

A Comparison of Niche Construction Theory and Diet Breadth Models as Explanatory Frameworks for the Initial Domestication of Plants and Animals

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Abstract The initial domestication of plants and animals and the subsequent emergence of agricultural economies in different world regions represent a major evolutionary transition in human history. Here, two alternative and antithetical explanatory frameworks for initial domestication are compared—one based on diet breadth modeling and the other on niche construction theory. This side-by-side comparison of these two alternative explanations follows them through the basic sequence of stages involved in the scientific method: hypothesis formulation, plausibility consideration, and actual testing of the two hypothetical explanations by measuring their relative strengths with the available archaeological and paleoenvironmental data from two independent centers of domestication in the Americas—eastern North America and the Neotropics. Although focused on the question of initial domestication, this comparative analysis also addresses the broader issues of the appropriate role of theory in the development of hypotheses of past human behavior and the proper use of the scientific method in archaeological inference. Explanations based on diet breadth modeling are found to have a number of conceptual, theoretical, and methodological flaws; approaches based on niche construction theory are far better supported by the available evidence in the two regions considered.

Keywords Agricultural origins · Domestication · Diet breadth model · Optimal foraging theory · Niche construction theory · Human behavioral ecology

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Introduction

By about 10,000 years ago, human societies in eight or more regions of the world had begun to independently domesticate a wide range of different plant and animal species, initiating one of the most important evolutionary transitions in human history. Over subsequent millennia, the farming economies based on these domesticates have allowed humans to inexorably expand agricultural landscapes and gain ever-increasing control of the earth's terrestrial ecosystems (Smith and Zeder 2013).

Archaeologists and biologists have long sought a better understanding of the transition from hunting and gathering to farming, and research on agricultural origins has dramatically accelerated over the past several decades (e.g., Bar-Yosef and Price 2011). This significant increase in research on initial domestication and agricultural origins has been fueled largely by the application of new methods for the recovery, dating, and analysis of archaeobiological datasets, the expanding employment of these methods worldwide, and the parallel rapid improvement and application of genetic approaches to analyzing ancient and modern domesticates (Allaby et al. 2014; Fonseca et al. 2014; Sarkissian et al. 2014; Zeder et al. 2006).

These new approaches and the new empirical datasets they have produced have in turn reshaped both how this major evolutionary transition is perceived and how researchers are achieving a better understanding of the shift from hunting and gathering to farming economies. The vast majority of this recent and ongoing research on agricultural origins exhibits a common perspective—a shared paradigm—under which scholars from several disciplines are pursuing “normal science” (Kuhn 1962). A central aspect of this shared paradigm is that rather than being viewed as a single monolithic research question, “agricultural origins” is now increasingly recognized as being a higher order “general area of inquiry” or “research domain.” This research domain encompasses a substantial expanse of space and time and a wide range of different research questions, datasets, scales of analysis, and analytical approaches.

Spatially, the shift from hunter–gatherer subsistence systems to farming economies is now being actively considered by researchers in an increasing number of world areas, including both those regions that witnessed the independent domestication of plants and animals, as well as other regions into which domesticates and farming economies subsequently diffused. While offering variations on a common theme, each region represents a distinct evolutionary trajectory, and when considered together, they provide a rich set of comparative case studies for anyone interested in looking for variables that may have played a role in agricultural origins across a number of different areas of the world.

Temporally, the transition from hunting and gathering to agricultural economies is also now known to have been quite a long process. In Mexico, for example, domesticates first appear in the archaeological record by 10,000 BP, while the earliest evidence of farming villages does not appear for another 6,000 years, at ca. 4000 BP. Similarly, in eastern North America, the earliest evidence for domesticates dates back to 5000 BP, while evidence for the development of agricultural economies does not appear for about another 4,000 years, at ca. AD 800–1000

(Smith 2001a, 2006a). Given this long period of “low-level food production” (Smith 2001b) that separates initial domestication from the subsequent emergence of unequivocally “agricultural” economies, i.e., “the near total reliance upon domesticated plants or animals” (Winterhalder and Kennett 2006, p. 3), it is worthwhile to recognize initial domestication and the subsequent development of agricultural economies as representing two distinct evolutionary transitions that were separated by thousands of years.

Developmentally uncoupling initial domestication from agricultural origins brings into clear focus an important difference between these two temporally separate transitions. On the one hand, identifying the initial emergence of agricultural economies in the archaeological record of different world regions remains complicated for a number of reasons—primary among these being a lack of consensus regarding how to define the lower boundary of what constitutes “agriculture,” combined with the absence of clear archaeological markers for such a boundary, however it is defined. In contrast, there are numerous well-documented and widely accepted archaeological markers of initial domestication (Zeder et al. 2006). It is this difference in archaeological visibility between initial domestication, on the one hand, and the subsequent initial emergence of agricultural economies, on the other, that accounts for the large disparity in research on the two transitions. The vast majority of research on “agricultural origins” is actually focused on initial domestication, with far fewer studies addressing the subsequent development of agriculture. As a result, research, analysis, and interpretation identified as addressing “agricultural origins” almost invariably are focused on initial domestication.

Research on initial domestication, in turn, is carried out at four different nested scales of analysis and interpretation, ranging from tightly focused to quite general. Within each of these scales of analysis, a community of scholars shares a common perspective and paradigm regarding what the important questions are, what the appropriate methods and standards of evidence are, and what guidelines should be followed in the analysis and interpretation of empirical datasets. At the same time, exemplars—paradigmatic case studies that provide concrete models of how research should be carried out—also can be found at each of the four scales of research on initial domestication. Perhaps most importantly, the community of scholars operating within the current paradigm for research on initial domestication also shares a common general perception of what constitutes acceptable and worthwhile explanations.

First-level analysis

The first, or primary scale or level of analysis, which accounts for a sizable majority of studies on domestication, involves researchers considering multiple and diverse aspects of the domestication of different individual species. Biologists and archaeobiologists, for example, are identifying new archaeological indicators of previously undocumented domesticate species (e.g., Perry and Flannery 2007); using small-sample AMS radiocarbon dating to establish when and where a wide range of different species of plants and animals were initially domesticated; employing genetic profiling to identify the wild progenitor of many different

domesticate species; and documenting the cultural/behavioral and environmental contexts of the initial domestication of different species.

Second-level analysis

A second, higher-order level of analysis and interpretation involves the coalescence of the available, tightly focused, primary studies that consider different aspects of the domestication of a particular species into an overall profile of domestication for that species. Because of the ongoing and constantly expanding scope of research on domestication, such efforts at combining and synthesizing all of the available information for a particular species are resulting in the generation and constant updating of individual histories of domestication of an increasing number of plant and animal species worldwide (e.g., Perrier et al. 2011; Smith 2014; Staller et al. 2006; Zheng et al. 2014)

Third-level analysis

In a similar fashion, the various domestication profiles of individual species that were brought under domestication in the same world regions are being coalesced to form regional-scale syntheses of the transition from hunting and gathering to low-level food production for all of the different independent centers of domestication that have been identified worldwide, as well as those areas that witnessed the subsequent introduction of domesticates and food-production economies. Such regional-scale developmental syntheses—overviews of the timing, sequence, and species composition of the plant and animal domesticates of emerging low-level food production economies in different world areas—fall comfortably into the long-established general “regional synthesis” genre of archaeological explanation. Regional-scale syntheses of initial domestication (aka “agricultural origins”) are often compiled in edited volumes (e.g., Bar-Yosef and Price 2011; Cowan and Watson 1992), and less frequently in single-author global treatments of agricultural origins (e.g., Bellwood 2004; Smith 1995).

