Niche Construction: Implications for Human Sciences

KEVIN N. LALAND and MICHAEL J. O'BRIEN

Abstract

Niche construction is the process whereby organisms, through their activities, interactions, and choices, modify their own and each other's niches. By using and transforming natural selection, niche construction generates feedback in evolution at various levels. Niche-constructing species play important ecological roles by creating and modifying habitats and resources used by other species, thereby affecting the flow of matter and energy through ecosystems. This process is often referred to as *ecosystem engineering*. This engineering can have significant downstream consequences for succeeding generations—often referred to as an *ecological inheritance*. One key emphasis of niche-construction theory is on the evolutionary role played by acquired characters in transforming selective environments. This is particularly relevant to human evolution, where our species has engaged in extensive environmental modification through cultural practices. Humans can construct developmental environments that feed back to affect how individuals learn and develop and the diseases to which they are exposed. Here we provide an introduction to niche construction and illustrate some of its more important implications for the human sciences.

INTRODUCTION

A striking feature of the natural world that evolutionary biology sets out to explain is the hand-in-glove complementarity of organisms and their environments. The conventional view of evolution is that species, through the action of natural selection, come to exhibit those characteristics (adaptations) that best enable them to survive and reproduce in their environments. Organisms are perceived as molded by selection to become well adapted (Figure 1a). In contrast, the niche-construction perspective provides a second route to the adaptive fit between organism and environment by emphasizing the capacity of organisms to modify environmental states, often, but not exclusively, in a manner that suits their genotypes (Figure 1b). Such matches are the dynamic products of a two-way process that involves organisms both

Emerging Trends in the Social and Behavioral Sciences. Edited by Robert Scott and Stephen Kosslyn.
 ISBN 978-1-118-90077-2.

