Chapter 17
Niche Construction Theory and Human Biocultural Evolution

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Introduction

Niche construction can be minimally defined as the process whereby organisms modify—deliberately or inadvertently—their own and other organisms' selective environment to such a degree that it changes the selection pressures acting on present and future generations of said organism or organisms. The genealogy of niche construction theory (NCT) is conventionally traced back to the arguments of Richard Lewontin (1970, 1978, 1983) who suggested that in contrast to traditional, strictly asymmetrical views of adaptation positing that "organisms adapt to their environments, never vice versa" (Williams 1992, p. 484), organisms in fact can and do have a significant and (critically) often selectively relevant influence on their environments. At this time, new quantitative models for capturing the evolutionary interactions between cultures and genes, so-called dual-inheritance or gene-culture co-evolutionary models, were also emerging (Cavalli-Sforza and Feldman 1973a, b; Feldman and Cavalli-Sforza 1975, 1976; Cavalli-Sforza and Feldman 1981). While Lewontin himself was not really taken by the idea of applying evolutionary models to culture change (Fracchia and Lewontin 2005), the respective insights from natural history and formal modelling were combined by Oxford ecologist John Odling-Smee (1988, 1995) in the 1980s and early 1990s into initial arguments for the importance of what he labelled niche construction. Odling-Smee stressed that from this point of view, adaptation can be the result of two processes:

1. Environment > selection > adapted organism
2. Organism > niche construction > modified environment

The eventual result of both pathways is a fit between organism and environment—adaptation—yet the process differs in important ways. Niche-constructing behaviours can act in many ways and lead to different outcomes that can both counteract selection pressures generated by the external environment and initiate more active niche changes such as range expansions (Laland and Brown 2006).

Sometimes known as a triple-inheritance model, the emergence of NCT can be seen in the context of approaches that developed from evolutionary biology in the latter part of the twentieth century and which were broadly aimed at addressing and explaining, with varying degrees of success, human behaviour and cultural evolution—sociobiology, memetics, behavioural ecology and gene-culture

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co-evolutionary theory (see Laland and Brown 2011, for an extended discussion of these different approaches). Throughout the 1990s and early in the current millennium, NCT was being investigated extensively through, in particular, quantitative modelling. The influential behavioural scientist Kevin Laland from St. Andrews University (UK) and computational biologist Marcus Feldman from Stanford University (USA) joined forces with Odling-Smee, and in 2003, the landmark monograph on NCT appeared, marshalling considerable theoretical and empirical support for the relevance of such behaviours as an important evolutionary process (Odling-Smee et al. 2003).

Humans are far from the only organism that persistently modify their environs leaving landscape-scale signatures (Corenblit et al. 2008; Corenblit et al. 2007; Erwin 2008). Yet, together with colleagues from philosophy (Sterelny 2007, 2011), ecology (Laland et al. 1999; Odling-Smee et al. 2013; Boogert et al. 2006; Laland and Boogert 2010; Matthews et al. 2014), developmental biology (Laland et al. 2008; Flynn et al. 2013) and, eventually, archaeology (Shennan 2006; Laland and O'Brien 2010; O'Brien and Laland 2012), an argument in favour of an extended evolutionary synthesis (EES) relevant first and foremost to human biocultural evolution has been made (Laland et al. 2015; Uller and Helanterä 2017; Müller 2017; see also http://extendedevolutionarysynthesis.com/). This EES focuses on two key concepts: *constructive development* and *reciprocal causation*. Both are aspects of niche construction where the actions *on the environment* (at varying scales) *by individual organisms* modify the developmental and/or selective processes acting on their offspring, themselves and/or other organisms.

Despite the evident productivity of NCT, it is far from accepted in all corners of biology or related disciplines. Critical attitudes range from outright and at times rather aggressive rejection (e.g. Gupta et al. 2017b; Futuyma 2017) to more productive dialogues (e.g. Scott-Phillips et al. 2014). These critiques maintain that evolutionary dynamics can be more parsimoniously explained by standard evolutionary theory and that NCT is no more than a highest-order perspective providing no specific ways to be measured and evaluated and hence offering no explanatory power beyond existing models. The supporters of NCT usually counter such attacks with generally measured responses and the intention to clarify misunderstandings or diverging views (Feldman et al. 2017; Mesoudi et al. 2013; Laland et al. 2000; Laland and Sterelny 2006). These efforts are not always crowned with success and consensus (Gupta et al. 2017a), but for those studying human biocultural evolution, the main attraction of NCT remains: organisms—in our case humans and their behaviours—are given a critical role in the evolutionary process, and the evolutionary process is seen as more than genetic change in individual organisms. Three aspects are particularly pertinent:

- First, the notion of *agency* that has had a major influence on archaeology over the last few decades but is generally linked to theoretical approaches antagonistic to evolutionary ones can be readily integrated (Smith 2013; Shennan 2004; VanPool and VanPool 2003; Riede 2005a).
- Second, many archaeological features—huts and houses, hearths, corrals, hunting stands, irrigation canals, farming terraces and the like; Oswalt (1976) calls them *facilities*—are constructed collectively and have lifetimes beyond those of their makers. They effectively become parts of the environment for subsequent generations who were not part of the initial erection of these facilities. These features can only be poorly captured by traditional dual-inheritance models, which focus more on knowledge and material culture clearly linked to individuals and more or less readily tractable pathways of social information transmission. The longevity of these installations and environmental modifications is termed ecological inheritance, which in NCT complements the domains of cultural and genetic inheritance. Environmental archaeologists can identify these signatures of past actions on the environment and often reasonably demonstrate that they have had ecological legacies of selective relevance (Szabó 2010; Butzer 1982; Dincauze 2000; Normand et al. 2017; Kluiving 2015)—even if those consequences are intended or unintended or positive or negative in the short or long run (Dincauze 1993).