Fourth-level analysis

Finally, global-scale, general synthesis frameworks of explanation for initial domestication, which are applicable to multiple world areas, are occasionally proposed. Such general explanations of domestication attempt to identify and focus on the common underlying causal variables involved in domestication worldwide. Rapidly expanding empirical datasets available for different domesticate species and for different world areas, as documented in regional-scale syntheses, are facilitating the search for common variables across regions, while also steadily increasing the amount and the variety of relevant data that any proposed global synthesis explanation must contend with.

Although a variety of such global-scale efforts to account for the shift from hunting and gathering to food production have been proposed over the last 100 years (Zeder 2009a; Zeder and Smith 2009), two newly formulated alternative

and antithetical explanations for initial domestication have recently gained prominence—the first based on diet breadth modeling (DBM) of the optimal foraging theory (OFT) family of models (Gremillion 1998, 2004; Kennett and Winterhalder 2006; Piperno 2006, 2011), and the second on niche construction theory (NCT) (Smith 2007b, 2011a, b, 2012; Smith and Yarnell 2009; Smith and Zeder 2013; Zeder 2012).

In the following sections of this article, I provide a detailed side-by-side comparison of these two mutually exclusive explanatory frameworks, covering a range of topics from the theoretical foundation of each to the manner in which each employs the scientific method, and the extent to which each is supported by the available and relevant archaeological, archaeobiological, and paleoecological data. This comparison of DBM-derived and NCT-based explanations of initial domestication is greatly facilitated by a recent article by Gremillion, Barton, and Piperno (2014) in which they present a comprehensive overarching synthesis of the OFT/DBM perspective and approach to explaining the initial domestication of plants and animals worldwide, as well as a critique of the current paradigm. This excellent summary of the OFT/DBM conceptual, theoretical, and methodological framework both provides a starting point and suggests an organizational structure for assessing the relative explanatory strength and global applicability of DBM-based and NCT-derived accounts of domestication.

The optimal foraging/diet breadth critique of the current paradigm

In their overarching synthesis of the OFT/DBM approach to explaining initial domestication, Gremillion et al. (2014) call upon researchers operating under the existing paradigm to instead join them in adopting a better perspective, a better paradigm—one based on solid theoretical principles and rigorous methodology. This emphasis on the appropriate and rigorous adoption of theory and method in addressing the question of initial domestication offers an excellent framework for comparing DBM and NCT explanations in the following sections of this article. In their overview, Gremillion et al. (2014) clearly articulate many of the general principles and concerns that have been expressed over the past several decades by researchers employing the OFT/DBM perspective. Focusing primarily on regional-scale syntheses carried out under the current paradigm, Gremillion et al. (2014), for example, call for causal explanations of initial domestication rather than the cultural–historical narrative that such regional summaries often take. They also argue that potential explanations of domestication must be generalized enough to be applicable to many different world regions, rather than being region-specific, and that following OFT principles, they must be initially formulated in a top-down manner, from the established higher-level theory, rather than in a “particularistic” bottom-up inductive approach based on empirical data. Gremillion et al. (2014) also ask researchers to rigorously employ the hypothetico-deductive version of the scientific method in testing their proposed explanations.

Interestingly, although not explicitly acknowledged, the synthesis overview of the OFT/DBM “paradigm” offered by Gremillion et al. (2014) evokes in both tone

and message many of the more strident aspects of the “New Archaeology” debates of the 1960s and 1970s that marked a paradigm revolution of sorts, and which called for the replacement of descriptive culture historical narratives with processual analyses and causal explanations derived from higher-level theory. In the paradigm crisis of four decades ago, accompanying the calls for the pursuit of cultural process analysis and causal explanations, there also were long and often painful dialogues regarding the need for archaeology to become less historical and more scientific (Sabloff et al. 1973; Smith 1977). These discussions often centered on which form of scientific reasoning should be adopted. Somewhat surprisingly, as I discuss below, the perhaps inadvertent *déjà vu* adoption by Gremillion et al. (2014) of the main points of the New Archaeology debates of four decades ago does not include any apparent appreciation or awareness of how those debates of a past generation were eventually resolved, particularly in regard to the appropriate use of theory and method in archaeology (Hill 1972; Sabloff et al. 1973; Smith 1977).

While acknowledging that other overarching frameworks might be employed, Gremillion et al. follow OFT/DBM principles in arguing that neo-Darwinian evolutionary theory is essential in order to understand the initial domestication of plants and animals worldwide: “evolutionary theory... must play a central role in OA [origins of agriculture] research” (Gremillion et al. 2014, p. 6171; see also Piperno 2006, p. 137).

Coupled with the OFT/DBM perspective that proposed explanations of initial domestication must be both generally applicable rather than region-specific and must be derived from higher-level evolutionary theory, Gremillion et al. (2014) argue that once formulated, the relative strength of any such evolutionary explanation must be determined within a particular version of the scientific method—the hypothetico-deductive method. Concern is expressed regarding the lack of scientific rigor among particularists and the “erosion of scientific method” by those who have chosen “to abandon the iterative process of hypothesis testing, revision, and retesting that drives incremental advances in scientific understanding,” and they call for “a systematic program of theoretically driven hypothesis testing” carried out within a hypothetico-deductive framework in order to establish how well a proposed explanation for initial domestication is supported by available archaeological evidence (Gremillion et al. 2014, pp. 6171, 6172).

Gremillion et al. (2014) also lump the current non-OFT/DBM explanations of initial domestication developed under the established paradigm under the general heading of “particularism.” This label of particularism appears to encompass a remarkably broad spectrum of researchers, including, for example, all of the other participants in the special feature of PNAS in which the Gremillion et al. (2014) article appears, as well as all of the participants, excepting Piperno, in the recent Wenner Gren conference on the origins of agriculture (Bar-Yosef and Price 2011), along with numerous other researchers worldwide.

Particularist researchers operating under the established paradigm are considered parochial in that their focus is constrained within their particular region of interest, and their explanations are inductive in nature—data-based, bottom-up, and undisciplined—i.e., “fashioned from a hodgepodge of factors and variables selected at the discretion of the researcher” (Gremillion et al. 2014, p. 6172). Following a

general OFT perspective, such particularist explanations also are characterized as insufficiently theoretical and under-theorized: “current expressions of particularism, rather than disavowing theory, embed it in arguments without explicit acknowledgement or relegate it to a minor role that prioritizes empirically based inference” (Gremillion et al. 2014, p. 6172). Based on general OFT principles, Gremillion et al. (2014, pp. 6171, 6172) also are troubled by “a lack of a general theory for human behavior” and “the absence of theoretically based assumptions” among particularists, as well as by “the erosion of scientific method” caused by the current expressions of particularism, which “highlight local events and processes and downplay general principles” and do not interpret “human behavior as a product of natural selection,” thereby missing “the opportunity to explore commonalities in human behavior that enable comparative analysis of agricultural origins.” In contrast to the prevailing paradigm, the OFT/DBM approach “examines theoretical assumptions before interpreting data,” draws upon these “theoretically based assumptions,” and derives potential explanations from “high level bodies of general theory.” In contrast, particularist efforts are described as being inductive rather than deductive and as emerging out of empirical data at a parochial, regional scale of analysis rather than from “broadly applicable principles” (Gremillion et al. 2014, pp. 6171, 6172). Gremillion et al. (2014) single out the alternative NCT explanation of initial domestication for specific criticism, citing its lack of a general theory of human behavior and its employment of “vaguely conceptualized properties or goals” that “betray embedded assumptions about the ecological situations that humans prefer and presumably strive for” (Gremillion et al. 2014, p. 6173).