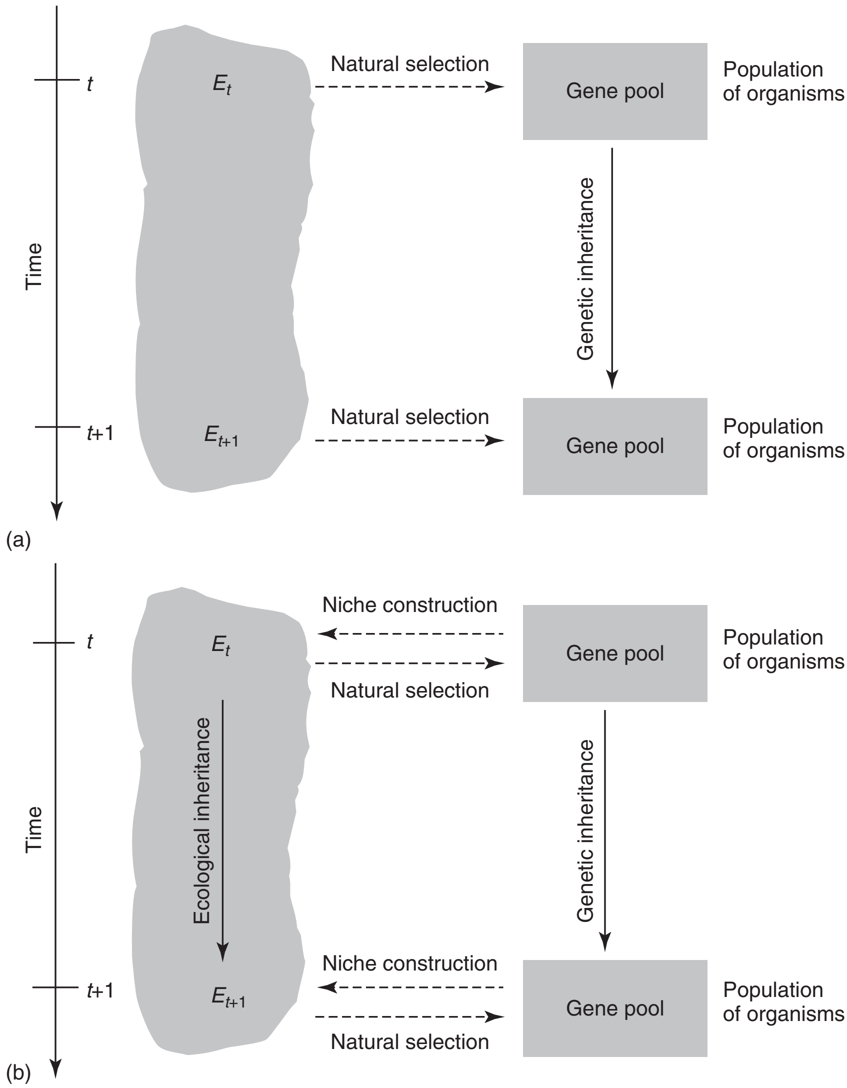

Figure 1 Two views of evolution (from Laland & O'Brien, 2011). Under the conventional perspective (a), niche construction is recognized as a product of natural selection but not as an evolutionary process. Inheritance is primarily genetic. Under the niche-construction perspective (b), niche construction is recognized as an evolutionary process. Here, ecological inheritance plays a parallel role to genetic inheritance.

responding to "problems" posed by their environments through selection and setting themselves new problems by changing environments through niche construction. Niche-construction theory thus treats evolutionary change as organisms codirecting their own evolution.

FOUNDATIONS

Niche construction is all around us, often occurring in subtle ways, as illustrated by animals building nests and burrows, plants changing levels of atmospheric gases, and bacteria fixing nutrients. This emphasis on the modification of habitat by organisms is shared by ecologists who emphasize "ecosystem engineering," by which organisms modulate flows of energy and matter through environments (Cuddington, 2011). Such engineering activity can have significant impacts on community structure, composition, and diversity. Young beavers, for example, inherit from their parents not only a local environment comprising a dam, a lake, and a lodge but also an altered community of microorganisms, plants, and animals. Moreover, niche construction/ecosystem engineering can generate long-term effects on ecosystems. For example, beaver dams deteriorate without beaver activity, but this leads to meadows that can persist for nearly a century and rarely return to the original vegetation. Such legacies are known as *ecological inheritance*—modified biotic and abiotic states, bequeathed by niche-constructing organisms to descendant organisms—and can be viewed as an additional inheritance system (Figure 1b).

Ecological inheritance requires 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 (Odling-Smee & Laland, 2011). Through their niche construction/ecosystem engineering, organisms produce and destroy habitats and resources for other organisms, generating an additional "engineering web" of connectedness and control that regulates ecosystem functioning in conjunction with the well-established webs of trophically connected organisms. Environmental changes that exemplify human niche construction, such as habitat degradation, deforestation, and industrial and urban development, often destroy the control webs that underlie ecosystems. Fortunately, we can use our own niche construction and that of other engineering species in novel restoration and management methods that complement established conservation strategies (Laland & Boogert, 2010).

MODERN RESEARCH

Many researchers, including human scientists, have found the niche-construction framework useful. For instance, archaeologist Smith (2011) proposes a cultural niche-construction model of initial domestication that presents a fresh alternative to optimal-foraging-theory accounts of the origins of agriculture and supersedes it in explanatory power. Linguist Bickerton (2009) builds a new account of the evolution of language around niche-construction theory. Buchanan *et al*. (2011) apply it to ethnographic data to explore the causes of cross-cultural variation in the diversity of subsistence toolkits, finding that predictions from niche-construction theory provide a good fit to the data, unlike established theories. Other successes include a suite of novel theoretical and empirical findings related to landform, ecosystem and population dynamics, macroevolutionary change, cultural evolution, and agriculture (e.g., Kendal *et al*., 2011; Rowley-Conwy & Layton, 2011).

The niche-construction perspective encourages the tracing of causal influences through ecosystems rather than treating each bout of selection separately, such that the full ramifications of anthropogenic activity can be better understood. This can be illustrated by the familiar example of West African populations who cut clearings in forests to grow their yams. When it rains, these clearings inadvertently create puddles that function as breeding grounds for malaria-carrying mosquitoes. Exposure to malaria in turn favors the hemoglobin sickle-cell allele (HbS) that confers resistance to malaria in heterozygote humans. Here, causality flows through the ecosystem, from cultural to genetic and back to cultural processes, and from one species to the next, driven by iterative bouts of niche construction and selection, at multiple levels (O'Brien & Laland, 2012) (Figure 2).