- Third, traditional evolutionary approaches as well as cultural evolutionary models such as dual-inheritance theory are rarely if ever concerned with the environmental outcomes of cultural processes. The unit of interest is the organism. For those also genuinely interested in the changes of the environment that are brought about by humans but are selectively relevant for both humans and other species, NCT offers the necessary scope. It is not essential to invoke NCT in every case study. Many cultural evolutionary processes can be understood in less holistic terms. Yet, when the selective feedforward potential of modified environments is also of concern, these inherited environments need to be formally accounted for in our models. Furthermore, as I argue towards the end of the chapter, this focus on the environment articulates archaeology with contemporary concerns about human impacts on ecosystems at a global scale and the emergence of the Anthropocene (Fox et al. 2017; Boggs 2016; Kluiving 2015; Smith and Zeder 2013).

Independently of the emergence of NCT, environmental archaeologists have argued that their discipline offers “a holistic view of past ecosystems and their workings, a view which is valuable both within archaeology and to other disciplines” (O’Connor 1998, p. 5). In the sense that environmental archaeology is the study of human palaeoecology, coupling this record to explicit models for how such behaviours change over time, the role of individual and collective agency and their role in a broader evolutionary process are not only conceptually attractive but also useful for generating specific hypotheses (Riede 2012).

In the following, I begin with outlining the terminology used to conceptualize and describe the elements specific to ecological inheritance and niche construction. I outline the kinds of processes that can be seen as niche construction. I will then use this terminology and processual taxonomy in an initial discussion of an iconic non-human example of niche constructor, the beaver, to further outline the basic tenets of NCT. I then move quickly on to how humans are part of wider niche construction processes and to how humans have constructed their own niche. In this, I selectively focus on the themes of fire use, changing human-animal and human-plant relations (extinction and domestication) and cognitive niche construction. I draw on chronologically disparate examples to stress the evolutionary importance of many of these behaviours and how they have acted on hominins from the deep past to the present. My final examples link NCT to the notion of the Anthropocene that reflects the now pervasive nature of humanly induced ecosystem impacts on scales that range from local to global. In this context, NCT provides an evolutionary backdrop to how we have ended in this situation where one species has a near-comprehensive ecological legacy rife with unintended consequences but also offers hope for how evolutionarily informed actions can help us deal with these quandaries in the present and future.

The Terminology and Taxonomy of Ecological Inheritance and Niche Construction

Anthropologists have long appreciated that material culture constitutes an “extra-somatic means of adaptation” (Binford 1962, p. 218). This notion, going back to White (1959), presaged Dawkins’ (1982) famous discussion of the extended phenotype, which then has again been adapted to anthropological concerns within the emerging evolutionary archaeological paradigm of the 1990s (e.g. O’Brien and Holland 1992, 1995). While it then became quickly apparent that the extended phenotype approach with its strong focus on genotypic selection as a driver of change also in the phenotypic extensions was not as well-suited to understanding cultural change as gene-culture co-evolutionary/dual-inheritance models, it has become equally clear that the actions of organisms on the environment that form such extended phenotypes critically modify those organisms’ physiological niche parameters (Turner 2000). Importantly, if and when these phenotypic extensions affect not only

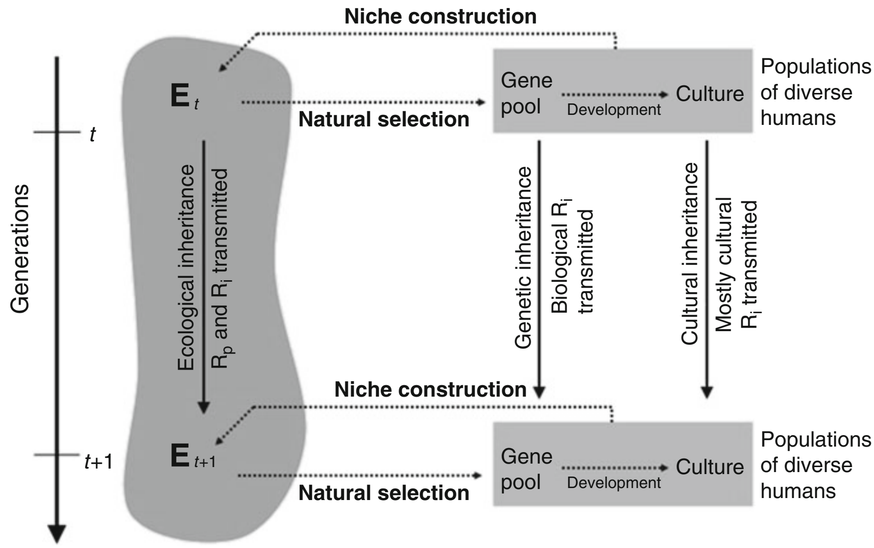

Fig. 17.1 The three domains of inheritance of niche construction theory: genetic, cultural and ecological with the respective resources (R_p, R_i) that are transferred. Redrawn and adapted from Odling-Smee (2007)

Table 17.1 A taxonomy of physical and semantic or informational resources that are transmitted or persist as part of ecological inheritance

Transmission channel	Resource transmitted: R_i | Rp	Type of inheritance
Internal environment	R_i: semantic resources	• Genetic inheritance • Epigenetic inheritance
	R_p: physical resources	• Cytoplasmic inheritance
External environment	R_i: semantic resources	• Cultural transmission, knowledge, know-how
	Rp: physical resources	• Inheritance of altered environs ranging from clothing to landscapes

Adapted from Odling-Smee (2007)

the organism of origin and leave selection-modifying legacies over considerable periods and across generations, they become ecologically inherited (Fig. 17.1): "Ecological inheritance does not depend on the presence of environmental 'replicators' but merely on intergenerational persistence (often through repeated acts of construction) of whatever physical—or, in the case of humans, cultural—changes are caused by ancestral organisms in the local selective environments of their descendants" (O'Brien and Laland 2012, p. 436).