The established paradigm, the OFT/DBM critique, and the logical structure of archaeological inference

The overarching synthesis of the OFT/DBM perspective and the critique of the prevailing paradigm offered by Gremillion et al. (2014) reprise/resurface a number of important issues regarding the general structure of archaeological inference first debated four decades ago. How do we know what we know, and what is the most appropriate and robust logical route to gaining a better understanding of past reality? Should the “undertheorized” and “particularist” researchers operating under the established paradigm abandon it in favor of an OFT/DBM approach? What is the role of theory in the formulation and assessment of the strength of proposed explanations of initial domestication? Is explicit acknowledgment of one’s theoretical perspective essential, and must proposed explanations of past reality, including initial domestication, be derived from overarching evolutionary theory? Do regional-scale case study applications of OFT and DBM provide compelling explanations of initial domestication that are superior to those developed under the existing paradigm? Is the hypothetico-deductive method of scientific reasoning superior to the form of empirically based inductive inference ascribed to particularists, and is the hypothetico-deductive method widely employed in archaeological inference?

Consideration of these and other issues and questions are explored in the following sections of this article, as the DBM approach is compared, side by side, with the alternative and antithetical framework of explanation for initial domestication derived from NCT and developed under the existing “particularist” paradigm. Following the call for rigorous and appropriate employment of evolutionary theory and the scientific method (Gremillion et al. 2014), this comparison of the two alternative explanatory frameworks follows them through the basic sequence of steps or stages involved in the scientific method: (1) hypothesis formulation, (2) determining the plausibility of alternative hypotheses, (3) formulation of predictions or test implications for alternative hypotheses, and (4) testing the competing hypotheses against empirical reality. Archaeological, archaeobiological, and paleoenvironmental datasets from two independent centers of domestication in the Americas—eastern North America and the Neotropics—are employed in the actual testing of the DBM and NCT explanations for initial plant domestication.

The initial formulation of hypotheses: Where do proposed explanations of past or present-day reality come from?

The first challenge facing anyone interested in employing the scientific method to explain some aspect of empirical reality involves coming up with a hypothesis, which can be defined as a statement that “is taken as a premise, in order that its logical consequences can be examined and compared with facts that can be ascertained by observation” (W. Salmon 1963, p. 77). Philosophers of science have long been interested in how possible explanations of reality, past or present, are initially developed—where the ideas come from. It remains one of the most interesting and elusive aspects of the scientific cycle (Simon 1973).

The origin of optimization theory and diet breadth models and hypotheses: Neo-Darwinism or microeconomics?

Following standard OFT principles, Gremillion et al. (2014) argue that to have any explanatory value, hypotheses—potential explanations—for the initial domestication of plants and animals, as well as other major transformations in human history, should be derived, at the onset, from high-level, coherent, and consistent bodies of general theory of human behavior, rather than from any observations of empirical reality. Particularist explanations are inadequate because they emerge out of direct observation of empirical reality.

While acknowledging that in terms of considering which high-level body of general theory to employ, evolutionary theory is not “...the only realm from which to choose,” Gremillion et al. (2014, p. 6171) argue that neo-Darwinism has “earned status as an overarching framework for explaining the diversity of life,” that “...evolutionary theory is central to understanding the root causes of human behavior and indeed culture itself,” and that “...evolutionary theory (broadly construed to include cultural as well as biological processes) must play a central role in OA research” (Gremillion et al. 2014, p. 6171). While neo-Darwinism occupies

the highest and most inclusive ranking in their canon of evolutionary theory (Fig. 1), several other disciplines and subdisciplines are subsumed under it, and each of these are informed and empowered from above: “high-level bodies of general theory inform middle- and lower-level theories that in turn generate testable hypotheses” (Gremillion et al. 2014, p. 6172). Evolutionary ecology is nested comfortably under neo-Darwinism, and behavioral ecology (including human behavioral ecology—HBE) in turn is included under evolutionary ecology. Optimal foraging theory is nested within HBE, and diet breadth models are identified as one of the family of optimal foraging models with particular relevance to agricultural origins. Although higher levels of theory are often invoked (i.e., neo-Darwinian evolutionary theory, evolutionary ecology, human behavioral ecology, and optimal foraging theory) in support of the position that explanations for initial domestication be derived from neo-Darwinian evolutionary approaches, a primary focus is on the fifth and lowest rung in the hierarchy of evolutionary theory—diet-breadth models—and on the central role they should play in any efforts to explain initial domestication and the emergence of agricultural economies. Within the family of OFT models, only the DBM has been employed in efforts to explain initial domestication, since it provides a predictive model that establishes the conditions under which lower-ranking resources like the progenitors of crop plants will enter the diet of foragers prior to their eventual domestication. The DBM “is particularly well suited for studying major directional changes in human subsistence over time because of its ability to make robust, qualitative predictions of prey choice and dietary diversity” (Piperno 2006, p. 141).

Given the exclusive application and central role assigned to diet breadth models, it is worthwhile to briefly describe the model, as recently presented by Winterhalder and Kennett (2006). The basic DBM begins with individual foragers as they decide whether or not to harvest a resource they encounter as they move through their local environment. Under the DBM, the forager’s decision will be based on the energy value, ease of capture, and post-acquisition handling costs of the encountered resource. Over time and according to the model, the decisions of an individual as he/

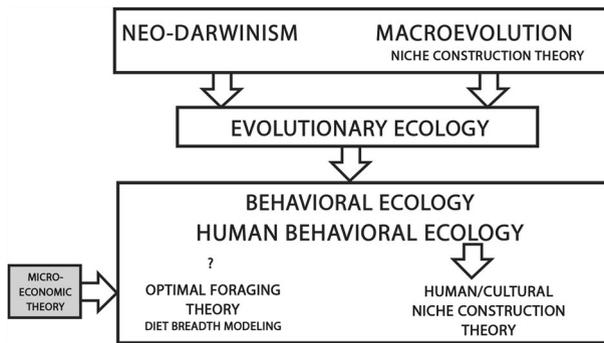


Fig. 1 The hierarchical canon of evolutionary theory as outlined in Gremillion et al. (2014), with macroevolution, niche construction theory, human/cultural niche construction theory, and microeconomics added to the schematic organizational framework

she encounters different resources of various energy values can then be aggregated, along with the similar decisions of other individuals following the rules of the model, to predict the behavior of larger groups and how those aggregated individual decisions can be observed in the archaeological record.

Decisions made under the rules of DBM should lead to the optimization of some aspect of resource selection that is in turn assumed to increase the fitness of the individual and the larger group. The most commonly employed “currency”—that aspect of resource selection that is optimized, and the one employed in DBM efforts at explanation of initial domestication—is energy or net caloric returns (other currencies include nutritional balance and risk avoidance; see Winterhalder and Kennett 2006).

