrs and other Euro-Americans constituted part of the niche that the *cattle* had constructed.

As important as this deep history or macroscale perspective is, however, the value of such niche construction theory would be greatly increased if it were also capable of illuminating smaller scales of historical change. In the case of early Montana ranching, I would suggest it can do so in four specific ways.

Hybrid Human-Cattle Niche Construction

Both human niche construction and neo-materialist theory need to recognize that in at least some cases, and perhaps many, humans did not construct their niches alone. Rather, the material world they interacted with possessed its own intelligence and creative powers. Kohrs's Texas longhorns were the descendants of Spanish and Portuguese breeds, most likely from the southern Andalusian region of the Iberian Peninsula, shipped to the new world by the conquistadors in the sixteenth century. The animals thrived in the scrubby woodland of southeast Texas, where their Spanish and later Mexican "owners" let them run free to fend for themselves. Intelligent, fast breeding, and well armed, the longhorn cows and bulls could protect themselves and their offspring from many predators and survive the winter without being fed by humans. Nonetheless, these semiferal longhorns still carried the genetic markers of their earlier coevolutionary history with human beings in India and Iberia.

When, after many decades of neglect, horseback-mounted men suddenly began to take a renewed interest in them in the second half of the nineteenth century, the longhorns were not so skittish or aggressive that they saw the men as a mortal threat to be attacked or resisted at all costs. The longhorns could be herded, albeit reluctantly and not without danger, up to lucrative markets at the rail terminals of the newly sprouted cattle towns of the Midwest. Eventually, the hardy animals would even walk all the way north to the ranches in the central and northern Great Plains, including Kohrs's ranch in southwestern Montana. There, Kohrs and his ranch hands depended on the longhorns' ability to travel freely over a vast range, using their own intelligence and adaptability to seek out the most nutritious bunch grasses and water sources, as well as to protect themselves and their offspring from predators and (somewhat less successfully) harsh weather conditions. The resulting ecological niche was in many ways a continuation of a previous niche created by deer, elk, and other undomesticated grazers, yet this niche was now maintained through a combination of human and longhorn skills and intelligence, a type of hybrid niche construction that benefited both organisms—at least until one slaughtered and ate the other.

Niche Construction, Energy, and Social Power

This human-cattle niche was a highly efficient means of concentrating the physical energy stored in the grasses of the high plains, energy that in turn became the basis for human social power, which permitted some to more powerfully shape new material niches. Eventually, Kohrs would raise some 200,000 head of cattle and own nearly a million acres of land scattered around four US states and two Canadian provinces. Kohrs became one of the original "Cattle Kings" who dominated the early politics of many western plains states, and he served as a territorial and later a state senator. When Kohrs built a fine new mansion in Helena, the Montana state capitol, it might seem irrelevant whether the dollars that paid for it came from cattle raising, mining, or even betting on horse races. Yet a materialist analysis would stress that Kohrs's mansion was, in part, a reformulation of the energy first captured by the niche he and his longhorn cattle had created on the early open range of southwest Montana. As Edmund Russell and his colleagues (2011) rightly suggest, the ability of some humans to control and direct the planet's finite flows of energy provides the essential material basis for their ability to exert control over other humans. "All power, social as well as

Figure 1: Conrad Kohrs's mansion in Helena, Montana, ca. 1955. Source: US Library of Congress.

physical," they argue, "derives from energy." Moreover, once built, Kohrs's mansion became part of a new material niche that generated further social power for Kohrs by helping to shape how other human beings thought and acted. Kohrs's mansion was not just a *symbol* of his power; rather, it literally constituted his power, even long after he was dead. As humans grew up and lived in the material niche Kohrs had helped to create, their own ways of thinking and acting would be shaped by his mansion—a concrete example of Laland's extragenetic transmission of developmental organismal traits between generations.

Niche Construction and Cowboy Culture

Given the importance of the longhorns' own intelligent adaptability in creating the ecological niche of western open-range cattle ranching, a neo-materialist approach would also question precisely where the resulting "culture" of cowboys and ranching originated. Much of what we consider to be the exclusively human-made culture of ranching—cowboys, roundups, the supposed freedom of the open range—were really

Figure 2: Kohrs himself recognized the importance of his longhorn cattle by displaying these impressive horns in his Deer Lodge Valley ranch house. Like his Helena mansion, the horns would also be a small part of an enduring material niche that would shape humans to this day (courtesy of the author).

behavioral by-products both enabled and dictated by the animals themselves. In sum, there was some piece of the human in the cattle and of the cattle in the human that we have only just now begun to recognize and reckon with. It risks belaboring the obvious to point out that there could be no cowboys without cows, yet it is extraordinary how little scholarly attention has been paid to the role of these animals in creating the culture of ranching.

Americans like to celebrate the western cowboy as the epitome of individual and mostly male freedom, when he would be better understood as a human whose culture and ways of thinking were, to a significant degree, shaped by the need to cooperate closely with another social animal. There is a growing body of scientific evidence that the material differences between raising organisms like wheat and rice may profoundly influence sociocultural phenomena, such as whether a society emphasizes the good of the group or of the individual. Is it not likely that raising longhorn cattle had a similarly profound influence on the "human" sociocultural systems of western ranching?

Niches, Bodies, and Brains

Fleshing out (literally) the connections between niche construction and human culture as an embodied and even genetic phenomenon is perhaps the most intriguing, though still somewhat preliminary, possibility. That longhorn and other cattle evolved genetically is undoubted. Kohrs and other ranchers increasingly bred their cattle with the deliberate goal of increasing growth rates and production of desired types of meat. However, the niches the cattle had helped to create also influenced the animals. In the early decades of open-range ranching, even the tough and intelligent longhorns suffered high mortality rates during severe winters, most famously during the "Great Die-Up" of the winter of 1886–87 when hundreds of thousands of cattle perished. Such severe environmental conditions selected for cattle that were better able to survive cold weather. There is also fragmentary but intriguing evidence that the longhorns, whose bodies were better suited to warmer climates, could become acclimatized to cold winters over several years in the north, both through biological and behavioral changes. Cattlemen reported that some cattle that survived earlier winters learned to dig through crusted layers of snow to reach forage—a behavior that older cattle might have passed on to subsequent generations.

On the human side, as already noted, some populations have evolved on a genetic level through their long association with cattle, most obviously through the ability of many Euro-Americans to drink milk into adulthood. However, at a smaller time scale, historical change might also be found in nongenetic biological interactions. When humans consumed the meat of longhorns as a source of bodily energy, these animals in effect became part of the human ecological niche. The alteration of vast swaths of western North America to niches suitable for large-scale ranching greatly increased the supply of cattle in the late nineteenth century. Combined with improvements in transportation, mass production techniques in slaughterhouses, refrigeration, and other technologies, the cost of beef declined and consumption soared. North Americans who had previously eaten mostly grains began to consume far more protein. Some historians have credited the increased consumption of beef with improvements in health and average height, while others have emphasized its adverse effects, for example on cardiac health. Recent insights into the importance of the human microbiome and its effects on bodily health, mood, and cognition also raise intriguing questions about the possible historical effects of this massive increase in the consumption of beef and protein. If, as the director of the US National Institute of Mental Health recently said, "we are more microbial than human," then perhaps we need to think of ourselves as being to some degree the products of microbial niche construction.

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David A. Bello

How Do Humans and Locusts Make Space in an Early Modern Chinese Grain Field?

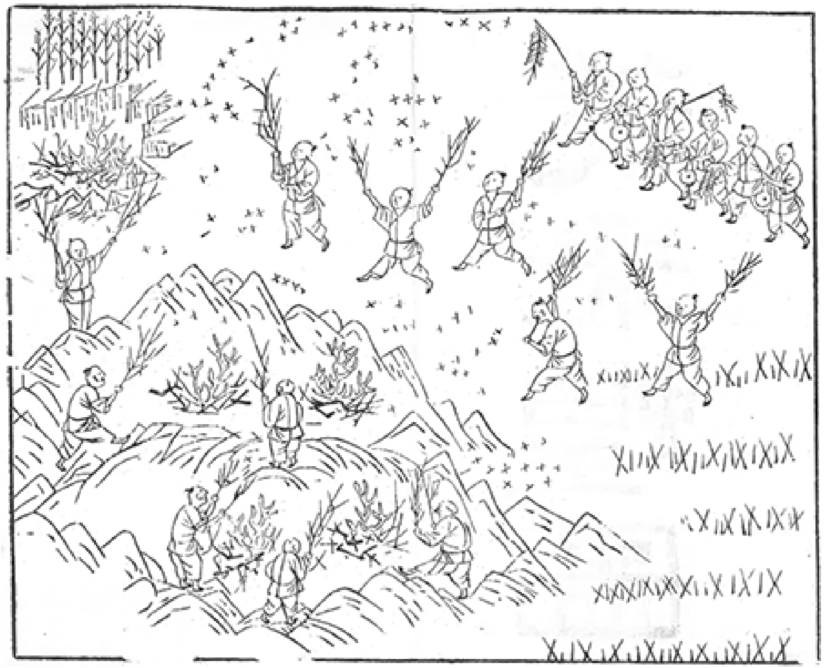

Figure 1: Farmers attempting to burn locusts in the fields. Source: Chen Chongdi (陳崇砥), Locust Control Manual (治蝗書), Banxi zhai, (1847) 1880 ed.

