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# Niche construction, innovation and complexity

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ABSTRACT

Niche construction is the process of environmental modification by organisms. By transforming natural selection pressures, niche construction generates feedback in evolution at various different levels. Niche-constructing species play important ecological roles by creating habitats and resources used by other species and thereby affecting the flow of energy and matter through ecosystems (ecosystem engineering) and can be a source of legacy effects to descendant populations (ecological inheritance). Niche construction theory (NCT) emphasizes how acquired characters play an evolutionary role through transforming selective environments, a point germane to human evolution, where we see extensive environmental modification through cultural practices. Theoretical findings stemming from population-genetic and population-ecology modelling of niche construction suggest that niche construction can be a source of evolutionary innovation and stability, and can generate unusual evolutionary dynamics, such as time-lagged (i.e. inertia, momentum) and autocatalytic responses to selection, and coevolutionary feedback between levels (e.g. gene-culture coevolution). Similar dynamics are predicted in analogous cultural systems subject to human niche construction. Here we present an accessible introduction to NCT and then briefly reflect on how it might be used to study human innovation and complex systems.



## 1. An introduction to niche construction theory

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

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is that species, through the action of natural selection, come to exhibit those characteristics that best enable them to survive and reproduce in their environments. Organisms are generally perceived as being moulded by selection to become well adapted to their environments (Fig. 1a). Under this perspective, “adaptation is always asymmetrical; organisms adapt to their environment, never vice versa” (Williams, 1992,p. 484).

In contrast, the niche-construction perspective emphasizes a second route to the adaptive fit or “complementary match” between organism and environment: It places emphasis on the capacity of organisms to modify environmental states (Lewontin, 1983; Odling-Smee, 1988; Odling-Smee et al., 2003), often but not exclusively, in a manner that suits their genotypes (Fig. 1b). Such matches should be thought of as the dynamic products of a two-way process that involves organisms both responding to “problems” posed by their environments through natural selection and setting themselves some new problems by changing environments through niche construction (Lewontin, 1983, 2000; Odling-Smee, 1988). Niche construction theory (NCT) thus treats evolutionary change as ‘reciprocally caused’ (Laland and Sterelny, 2006), with organisms viewed as co-directing their own evolution. To quote Levins and Lewontin (1985, p. 106): “The organism influences its own evolution, by being both the object of natural selection and the creator of the conditions of that selection”.

Niche construction enables and protects our species’ very existence on this planet: Our oxygen-rich atmosphere would not exist if it were not for the niche-constructing cyanobacteria that started to harvest light and release oxygen ca. 3.6 billion years ago (Stal, 2000), and niche-constructing mangroves reduced the damage and number of deaths in Indian coastal villages caused by destructive tsunami waves (Danielsen et al., 2005) and cyclones (Das and Vincent, 2009). Although niche construction is thus all around us, it often occurs in subtler ways, as illustrated by animals building nests and burrows, plants changing levels of atmospheric gases and bacteria fixing nutrients. In fact, all living organisms construct aspects of their world. In doing so they also fashion new agendas, changing the environment in which they and others about them grow, develop, and learn, frequently in ways that revise the pattern of natural selection acting back on their population as well as on other species that cohabit their niche.

This emphasis on the modification of habitat and resources by organisms is shared by ecologists who emphasize the significance of “ecosystem engineering” by which organisms modulate flows of energy and matter through environments (e.g. Cuddington et al., 2007; Jones and Lawton, 1995; Jones et al., 1994, 1997). 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 (Naiman et al., 1988; Wright et al., 2002). In another example, Lill and Marquis (2003) describe how some caterpillars build shelters from leaves and silk, providing a habitat that is colonized by many other insects. They established that removal of caterpillar-built shelters significantly decreased the mean species richness of insects in the trees, whereas trees with artificial shelters mimicking those manufactured by the caterpillars exhibited increased species richness. Here species diversity depends critically on niche construction.

Niche construction can generate long-term effects on ecosystems. For instance, 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 (Hastings et al., 2007). Such legacies are known as ‘ecological inheritance’, which comprises modified biotic and abiotic states, bequeathed by niche-constructing organisms to descendant organisms (Odling-Smee et al., 2003), and can be viewed as an additional inheritance system (Fig. 1b). Many of the ecological processes that trigger evolutionary episodes depend on niche construction and ecological inheritance (Odling-Smee, 1988). 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, 2010; Odling-Smee and Laland, 2011). This is relevant to the conservation and management of biodiversity and natural resources. Through their niche construction/ecosystem engineering, organisms produce and destroy habitats and resources for other organisms, generating an additional “engineering web” of connectance and control that regulates ecosystem functioning in conjunction with the well-established webs of trophically-connected