Within the domain of ecological inheritance, different kinds of resources can be passed on or persist from generation to generation (Table 17.1). Physical resources (R_p) are literally modified components of the environment—caches, huts, houses, fields and so on. Semantic or informational resources (R_i) are more difficult to capture archaeologically but would cover what is today often referred to as traditional ecological knowledge (TEK; Berkes et al. 2000; Inglis 1993) about the environment and its instantiations. This is at times codified not only in stories and legends (Sugiyama and Sugiyama 2009) but also in art and other artefacts (Barton et al. 1994; Mithen 1991). This is knowledge—counter to Odling-Smee (2007) not strictly identical, in my view, with the kind of knowledge primarily captured by cultural inheritance studies—that plays a critical part in how human communities act in and on the environment. This collectively held knowledge about the environment and about how to modify has evolutionary consequences and often leaves archaeologically visible signatures (Rockman 2009).

Table 17.2 A basic categorization of niche-constructing behaviours

	Perturbation	Relocation
Inceptive	Organisms initiate a change in their selective environment by physically modifying their surroundings	Organisms expose themselves to a novel selective environment by moving to or growing into a new place
Counteractive	Organisms counteract a prior change in the environment by physically modifying their surroundings	Organisms respond to a change in the environment by moving to or growing into a more suitable place

Adapted from Laland and O'Brien (2010)

Table 17.3 Examples of niche-constructing behaviours by humans and affecting humans classified according to the NCT resource and process taxonomies

NC behaviours	R_p/R_i	Effects	NC categories	References
Non-human animals affecting the human niche				
Beaver (*Castor fiber*) damming	Physical	Creates long-lasting lake habitats and patches of open landscape, attracting human settlement	Inceptive, perturbational, later counteractive	Coles (2006), Wright et al. (2002), Brown et al. (2017)
Humans affecting their own niche				
Caching	Physical and semantic	Changes the distribution of critical resources in the landscape	Initially inceptive, later counteractive, perturbational	Potts (1994), Riede (2005b)
Way-marking	Physical and semantic	Creates long-lasting pathways through a landscape	Inceptive, perturbational	Rockman and Steele (2003), Pasda (2004), Odgaard (2007)
Humans affecting their own and other organisms' niches				
Plant domestication	Physical and semantic	Changes genetics and morphology of plant species and creates the agricultural niche	Inceptive, perturbational	Coward et al. (2008), Smith (2007), Terrell et al. (2003), Rindos (1984), Zeder (2017)
Animal domestication	Physical and semantic	Changes genetics and morphology of animal species and creates the pastoral niche	Inceptive, perturbational	Bleed (2006), Zeder (2017)
Expansion into new habitats	Physical and semantic	Introduces foreign species (including humans) into new habitats, often with genetic effects for many species	Relocational, may be inceptive or counteractive	Kirch (1997), Bellwood (2005), Kennett et al. (2006)
Fire management	Physical and semantic	Clears patches of landscape for new growth and animal feed	Perturbational	Mellars (1976), Bird et al. (2008); also see Bond and Keeley (2005), Schwilk (2003) and Verdú et al. (2007)
Art and play objects	Physical and semantic	Assists in the transmission of ecological information; territorial markers	Inceptive	Mithen (1991), Barton et al. (1994), Riede et al. (2018)

The process of niche construction has been classified into the four basic categories of perturbation and relocation effectively reflecting whether the behaviour in question involves movement into novel environments or not and inceptive versus counteractive behaviours reflecting whether the behaviour in question creates novel selection pressures or whether it modulates and buffers existing ones (Table 17.2). Numerous phenomena observed in the archaeological record can be classified according to these simple resource and process taxonomies (Table 17.3). Such novel ways of describing often well-known phenomena facilitate comparison between phenomena and allow an articulation with specific methods that have already been applied within NCT studies.

The Beaver as Ecosystem Engineer and Niche Constructor

Beavers (*Castor fiber*) are widely acknowledged as a so-called ecosystem engineer, a species whose activities demonstrably impact its surrounding environment, as was in fact already noted by pioneering anthropologist Lewis Henry Morgan (1868) in a monograph dedicated to this fascinating animal and its effect on surrounding environs. Beavers constitute also a much-used example within the NCT literature. As a beaver fells trees to make its home, it modifies the adjacent ecosystem, potentially opening the shoreline to new plants and exposure to sunlight, even altering erosional processes that may affect the surrounding environments (Wright et al. 2002; Naiman et al. 1986; Puttock et al. 2017). The reason I use the beaver as example here is that Richard Dawkins (1982) famously used this creature to explicate his notion of the extended phenotype, where the underlying alleles for dam-building evolve in essentially the same way as any other aspects of the beaver genotype, i.e. via natural selection. This view arguably fails to fully appreciate the extent of ecological and hence selective consequences of beaver dam-building. Importantly, the dam-building beavers' offspring are born into a world that already has a dam. Consequently, the dam can no longer be adequately seen as merely an extension of the original beavers' geno- and phenotypes—especially once individuals belonging to that generation pass away—but rather also as part of the new beaver generation's environment, an ecological inheritance of primarily R_p with selective and perhaps also developmental repercussions. Over generations, this niche construction behaviour changes from inceptive to counteractive, and a feedback loop develops in which the environment or niche is changed through an organism's activities, which in turn alters those very activities, in turn altering the environment and so on (Fig. 17.2).