For over two thousand years, under the successive supervision of 25 dynasties, farmers in China devoted themselves to creating agricultural spaces for plants such as rice, wheat, and millet. Although an excellent source of sustenance for the population, these spaces had the unintended consequence of becoming a breadbasket for pests. So began an inadvertent, grassroots, scorched-earth competition between humans and locusts for occupancy of the fields—locust swarms on the wing would threaten to devour the cereal plants down to the ground, and the farmers would then take up burning brands as a last resort—a scenario that has been captured in figure 1.

At first glance, figure 1 simply depicts an agricultural scene involving people and insects in a field, but the vertical caption on the right noting a "picture of burning flying locusts" certainly doesn't speak for all of the actors in this scenario. It says nothing about why people need to burn locusts, and it's equally silent about the actual space: the contested niche that humans and locusts want to control but cannot simultaneously occupy. As an environmental historian, I want to keep people in the picture but without overlooking everything else around them. For me, figure 1 is a sketch of the idea that if humans had not decided to satisfy their taste for cereals by building a habitat for more of these plants than would otherwise have been able to grow, there would have been little, if any, grounds for human-locust competition. Niche construction theory makes this sort of altered perspective possible. Through it, I can form a sharper image of how humans fit into the environmental picture as part of a whole, rather than as the whole picture.

Niche construction theory defines "humans" as members of a larger constellation that includes the nonhuman environment, from which congenial spaces ("niches") are deliberately put together ("constructed") for the benefit of the builder species. Construction is the physical connection people make between the human and nonhuman worlds that is historically expressed as a niche. Their interactive collaboration merges into a landscape of mutual relationships—rather than being cropped out into individual portraits—that historians can trace through niche construction theory.

Agri-niches: Chinese Empire's Natural Habitat

The landscape I focus on in my work is that of China during its last dynasty, the Qing, from the mid-seventeenth through to the mid-nineteenth centuries. At this time, China rapidly integrated substantial new territories, expanding into Manchuria, Mongolia, Tibet, and Turkestan (or "Xinjiang"), to reach the largest territorial extent of any Chinese empire. Part of the reason for this achievement is that the Qing founders were not ethnic Chinese ("Han") but Manchus, formed from diverse groups mainly indigenous to Eurasia's forested seacoasts on the northeastern frontier of China proper. For nearly a century and a half from 1644, the Manchus used their multiethnic experience, which combined Inner Asian mounted military power and Chinese bureaucratic institutions, to extend and consolidate their control of these vast and very different territories under a single imperial state.

Different Qing subjects used their ecological surroundings in different ways, including herding, foraging, and agro-pastoralism across Inner Asia. The vast Han Chinese majority, however, mainly relied on a particular sort of rather intensive agriculture that not only fed most of the empire, but also paid for its bureaucracy. This was possible in many parts of China proper thanks to the congenial soil and climate, as well as to the vast river systems—especially the Yellow and Yangzi—that China's extensive irrigation and flood control system had been developed over centuries to exploit. The imperial administration spent a great deal of its energy maintaining the stability of this agricultural core, which emerged from a combination of natural conditions and human actions that affirmed the Qing identity of the people and kept them fed and taxed as Qing citizens.

Indeed, agriculture was so important that imperial administrators sent in a constant stream of reports, or "memorials," to the throne in Beijing about how to keep farming sustainable under constantly changing environmental conditions. One of the most visible and dramatic results of centuries of the intersection of human action and natural change is the Pearl River delta, an area that now includes the major Chinese cities of Canton (Guangzhou), Macao, and Hong Kong. From the end of the thirteenth to the end of the sixteenth centuries, the delta's natural silt build-up was accelerated and concentrated by dikes and polders (low-lying tracts of land enclosed by dikes) to produce rich fields of a quality second only to those of the Yangzi River delta further north. The "construction" of the Pearl River delta "niche" was a creative long-term human response to flooding and erosion, which, along with drought, were the most serious challenges to Chinese agriculture.

Other niche threats, however, were more difficult to convert into an advantage no matter how much time was spent working on them. Locusts were among the most persistent of such difficulties, as outlined by one official, named Shi Mao, in 1759. In a memorial to his ruler, the Qianlong Emperor (r. 1736–95), entitled "A Memorial That Respectfully Lays Out the Circumstances of Locust Catching," Shi Mao stressed that "the capture of locusts" by otherwise busy Han farmers "cannot be done in a perfunctory or crude manner." He was worried that these distracted, part-time bug catchers might not realize that there was a critical time to strike: the grasshoppers were much easier to contain early in their lifecycle, before they had sprouted wings. Shi's memorial explained how necessary it was to exploit opportunities that would allow farmers to avoid disruptive overlaps between cereal and locust reproductive cycles.

Shi Mao was attempting to deal with a human niche construction phenomenon: conflicting human and locust behaviors, which were complex responses to the surrounding ecology and to each other. The initial complex human action, cultivation of agri-niches, had created the right conditions for a corresponding response from the grasshoppers. As humans labored to grow food, they were also, inadvertently, raising a crop of hungry locusts in the same tasty niche.

Genetic Significance of Agri-niche Construction

Human niche construction theory suggests that people tend to behave in ways that modify their surroundings to reduce survival pressures—such as competition, disease, or predation—influencing the course of their own evolution, as well as that of other species. While such behavior is partly hereditary, this very complicated process involves more than just flipping a genetic switch. There is also a cultural component that includes socially learned behaviors, which may depend in part on how genetic makeup is expressed under various ecological and social circumstances. Niche construction theory explains how organisms leave niches behind as an inheritance that continues to shape the physical and cultural expressions of their descendants' genetic code in a way that is as definitive as the wings of a locust.

Agriculture illustrates the transmission and inheritance of genetic and cultural traits; however, though it might seem like a human creation, agriculture is not at all exclusive to our species. Leaf-cutter ants are probably the best example of an insect that lives off farming. The ants cultivate fungus from leaf mulch, which is then processed and spread to create a habitat that would not exist without their behavior. Indeed, certain species of cultivating ants have evolved to live off a single kind of fungus that grows in their underground gardens and nowhere else. The cultivation behavior and the fungus itself are exclusively passed down through the generations of these species to constitute a distinctive "culture," which also leaves particular physiological marks. Leaf-cutter ant exoskeletons, for example, have evolved to house a beneficial bacterium—which seems to have developed alongside the ants' cultivation of the fungus—that acts as a kind of antibiotic against the main infection that uniquely infests the ants' fungal habitat. In this respect, leaf-cutter ants have literally been shaped by their niches even as they construct them. Ethnic Chinese may have been similarly shaped by eating cereal products of their agri-niches to the near exclusion of other food staples like dairy products, leaving the current population of China with a genetic legacy unusually rich in lactose intolerance.

Grasshoppers aren't farming insects, but their behavior and development can likewise be profoundly altered by human farming. Some species of normally solitary grasshoppers are attracted by high concentrations of cultivated cereals—like the sorghum grown in north China, for example—because these plants lack natural chemical deterrents to repel them. As the grasshoppers crowd together, they rub against each other to activate touch-sensitive chemical receptors on the insects' hind legs. These receptors produce a neurotransmitter, serotonin, which induces behavioral changes like swarming. The grasshoppers also undergo physiological changes to develop wings. So, human construction of an agricultural niche produces not just cereals, but also locusts.

Locusts, however, do not stop there, but generally move on to niche destruction, which is mainly why they are historically significant. The empire's human-built agrarian niches had room for *either* cereals or locusts, but no capacity for full double occupancy. In this way agri-niches were both too limited and too accommodating. They could not feed every hungry mouth, but could easily fill the stomachs of either crowd depending on which one could get there first. Unless humans changed their own behavior, the natural advantages of locusts would likely ensure that the insects would catastrophically fill agri-niches long before people could reap their benefits.

Qing Agri-niche Competition

The insect lifecycle set the pace of the race between humans and locusts to occupy agri-niche turf. As emphasized in a locust control manual published by Chen Chongdi in 1874, farmers had to adapt their defensive measures to stages of locust development:

> All methods of controlling [locusts] must be divided into three stages: when they have not yet spawned, [when] they emerge as juvenile locusts [and when] they grow wings to become locusts. To control adult locusts is not as easy as controlling juvenile locusts, which are, in turn, not as easy to control as the spawn . . . Those who are concerned about dealing with this distress of the people should do so in its early stages.