This tracing of causality is also a theme of a recent development in ecology, known as *eco-evolutionary dynamics* (Odling-Smee *et al*., 2013). More generally, niche-construction theory has established that genetic and cultural processes can also affect the rate of change of allelic frequencies in response to selection and greatly influence the pattern and rate of evolutionary processes.

Niche-construction theory promotes a systems approach to exploring human evolution and ecology, and a key issue for future researchers will be to devise realistic means of doing this. The sheer complexity of engineering webs and the challenge of tracing causal chains through ecosystems appear to be a daunting ordeal. In reality, standard methods regularly and successfully deployed by archaeologists, ecologists, and evolutionary biologists can be combined to good effect (Laland & O'Brien, 2010; O'Brien & Laland, 2012). What is different is the focus of investigation, which moves from the study of the ecological impact or evolutionary response in a single taxon to the investigation of human eco-evolutionary systems, pathways, or networks. This requires that researchers go beyond the normal practice of evolutionary biology and ask, "What causes the selection pressures leading to a specific evolutionary response?" rather than treating those selection pressures as a starting point. It also requires researchers to go beyond the normal practice of ecosystem ecology and ask, "What evolutionary ramifications follow from species' ecological impacts on biota and abiota?" The key to progress is to break down complicated pathways in networks into

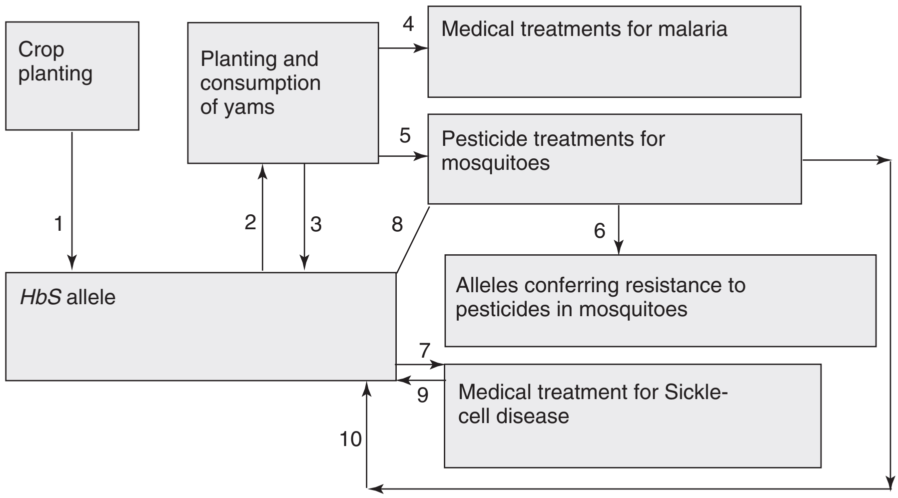

Figure 2 Construction chain depicting the causal influences following a cultural niche-constructing practice, here the planting of yams in West Africa (from O'Brien & Laland, 2012). Planting, which involves deforestation, (*1*) inadvertently promotes the spread of malaria by leaving standing pools of water, leading to selection for the hemoglobin sickle-cell (*HbS*) allele. The resulting incidence of sickle-cell disease (*2*) favors the planting of yams and other crops with medicinal benefits [yams contain the anti-sickling agent thiocyanate (Agbai, 1986)], which (*3*) further promotes the spread of (*HbS*) and (*4*) scaffolds the development and/or application of medical treatments for malaria, as well as (*5*) pesticide treatments for mosquitoes, which (*6*) generates selection for alleles conferring resistance to pesticides in mosquitoes. The spread of sickle cell (*7*) scaffolds the development and/or application of medical treatments for sickle-cell disease. Pesticide treatment of mosquitoes (*8*), medical treatment for sufferers of sickle-cell disease (*9*), and malaria victims (*10*), affect the intensity of selection on the (*HbS*) allele.

tractable component pieces, subject each to analysis, and then reconstruct the network, including the strength of interactions and how they vary over time to gain a systems-level understanding. Where relevant data are available, statistical approaches such as structural equation modeling and causal graphs can help isolate or confirm putative causal influences and/or reject causal hypotheses that are inconsistent with the data.