Beaver dams are *facilities*, constructions with effects on the environment and a longevity well beyond the generation of organisms that initially built them. For the beaver cups born in the dam, it is the environment, and it has significant selective effects. It is no big leap from beaver dams the human constructions such as huts, houses and irrigation canals. But there is more: the actions of beavers have also long since attracted humans to those very same habitats (Coles 2006). Indeed, Tolksdorf et al. (2017) have recently demonstrated the close cohabitation of Late Palaeolithic foragers and beavers in the same habitat, and Brown et al. (2017) have further compiled faunal evidence as well as indications

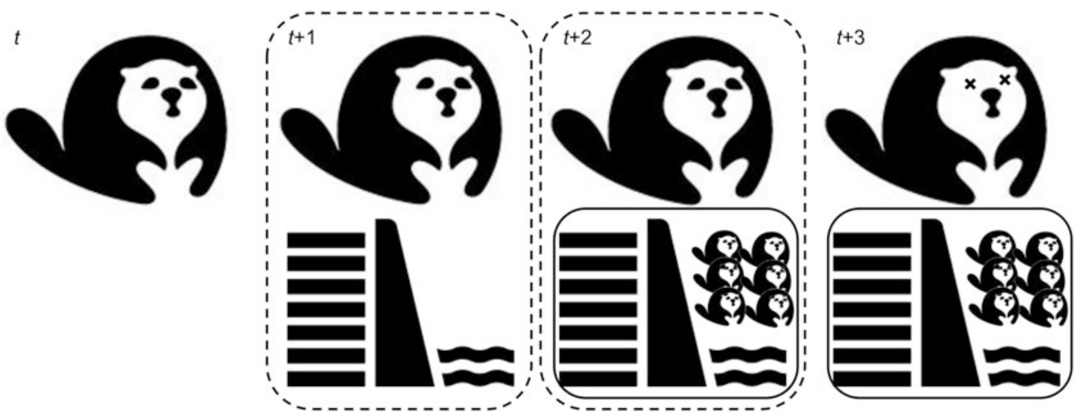

Fig. 17.2 A schematic of how a regular phenotype at t becomes an extended phenotype in $t + 1$ and then transforms into the constructed niche of a new generation of beaver pups at $t + 2$ born into the phenotypic extension of the previous generation. At $t + 3$, the original niche-constructing individual is dead—the current individuals and their offspring hence live in a niche containing many selectively significant elements that are ecological inherited. Dashed lines mark the extend of the extended phenotype; solid lines mark the constructed niche. Beaver individuals at $t + n$ will continually and further modify this constructed niche, and the distinction between any given individual's extended phenotype and their and other individuals' inherited niche cannot be drawn precisely

from Late Palaeolithic (Magdalenian) art that suggest a strong attraction of humans—in Paleoarctic Europe at least—to beaver-modified habitats. Humans learned that these beaver-created habitats offered opportunities for increased hunting success of both beavers and other animals. Within the NCT terminology, then, beavers are the primary niche constructors in this example, affecting both their own niche and that of *Homo sapiens*. Both species have their own trajectories of *genetic inheritance*. At the same time, the ecological knowledge and the know-how used to manufacture the relevant tools for hunting are part of the *ecological* (R_i) and *cultural inheritance* of these Late Palaeolithic groups. Their ecological footprint and hence the *ecological inheritance* (R_p) at the landscape scale were still ephemeral at this time, although their ability to modify landscapes may hitherto, as Brown et al. (2017) point out, been underestimated.

Indeed, the Magdalenian niche contained other constructed R_p elements: They erected tents, made fireplaces and flooring (e.g. Jöris and Terberger 2001), lighted fires that affected their surroundings (Bos and Janssen 1996) and domesticated dogs (Pionnier-Capitan et al. 2011; Musil 2000; Larson et al. 2012). They also furnished the ontogenetic niches of their offspring with play objects (e.g. Langley 2018; Nowell 2015) that are argued to have had effects on their cognitive development (Riede et al. 2018). I will return to some of these examples and facets of niche construction below. Before moving on, however, note that in the long run the niche construction balance between *Homo sapiens* and *Castor fiber* in Europe shifted very much in favour of the former and eventually led to the extirpation of the beaver from many regions (Coles 2006)—a common effect on animals of human niche construction behaviour (e.g. Sandom et al. 2014).

Constructing Niches Through Fire

Hominins are associated with fire since at least 1.5 million years ago (Gowlett 2016). While the chronology of the transition from serendipitous to habitual fire use is disputed (Parker et al. 2016; Shimelmitz et al. 2014; Gowlett and Wrangham 2013), the impact of fire on hominin lifeways and selection has received considerable attention. Based on evidence from a wide range of disciplines, Wrangham (2009) has suggested that the ability to heat-treat foodstuff was essential for allowing Middle Pleistocene hominins to disable toxins and unlock much increased calories of a wide range of foodstuffs. This suggestion interacts well with both the earlier "expensive tissue hypothesis" (Aiello and Wheeler 1995) that addressed the energetic trade-off between guts and brains in the *Homo* linage and the notion that campfires also served as critical foci of social life and knowledge transmission (Wiessner 2014; Stiner and Kuhn 2016). The habitual use of fire sometime after 500,000 years ago (Shimelmitz et al. 2014) almost certainly facilitated the large-scale and successful expansion of the hominin range around this time, especially into higher latitudes (Hosfield 2016).