Locusts were most vulnerable as eggs and hatchlings during sowing season—one of the busiest times of the year for farmers—and then rapidly underwent a series of physical transformations culminating in winged swarms that were far more difficult to contain. By the time grasshoppers had sprouted wings between the sowing and harvesting seasons, farmers already had their hands full with maintaining the agri-niches that they had constructed. People who studied the problem came up with many elaborate proposals to solve it. One 1760 plan required the mobilization of what a critic estimated as more than 7,500 people in just two districts to maintain an early warning and eradication system that could deal with the dispersed and rapid nature of locust reproduction and development across agri-niches. Implementation of such a system, which probably never happened, would take up an impractical six months annually. Figure 2 nevertheless gives some idea of what the 1760 plan, or any other kind of organized eradication effort, may have looked like:

Figure 2: An eradication effort in which farmers would sweep the fields for locust eggs. Source: Chen Chongdi (陳崇砥), Locust Control Manual (治蝗書), Banxi zhai, (1847) 1880 ed.

From a traditional Chinese agrarian viewpoint, this is an image from a nineteenth-century locust manual depicting farmers digging eggs out of the fields, as Chen envisioned. From a niche construction point of view, it is a very human scene—partly genetic, partly cultural—of an attempt to make human surroundings more inhabitable than if things were left to nature alone. From where I sit as an environmental historian, both blend together to afford a view of people who, because they depend on growing plants, must observe how insects develop if they wish to maintain relationships with those who need their crops for food and revenue.

I can also see, from the relations between Chinese farmers and their preferred cereal crops, that species' need for space is not always competitive. It is, however, generally transformative as niches are constructed, dismantled, and reconfigured, intentionally or otherwise. Niche change and species change are mutually conditioning, in some cases even down to the genetic level. Humans cannot be excluded from this picture any more than they can live without habitats. Ideas like niche construction theory make it plain to see that ecology and society are always part of the same environmental space.

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Ove Eriksson and Matilda Arnell

How Did Infields Shape the Scandinavian Cultural Landscape?

Mention of the Swedish countryside often evokes images of sweeping fields, beautiful pastures, and wooded meadows. For many the presence of idyllic grasslands is a necessary component of the romanticized traditional Swedish landscape. However, it is more than just their beauty that makes seminatural grasslands so interesting: their existence tells a captivating tale of human development, and how it gave form to the Swedish cultural landscape. “Seminatural” suggests these grasslands were partly managed and maintained by humans, primarily through grazing and mowing—practices that persisted over several centuries, as indicated by the presence of grasslands on old cadastral maps from the seventeenth and eighteenth centuries. Today, in addition to preserving a richness of plant life free from the influence of fertilizers and plowing, these grasslands also harbor an abundance of insects, birds, and fungi.

The corresponding author of this paper (Ove Eriksson) first became involved in research focusing on Swedish cultural landscapes during the late 1980s, when the Swedish government initiated programs that sought to conserve seminatural grasslands. The government supported farmers by means of subsidies to assist them in managing and maintaining the land, usually through cattle or sheep grazing. I was intrigued: How had these beautiful grasslands come about? How had they been sustained for more than 1,000 years, and to what effect? In my search for answers, I had to move beyond my own background in evolutionary plant ecology and embrace the less familiar fields of history and archaeology. But crossing the scientific boundaries between natural sciences and the humanities is challenging—research methods and concepts are different, and even communication, not to mention direct collaboration, can be difficult.

That is why *Niche Construction: The Neglected Process in Evolution* by Odling-Smee, Laland, and Feldman was an eye-opener when it was published in 2003. The book captures the essence of how to study interactions between species and their environment, and it laid the foundation for a conceptual basis for research on the controversial issue of “culture versus nature.” Since then, the study of human niche construction has matured and developed, in part through the work of scholars in the humanities.

Accordingly, the coauthor of this paper, Matilda Arnell, and I recognized the value of this theory as a tool to trace the development over time and the enduring presence of infield systems in the Scandinavian cultural landscape.

Infields through the Lens of Human Niche Construction

The infield system in Scandinavia is believed to have been developed during the first centuries CE (the early Scandinavian Iron Age), and it was maintained as a component of agriculture until the late nineteenth to early twentieth centuries. Infields are the areas that farmers once used for making hay or as crop fields; close to farms, they were enclosed to prevent uncontrolled grazing by livestock and wild herbivores. Farmers used the extensive outlying land beyond the infields to graze livestock and to collect natural resources, such as twigs and leaves, firewood, and wild fruits. Typically, twigs and leaves were harvested from coppicing and pollarding—pruning methods to stimulate new growth—for use as winter fodder. Towards the end of the nineteenth century, farmers abandoned outland livestock grazing and began to use the crop fields to produce winter fodder for livestock, rather than as seminatural hay meadows. Of course, agricultural technology changed considerably between the early Iron Age and the nineteenth century, but the essential elements—the enclosed infields and the outland—remained broadly the same over a period of approximately 1,500 years. Today, remnants of infield systems are small and isolated and have become a focus of conservation programs.

The construction and maintenance of these infields had a significant impact on the development of cultural practices in Scandinavia and the resulting biodiversity in the region, making niche construction theory an appropriate starting point for our analysis. Odling-Smee et al. define niche construction as "the process whereby organisms, through their metabolism, their activities, and their choices, modify their own and/or other species' niches" (2003, 419). Human niche construction theory in particular can help to reveal the interactions between humans and nature, given that it involves human culture in all its manifestations. Human niche construction implies that there is a continuous reciprocal interaction between human culture (including for example management methods, cultural perceptions, and social relations) and the environment (including wild species of plants, insects, birds, and fungi), affording us a unique perspective on the effects of culture on nature, and vice versa.

A Haven for Biodiversity

Long before people created infields, vast areas in southern Scandinavia were deforested, creating pastures and smaller areas of cropland. Agriculture was introduced in Scandinavia around 4000 BCE, so when the infield system was introduced during the first centuries CE, the landscapes already had a long history of openness (an important characteristic of infields). Farmers invested time and labor in creating and maintaining infields, fences, and stone walls and building byres to house livestock indoors during winter; this ensured that the cultivated land and its structures became more stable, permanent fixtures than they had previously been and therefore needed to be maintained over time. Ecologists call this a spatiotemporal stabilization of the grasslands habitat. In fact, we know from archaeological evidence that many farms still in existence have been located in the same place since around the fifth or sixth centuries CE. Moreover, some farms in Sweden retain pre-Christian names today. Since Christianity was only introduced in Scandinavia during the eleventh and twelfth centuries, this is further evidence of their stabilization in time.

This spatiotemporal stabilization—the result of sustained management through hay cutting and controlled grazing—led to conditions that favored several plant and animal species that were able to colonize the grasslands. Continuous management guaranteed these species populations a very low risk of local extinction. Thus, over time, they started to accumulate in the infield grasslands and the neighboring outland, the effect of which is still visible today. For example, well-managed former hay meadows may harbor over 50 different plant species per square meter.

Infield management also created other ecological patterns. Farmers often cultivated trees—primarily deciduous trees, such as ash, elm, birch, and lime—within the infields as an important source of building material. Trees were also subject to pollarding, and the harvested twigs, leaves, fruits, and nuts were a source of winter fodder for livestock. Large trees may also have been maintained for religious reasons. The presence of trees created a structure of semi-openness in the landscape and supplied substrate for numerous insects and fungi that exploited the tree trunks. Overall, the infield system created a niche space for a tremendous diversity of organisms, and it is this diversity—along with our appreciation of the cultural landscape—that has prompted modern conservation efforts. These efforts are also similar to human niche construction, although the mechanisms behind niche construction are different. Because the areas of seminatural grassland that remain today are small and remote and it is very difficult to maintain the management practices used historically, the "modern" version of the historical cultural landscape is subject to new dynamics, only to some extent reflecting the past.

Evolving Cultural Concepts

Spatiotemporal stabilization not only had an important influence on the natural environment, but resulted in fascinating cultural developments as well. Since people invested such a great deal of time and effort in creating functional hay meadows (especially wooded meadows), enclosure systems, and additional buildings, it makes sense that they would be more inclined to view this land as their private property. However, though history shows that various status objects, and most likely livestock and slaves, had long been owned and controlled by high-status persons—most evident, perhaps, during the peak of the Bronze Age (ca. 1500–500 BCE)—it's uncertain if people in Scandinavia had considered the concept of land ownership prior to the implementation of the infield system.

A few remarks in the classical literature, such as Caesar's *De bello Gallico* (written 58–52 BCE) and Tacitus's *Germania* (written 98 CE) indicate that "Germanic people" did not typically own land privately. In the Old Norse literature (written 800–1200 AD), including the Icelandic Sagas, there is much reference to land ownership and to a family's right to their property, often based on alleged succession lines of their ancestors. Scholars believe that this literature reflects cultural perceptions that are several centuries older, suggesting that people at the time recognized private land ownership and considered it important to prove that they and their families had an inherited right to their land. Land ownership also laid the foundation for a much more structured society, ultimately developing towards the chiefdom society suggested by finds such as the Swedish Vendel graves (similar to the more famous Sutton Hoo grave, now on display at the British Museum in London).