A focus on niche construction has important implications for how researchers view the relationship among genetic evolution, developmental processes, and cultural change. First, niche-constructing organisms cannot be treated as merely "vehicles" for their genes because they also modify selection pressures in their own and in other species' environments. In the process, they introduce feedback to both ontogenetic and evolutionary (genetic and cultural) processes. Alongside others, we have suggested that this active, constructive conception of the role of organisms in evolution, and indeed in ontogeny, fits well with conceptualizations of human agency that are widespread within the human sciences (Laland & O'Brien, 2010, 2011; Laland *et al*., 2000; O'Brien & Laland, 2012; Odling-Smee *et al*., 2003). Second, there is no requirement for niche construction to result directly from genetic variation in order for it to modify natural selection. Humans modify their environments largely through cultural processes, and it is this reliance on culture that lends human niche construction a special potency (Kendal *et al*., 2011).

This dual role for phenotypes in evolution does imply that a complete understanding of the relationship between human genes and cultural processes must not only acknowledge genetic and cultural inheritance but also take into account the legacy of modified selection pressures in environments (Odling-Smee & Laland, 2011). It is readily apparent that contemporary humans are born into a massively constructed world, with an ecological inheritance that includes a legacy of houses, hospitals, farms, factories, computers, satellites, and the World Wide Web (Flynn *et al*., 2013).

All organisms inherit genetic information, and this is the most fundamental source of information that underpins niche construction. However, some factors in the environment can potentially change many times within the lifespan of the animal, and natural selection has selected for processes allowing individuals to adjust on a within-lifetime basis, some of which are adaptations for acquiring knowledge. The processes underpinning learning have also been shaped by natural selection, leaving some associations formed more readily than others. However, it does not follow that all acquired knowledge need be pre-specified by selection or under genetic control. In theory, our genes could specify a tolerance space for our acquired information and less frequently the content within it. In contrast to the position of most evolutionary psychologists (e.g., Pinker, 1997), that would leave human learning a relatively open program—one capable of introducing novelty into phenotypic design space and modifying environmental conditions in a manner that potentially generates selective feedback at multiple levels.

ISSUES FOR FUTURE RESEARCH

The discussion highlights an important issue for future research: investigation of the extent to which human cultural practices are controlled by genetic information and the nature of the evolved predispositions that shape human cultural learning. This is currently very much a moot point among evolution-and-human-behavior researchers, with evolutionary psychologists and cultural evolutionists taking very different positions (Laland & Brown, 2011). Is human social learning shaped by evolved structure in the mind to be biased to acquiring content—from choosing sugar-rich foods to admiring specific body shapes—that proved adaptive among our

Pleistocene ancestors, as suggested by many evolutionary psychologists? Alternatively, is human learning dominated by general rules, such as copying the highest payoff behavior or conforming to the local norm, acquired largely independent of their content, as claimed by cultural evolutionists?

One major difference that niche construction makes to the evolutionary process is that acquired characteristics can play a role in evolution through their influence on the selective environment. The existence of examples such as the evolution of adult lactose absorption and salivary amylase in response to dairy products and starch introduced into human diets by human agriculture shows that human activities can generate novel phenotypes and modify selection, but it remains to be seen how representative these are (Laland *et al.*, 2010; O'Brien & Laland, 2012).

Niche construction modifies selection not only at the genetic level but at the ontogenetic and cultural levels as well, facilitating learning and mediating cultural traditions, with consequences that not only feed back to the constructor population but also modify selection for other organisms. For example, the construction of towns and cities created new health hazards associated with large-scale human aggregation, such as the rapid and large-scale spread of disease, resulting in epidemics. Humans may respond to this novel selection pressure exclusively or in combination (i) through biological evolution, with selection of resistant genotypes, (ii) at the ontogenetic level, for instance, by developing antibodies that confer some immunity, or (iii) through cultural evolution—for example, by creating hospitals, medicines, and vaccines. Future research will establish the prevalence of these different types of response and delineate rules specifying when each occurs.