In the “energy as currency” version of DBM, the amount of energy encapsulated in a resource package, combined with its ease of acquisition and post-acquisition handling costs, determines whether the forager will decide to pursue and harvest a resource once it is encountered, or if he/she will continue to search “with the expectation of locating more valuable resources to pursue” (Winterhalder and Kennett 2006, p. 14). If continuing to search for a more valuable resource is expected to yield a higher payoff in terms of energy capture than the resource a forager has just encountered, “even after allowing for additional search time, then the optimizing forager will elect to pass by the encountered resource, and will continue to do so no matter how frequently this type of resource is encountered” (Winterhalder and Kennett 2006, p. 14).

Under the rules of DBM, foragers formulate and always follow an explicit ranked list of all the resources in an environment, with the ranking of any resource based on its energy value (energy content + handling and processing costs). Starting with the highest ranked, most profitable resource (e.g., large-bodied slow prey with low handling cost), and working down the ranked list, a knife-edge boundary is eventually reached when the next lower resource on the ranked list is estimated to provide a lower energy yield than the overall energy yield of the ranked resources above it (Winterhalder and Kennett 2006). According to the DBM, regardless of their abundance, resources below this “optimal diet” boundary line will always be passed by: “...resources within the optimal diet are always pursued when encountered; those outside the optimal diet will always be ignored. There are no ‘partial preferences,’ such as ‘take this organism 50% of the time it is encountered’” (Winterhalder and Kennett 2006, p. 15).

This knife-edge boundary that divides optimal diet resources above the line from those that are always shunned because they fall below the line plays the central role in efforts to employ DBM in explanations of initial plant domestication worldwide. Small-seeded plants and those species having underground storage organs are considered to always fall below the optimum diet line, based on their low energy value and high processing costs (Gremillion et al. 2014), and as a result, under the rules of the DBM, they will enter the diet of foraging populations only when the optimum diet boundary line has been pushed down the ranked resource list to include them.

Such a downward movement of the boundary line (and the addition of the lower-ranked previously excluded resources such as small-seeded plants and tubers) is

often termed “resource intensification” and identified as being the result of declining foraging efficiency due to “resource depression”—a reduction in the relative abundance and frequency of encounter of higher-ranked resources by human foragers (Winterhalder and Kennett 2006, p. 5). Under the DBM, resource depression—an imbalance between resource availability and human demand, and the resultant downward shift in the boundary line that results in the initial inclusion of potential domesticates in a forager’s diet—represents an adaptive response by forager populations to an environmental change. Such disruptions can be either on the supply side (a change in the local biotic community that results in a lowering of the human carrying capacity of a resource catchment area), or on the demand side (e.g., an increase in human population density resulting in higher harvesting levels of local resources).

Despite the call for researchers to employ the hypothetico-deductive method of scientific inference and pursue the “iterative process of hypothesis testing, revision, and retesting that drives incremental advances in scientific understanding” (Gremillion et al. 2014, p. 6172), efforts to employ DBM as an explanatory framework for initial domestication have not so far included any explicit statements of hypotheses to be tested, but rather rely on the abstract theoretical model briefly outlined above. Given the rigid and formulaic aspects of DBM, however, an explicit hypothesis regarding domestication can be easily derived.

A DBM-derived hypothesis for initial domestication by small-scale hunting and gathering societies is that it was an adaptive response to resource depression. This resource depression—an energy imbalance between supply (optimum diet resources) and demand (human food requirement)—resulted in diet breadth expansion and the lowering of the optimum diet boundary line farther down the resource rank order and the addition of lower-ranking, lower-value plant and animal resources that were not previously utilized. Resource depression and the resultant initial addition of potential eventual domesticates into the optimum diet is caused either on the demand side—a result of human population growth (an inexorable universal trend, or occurring as societies are confined within increasingly inadequate resource territories, or forced into marginal environments), or on the supply side—a result of climatic and environmental change leading to a reduction in the relative biomass of optimum diet species in the environment. Once added to the optimum diet of small-scale hunting and gathering societies, low-value small-seeded plants and tubers were eventually domesticated.

When the DBM-derived “resource depression, diet breadth expansion” hypothesis for initial plant domestication in the Americas is explicitly stated, one of its most obvious shortcomings comes into clear focus. While the DBM provides a potential explanation for the initial addition of a variety of low-value plant or animal resource into the optimum diet of hunting and gathering societies, it offers no explanation or behavioral context or higher-level general theory of human behavior regarding how and why some of those newly added resources are subsequently brought under domestication for the first time (Smith 2006b, p. 300). The explanatory focus is shifted away from domestication itself to the precursor resource selection decisions that “bring foragers into contact with potential domesticates,” and how these newly encountered potential domesticates “enter the optimal diet,

initiating the process of domestication under coevolutionary pressures” (Winterhalder and Goland 1997, p. 147).

Since it offers only a potential precursor account of how species that were subsequently domesticated may have been initially added to the diet of forager groups at some point in time prior to their actual domestication, rather than addressing the actual domestication process itself, DBM would appear to provide, at best, only a potential account of a preliminary prerequisite step in the trajectory toward domestication—i.e., to be brought under domestication, candidate species must first enter the diet.

Several other problems with the DBM emerge when its relationship to the higher-level evolutionary theories from which it is derived are considered. OFT/DBM, as well as their higher levels of evolutionary theory—neo-Darwinism, evolutionary ecology, and human behavioral ecology—do not include universal laws, covering laws, or even law-like statements (Gremillion et al. 2014). It is argued, however, that OFT/DBM “variables, processes, and assumptions—often remain relevant at a more modest level of generality” and that “OFT is one class of models with a reasonable purchase in the explanatory realm” (Gremillion et al. 2014, pp. 6172, 6174).

Embedded within the general OFT/DBM argument regarding why explanations derived from OFT/DBM must play a central role in accounts of plant and animal domestication and agricultural origins, while those developed within the established particularist paradigm are not worth considering, is an unstated *a priori* assumption or belief that any proposed explanation for past or present-day reality can be accepted or rejected—before it is even formulated or subjected to testing to ascertain how well it accounts for observed reality or how well it fits available data—based on whether or not it can demonstrate its pedigree as derived from a nested series of higher-order theory that begins with neo-Darwinian evolution and ends with OFT and, in most cases, the DBM. Simply put, it is assumed that proposed explanations derived from this cascade of linked theoretical frameworks are imbued with greater explanatory power than any proposed particularist explanation because OFT/DBM explanations derived in this manner are informed and reified by higher-level evolutionary theory.

Although the proponents of OFT/DBM may prefer to draw their proposed explanations of initial domestication and the emergence of agriculture exclusively from what they consider to be broadly applicable OFT/DBM principles, such OFT-derived explanations cannot at the outset of the scientific process be assigned any greater explanatory potential or power, relative to other proposed explanations, before they are subjected to plausibility consideration and subsequent tests against empirical reality: “Specific hypotheses generated on the basis of foraging theory principles or expectations derive no predictive power or explanatory status from their source” (Smith 2006b, p. 297). In the absence of general covering laws, all proposed alternative explanations or hypotheses, once formulated (hypothesis formulation), are equal in standing until they are subjected to a careful and balanced assessment of their probability or plausibility of being successful (plausibility consideration) and, if retained, are subsequently subjected to comparison with available and relevant empirical datasets (empirical testing). This rejection under

OFT/DBM guidelines at the very beginning of the scientific process of any hypothesis not derived from higher-level theory is in direct contradiction of the general logical structure of the scientific method.