Tools are a further cultural feature of the infield system: metal tools such as leaf knives, iron sickles and scythes, and hay rakes appear around the same time as the infield system became established. The presence of shears also suggests that clothing was in-

Figure 1:
A present-day view of remnants of the infield system. The photo shows a former cattle path leading out from a farm through the infields to the outlying land in Yttra Berg, Halland province, Sweden (courtesy of the author).

creasingly made from wool from domesticated sheep, replacing earlier material from cattle and wild animals. Over time, as the management systems improved, the size and form of these tools changed, for example the length of blades on scythes. Today, we can still see evidence of the temporal sequence of meadow management (which likely developed quite early): some areas continue to use old-fashioned methods to make and harvest hay, such as spring raking (the removal of dead leaves and grass), after-harvest grazing by livestock (which also ensures nutrients are cycled back into the meadow), and pollarding.

The Challenge of Complex Interactions

We have thus far concentrated on the interaction between "culture" (tools, management systems, perceptions, and social inequality) and "nature" (vegetation types, structure of the landscape, and biodiversity) as a dual causal relationship, where cultural phenomena *lead* to natural phenomena and vice versa. Some might consider this to be an oversimplification. Take ownership as an example, which involves several interrelated factors: (i) physical objects such as houses, enclosures, and tools; (ii) living creatures such as livestock, trees, grasses and forbs, and wild game for hunting; (iii) management procedures such as hay cutting, pollarding, crop rotation, herding livestock, and food and clothing production; and (iv) cultural perceptions such as "family," "home," and "religion." If we try to connect all these factors, we soon realize that we are dealing with a complexity that is far beyond a simple reciprocal causal interaction. Furthermore, while infields were certainly part of the evolution of the concept of ownership, such a perception was of course influenced by many other factors. People in Scandinavia have long been part of a much wider geographical context, and it is now quite clear that Bronze Age societies were involved in complex networks of interactions across much of Europe. Although interactions were far more localized from 500 BCE onwards due to the local production of iron, people in Scandinavia were still traveling and trading across Europe, making the influence of the Roman Empire inevitable.

So, how to account for these convolutions? While it may not be able to explain every one of the aforementioned interactions, human niche construction nevertheless remains an extremely valuable tool to understand them, shedding light on how the human construction and management of infields maintained a spatial continuity that significantly altered, and continues to influence, how humans and other organisms have developed.

The infield system—a complex of interactions that existed and developed over 1,500 years—may have changed over time, but the essential element of a spatiotemporal stabilization was preserved. This stabilization impacted developing phenomena related to both cultural and ecological systems, affecting people's way of living as well as patterns and processes in "wild" nature. Using the theory of human niche construction provides a means to cross scientific boundaries and is an important step in untangling the multiplex interactions that govern our world. It will be fascinating to see how this history continues to unfold.

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Mariagrazia Portera

Why Do Human Perceptions of Beauty Change? The Construction of the Aesthetic Niche

Why do humans, in almost every culture in the world, invest so much time in search of beauty and so many resources in the beautification of their bodies, natural objects, and surroundings? What is beauty, and does a universal standard of beauty exist?

Over the last two decades, these questions have been the subject of renewed interest and attention from scholars in both philosophical aesthetics and empirical sciences. There is research which claims that when people are asked what constitutes a beautiful landscape, they almost always focus on the same few biologically salient elements—water courses, scattered trees, and wide horizons, for example (Orians 1992). However, recent neuroimaging studies show that even very different perspectives on beauty trigger the same networks in the brain, suggesting that an unequivocal, universal characterization of beauty is difficult (Vedder et al. 2015). At first glance, aesthetics and empirical science couldn't seem to be farther from each other, yet both approaches shed light on what constitutes beauty, and the human experience of it.

In this paper I argue that a *biological* theory—namely, niche construction theory—may better help us to understand how aesthetic standards flourish and evolve within human societies and cultures. In so doing, I hope to move beyond the opposition between natural and cultural definitions of beauty and provide a set of useful conceptual tools to address universality and relativity, and the objectivity and subjectivity of the human aesthetic experience.

Cultural Niche Construction

Beauty is a multifaceted concept, a *unitas multiplex*. Despite its many elements, our species tends to agree on the attractiveness of certain basic features, which is largely a result of evolutionary constraints on our cognitive or perceptual systems. This is likely why, according to neuropsychological studies, we are predisposed to symmetric forms and contours and why we are innately attracted to other humans' faces—because by focusing on symmetrical features, we can more easily make sense of what we see, hear, or experience. Babies in particular tend to find human faces more attractive than other types of visual stimuli since it may improve their chances of survival; they are still vulnerable at this stage and require parental care and protection. Within these basic cognitive and biological constraints on beauty and attractiveness, however, I argue that a significant part of what we experience as beautiful is the result of a reciprocal, constructive relationship between us and our physical, biological, and cultural environments: an *aesthetic niche* construction process.

Niche construction is the process by which organisms simultaneously shape and are shaped by their ecological environments, at various levels. Beavers with their dams, earthworms with their burrows, and bowerbirds with their nests—all are examples of niche-constructing animals. Niche construction processes include the interaction of three basic factors: environmental modifications as a result of an organism's actions; a subsequent alteration of the (evolutionary) pressures acting on the niche-constructing organism; and the transmission of these modifications over generations in the form of *ecological inheritance*.

Although the first formalized articulation of niche construction theory dates back to no more than a couple of decades ago (see Odling-Smee et al. 2003), Charles Darwin had already begun to explore its core concept at the end of the nineteenth century. What's more, Darwin seemed to be aware of an intriguing relationship between what would later come to be known as niche construction theory and the aesthetic domain. In the last paragraph of his book *The Formation of Vegetable Mould, through the Action of Worms* (1881), while describing the ways in which earthworms construct their own niche, Darwin writes: "When we behold a wide, turf-covered expanse, we should remember that its *smoothness*, on which so much of its *beauty* depends, is mainly due to all the inequalities having been slowly levelled by worms. It is a marvellous reflection that the whole of the superficial mould over any such expanse has passed, and will again pass, every few years through the bodies of worms" (my emphasis). A thought-provoking link is drawn here between a niche-constructing species—earthworms—and the beauty of the English fields. Earthworms construct their niche through castings and excretions, actively shaping the English landscape, leveling its rough irregularities and slowly transforming them into smooth surfaces. In doing so, they contribute to the construction of what Darwin, as a nineteenth-century

English gentleman, finds beautiful (smooth) in the English countryside. Is this a natural beauty, or not? And what does “natural” mean (as opposed to “cultural”), in the context of a niche construction process?

Compared to processes such as Richard Dawkins’s extended phenotype, niche construction theory places additional emphasis on the role played by acquired characteristics in transforming selective environments. This is particularly relevant to human evolution given that we humans—the most spectacular niche-constructing species—have been constantly altering our selective environments through (acquired) cultural practices since our emergence as a species. In a cultural niche construction process, one or more culturally acquired traits (such as the introduction of a new farming method, or the development and spread of a new set of religious norms) can affect the evolution of other biological or cultural traits by altering the environment in which they evolve, with a feedback action from “culture” to “nature” and vice versa.

The Evolution of Aesthetic Inheritance

Aesthetics and the arts have contributed impressively to the transformation of our physical, cultural, and social environments. Humans cannot help beautifying and ornamenting their bodies, tools, houses, and surroundings (Dissanayake 1992). We live in a highly “aestheticized” world, with an ecological inheritance that today includes architectural works and monuments in our cities, designer objects in our homes, art museums, fashion trends, artistic and aesthetic practices and performances in everyday life, and tools and resources that facilitate (intentionally or unintentionally) the learning and transmission of aesthetic and artistic traditions across generations.

Furthermore, our aesthetic experiences and our appreciation of the arts have coevolved with the active “aestheticization” of our environment. For instance, the spread of linear perspective in western European painting has coevolved with our ability to appreciate it since at least the sixteenth century. Linear perspective (itself a “cultural” trait) became largely accepted as the most “natural” (and therefore beautiful) way to represent three-dimensional objects on a two-dimensional surface. Similarly, western European culture now considers mountain and winter landscapes to be “aesthetically significant,” whereas these might have been judged differently only three or four centuries ago.

Figure 1: Neanderthals from the site of Krapina, Croatia, may have manipulated eagle talons to make jewelry 130,000 years ago, before the appearance of modern humans in Europe. Photo by Luka Mjeda, Zagreb (CC BY-SA 3.0)

Over the course of evolutionary time, our aestheticized environment has been exerting a sort of feedback action on us, with the emergence—among other effects—of new selective pressures. Indeed, it has been documented (mostly on the basis of paleoanthropological evidence from contemporary hunter-gatherer societies) that soon after they developed and spread in human populations, works of art, aesthetic practices, and rituals began to be used as sociocultural tools for individual recognition—strengthening collective identity and ostracizing strangers. To share a particular aesthetic heritage became a sign of commitment and belonging to the community, and a means of distinguishing (or "selecting") one's own community from other groups, particularly as human populations became larger and more extended (fig. 1). One of the reasons for the proliferation of so many different standards of beauty and aesthetic norms, documented by anthropological and ethnographic research, may lie in this dual desire for cohesion, on the one hand, and for distinction, on the other hand. According to some scholars, the emergence of an aesthetic sense and the spread of artistic practices among human populations may have played a role in driving the evolution of the human brain in general, and of the human faculty of language in particular (Dissanayake 1992).