But as alluded to above, the use of fire by hominins also left landscape-scale imprints that also modified selective pressures. While such impacts are ephemeral in the Pleistocene (Daniau et al. 2010), evidence from the early Holocene onwards points to intentional fires as a major means of modifying landscapes from well before the beginning of agriculture. Such modifications were aimed at creating landscapes more favourable for desired plant (Moore 2000) and animal species (Mellars 1976), and their consequences are visible in ecological proxy records (e.g. Olsson et al. 2010; Innes et al. 2013). The impact of human fire regimes has also been studied extensively outside of Europe. Australia, in particular, has yielded remarkable evidence not just for the intentional use of fire—known as fire-stick farming—but its landscape-scale consequences. In a detailed series of studies, Hill et al. (1999) and Bird et al. (2005, 2008, 2016) have documented how Australian Aborigines deploy fire as part of their hunting strategy and, using remote sensing as well as traditional ecological census methods, how this changes the community structure of vegetation cover at the regional scale. Importantly, the latter effect is incidental to the hunters' original intention to ease their prey harvest.

Yet, it is precisely these incidental effects that have the greatest ecological and evolutionary effects on flora and fauna that is now evidently adapted to such fire regimes (Codding et al. 2014; Pyne 1991). The results are subtly but effectively “domesticated landscapes” (Terrell et al. 2003, p. 323) or constructed niches that are common amongst many traditional societies the world over. In contrast to the beaver example above, fire-stick farming is an example of niche construction by small-scale human foraging groups where they are in the ecological driving seat.

Changing Relations Between Animals, Plant and Humans

Prior to the global spread of *Homo sapiens* to even the most remote corners of the earth, faunal and floral communities looked quite different, in large part because the presence of very large animals (megafauna) has significant effects on both predators and plants (Malhi et al. 2016; Sandom et al. 2013). There is considerable controversy about the impacts or otherwise of humans on individual species and in particular regions such as the Americas (e.g. Grayson and Meltzer 2003, 2004; Fiedel and Haynes 2004; Johnson et al. 2013; Lima-Ribeiro and Felizola Diniz-Filho 2013). Seen across regions, however, it seems likely that the arrival and continued presence of humans in especially naïve ecosystems had dramatic consequences for first the larger animals and that these effects then trickled through trophic hierarchies to also affect organisms at lower levels (Sandom et al. 2014; Bakker et al. 2016). Such impacts can readily be seen in a niche construction light, where the impact of humans on the selective pressures acting on specific organisms entails marked changes in ecosystem composition and function. It is also a strong case demonstrating the unintended perturbational consequences of such niche impacts.

In reverse, it has long been appreciated that the beginning of animal and plant domestication in the period between ca. 20,000 and 10,000 BP constitutes a major inflection in human biocultural evolution. While some see this as a revolution—classically, Gordon Childe (1936) coined the Marxist-inspired label of the “Neolithic Revolution” in his for contemporary eyes anachronistically but otherwise aptly titled monograph *Man Makes Himself*—it is now considered the model case for human niche construction that recursively impacts a wide range of other species as well as the human niche constructors themselves (Watkins 2017; Sterelny and Watkins 2015; Zeder 2016, 2017). Melinda Zeder (2006; also Zeder et al. 2006) has provided lucid discussions of the intersections between the genetic, behavioural, morphological and material dimensions of the domestication process. Different species of animals and plants respond differently and at different speeds to human interventions; also, the different components of domestication—behavioural adjustments, alterations in the geno- and phenotypes of the target species and the emergence of particular material trappings associated with domestication—should not be seen to proceed in a lockstep fashion. Genetic change, the benchmark of domestication, is merely the endpoint of what is best thought of as a continuum of processes. Archaeology can provide insights into the (conscious or unconscious) manipulations of the behaviour, distribution and breeding patterns of candidate domesticates long before genetic change actually took place and became dominant in the target population. The demographic success of the niche-constructing population itself, here *Homo sapiens*, is also reflected in a range of archaeological proxies, such as range expansion, increases in the number and/or size of sites or the number of ^{14}C dates in a given period (Chamberlain 2006; Riede 2009a).

The first animal domestication began well before the Neolithic. Wolves came into close association with humans in the Late Pleistocene, close enough to lead to commensal, symbiotic and eventually domestication relations, possibly in several locations around the globe (Thalmann et al. 2013; Larson et al. 2012; Savolainen et al. 2004; Savolainen et al. 2002; Vila et al. 1997; Pang et al. 2009). There is considerable controversy about the timing and exact process, however, as genetic evidence conflicts with regard to a single (Europe or Southeast Asia) versus multiple (Europe and Southeast Asia) domestication centres as well as its timing (>100,000 years BP vs. <20,000 years BP). Independently of the precise when and where of dog domestication, the intimate and long co-evolutionary relation between *Canis* and *Homo* has altered not only dog genetics and physical appearance but also their vocalizations and cognitive abilities. Dogs can serve as sources of warmth, comfort and food, and they can carry loads and aid in hunting. Taming and keeping dogs are costly but also usually provide tremendous benefits to their users (Koster 2008; Lupo 2017). It is here at the intersection between everyday decision-making processes and their long-term consequences on both the niche constructor and their subject—in the words of Stiner and Kuhn (2016, p. 177) “the ‘sweet spot’ between optimality theory and niche construction theory”—that we can understand dog domestication.