In contrast to the negative characterization provided of potential explanations proposed under the current “particularist” paradigm that “prioritize empirically based inference” and “rely on inductions that are expected to stand on the strength of available evidence alone” (Gremillion et al. 2014, p. 6172), such inductive formulation of hypotheses based on observation of empirical reality is perfectly appropriate within archaeology. Inference and confirmation in archaeology are, in fact, always inductive (M. Salmon 1976; Smith 1977). The initial formulation of any OFT/DBM-based explanation, like any other attempt at explanation in archaeology, is a logically inductive enterprise, since any test implications or observational predictions are not logically deduced from hypotheses (they do not follow *of necessity* from them), but rather are “inductive implications” that are “inferred with high probability” (M. Salmon 1976, p. 378).

The particularist explanations of initial plant domestication that are developed through induction, from observation of empirical reality, in fact, fall under the same process of inductive reasoning as those derived from higher-level theory. In addition, even if OFT/DBM researchers believe and state that they are employing the hypothetico-deductive method in their reasoning, they are not. The hypothetico-deductive method cannot be employed in archaeology (M. Salmon 1975, 1976; W. Salmon 1963, 1967; Smith 1977). The general method of scientific inference that is appropriate to employ in archaeology generally, including efforts to explain initial domestication, was outlined a half-century ago (W. Salmon 1963, 1967) and described in detail more than 35 years ago under the “hypothetico-analog” label, since argument by analogy plays an important and unavoidable role in archaeological inference (Smith 1977; see Smith 1978 for a monograph-length case study application of the hypothetico-analog method of inductive confirmation in archaeology).

There also is a long and rich history of remarkable explanations of evolution (including cultural evolution), evolutionary history, and the diversity of life being formulated on the basis of close and careful observation of empirical reality. Charles Darwin’s theory of natural selection, for example, which is the highest-ranking general theory invoked by OFT/DBM proponents, was developed, as every student of evolution learns early on, out of Darwin’s long and quite varied observation and compilation of empirical data and, most famously, his journey to the Galapagos Islands on the HMS Beagle. It is more than a little ironic that Darwin and his theory of the origin of species would clearly fall under the “particularism” label, while at the same time his inductively formulated, empirically based theory of evolution occupies the pinnacle of the OFT/DBM hierarchical evolutionary canon.

It also is important to consider the origin of OFT and its diet breadth models. Both are identified as a tool of the research program of HBE, with HBE being included under evolutionary ecology, and evolutionary ecology in turn being a subdiscipline of neo-Darwinian evolutionary theory (Fig. 1). In this hierarchy of increasing generality, “higher-level bodies of general theory inform middle- and lower-level theories that in turn generate testable hypotheses” (Gremillion et al.

2014). Within this strongly linked and nested hierarchy of canon theory, with lower-level theory being derived from, and informed by, higher-level overarching theory, OFT/DBM principles are presented as derived from, informed by, and supported by each level of higher, more inclusive, and more generally applicable theoretical canon, beginning with neo-Darwinian evolutionary theory, down through evolutionary ecology and human behavioral ecology.

Optimal foraging theory and its family of models, including DBM, however, have quite a different origin: they were not derived from or informed by any higher levels of evolutionary theory (i.e., evolutionary ecology and neo-Darwinian evolutionary theory); rather they came into biology through a side door. In the mid-1960s MacArthur and Pianka (1966, p. 603) suggested that “[t]here is a close parallel between the development of theories in economics and population biology” and proposed the application of optimization theory of microeconomics to population biology. When initially proposed for application in population biology less than 50 years ago, optimization was not an already well-established modern biological principle nor a standard approach in biology derived from evolutionary ecology and neo-Darwinism; rather it was clearly recognized as a borrowed hypothesis in need of testing: “Hopefully, natural selection will often have achieved such optimal allocation of time and energy expenditures, but such ‘optimum theories’ are hypotheses for testing rather than anything certain” (MacArthur and Pianka 1966, p. 603). So rather than being derived from higher-level evolutionary theory and suffused with all of the associated explanatory power, status, and support, OFT and its DBM were developed out of models borrowed from microeconomics.

In the half century since MacArthur and Pianka introduced “optimum theories” from microeconomics into population biology, OFT and DBM are portrayed as having become established as “modern biological principles” and “now standard approaches in biology” (Gremillion et al. 2014; Piperno 2006). Optimization theory, however, is far from being embraced as an established principle and standard approach in biology. There has, in fact, been considerable and still ongoing debate over the last five decades regarding both the degree to which the principle of optimization fits within evolutionary theory (i.e., does optimization behavior result in increased fitness or provide organisms with a selective advantage and increased fitness?), as well as the relative explanatory value and general utility of OFT and DBM in biology. In a growing number of assessments across multiple disciplines, optimization theory has been shown to not be supported by real-world datasets (e.g., Gray 1987; Jones 1999; Levi et al. 2011; Pierce and Ollason 1987; Sih and Cristensen 2001; Simon 1999; see extended discussion and additional references in Smith 2012; Zeder 2012).

The origin of niche construction theory: Macroevolution and asymmetrical adaptation

In contrast to OFT/DBM, which have their origin in microeconomics and whose incorporation into modern biology and neo-Darwinian evolutionary theory as accepted principles and standard approaches over the past half decade is

questionable at best, niche construction theory (NCT) was developed directly out of macroevolutionary theory in the mid-1980s (Fig. 1). Macroevo-lutionary theory was formulated as a direct challenge to the then dominant neo-Darwinian view of evolution that had been created out of combining Darwinian concepts of natural selection with principles of population genetics, and which considered evolution to be confined to changes in allele frequencies within individual organisms resulting from gene flow, genetic drift, and natural selection shaping phenotypic expression of random genetic variation (Gould 2002; Gould and Lewontin 1979).

In contrast to the tightly focused “trait-level” selectionist approach of neo-Darwinism, macroevolutionary theory focuses at a “macro” scale of analysis—on organisms as integrated wholes or constellations and hierarchies of interacting traits; organisms changed and were shaped as much by historical contingencies and constraints to change as by the specific adaptive attributes of individual traits (Elredge 1989; Elredge and Gould 1972; Gould 1989, 2002; Gould and Lewontin 1979; Seilacher 1972; Vrba and Eldredge 1984).

One of the key differences between the application of neo-Darwinism and macroevolutionary theory in both biology and in archaeology centers on the issues of directionality and intent in evolution. In evolutionary biology, neo-Darwinism rejects the possibility of evolution being directional, while for macroevolutionary biologists, evolutionary change may be highly directional in nature, following developmental corridors shaped by structural and historical constraints and by the hierarchical nature of evolutionary process. Similarly, while neo-Darwinian archaeologists disavow any element of human intent in culture change (Gremillion et al. 2014; Lyman and O’Brien 1998), macroevolutionary archaeologists view human agency as a key component of cultural evolution that allows cultures to respond to pressures more quickly and with a greater degree of flexibility and directedness than found in biological evolution (Chatters and Prentiss 2005; Rosenberg 1998; Spencer 1997; Zeder 2009a, b, 2012).