Moreover, as the British anthropologist Alfred Gell (1998) has suggested, drawing on research into contemporary populations in Papua New Guinea, the beautiful objects that humans create and assemble, and with which they surround themselves, seem to exert a powerful influence (or "pressure") on the members of the population. It is as if these things were living persons and not just passive objects: "works of art, images, icons, and the like have to be treated [. . .] as person-like: that is, sources of, and targets for, *agency*" (Gell 1998, my emphasis). As objects, artworks are able to captivate and enchant their audiences, influencing their thoughts and actions, fascinating and persuading them, behaving as actors in the social system. This is no less true for us in our

Figure 2:
Canoe prow from Papua New Guinea, probably the Trobriand Islands.

modern societies than it was for the indigenous population of Papua New Guinea described by Gell. Just as the beautiful, richly decorated prows of the Trobriand Islands canoes fascinated and even dazzled their Polynesian spectators, winning them over in commercial transactions (one of Gell's most famous examples, see fig. 2), it is not uncommon for us today to be similarly captivated by a work of art, allowing it to influence our thoughts and feelings. The piercing gaze of one of Rembrandt's self-portraits, the elaborate architecture in an El Greco painting—these act on us as if they were living persons, not canvases. They affect our thoughts, decisions, intellectual and material resources, and power.

Within the aesthetic/artistic niche, family structure, social group, and cultural and geographical circumstances seem to determine and influence the development of individual aesthetic tastes and preferences, at least to a certain extent. Even before they come into the world, human babies are exposed to the standards of the sociocultural niche they are embedded in, and they are actively influenced by their parents' choices and preferences. They receive an *aesthetic inheritance* from their parents and forebears, which shapes—though not in a deterministic way—their future aesthetic approach to the world. What's more, because these acquired aesthetic practices, traditions, and values are handed down from generation to generation, they often appear to be "natural." In other words, the cultural memory of the creation and development of aesthetic standards, behaviors, and rules is frequently lost or weakened, or (perhaps epigenetically) assimilated (see Portera and Mandrioli 2015).

Conclusion

For the past few decades, it has frequently been suggested that evolutionary theory cannot easily be integrated into the human sciences: First, because human scientists are more interested in human behavior and cultural processes than they are in genes (indeed, the modern evolutionary synthesis has long focused primarily, and almost exclusively, on genetics); and second, because philosophers and human scientists consider the adaptationist accounts of many evolutionary psychologists too reductionist to be seriously taken into account (see Laland and Brown 2006; Davies 2012). Niche construction theory seems to provide a viable alternative to this incompatibility. It places an emphasis not only on genes, but also on (cultural) niche-constructing behaviors and their feedback action on biological evolution. It further provides an effective framework for conceptualizing the mutual relationship between *organisms* and their *environments*, thus undercutting the old dichotomy between nature and nurture, biology and culture (Fox Keller 2010). In recent years, cognitive scientists have convincingly demonstrated that human cognition and experience develop in strict interaction with the environment in which humans live: Our mind is *embodied* and *embedded*—it extends into our bodies, environments, and niches, actively shaped by them and shaping them in turn. This is especially true of aesthetics, whose norms, traditions, and standards of beauty depend on the ecological circumstances in which humans live and act.

As biologist Kevin Laland writes, social and human scientists, philosophers, and aesthetologists “do not need to be told” by ecologists and evolutionary biologists that “humans build their world,” which for the most part includes their aesthetic standards and norms. However, human and social scientists may “feel more comfortable with a conceptualization of evolution that [. . .] has an emphasis that aligns with their own thinking” (Laland and O’Brien 2012). I couldn’t agree more.

So, why do we, as humans, not have just one standard of beauty? Aesthetic and artistic behaviors, preferences, and habits are neither completely *given* at birth nor encoded in our genome; rather, they are the hybrid result of a mutual interaction between humans and their multifaceted world.

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Laura Jane Martin

How Does Architecture Affect the Evolution of Other Species?

As much as other species, humans modify the environment, affecting both the evolution of their own species and the evolution of others. Take a species that we happen to know quite a lot about: the German cockroach (*Blattella germanica*). One of 51 species of the genus *Blattella*, the German cockroach has become so specialized in the human-built environment that it is not known to occur anywhere else (Roth 1995). Recent studies have demonstrated that some populations of German cockroach have evolved an adaptive behavioral aversion to glucose in the poison baits set by apartment residents. In this essay, I explore how the spaces closest to us, our own buildings, affect the evolution of other species. I also discuss how the small spaces of human houses allow us to approach larger questions about the Anthropocene and how humans affect Earth itself. After all, no species exists in a vacuum (even the cockroaches we may vacuum up).

In "Evolution of the Indoor Biome" (Martin et al. 2015), my coauthors and I estimated that the human-constructed indoor biome—a formation of plants and animals that have common characteristics—occupies somewhere between 1.3 percent and 6 percent of global ice-free land area, an area as extensive as other small biomes such as flooded grasslands and tropical coniferous forests. Together with the German cockroach, thousands of species—perhaps hundreds of thousands—live in this large indoor biome, many of them preferentially or even obligately. In just one study of 40 houses in North Carolina, USA, researchers documented more than 8,000 bacterial and archaeal taxa (simple, single-celled organisms) (Dunn et al. 2013). And yet, we have studied only a small fraction of those species found indoors, mainly those we consider pests. Just as in rainforests, most taxa (microbes) of the indoor biome have yet to be discovered.

In preparing for this paper, I found myself thinking about how the niche construction framework maps onto recent efforts of environmental historians and anthropologists to study the role of nonhuman species or materials in history-making. One particularly influential framework for doing this has been "actor-network theory" (Latour 2005), which insists that human and nonhuman agency are to be treated on an equal footing. Many people object to the way actor-network theory employs agent similarity on the

Figure 1: Our homes, like this one in New Orleans, often provide pests with the perfect environment in which to flourish (courtesy of the author).

grounds that human actions are propelled by intentions, whereas those of machine tools or microbes are not. To address this concern, Andrew Pickering (1993) suggests that we turn our attention to the moments when human agency confronts the "contours of nonhuman agency." He conceptualizes this process as a dialectic of resistance and accommodation, "the struggle between the human and material realms in which each is interactively restructured with respect to the other."

The indoor biome challenges us to consider the roles of both humans and nonhumans in historical and evolutionary change and at the same time complicates the question of intention. Humans do intentionally build structures to differentiate indoor and outdoor environments, but they do not intend for species other than humans to inhabit them (with the exception of pets, some food animals, and sometimes plants). We do not build houses for the sake of cockroaches, or cellar spiders, or the molds that live on showerheads. And yet, these species occupy the places we build. They even evolve to live in them. In some cases, we notice these species and change our building practices; in others, we don't. Whether humans notice them or not, these species constitute our environment, too, and play their part in our own evolutionary trajectories. Physical and biological environments do much more than simply resist our intentions—as human niche construction suggests, these environments might even shape them—and yet, many environmental historians describe nonhuman actors, or nature, as simply "resisting" or "pushing back on" human activities. Similarly, science and technology studies (STS) scholars often focus on the resistance of the material world to human agency. What would it mean to write a history in which the environment is a collaborator rather than an obstacle?

The indoor biome challenges us to think beyond the limited metaphor of resistance. There is a poverty to the view that nature acts only by helping or hindering human action—resistance and accommodation are only the extremes of a spectrum. Nature does act, despite its lack of a human voice or political incorporation. The natural world and human culture exist in a relationship that exceeds a structure/agent relationship, as nature and culture are intertwined and are continuously constructed. The indoor biome is a human creation whose novel environment influences the ecology and the evolution of humans, but also hosts many other (overlooked) species that create their own novel environments. By combining actor-network theory's interest in carefully identifying how actor networks are continuously reshaped—which things interact with one another—and human niche construction theory's careful attention to describing evolutionary processes—i.e., which things influence each other's development—we can begin to decipher the puzzle that is history.

If ecology is the study of the relationships between organisms and environments, and evolutionary biology is the study of how organisms change over time, then how do we understand the relationship *among* organisms, environments, and evolution? Richard Lewontin's *The Triple Helix* (2000) is a particularly useful tool for thinking about this relationship, whether in the indoor biome or elsewhere. With this book, Lewontin unearthed a set of questions that had fallen between the cracks of disciplinary walls. The triple helix is Lewontin's symbolic rejection of the division between ecology and evolutionary biology. With this rejection, he complicates the linear narrative that genes determine organisms, which then adapt to their environments. The triple helix metaphor suggests that organism, environment, and evolution are three intertwined elements that must be studied together: geneticists may pull apart DNA's *double* helix to read

Figure 2: Creating indoor environments that reflect the outdoors—cacti viewed from inside a house in the Sonoran desert, Arizona (courtesy of the author).

its code, but we can only understand DNA's function by considering it whole, in action at multiple scales. Lewontin contends that organisms, influenced in their development by their surroundings, in turn change and even create the environments they live in.