It is likely that humans engaged with such experimentation repeatedly and at different times. In Europe, fossil evidence supports incipient but perhaps curtailed domestication attempts in the early Upper Palaeolithic (Germonpré et al. 2009, 2012; Ovodov et al. 2011), followed by a more sustained and successful domestication in the Late and Final Palaeolithic (e.g. Grote 1994; Napierala and Uerpmann 2012; Musil 2000; Street 2002). This latter domestication had further implications for range expansion and economic strategies for Late and Final Palaeolithic hunter-gatherers. The recolonization of the northern European lowlands in the early part of the Late Glacial, for instance, was dependent on foragers being able to efficiently exploit reindeer. The so-called Hamburgian culture is associated with this initial colonization pulse, although much circumstantial evidence suggests that this was ultimately a failed expansion attempt (Riede and Pedersen 2018; Riede 2007, 2009b, 2014). Later on, the region was again colonized by specialized reindeer hunters, this time of the Ahrensburgian culture, where there is evidence of dogs. The coupling of this repeated emergence of specialized reindeer hunting and the use of domestic dogs has been the subject of a detailed NCT-driven analysis. By applying the tools of cultural phylogenetics (Gray et al. 2010; O’Brien et al. 2008) and the comparative method (Freckleton et al. 2002; Mace and Pagel 1994), Riede (2010, 2011) has analysed the correlation between reindeer specialization and dog use as well as the order of emergence. This analysis consists of two steps: first, lithic artefacts are used for deriving explicit hypotheses for the historical relationships amongst Final Palaeolithic communities of flint-working practice in the form of phylogenies, and then, the presence/absence of reindeer and dogs as seen in the faunal evidence is plotted on these phylogenies—all within a Bayesian statistical framework.

The results of this analysis support the hypothesis that the emergence of successful reindeer-specialized adaptations in the absence of dogs is very unlikely and, hence, that the adaptive strategy of the Hamburgian culture was inherently unviable. Conversely, the domestication and use of dogs as transport and hunting aids strongly facilitated the range expansion and reindeer-hunting specialization. In NCT terms, the construction of the dogs’ niche by Final Palaeolithic humans through their interactions and the material trappings of dog keeping (Bleed 2006; see also Guagnin et al. 2018) led to a selective feedback loop on both *Canis* and those human populations using dogs: They grew and expanded suggesting modified selection pressures and an improved fit between Late Pleistocene environs and these hunter-gatherers. The statistical support for these niche construction pathways was weak, however, reflecting the relatively ephemeral niche modification enacted by these small groups. Using other methods, the niche-constructing behaviours of prehistoric foragers can be assessed (e.g. Riel-Salvatore 2010; Riel-Salvatore and Negrino 2018), yet the application of phylogenetic methods allows for a stricter control of the historical relatedness amongst the units of analysis, when it comes to seeking correlations amongst traits. Accounting for this relatedness is a fundamental issue in cross-cultural analysis and can be tackled via such comparative methods (see Chap. 9, this volume).

A major inflection in the ability of *Homo sapiens* to affect their environment occurs with the emergence of fully agricultural and pastoral economies: the Neolithic (Rowley-Conwy and Layton 2011). Niche construction theory offers explanations for increasing patch and resource investments (Mohlenhoff and Codding 2017; Zeanah 2017), and, as already alluded to above, Zeder (2016, 2017) has described how the domestication of plants and animals themselves in the Levant and elsewhere (e.g. Allaby et al. 2017) can be understood—at the scale of path-dependent macroevolution—as a niche construction process. Indeed, the ever-greater resolution in our assessments of past human-animal and human-plant relations afforded by new field data and applications such as stable isotope analyses provides detailed insights into dependencies and management practices already well before fully agricultural economies were in place. Maring and Riede (2019), for instance, argue that the complex hunter-gatherer-fishers of the Late Mesolithic in southern Scandinavia had close relations with wild boar somewhere on the trajectory towards domestication. Radiocarbon dating demonstrates that the wild boar specimens in question substantially predate the arrival of agriculture in the region; an osteological assessment does not indicate full domestication; their isotopic values, however, clearly indicate a marine diet otherwise only observed in clearly domesticated pigs from much later prehistoric contexts (e.g. Jones and Mulville 2018; Jones and Mulville 2016) or contemporaneous and clearly domesticated dogs (Fischer et al. 2007). This analysis, using tools specifically designed to elicit information on two specific domains of change associated with domestication (diet/behaviour and skeletal morphology), has revealed how behavioural changes preceded morphological and presumably genetic changes along the domestication continuum, although the latter will need to be demonstrated using ancient DNA approaches. While other explanations for this pattern are possible (cf. Chamberlain et al. 2005) and low sample size only allows for preliminary conclusions, the notion of important land and resource management that had environmentally mediated selective effects on other organisms is fully in line with other evidence (e.g. for fishing facilities, forest manipulation) from this period.

In addition to such largely discovery-driven approaches drawing on new archaeometric techniques, O'Brien and Laland (2012) underline, using causal graph methods, the important point that the major changes in range and genetic composition of both humans and domesticates in the Neolithic often took pathways that included major environmental modifications, rather than arising directly from some individual actions or through cultural transmission trajectories adequately modelled as traditions.