Along with developing new perspectives regarding the roles of directionality and intent or agency in evolution that are in direct opposition to the tenets of neo-Darwinism, macroevolutionary theory also produced a major redefinition of the concept of adaptation and its role in natural selection. A “unidirectional” or “asymmetrical” definition of adaptation was the consensus within evolutionary theory up through the 1970s and is still a key component of neo-Darwinism. According to this traditional definition, adaptation is a one-way street in which environments change and species adapt: “Adaptation is always asymmetrical; organisms adapt to their environment, never vice versa” (Williams 1992, p. 484). The principle of asymmetrical adaptation also plays a prominent central role in OFT and DBM, and, as discussed above, it is a clear and explicit component in the neo-Darwinian application of OFT/DBM efforts to explain initial domestication.

In 1983, however, Lewontin (1983) argued that organisms do not simply respond to the environment but in fact interact with and modify their surroundings—they actively engineer ecosystems, and they shape their own niches. Expanding on Lewontin’s original proposal, Odling-Smee et al. (2003, p. 18) argue that niche construction is universal and should be regarded, along with natural selection, as a second major participant in evolution: “There are in fact two logically distinct

routes to the evolving match between organisms and their environments: either the organism changes to suit the environment, or the environment is changed to suit the organism.”

The core principle of NCT and cultural or human niche construction is the deliberate engineered enhancement of ecosystems. Niche construction occurs when an organism modifies the relationship between itself and its environment. Such modification has the potential to provide individuals and populations with an evolutionary advantage. By altering their surrounding environments, and associated selective pressures, populations can increase the chances of survival of subsequent generations of their species: “Niche construction by organisms significantly modifies the selection pressures acting on them, on their descendants, and on unrelated populations,” and as a result, “niche constructing organisms frequently influence their own evolution by modifying their own selective environments” (Odling-Smee et al. 2003, p. 2).

Situating macroevolutionary theory and niche construction theory within the hierarchy of higher-level evolutionary theory as outlined by Gremillion et al. (2014) provides a clear outline of how NCT relates to the various levels and forms of theory they discuss, particularly HBE and OFT/DBM (Fig. 1). Macroevo­lutionary theory can be added to the top tier of theory, as an equal and antithetical alternative to neo-Darwinism, with NCT representing an integral aspect of it. Cultural niche construction theory (CNC) in turn falls within HBE, where it provides an antithetical alternative to the OFT family of models, including DBM. This placement of macroevolutionary theory, niche construction theory, and cultural niche construction theory into the theoretical template outlined by Gremillion et al. (2014) underscores the necessity of recognizing that HBE accommodates a rich variety of different theoretical perspectives and analytic approaches and is not populated exclusively by adherents of OFT (Smith 2012, p. 269; Zeder 2012, p. 260).

Human or cultural niche construction research, in fact, is not a new addition to HBE; rather it has been a long-term very productive component of behavioral ecology. This is not surprising, given that humans are “the ultimate niche constructors” (Odling-Smee et al. 2003, p. 28; Smith 2007a). Human ecologists have been documenting and analyzing niche construction efforts by small-scale human societies worldwide under a variety of different labels for more than 80 years (e.g., anthropogenic ecology, engineered environment, environmental manipulation, forest management, indigenous management, traditional resource management, etc.) (Smith 2011b, table 1), and CNC is increasingly yielding significant new evolutionary insights (e.g., Bliege Bird et al. 2008, 2012). In contrast to the DBM-based proposed explanation for initial domestication, the CNC hypothesis can be directly and clearly linked to higher-level evolutionary theory.

An NCT-derived explanation of initial domestication (Smith 2012) can be explicitly stated. Small-scale foraging societies occupying the resource-rich ecosystems (e.g., river floodplain corridors and lake and marsh/estuary margins) that emerged during the early and middle Holocene in many regions of the world established small central-place settlements consisting of a dozen or so household units. Ranging outward from these settlements, they established and maintained resource catchment zones that included a high density and diversity of plant and

animal resources. Detailed traditional resource management systems were developed, refined, and passed down from generation to generation through cultural inheritance, and components of resource-zone biotic communities were comprehensively “auditioned” to assess their potential both for sustained economic utilization and as targets of niche construction. Of the wide range of species subjected to varying degrees and forms of trial-and-error experimental manipulation and life-cycle intervention, many were identified as low-value candidates for enhancement, while others with economic utility responded in ways that encouraged and rewarded additional investment of human capital. The positive feedback loops that formed between small-scale societies and some members of this latter species group resulted in important and sustained traditions of management of essentially “wild” populations, while others led to domestication.

Although the term “resource-rich” has recently been labeled as an “undefined or vaguely conceptualized” property (Gremillion et al. 2014, p. 6173), the concept of an ecosystem being rich in resources is straightforward. It simply means that the types of environments so described (e.g., river floodplain corridors, lake and marsh/estuary margins) provide an abundance and a variety of resources that are of potential value to forager societies. The term “resource-rich” can be quantified in terms of biomass of useful species per unit of area, and it can be measured in the archaeological record in terms of the range and abundance of species present in archaeobiological assemblages recovered from archaeological sites. As proposed in the CNC theory of initial domestication, foragers occupying such resource-rich environments are able to establish and maintain local resource catchment zones within which a high density and diversity of plant and animal resources were available for experimentation and management. The concept of human foragers being attracted to settings having abundant resources and high carrying capacity is not new. Employing the descriptive phrase “significant supplies” rather than “resource-rich” (the two terms would appear to be relatively equal in terms of their degree of definition and conceptualization), Piperno and Pearsall, for example, describe such settings in the Neotropics as follows:

Rivers and the edges of lakes and swamps also offer more favorable conditions of settlement and resource supply than those of the interior forest. They may hold significant supplies of native fish as well as capybaras, turtles, iguanas, shore birds, and other high quality resources. Many species of palms form dense aggregations on swampy soils and around the edges of shallow or seasonal water bodies, whereas they are much more dispersed in the dryland forest. Peccaries, tapirs, pacas, and other frugiverous mammals will congregate around these areas in order to feast on the copious palms fruits that are available (Piperno and Pearsall 1998, p. 74).

This CNC hypothesis and the higher-level NCT and macroevolutionary theory from which it is derived are all directly and explicitly antithetical to both OFT/DBM and neo-Darwinian theory in that they reject asymmetrical adaptation that is at the core of OFT/DBM. Although Gremillion et al. (2014) argue that niche construction is compatible with OFT/DBM, human enhancement of “natural” ecosystems is very rarely considered in OFT/DBM applications, and then in a marginal and often

imbedded rather than explicit manner, leaving OFT/DBM approaches “undertheorized” in this regard. For example, in Kennett and Winterhalder’s 2006 edited volume, *Behavioral Ecology and the Transition to Agriculture*, which showcases the full range of OFT approaches to agricultural origins, there is no mention of “niche construction” or equivalent terms for human–environmental management, and no consideration of human enhancement and encouragement of resources. Underscoring this absence of any consideration of human niche construction or inclusion of deliberate environmental enhancement by human foragers in OFT/DBM approaches, Gremillion et al. (2014) are careful to refer to the higher-level and more inclusive disciplinary category of behavioral ecology rather than OFT/DBM in their brief consideration of niche construction, citing the “active role of humans in shaping their habitats” that are sometimes included in “applications of behavioral ecological models in archaeology” (Gremillion et al. 2014, p. 6175).