Niche construction theory similarly explores these feedback actions and draws attention to historical processes. Through the metaphor of construction, organisms, including humans, shape their environments and, in part, their evolutionary trajectories. Niche construction theory is especially compelling because it specifically challenges the distinction between evolutionary causes and evolutionary effects. A human creates shelter by building a home, and that environment in turn exerts selective pressure on the human, say, by protecting it from extreme cold—but hurricanes still come through. This illustrates that while organisms create opportunities, such as shelter, in their worlds—or at least, some of them—they also have to adapt to selective pressures in the process, some of which are a result of their own actions and others which are beyond their control. What links the triple helix and niche construction is their common attempt to describe relationships that traditional academic boundaries have rendered invisible.

These relationships are the key to understanding both how architecture affects the evolution of other species and how, on a larger scale, human actions affect the earth itself. Unlike Lewontin's triple helix or niche construction theory, much scholarship on the recent concept of the Anthropocene still emphasizes its effects and overlooks the processes involved (but see Ellis 2015). Proponents of the term "Anthropocene" argue that we live in a geological age of our own making, an epoch that began at the moment when human activities started to have a significant global impact. They believe that the signature of human activity in sediments and ice cores justifies the distinction of an Anthropocene from the preceding geological epoch, the Holocene. Their overarching question is whether aluminum, concrete, and plastic "technofossils," or the detonation of thermonuclear weapons, will define our times. It is a question of the physical record of history, and not how that record was laid down. Consequently, those who seek to define the "age of humans" elide fundamental questions of human agency, equity, and responsibility. Not all humans equally participated in the development and detonation of thermonuclear weapons; the average human does not emit five metric tons of carbon per person per year—the average US American does. And even the average American is a statistical artifact, a technofossil, if you will, given that the distribution of resources in the United States is spectacularly skewed. In flattening the impact of humans, the Anthropocene provides absolution to some. But it fails to point to political solutions as it views history as a determined past and not a dynamic process. This is where niche construction theory, actor-network theory, and other process-oriented methods have much to offer Anthropocene studies.

Studying the influence of the human-built environment on the evolution of other species opens up new questions for biologists, anthropologists, architects, and environmental historians. Perhaps buildings—and the interactions they reveal—allow us a new way of thinking about human niche construction and the Anthropocene. Rather than treating today's environments as though they were the inevitable outcomes of history, we should seek to understand the contingency of historical paths, the ways in which we seek to systematically exclude some humans (and, yes, most nonhumans) from history-making, and the diversity of other worlds that were and that continue to be possible.

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Sjoerd J. Kluiving and Arthur Hamel

How Can Archaeology Help Us Unravel the Anthropocene?

Both scholars and the public have long argued over *when* the Anthropocene began, and these discussions have almost exclusively focused on the impacts of human activity on the planet. As geoarchaeologists, we consider the far more interesting question to be *why* it began. What were the underlying causes of the changes that resulted in this new epoch, and how can we trace them? The answer lies in humans' relationship with the environment—by looking at changes in human behavior over time we find a compelling explanation for how and why the Anthropocene emerged. Prior debates have highlighted a range of difficulties in pinpointing these causes. For example, it is nearly impossible to correlate the causes of planetary changes directly with their respective effects; even a complex systems approach alone is insufficient to account for them. Niche construction theory provides us with a new perspective on the causes and effects of the Anthropocene, allowing us to reconcile the Earth complex systems approach with human-induced changes in this system.

Although popular in ecological and biological sciences, in archaeology niche construction theory has been largely neglected. However, not only are humans' behavioral changes visible on a global scale, these changes have been recorded in archaeological data. From a geoarchaeological perspective, human niche construction is the ability of humans to adapt to their environment or to alter it to such an extent that anthropogenic cycles change, or even replace, natural cycles. Humans are considered the ultimate niche constructors (Odling-Smee et al. 2003), because their influence is currently far more intrusive and overwhelming than that of any other living creature on Earth.

We argue that it is possible to date the onset of the Anthropocene through an analysis of global changes in human niche construction using (geo)archaeological data, which sheds light on why the Anthropocene began. In particular, this essay addresses three issues that together offer a new perspective on the causes and effects of the Anthropocene: how the onset of the Anthropocene has been determined so far, especially in the geologic record; the importance of human activity in determining the causes of anthropogenic change; and finally, how these approaches combined offer an alternative explanation for the onset of the Anthropocene—one that corresponds to the concept of "runaway sociocultural niche construction," which requires an ongoing cycle of adaptation to human-induced changes (Ellis 2015).

Defining the Anthropocene

Coined in 1999 at a conference by Nobel Laureate Paul Crutzen, the proposed geological epoch of the Anthropocene marks the termination of the Holocene (Crutzen and Stoermer 2000) and recognizes the significant global impact of human activities on the Earth's ecosystems. But how are we able to identify the transition from one epoch to the next? What evidence do we use and what form does it take? To decide the lower boundary of an age— i.e., when it began—geologists use the GSSP (Global Stratotype Section and Point). A GSSP defines the baseline of the deposits from the stratigraphic period to which the GSSP is related. It stands to reason that for this evidence to be widely present in the geologic record, events must occur at a global scale. Geological processes may be characterized by exceptional large-scale changes, such as meteoritic impact, supervolcanism, continental shift, mass extinction, or by cyclic climate oscillations in the system. However, there are exceptions such as the Holocene, whose lower boundary is defined (in an ice core) by a number of years rather than by geological evidence—in this case, 10,000 carbon years before present (BP). Following this logic, geological data alone are not sufficient to define the Anthropocene; we should also take into account human activity, which has affected the Earth substantially. While the geological timescale is based on observable changes in the Earth's crust, signs of human activity are recorded in different ways at different times and in different places.

The Industrial Revolution (1750–1800 CE) has been proposed as one possible onset of the Anthropocene, since increased concentrations of methane and carbon dioxide resulted in global atmospheric changes. Another suggestion is that the atomic explosions of 1945 were responsible for a record change in the amount of measurable radionuclides (Waters et al. 2016). Agriculture and global atmospheric changes from 8000–5000 BP led to the "early anthropogenic CH_4 hypothesis," where notable increases in methane (CH_4) were attributed to the spread of early agriculture, specifically rice cultivation in Asia around 8000 BP (Ruddiman et al. 2008). We can also trace changes in the Earth's surface from human activity: hunter-gatherers in the early Holocene impacted the terrain through harvesting and overhunting, which changed plant and animal populations; since then, much of the terrestrial planet has been modified by sedentary civilizations. They have altered the soil through plowing, fertilizers, contamination, soil sealing—a loss of soil resources due to housing and infrastructure construction—and even embellished the land with artifacts.

Given the validity of all of these theories, it is clear why it has been so difficult to isolate the causes of anthropogenic changes and the advent of the Anthropocene.

Complex Systems and the Inadequacy of the Nature/Culture Dichotomy

The Anthropocene is based on the premise that humans—just one species—have gained the capacity to transform the Earth system; it is therefore important to recognize human exceptionalism as a relatively novel global force. Moreover, because humans are both researcher and research subject, the Anthropocene discussion must take into consideration the values and possible biases of the researcher, rather than simply be limited to the Earth sciences. The concept of the Anthropocene has implications far beyond the spectrum of geological sciences into social, political, legal, psychological, philosophical, and cultural disciplines, as well as the arts. Given the inherent complexity of human psychology and human societies, we need to approach human interactions with the environment from a holistic perspective.

So far, the dialectic between nature and culture has persisted in climate change and Anthropocene debates. Nature constitutes natural processes, neither touched nor influenced by humans, acting on the Earth system; whereas Culture refers to the material cultural remnants of past and current societies, as well as the natural processes that have been modified and/or encouraged by human actions. However, the reduction of the Earth system to an opposition between humans and their environment has brought the discussion to an impasse. Terms like “nature,” “culture,” or “natural environment” are often too broad in meaning—for instance, the concept of ecosystems better reflects the systemic relations of the ensemble of life (including humans) and its physical environment than “natural environment” (Ellis 2015). So, it is interesting that, even though global Earth modeling works on the premise that Earth is a complex system, people continue to use this linear nature/culture approach. The complex systems approach addresses the issue in a more holistic way, integrating humans fully as an element of the Earth system.

Climate change is an example of a complex system: the gradual rise in carbon dioxide concentrations may have a limited impact on climate until it reaches a certain threshold, which triggers a brutal change in the Earth system. In this case, causes and consequences do not have a direct correlation, which makes it rather difficult to establish the trigger using a linear approach. Complex systems move between stable states and are driven by major feedback loops. They are also resilient to disturbance and do not necessarily react linearly to changes. This can further be seen in a gradually eroding valley, where the system is forced past a bifurcation point: when the lateral erosion of rivers removes the ridge that divides two separate stream valleys, the drainage system, and therefore landscape stability, suddenly changes. This makes predicting responses much harder given their abrupt nature. The effects of changes can therefore be *asynchronous*, *inverse*, and/or *disproportional* to the causes. The complex systems approach complements the nature/culture approach by showing how effects can be indirect and disproportional, even if they are caused by human activities. The concept of human niche construction is a useful way to account for the human role in environmental change while also focusing on the fact that these changes do not take place in a vacuum; rather they are embedded in networks of reciprocal interactions and involve adaptations of both species and ecosystems.