In addition to animals and their products being available in a stable fashion within such economies, Johannsen (2007) has also pointed towards the use of animals as "machines" that transforms the human and domesticate niches, all of which leaves clear traces in the genetic and archaeological (osteological, material, landscape) records. O'Brien and Bentley (2015) have further supplemented this discussion of Neolithic agriculture with detailed arguments about the role of food storage as a crucial element in this constructed niche. Building on these insights about causal pathways from cultural behaviour impacting the environment to modified selective and developmental niche construction, Johannsen (2010) and Sterelny and Watkins (2015) also outline how these developments would have quite fundamentally impacted the cognitive environments of individuals living in these societies: the niches into which Neolithic individuals were born and raised were furnished with different and more manifold artefacts and humanly modified landscapes (e.g. monuments) that facilitated different ways of conceptualizing the world. In turn, these conceptualizations then produce new forms of material culture and behaviour, establishing ever more firmly the feedback between the built environment, new technologies and new forms of sociality.

Most recently, the toolbox for studying the changing human-environment relations associated with the origins of agriculture is expanded to include distribution modelling. Developed in ecology to interrogate the precise causal effects of topographic and climatic factors on the spatial component of a given organism, these powerful tools facilitate detailed studies of adaptation (e.g. Guisan et al. 2017) also in palaeobiological settings (Svenning et al. 2011; Brewer et al. 2012). Distribution models have seen some early application in palaeoanthropology (Franklin et al. 2015) and in modelling some key agricultural species in different parts of the world (d'Alpoim Guedes et al. 2016). Whitford (2018) has recently presented a significant extension of the method by using archaeological taxa—different Neolithic cultures—as basic units of analyses. He showed how spatially the unmodified ecological setting interacted with the niche-constructed subsistence practices of early framers moving out of the Mediterranean and into the continental ecotones in northern Greece and Bulgaria. It is noteworthy that distribution modelling tools are generally freely available and are experiencing rapid development allowing code-sharing and replicability (e.g. Kass et al. 2018), which is also becoming an increasing issue in computational and indeed general archaeology (Marwick et al. 2017; Marwick 2017). The input data required for distribution models—principally climate model data, topographic information and distribution information for the taxa of interest—is often quite readily available in archaeological cases, signalling an exciting future for this suite of methods as a key approach in capturing past human adaptation and niche construction dynamics.

Cognitive Niche Construction

Experimental primate studies show that provisioning with tools changes the neuronal architecture as behaviours integrate objects (Iriki and Sakura 2008). Iriki and Taoka (2012) have argued that this plasticity opens up for a form of developmental niche construction, where the furnishing of early-life niches in hominin evolution is decisive in how neuronal structures develop, and that over time such feedback relations lead to lasting modifications in brain structure. The importance of object provisioning for developing problem-solving skills but also for simply mastering the many material culture-related skills in human communities is supported by computational modelling (Kerr 2007; Kerr and Feldman 2003), by developmental psychological studies and by ethnographic investigations of social learning (Kline 2015; Kline et al. 2013).

It has been argued that *Homo sapiens* is uniquely evolved to learn but also to be receptive to pedagogical interventions (Gärdenfors and Högberg 2015; Csibra and Gergely 2011). The role of object provisioning, however, has only been integrated into this line of thinking recently. Riede et al. (2018) have argued against a background of existing psychological and primatological studies that object provisioning and object play—covering both R_p and R_i—have important modifying influences on the ability of individuals to become competent but also to innovate within certain technological domains. This is particularly relevant with regard to technologies that are cognitively opaque, i.e. whose functional properties emerge only in the non-obvious interaction between its different parts. Put simply, if you are given a miniature bow from early on in life, you are not only more likely to become a proficient bowyer but also to be able to see how this technology can be improved—also under the strict cost-benefit calculations of life-history trade-offs in traditional societies. We see this as a form of inceptive developmental niche construction. The model and its predictions are borne out in a range of archaeological examples—from Arctic prehistory to the invention of the wheel and from the Magdalenian to the Middle Stone Age—where the presence of play objects and object play correlates with increased rates of innovation also in full-scale adult technologies.

So, the different cultural components of human-constructed niches arguably have a direct effect on development, which later on would often have selective effects also. But it is not only these objects but also, as already alluded to above, the built environment that shapes cognitive evolution. Like nests, clothing, papooses, tents, huts and buildings serve as buffers between the external unmodified environment and the immediate niche parameters. Clothing, for instance, has made a crucial difference for anatomically modern humans moving into higher latitudes (e.g. Collard et al. 2016; Gilligan 2010) but has also provided novel selection environments and evolutionary opportunities for facultative human parasites: human clothing is the unintentionally constructed niche of the human body louse (Kittler et al. 2003). But buildings can do more still. Being often long-lasting, they reflect more obviously ecological inheritances; they also impact on how humans experience and think about the world. This is especially pertinent to religious buildings that are designed to leave strong cognitive signatures (Jessen 2012; Bulbulia 2008). Unlike in primate studies, however, it is impossible to easily verify the impact of such niche furnishings on neuronal structures. Future studies employing brain imaging techniques, for instance, may be able to substantiate the actual causal (developmental and neuronal) pathways for this form of cognitive niche construction. These uncertainties notwithstanding, NCT strongly supports the notion—the hypothesis—that the environment you are born into and grow up in at once limits and facilitates the further development of ideas, behaviours and material culture—not only in deep time but also in the present (Johannsen 2010; Sterelny 2007).