Plausibility consideration: Assessing the relative explanatory potential of alternative hypotheses based on prior performance

If the form of scientific inference that is actually practiced by most scientists (W. Salmon 1963, 1967), including archaeologists (M. Salmon 1975, 1976), is to be properly carried out, a researcher is required to consider the relative strength of not just the hypothesis he/she has formulated but also all other logically possible hypotheses that might account for the same set of logical consequences. As described by philosophers of science (e.g., M. Salmon 1975; W. Salmon 1967), scientists are expected to address the difficult issue of an abundance of alternative hypotheses: What are the chances that the deduced prediction would be true if the hypothesis we are testing is false, and some other hypothesis is true? Zeder (2012) provides an extended consideration of this issue in her discussion of the application of DBM in the Near East. The same question may be reformulated: “Are there other hypotheses which would be strongly confirmed by the same outcome?” (W. Salmon 1963, p. 82). This basic challenge of reducing the number of unlimited alternative hypotheses to be considered and subsequently subjected to testing is addressed through the complex process of “plausibility consideration,” which involves an assessment of the relative plausibility and prior probability of alternative hypotheses (M. Salmon 1976, pp. 378–379). Plausibility considerations involve “direct consideration of whether the hypothesis is of a type likely to be successful” (W. Salmon 1967, p. 118). “At this stage we are trying to determine whether a hypothesis deserves to be seriously entertained and tested or whether it should be cast aside without further ceremony” (W. Salmon 1967, p. 113). Such plausibility considerations are “not only admissible in the logic of confirmation, they are an indispensable part of it” (W. Salmon 1967, p. 118).

For archaeologists interested in employing the scientific method and working through plausibility consideration of alternative hypotheses, an initial decision involves the choice of a reference class, also referred to as “establishing boundary conditions” (Ascher 1961) or defining the “domain of applicability” (M. Salmon 1975, p. 461) within which prior examples or analogs can be demonstrated to have

been successful. In archaeology, plausibility considerations invariably take the form of argument by analogy (Binford 1967; Smith 1977): “A form of inference in which it is reasoned that if two or more things agree with one another in one or more respects they will probably agree in yet other respects” (Neilson 1956, p. 94). Prior examples employed in archaeological plausibility considerations should show a confirmed cause and effect relationship between the specific human behavior pattern considered in the hypothesis and a resultant pattern of material remains that can be observed in the archaeological record, thereby providing support for the viability of the hypothesis prior to testing.

Since archaeological inference in general is concerned with attempting to understand past human behavior, the most obvious initial boundary condition that is applied in defining the appropriate reference class or domain of applicability in archaeology is at the species level—prior examples or analogs that support the probability that the hypothesis is likely to be successful are limited in large part to those involving *Homo sapiens*. Analogs or prior examples drawn from human societies are preferable to those drawn from other species (e.g., the leeches, langurs, and fur seal examples cited in Gremillion et al. [2014, p. 6174] in support of the DBM). Within this species-level reference class, further narrowing of the domain of applicability can be made through consideration of the general level of sociopolitical complexity of potential ethnographic analog examples, as well as the nature of their subsistence economy and their environmental setting: “As a general rule, archaeologists employ the suggested criteria of similarity of environment and similarity of subsistence adaptation in defining the boundaries of a reference class” (Smith 1977, p. 606). The canon is to seek analogies in cultures that manipulate similar environments in similar ways (Ascher 1961, p. 319). Experimental archaeology and replication studies, as well as analogs focusing on the nonhuman side of human–environmental interactions, also supplement the range of potential non-ethnographic analogs that are available for possible consideration during plausibility consideration in archaeological inference (Smith 1977, p. 607).

The actual size of the reference class that is established in any archaeological situation and the nature of the boundary conditions that are employed will depend on the quality and the number of potential ethnographic and other analogs that are available. In his landmark study of Broken K Pueblo, for example, Longacre (1970, p. 28) restricted his plausibility consideration to a small reference class consisting of the Western Pueblos, whereas Binford’s (1972, pp. 42–44, 53–55) classic methodological study of smudge pits and hide smoking required a much larger selection of analog examples from the Great Lakes region, the Plains, and the southeastern United States.

Following these general guidelines, the appropriate reference class for establishing the prior probability of hypotheses attempting to explain initial domestication would encompass present-day and historically described small-scale human societies that were at a similar level of sociopolitical complexity and situated in similar environments to those societies that domesticated plants and animals in the distant past, and which span the transition from having no reliance to having a limited reliance on domesticates.

The absence of plausibility consideration in diet breadth model explanations of initial domestication

Plausibility consideration, an “indispensable” part of the scientific method, is explicitly omitted in diet breadth model applications. In place of the plausibility consideration phase of the scientific process, a simple litmus test is employed. Any hypothesis derived from OFT principles (most commonly incorporated within the DBM) is passed through to the final phase of hypothesis testing with no consideration of how well the OFT-derived hypothesis performed in explaining empirical reality in similar situations in the past. At the same time, no non-OFT-derived hypotheses are considered along with, or compared to, OFT-derived hypotheses or allowed through to empirical testing. By removing from consideration prior to testing all alternative hypotheses to those derived from OFT, such OFT-derived hypotheses are guaranteed to provide the best fit with empirical reality, since they are the only ones being considered.

While Gremillion et al. (2014, p. 6174), for example, make reference to a number of recent case studies of the attempted application of diet breadth models to account for the foraging behavior of both nonhuman (e.g., leeches, seals, langurs) and human populations, which have provided “valuable insights on varied topics,” none of the studies mentioned is employed in an effort to meet the plausibility consideration requirements of scientific reasoning and archaeological inference and to provide support for the pre-testing viability of the DBM model as an explanation for initial domestication. Surprisingly, one of the human case studies Gremillion et al. (2014) cite as evidence for the successful application of OFT/DBM to hunter–gatherer prey selection (Levi et al. 2011) instead provides a concise statement of the problem facing any effort to identify and employ a reference class composed of ethnographic hunter–gatherer case studies of the application of the diet breadth model: “Despite many applications of optimal foraging theory to human hunters, *human hunting does not meet the assumptions of the simple optimal foraging theory model*” (Levi et al. 2011, p. 173, emphasis added). Human ecologists studying small-scale hunting societies in an increasing variety of ecosystems are documenting patterns of decision making that are far more complex and involve a quite sizable and much more diverse set of rules than those set out in the basic DBM in which “optimal foragers are predicted to exhibit a knife-edge behavior, such that prey items are either fully included or excluded from the diet” (Levi et al. 2011, p. 172). In their recent study of an indigenous group in Manu National Park, Peru, Levi et al. (2011) found that resource selection was not based just on the three variables included in the simple DBM (i.e., prey size, ease of acquisition, and handling costs); rather it involved a complex and situationally variable mix of additional factors directly involving human intentionality, including distance from home, time available to hunt, amount of ammunition remaining, meat already acquired, and the maximum amount that could be carried home.

In another surprising choice, Jones’ (1999) classic synthesis and assessment of optimization theory in political science also is referenced as providing support for the “rational-actor optimization logic of HBE (e.g., that people will act in their own best interest with regards to survival-related utility)” (Gremillion et al. 2014,

p. 6173), which is considered a “general theory” or “template” for human behavior generated by natural selection. This method of hypothesis generation from general theory is contrasted with the particularist practice of employing “creative or arbitrary combinations of a ‘bounded rationality’... *drawn opportunistically from ethnographic or contemporary observations*” (Gremillion et al. 2014, p. 6173, emphasis added). Rather than providing support for the rational-actor optimization logic of OFT/DBM, however, Jones explicitly rejects rational-actor optimization as being essentially a theoretical construct of microeconomics having no real-world applications. Along with rejecting the optimization principle employed in OFT/DBM, Jones discusses at length the broad acceptance within political science of the bounded rationality view of the world that Gremillion et al. (2014) identify with the established and empirically grounded particularist paradigm of research on initial domestication and the misplaced reliance on ethnographic analogs.