A plausible hypothesis is that where a culturally transmitted response to human niche construction is not possible, perhaps because a population lacks the requisite knowledge or technology, then a genetic response will occur. A familiar example is the coevolution of dairy farming and the allele for adult lactose absorption, where several lines of evidence now support the hypothesis that dairy farming created the selection pressures that favored this allele in pastoralist populations. Cultural niche construction can also generate selection on other species, most obviously domesticates. The spread of dairy farming also affected geographical variation in milk-protein genes in European cattle breeds, which covary with present-day patterns of lactose tolerance in humans.

Recent thinking suggests that this kind of selective feedback from human cultural activities to human (and other species) genes may be a general feature of human evolution. Gene–culture coevolution may even be the dominant form of evolution experienced by our species. Geneticists have identified several hundred human genes subject to selective sweeps over the past 50,000 years or less. When one considers the functionality of these genes, it would seem many alleles have been favored as selective responses to human cultural activities (Laland *et al*., 2010). However, much work remains in order to confirm this.

In summary, niche-construction theory offers conceptual tools not yet readily used within the human sciences, such as a variety of experimental and theoretical methods for establishing where niche construction is consequential and quantifying its impact. Such tools may be pertinent for researchers interested in exploring the agency of humans in constructing their world and shaping their development. Niche-construction theory also offers theoretically and empirically derived insights into the dynamics of evolving systems, which could add to the tools used by archaeologists, anthropologists, and psychologists interested in understanding similarly complex dynamic systems.

REFERENCES

Agbai, O. (1986). Anti-sickling effect of dietary thiocyanate in prophylactic control of sickle cell anemia. *Journal of National Medical Association*, *78*, 1053–1056.

Bickerton, D. (2009). *Adam's tongue: How humans made language, how language made humans*. New York, NY: Hill and Wang.

Buchanan, B., O'Brien, M. J., & Collard, M. (2011). The impact of niche construction on the structure of toolkits of hunter-gatherers and food producers. *Biological Theory*, *6*, 251–259.

Cuddington, K. (2011). Legacy effects: The persistent impact of ecological interactions. *Biological Theory*, *6*, 203–210.

Flynn, E. G., Laland, K. N., Kendal, R. L., & Kendal, J. R. (2013). Developmental niche construction. *Developmental Science*, *16*, 296–313.

Kendal, J. R., Tehrani, J. J., & Odling-Smee, F. J. (2011). Human niche construction in interdisciplinary focus. *Philosophical Transactions of the Royal Society B*, *366*, 785–792.

Laland, K. N., & Boogert, N. J. (2010). Niche construction, co-evolution and biodiversity. *Ecological Economics*, *69*, 731–736.

Laland, K. N., & Brown, G. (2011). *Sense and nonsense* (2nd ed.). Oxford, England: Oxford University Press.

Laland, K. N., & O'Brien, M. J. (2010). Niche construction theory and archaeology. *Journal of Archaeological Method and Theory*, *17*, 303–322.

Laland, K. N., & O'Brien, M. J. (2011). Cultural niche construction: An introduction. *Biological Theory*, *6*, 191–202.

Laland, K. N., Odling-Smee, F. J., & Feldman, M. W. (2000). Niche construction, biological evolution, and cultural change. *Behavioral and Brain Science*, *23*, 131–175.

Laland, K. N., Odling-Smee, F. J., & Myles, S. (2010). How culture has shaped the human genome: Bringing genetics and the human sciences together. *Nature Reviews Genetics*, *11*, 137–148.

O'Brien, M., & Laland, K. N. (2012). Genes, culture and agriculture: An example of human niche construction. *Current Anthropology*, *53*, 434–470.

Odling-Smee, F. J., Erwin, D. H., Palcovaks, E. P., Feldman, M. W., & Laland, K. N. (2013). Niche construction theory: A practical guide for ecologists. *Quarterly Review of Biology*, *88*, 3–28.