Constructing Niches from the Pleistocene to the Anthropocene

Niche construction theory has developed out of earlier models of gene-culture co-evolution and provides a terminology, conceptual framework and suite of methods to study the ways in which lasting modifications of the external environment create intended or unintended developmental and/or selective legacies in generations of organisms subsequent to the ones that initiated such modifications. There is no denying that NCT is a higher-order model for evolutionary process whose explanatory ambition equally aims at large-scale patterns and processes. The corollary of this is that many other approaches such as those employing optimal foraging theory or dual-inheritance theory can be nested within it. Not all workers agree on such nesting (see Gremillion et al. 2014 versus Zeder 2014), but reconciliation is, following Stiner and Kuhn (2016), possible with optimality theory and niche construction perspectives providing complimentary insights at different scales (see Chap. 13, this volume). NCT is, I argue, particularly attractive to human scientists because it rests on the realization that humans especially have a degree of influence—agency—when it comes to shaping the environs and hence the selective pressures under which they come. NCT is furthermore particularly attractive to archaeologists given that the temporal dimension of such niche modifications is a critical factor in the model; NCT articulates well with environmental archaeology (Riede 2012), with behavioural ecology (Stiner and Kuhn 2016) as well as with more agentive approaches (Riede 2005a). This integrative capacity of NCT also comes into play in recent suggestions that anthropology more broadly—that is, including ethnography and social anthropology, which are traditionally difficult to reconcile with any form of evolutionary thinking—can be brought under the wing of evolutionary approaches (Fuentes 2009, 2016).

The literature on NCT and its archaeological applications is growing. Methodological diversity is a strength for any body of theory; a palette of different methodological approaches ranging from the descriptive to the strictly quantitative—including causal graphing, the comparative method using artefact phylogenetics, and modelling—has been brought to bear in this field. Empirical data range from quite traditional archaeological observations and typo-technological analyses to large-scale palaeogenetics. An important next step is that some or all of these methods are applied across multiple data sets and case studies. This would make the effects of different niche construction behaviours and their efficacy and effects more directly comparable and would lead towards the establishment of a standard methodological toolkit associated with this theoretical framework. My recommendation is that, in particular, cultural phylogenetics and distribution modelling are explored further within an NCT framework. The former offers the prospect of controlling for historical relatedness amongst the archaeological operational units of analysis and captures temporally unfolding processes well. The latter's strength rests in its spatial explicitness.

NCT posits that many organisms and above all humans modify their niche parameters so that developmental and selective processes are significantly altered. In parallel with the emergence and formalization of NCT, the idea of the Anthropocene was proposed (Crutzen and Stoermer 2000). The term Anthropocene was intended to signal that humans had collectively matched or surpassed natural forces in shaping biotic and abiotic dynamics on earth. Since its initial proposal, the term has engendered lively debate across the natural and human sciences: some reject it outright; others embrace it as a useful scientific or political concept (e.g. Malhi 2017; Finney and Edwards 2016; Swanson 2016; Carey 2016). Its reality *or* utility aside, there is also considerable debate about when the Anthropocene started—candidate dates range from the period of Late Pleistocene megafauna extinctions some 50,000–40,000 years ago at one extreme to the period of nuclear bomb explosions and the emergence of mass-produced and mass-consumed plastic around AD 1950 at the other (Zalasiewicz et al. 2015, 2017; Waters et al. 2016; Walker et al. 2015; Lewis and Maslin 2015). Numerous commentators stress that defining a late onset of the Anthropocene (i.e. AD 1950 or similar) ignores the long process that has brought humans in this position in the first place (Foley et al. 2013; Braje and Erlandson 2013). Indeed, plant and animal domestication (Braje and Erlandson 2013; Smith and Zeder 2013) and fire use and forest clearance (Glikson 2013; Ruddiman 2013)—the primary examples of human niche construction sketched out above—have also been put forward as either markers for the onset of the Anthropocene or as major milestones on the way towards it. Yet, NCT can also inform conservation and management practices in these novel ecosystems (Boogert et al. 2006; Laland et al. 2014; Laland and Boogert 2010). Returning to the Eurasian beaver, for instance, reintroductions of this species have been quite successful (Nolet and Rosell 1998) and now assist in land management in important ways (Puttock et al. 2017). Informed by NCT, this rewilding strategy—in its own right a deliberate, theory-driven attempt at contemporary niche construction based on scientifically derived predictions of the ensuing selective consequences—could restore many ecosystem services that *prior* human niche construction has disrupted (Ellis et al. 2016; Ellis 2015).

Both NCT and the notion of the Anthropocene remain contested in their own rights. With their intellectual origins in evolutionary and ecological theory on the one hand and political geology on the other, both address the ways in which humans in particular have modified and continue to modify their own and other organisms' niche parameters. It is being increasingly argued that the two concepts can be productively coupled in the sense that NCT provides a process-oriented, evolutionarily, ecologically and socially grounded mechanism for understanding the unfolding of the Anthropocene (Boggs 2016; Smith and Zeder 2013; Ellis 2015; Fox et al. 2017). Indeed, better articulating the idea of the Anthropocene with NCT also offers the potential for deriving action-oriented insights regarding the current socioecological crisis that are informed by biocultural evolutionary theory (Carroll et al. 2017; Ellis et al. 2016; Brewer et al. 2017; Brewer and Riede 2018, see also https://evolution-institute.org/). The jury is still out as to whether these two ideas stand the test of time and of scientific usefulness; both notions, however, seem to be doing a great deal of useful, integrative and interdisciplinary work in the present.

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