Human Niche Construction as Key to Defining the Anthropocene

At different rates and scales, humans have transformed their environment to make it safer and more comfortable. Just as beavers build dams to control water management and change river flow patterns in the process, humans build dams to generate hydroelectric power, to create transport routes, and to create safety for populations and impose groundwater and salt/sweet water flow regimes. We are also able to respond to new challenges by modifying our behavior, such as when we ban the manufacture of chlorofluorocarbons (CFCs) because they are responsible for the "hole" in the ozone layer, endangering the protection it offers against high doses of UV radiation. As a result, our species has relieved itself of a broad range of selective pressures, such as temperature, food production, and disease. Species affect evolutionary trajectories by acting on their selective environment and we can consider niche construction to be an evolutionary process (Laland and Brown 2006). Our species has the remarkable ability to adapt its niche construction behavior to achieve its goals in a broad spectrum of ecosystems (Odling-Smee et al. 2003).

Figure 1: Schwarzbach pond and peat bog (Kuchelscheid, Belgium). Photo by Jacopo Werther (CC BY-SA 2.0).

According to Smith and Zeder (2013) niche construction behavior can be traced as far back as the early hominids, but substantial change in human behavior occurred at the beginning of the Holocene (ca. 11,000–9000 BP). At this point in human history, at different locations across the globe, a major shift occurred in humans' adaptation of the surrounding ecosystem: the domestication of plants and animals. Just as we altered our environment to accommodate them, these domesticates substantially modified their ecosystem in turn—e.g., by introducing new arable species and exploiting an as yet untouched animal resource—and so we have been able to record this shift in subsistence and niche construction behavior within the framework of the social sciences. Niche construction can be divided into two categories: inceptive and counteractive (Kluiving et al. 2015). Inceptive niche construction refers to the initial modification of an environment, as might happen when a species migrates to a region for the first time or adopts new behaviors. Six thousand years ago in the western Netherlands people reacted to the threat of the rising sea level by raising the ground surface level with reed bushes, or moving to higher and drier places. Counteractive niche construction occurs as an adaptive response to an environment that has already been altered. The effects of deforestation on river sedimentation processes and early water management measures can be considered counteractive changes. It is this second model that is particularly relevant as a way of thinking about the Anthropocene.

We propose that the Anthropocene emerges as a "tipping point from inceptive to counteractive changes," which corresponds to the concept of "runaway sociocultural niche construction," as outlined by Ellis (2015). This particular transition emerges when continued human impact on ecosystems results in sustained changes to our environment, locking us into an ongoing cycle of adaptation. Although niche construction processes can also be seen in hunter-gatherer societies, for example in niche broadening—diversifying the type of animal hunted based on species extinction rates—it is the capacity to sustain this process, not just one phase or the other, that enables societies to gain the capacity to act on the Earth system at global scales and thus "cause" the Anthropocene.

Studies in this area similarly tend to focus on the causes of system changes rather than the effects. In the western Netherlands, for example, the sustained industrial extraction of peat has led to an unprecedented drop in the ground surface of approximately 10 meters across the entire coastal zone—an irreversible human-induced counteractive change that has caused significant flooding of the inhabited landscape. The Celtic cultivation of agricultural fields in the southeastern Netherlands led to soil degeneration in loam-deprived soils, which resulted in (sustained) mass migrations around 3000 BP. A comparison of these and several geoarchaeological case studies from northwestern Europe to the eastern Mediterranean reveals that the tipping point from inceptive to counteractive changes appears to parallel the onset of domestication (in Kluiving 2015; cf. Widgren 2012), although more research is needed to test this hypothesis.

Therefore, though the Holocene and Anthropocene are coeval, their causes differ: the focus "shifts … away from gaseous emissions of smoke stacks and livestock, spikes in pollen diagrams, or new soil horizons of epochal proportions to a closer consideration of regional-scale documentation of the long and complex history of human interaction with the environment that stretches back to the origin of our species up to the present day" (Smith and Zeder 2013).

In the years since the Industrial Revolution, humanity has not only exploited the environment and domesticated our landscapes—we have assumed *responsibility* for it. Some call this new environmental awareness the "green revolution," promising a sweeping change in human society and culture comparable to the Neolithic Revolution or the Industrial Revolution. This revolution, too, will likely have some kind of global impact on the Earth system in the future—at least, that is its goal—and might even be recorded as another geological subdivision (perhaps a sub-phase within the Anthropocene). Establishing *why* the Anthropocene began rather than *when* it began reinforces the search for proof that humankind is indeed responsible for global anthropogenic change. We believe that through transdisciplinary research involving the nature/culture dialectic and geoarchaeology, this shift in responsibility will eventually result in a corresponding duty of care towards nature and sustainable solutions for our planet.

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Erle C. Ellis

Why Is Human Niche Construction Transforming Planet Earth?

Rapid global changes in climate, the pollution of air, land, and sea, widespread species invasions and extinctions, and other massive environmental impacts are among the evidence that human societies are reshaping planet Earth. These changes are so transformative that many scientists are convinced humans have become a novel global force that has pushed Earth into a new period of geologic time: the Anthropocene. The question of when humans first became such a "great force of nature" is now widely debated. Yet the most important question is not when, but *why*. Why did humans and no other single species in Earth history gain the capacity to transform an entire planet? The key to answering this question lies in the unprecedented capacity of human societies to construct their ecological niche at increasing social and spatial scales, from the novel local ecological changes caused by mobile hunter-gatherers through hunting and the use of fire, to the global supply chains of the industrial world today.

Homo sapiens is not so distinctive biologically. We are just another species in the genus *Homo* with a few distinctive traits—and these do not even include stone tools or fire; other species of *Homo* wielded those hundreds of thousands of years before *H. sapiens* emerged among them in Africa. In my efforts to understand why behaviorally modern humans gained the extraordinary capacity to transform Earth, I discovered that it is necessary to go beyond biology—and even chemistry and physics—to examine and understand the many varied cultural forms and dynamic social changes in the human ecological niche over the past 50,000 years. To understand the emergence of humanity as a global force transforming Earth, we must view the human niche as a diverse and evolving sociocultural construct.

Like most ecologists whose work involves humans, I have tended to study the consequences of human activities rather than the causes. I've mapped the global ecological patterns produced by the different ways that humans use land—the anthropogenic biomes, or "anthromes"—which includes urban areas, villages, croplands, rangelands, and seminatural lands. In this research, I have depended primarily on empirical methods—direct analyses of data from remote sensing and agricultural and population censuses, among others. Yet the classic "natural" biome patterns of the Earth have long been mapped based on their theoretical relationships with the global patterns of climate; for example, tropical woodlands form in warm and moist regions, while tundra forms in cold and dry regions. In this way, the global patterns of biomes can be predicted and mapped by biogeographers based on global climate patterns. When I first began my work mapping anthromes, I wanted a similar theoretical model capable of predicting such patterns; yet I found no simple theoretical analog of a "human climate system" that was shaping the terrestrial biosphere into anthromes. Moreover, it soon became clear that to develop such a model would be no small task. And so I hesitated.

In the fall of 2012, after I gave a talk on "Ecology in the Anthropocene," the editor of *Ecological Monographs* asked me: "How would ecological concepts and ideas have to change if we (re)focused our attention on anthromes, not biomes, as an underlying biogeographic organizing schema?" With this question and the offer of a paper of unlimited length, I decided it was time for me to focus on the ultimate causes of human transformation of the biosphere. It took more than a year of broad and intensive reading—from textbooks to journal articles—before I began to feel that I was gaining a general theoretical grasp of human sociality, social processes, and social change. It was also clear that my act of crossing disciplinary lines was pushing me far beyond my comfort zone, and I encountered multiple theoretical dead-ends. From the point of view of some disciplines, my questions were just asking for trouble. What is it about humans that distinguishes us from other species? Why do behaviorally modern humans—and their various societies—transform ecology so much more than any other species, and in so many different ways? The very act of bringing together social, ecological, and evolutionary explanations still seems seditious, as each discipline tends to demand a different way of understanding why and how humanity and ecology interact. Both cultural determinism and environmental determinism still have their adherents. In the end, it became clear that a new theoretical synthesis of social and ecological change would be necessary to explain the diverse and unprecedented ecological transformations human societies have produced.

Here, I present the product of my theoretical investigations: sociocultural niche construction. This new evolutionary theory explains *why* the ecological niche of behaviorally modern humans reshaped Earth, and why the human ecological niche continues to be both diverse and dynamic as the result of ongoing processes of sociocultural evolution. Not only does this theory have profound implications for ecological science and conservation, it also challenges the classic environmentalist narrative that humans are environmental destroyers. Sociocultural niche construction requires a shift to a broader and deeper view of human societies as the shapers and stewards of the ecology of an increasingly used planet—a view that embraces Earth's ecological transformation over thousands of years through the actions of our ancestors.