Odling-Smee, F. J., & Laland, K. N. (2011). Ecological inheritance and cultural inheritance: What are they and how do they differ? *Biological Theory*, *6*, 220–230.

Odling-Smee, F. J., Laland, K. N., & Feldman, M. W. (2003). *Niche construction: The neglected process in evolution*. Princeton, NJ: Princeton University Press.

Pinker, S. (1997). *How the mind works*. London, England: Allen Lane.

Rowley-Conwy, P., & Layton, R. (2011). Foraging and farming as niche construction: Stable and unstable adaptations. *Philosophical Transactions of the Royal Society B*, *366*, 849–862.

Smith, B. D. (2011). A cultural niche construction theory of initial domestication. *Biological Theory*, *6*, 260–271.

KEVIN N. LALAND SHORT BIOGRAPHY

Kevin N. Laland is Professor in the School of Biology at the University of St Andrews (Bute Medical Building, Queen's Terrace, St Andrews, Scotland KY16 9TS, UK). His principal interests are in the general area of animal behavior and evolution, with a specific focus on animal social learning, cultural evolution, and niche construction. He is engaged in empirical studies of animal social learning and innovation, including experimental work with fish, birds, nonhuman primates, and humans. This laboratory work is complemented by theoretical investigations of the role of niche construction in evolution, the diffusion dynamics of learned behavior, and the coevolution of genes and culture throughout human evolution.

MICHAEL J. O'BRIEN SHORT BIOGRAPHY

Michael J. O'Brien is Professor in the Department of Anthropology and Dean of the College of Arts and Science at the University of Missouri (317 Lowry Hall, Columbia, Missouri 65211, USA). His principal interests are the dynamics of information flow in modern societies; the role of agriculture in human niche construction; the coevolution of genes and culture; and the first thousand or so years of the human occupation of North America.

RELATED ESSAYS

Global Economic Networks *(Sociology)*, Nina Bandelj *et al*.

Neighborhoods and Cognitive Development *(Psychology)*, Jondou Chen and Jeanne Brooks-Gunn

Coevolution of Decision-Making and Social Environments *(Sociology)*, Elizabeth Bruch *et al*.

Gender Segregation in Higher Education *(Sociology)*, Alexandra Hendley and Maria Charles
Elites *(Sociology)*, Johan S. G. Chu and Mark S. Mizruchi
Adaptation for Culture *(Anthropology)*, Jill M. Church
Delusions *(Psychology)*, Max Coltheart
Problems Attract Problems: A Network Perspective on Mental Disorders *(Psychology)*, Angélique Cramer and Denny Borsboom
Micro-Cultures *(Sociology)*, Gary Alan Fine
Architecture of Markets *(Sociology)*, Neil Fligstein and Ryan Calder
Culture and Social Networks *(Sociology)*, Jan A. Fuhse
Migrant Networks *(Sociology)*, Filiz Garip and Asad L. Asad
Ethnic Enclaves *(Sociology)*, Steven J. Gold
Cultural Neuroscience: Connecting Culture, Brain, and Genes *(Psychology)*, Shinobu Kitayama and Sarah Huff
The Psychological Impacts of Cyberlife Engagement *(Psychology)*, Virginia S. Y. Kwan and Jessica E. Bodford
Culture, Diffusion, and Networks in Social Animals *(Anthropology)*, Janet Mann and Lisa Singh
Knowledge Transfer *(Psychology)*, Timothy J. Nokes-Malach and J. Elizabeth Richey
Social Classification *(Sociology)*, Elizabeth G. Pontikes
Born This Way: Thinking Sociologically about Essentialism *(Sociology)*, Kristen Schilt
Primate Allomaternal Care *(Anthropology)*, Stacey Tecot and Andrea Baden
Creativity in Teams *(Psychology)*, Leigh L. Thompson and Elizabeth Ruth Wilson
What is Special about Specialization? *(Archaeology)*, Anne P. Underhill
AIDS and Social Networks *(Sociology)*, Alexander Weinreb *et al.*