When ecologists talk about the niche of a species, we are usually referring to its environmental requirements and tolerances, and the ways in which it is able to use resources. Rainforest species require moist environments, for example, and some species thrive based on their ability to harvest insects by poking a hole in the bark of a tree. Considered from a conventional evolutionary point of view, the niche of a species is the product of inherited genetic adaptations to environmental pressures over which the species has no control, such as the adaptations needed to thrive in a specific climate. Through processes of natural selection, species become adapted for life within their ecological niche, and when species are within their niche, their adaptive fitness is at its highest.

Recently, this "one-way" understanding of the ecological niche has been challenged by the observation that many species are not only adapted to environmental constraints beyond their control, but also actively engage in altering their environments profoundly—by building dams (beavers) and nests (some birds and insects, among other taxa), for example, or by releasing toxic chemicals that inhibit the growth of competitors (plants, microbes). Clearly, the relationship between organisms and their environments can also be a two-way street. These environment-altering species are known as "ecosystem engineers" by ecologists. When ecosystem engineers alter environments to such a degree that it affects their ability to thrive and to reproduce (their adaptive fitness)—or that of other species sharing their environments—this alteration is considered an evolutionary process in itself. The result: the production of an "ecological inheritance," and the basis for the new evolutionary theory of niche construction.

Niche construction theory is fundamental to explaining both why humans gained the capacity to transform Earth's ecology, and why different human societies have changed ecology in such varied ways over the long term. By combining niche construction theory with a theoretical understanding of humans' exceptional social and cultural capacities and their evolution, we have the basis for the theory of sociocultural niche construction.

Figure 1: Manuring and preparing soils for wheat planting, Xueyan, Jiangsu, China (courtesy of the author).

While many species are social (consider honeybees, for example), the extraordinary sociality of behaviorally modern humans marks us as Earth's first "ultrasocial" species. Humans have unrivaled capacities for learning from others and for transmitting this social learning—as cultural inheritances—both within and across generations. This makes it possible for human cultural inheritances to accumulate and evolve over time. Moreover, the very nature of human social life is itself structured largely by social learning, often requiring socially learned relationships with non-kin individuals for survival. This dependence on social learning means that the behaviors of human individuals, groups, and entire societies are incredibly variable—with different strategies for ecosystem engineering and exchange of food and other resources, different forms of social organization, and even different modes of social learning and cultural transmission, from languages, arts, and religion to other symbolic behaviors. The core behaviors needed to survive and to reproduce within behaviorally modern human societies are not determined by human biology—they must be learned.

In behaviorally modern human societies, direct interactions with the environment to procure food and other necessities—by foraging, farming, or even shopping at the supermarket—may be optional. Sustenance and other necessities can be gained through complex social relationships among unrelated individuals and even strangers, by sharing, bartering, or even ordering online using a credit card. The human ecological niche—how humans live in, utilize, and transform environments to survive and reproduce—is thus largely sociocultural, constructed and enacted within, across, and by individuals, social groups, and societies based on socially learned behaviors. Long-term changes in the construction of the human niche—the structure and functioning of human societies and their transformation and use of environments—are the product of evolution by natural selection acting on the individual and social modes of sociocultural niche construction. As with "human nature," the "human niche" is not determined by human biology but by sociocultural traits and their evolution at the individual, group, and societal levels. It might even be said that there is no "human niche"—that there are only sociocultural niches, and these are defined by the cultural traits of the society within which specific individuals have learned to live.

Cultural traits can evolve far more rapidly than biologically determined traits—one reason why human societies have evolved so many diverse and complex cultural forms, and why these have changed so much in the more than 50,000 years since humans first spread across the Earth out of Africa. Major bursts of sustained evolutionary change in the human niche, known as sociocultural regime shifts, have also been driven by processes of runaway sociocultural niche construction, as can be seen in the rise of agriculture. Cultivating soils can lead to a loss of nutrients; sustaining their productivity thus requires cultural adaptations such as the harvesting and use of manures to maintain soil fertility. This is a good example of how a specific suite of cultural and ecological inheritances, like cultivation, can lead to social and environmental changes so great that we must adapt to them by adopting ever more transformative cultural and ecological inheritances. These runaway processes of evolutionary change tend to lock societies into long-term cycles of adaptation in their sociocultural niche, as they work harder to sustain ever more demanding societies.

Hunter-gatherer (or small-scale) societies, some of which remain successful today despite the pressures of larger-scale agricultural and industrial societies, rely on remarkably complex sociocultural toolkits: these include social hunting, projectiles, resource sharing, niche broadening—expanding the range of utilized species when preferred species are driven to extinction—and even the propagation of favored species—the first stages of domestication. Agricultural societies built on these complex strategies by developing even more novel and transformative subsistence regimes, from domestication, tillage, and irrigation to manuring, taxation, and the marketplace. Social roles became more diverse and specialized in response to larger social groupings dependent on complex and unequal social organization. Societies also adopted more powerful and complex tools and technologies to increase productivity, resulting in greater alterations to the environment. While the use of fire for cooking and clearing land represents the first substitution of nonhuman biomass energy for human biological energy—used in engineering ecosystems and to digest food—farmers learned to supplement the energy of human labor with domestic livestock, wind, and hydropower. Industrial societies scaled up further with populations growing rapidly, sustained by expanding trade in food and other resources across Earth. These societies increased their use of fossilized biomass (coal, oil, natural gas) and non-biomass forms of energy—such as nuclear and solar power—to supplement and ultimately eliminate human energy in engineering ecosystems, the social allocation of food and resources, and even in communicating with one another.

Figure 2: Water buffalo plowing in preparation for rice transplanting, Dianbai, Guangdong, China (courtesy of the author).

While evolutionary processes are never simply linear or progressive, there are some remarkable general trends in human social change over the past 50,000 years. The potential scale of individual human societies has increased from a few dozen individuals to a few hundred million. The potential productivity of a single square kilometer of land to sustain human populations has been amplified through cooperative ecosystem engineering from sustaining less than 10 individuals to sustaining thousands. Energy use per human individual has also grown by a factor of more than 20 times through the use of non-biomass energy, now mostly from fossil fuels, while the flow of materials, energy, biota, and information across human societies has become essentially global and continuous. Quality of life has also generally improved: human individuals now live nearly twice as long on average as they did in the Paleolithic era. No doubt these long-term trends in human sociocultural niche construction have emerged in response to many different pressures—and even through random variations. But natural selection acting on human cultural and ecological inheritances has had the greatest impact on shaping how humans interact socially and ecologically, and is the ultimate cause of the unprecedented global changes human sociocultural niche construction has produced.

In recognizing the Anthropocene as a new epoch of geologic time, we are confronted with the reality that human societies are now a global force that is actively and continuously reshaping Earth. The dynamics of the human sociocultural niche—including its social organization, cooperative ecosystem engineering, exchange relationships, and energy systems—are now tightly coupled with long-term changes in the Earth that are altering the ecology of our planet profoundly and permanently. While it is possible that for most people times have never been better, the opposite is true for most other species—and there are strong indications that anthropogenic global changes in climate and biodiversity have the potential to derail the future of human societal development.

It should never be forgotten that, like biological evolution, sociocultural evolution is a process, not a destiny. Even the most successful large-scale societies of today could go the way of the dinosaurs. Indeed, with current trends, such an outcome seems increasingly plausible. Yet, we would also do well to remember that contemporary societies have managed to reduce and even eliminate pollutants; have protected and restored endangered species and their habitats; and that there is still considerable opportunity to implement the massive shift in energy systems needed to prevent catastrophic global climate change.

Societies are advancing in their ability to understand not just the consequences but the ultimate causes of human transformation of Earth. This knowledge has the potential to guide the development and implementation of more successful social strategies that might sustain both humans and nonhumans together more desirably on Earth. Humans have always been so much more than “destroyers of nature.” In an increasingly anthropogenic biosphere it is essential to shift the paradigm. Humanity long ago emerged as a global sociocultural force capable of altering Earth for better and for worse. We humans and all other species must now live together on a used planet reshaped by generations of our ancestors. It is time to go beyond the idea that we might somehow return to a "balance of nature" that would bring human societies back into a safe harbor in the "natural" world. It is time to embrace the sociocultural realities, strategies, and "cultures of nature" that might enable human societies to become better stewards of both humans and the rest of Earth's species in the Anthropocene.

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Sjoerd J. Kluiving currently holds the position of assistant professor at Vrije Universiteit Amsterdam and is an associate professor at Stirling University in Scotland, working in the fields of geoarchaeology, Quaternary geology, and landscape archaeology. As a geologist and physical geographer, he is involved in applying earth sciences to archaeology in interdisciplinary research and teaching, with an emphasis on the Anthropocene. Kluiving leads the International Association of Landscape Archaeology (IALA), uniting European geologists, archaeologists, and historians and he is a board member of the Environmental Humanities Center in Amsterdam. He has vast experience in convening interdisciplinary sessions in soils, landscapes, and archaeology at EGU, EAA, and LAC and is guest editor of multiple special volumes dedicated to these themes.

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Edmund Russell is a professor of history at Boston University. He researches environmental history, history of technology, and American history. His books include *Evolutionary History: Uniting History and Biology to Understand Life on Earth* (Cambridge, 2011) and *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring* (Cambridge, 2001). His research has won prizes in environmental history, history of technology, and history of science.