In his consideration of the development and broad acceptance of bounded rationality theory (employed by “particularists”) in the field of political science, Jones contrasts it to the comprehensive rationality and rational-actor expected utility models of economics, which form a core theoretical principle of OFT/DBM, in the actual testing of models against empirical reality.

Like comprehensive rationality, bounded rationality assumes that actors are goal-oriented, but bounded rationality takes into account the cognitive limitations of decision makers in attempting to achieve those goals. Its scientific approach is different; rather than making assumptions about decision making and modeling the implications mathematically for aggregate behavior (as in markets or legislatures), bounded rationality adopts an explicitly behavioral stance. The behavior of decision makers must be examined, whether in the laboratory or in the field (Jones 1999, p. 298).

Jones (1999) points out that the “rational actor expected utility” models of economics, which are explicitly equated with the “rational-actor optimization logic” and “survival-related utility assumptions of HBE” (Gremillion et al. 2014), have been found to provide a very poor fit with the real world and are no longer seriously considered an accurate descriptive theory.

There is no longer any doubt about the weight of the scientific evidence; the expected-utility model of economic and political decision making is not sustainable empirically. From the laboratory comes failure after failure of rational expected utility to account for human behavior. From systematic observation in organizational settings, scant evidence of behavior based on the expected utility model emerges (Jones 1999, p. 297).

In a particularly telling assessment, Jones discusses how researchers in economics and political science reacted to both the failure of the rational-actor expected utility models of economics that form the core of OFT/DBM and the success of the bounded rationality approach to explaining empirical reality attributed to the established particularist paradigm for research on initial domestication. “Bounded rationality and organizational identification (now considered a consequence of bounded rationality) won ready acceptance in political science, with

its emerging empiricist orientation, but they were largely ignored in the more theoretical discipline of economics” (Jones 1999, pp. 300–301). Or as Nobel laureate Herbert Simon put it, economists “mostly ignored [bounded rationality] and went on counting the angels on the heads of neoclassical pins” (Jones 1999, p. 300).

Jones’ analysis helps highlight the greater emphasis that OFT/DBM places on adherence to a particular theoretical perspective as opposed to the actual testing of alternative explanations for initial domestication. On the one hand, the rational-actor optimization logic and survival-related utility assumptions derived from the comprehensive rationality and expected-utility models in economics have been shown to lack any empirical support both in political science and more broadly in the social sciences. At the same time, OFT/DBM explicitly rejects the bounded rationality perspective that prioritizes actual comparison of theory against extant datasets, and which has been accepted across a wide range of disciplines in the social sciences and described as “the most important idea (even academic school of thought) that political science has ever exported” (Jones 1999, p. 300).

In a further substantial departure from standard application of the scientific method, OFT practitioners also restrict their analysis to a single hypothesis, DBM-derived or otherwise, as opposed to considering multiple alternative hypotheses. Rather than comparing competing hypotheses side by side, OFT/DBM proponents instead prefer to consider a single hypothesis, with the explicit commitment to then modify the original hypothesis as needed, describing the process as an “iterative process of hypothesis testing, revision, and retesting” (Gremillion et al. 2014, p. 6172). The relative value of this variation of the scientific method, of course, rests with the extent to which the process of revision and retesting of a single hypothesis actually involves the second-round consideration of alternative explanations, or if it consists of what Jones (1999, p. 310), in his characterization of the common practice of economists embracing comprehensive rationality, described as “post hoc theorizing” (see also Green and Shapiro 1994).

Although no formal DBM-derived hypotheses regarding initial domestication have been explicitly stated (with the exception of the one offered above), OFT-based potential explanations for domestication are invariably derived from DBM, since DBM alone among the OFT family of models can accommodate and potentially explain changes in prey selection and resource utilization: “the DBM is particularly suited for studying major directional changes in subsistence through time because of its ability to make robust qualitative predictions of prey choice and dietary diversity” (Gremillion et al. 2014, p. 6174).

Consideration of a single proposed explanation for initial domestication, invariably drawn from DBM, is counter to one of the basic hallmarks of the scientific method and scientific inference—the open and inclusive side-by-side consideration of a rich variety of alternative potential explanations, and their rigorous assessment and direct comparison with each other to determine which one provides the best fit with the available empirical information. This failure to employ a side-by-side comparison of a variety of competing hypotheses is particularly problematic in archaeology, where employment of the scientific method must invariably involve a reasoned selection between alternative explanations: “In

archaeological reasoning the issue is not and cannot be one of establishing or confirming the strength of a single hypothesis, but rather attempting to demonstrate which of a number of alternative, tentative solutions seems more correct” (Hill 1972, p. 83). “There is no single, totally accurate solution to any archaeological problem area, but rather only a choice as to which of a number of tentative solutions is best supported by the data available at any one time” (Smith 1977, p. 610).

In a now classic rationalization for the lack of concern by OFT researchers of their acknowledged failure to follow a long-established and essential aspect of the scientific method—the consideration of multiple alternative hypotheses (Chamberlin 1965; Smith 2006b)—Bettinger (2006, p. 321) states: “My more fundamental problem with the method of multiple working hypotheses is its suggestion that I should spend time developing plausible alternatives. In my view the responsibility for that falls squarely on those who doubt the hypothesis I’m working on; it keeps me busy enough as it is.”

Plausibility consideration and building a reference class for the cultural niche construction theory of initial domestication

The development of a hypothesis explaining initial domestication from NCT closely follows the standard and long-established procedure for plausibility arguments and reference class delineation in archaeological inference. The CNC reference class that is employed is defined by a clear and explicit set of boundary conditions and consists of present-day and historically described small-scale societies that span the transition from having no reliance to having a limited reliance on domesticates (Smith 2001b, 2011a, b, 2012). From this reference class of small-scale human societies, a set of five general attributes are drawn, based on consideration of synthetic studies carried out by scholars having substantial knowledge of both the small-scale societies included in the reference class and the topics under consideration (Smith 2012).

The societies in the CNC reference class (1) have well-defined resource areas; (2) maintain and consistently update a comprehensive knowledge of local ecosystems; (3) establish various forms of “ownership” of “wild” (nondomesticated) resources; (4) engineer ecosystems across multiple generations through traditional ecological knowledge transfer; and (5) increase the abundance, predictability, and accessibility of targeted wild species through ecosystem engineering or niche construction (see Smith 2012, pp. 261–266 for an extended discussion of these general attributes). These five higher-level general principles of human behavior provide the plausibility foundation of support for the CNC theory having a reasonable likelihood of success in accounting for initial domestication.

Having considered the relative pre-test strengths and weaknesses of the diet breadth model and the cultural niche construction theory as potential explanations of plant domestication, we now turn to comparing these two proposed explanations with each other and with empirical reality to determine which provides the most complete and most compelling account of how human societies in the Americas first brought plants under domestication. As we test these two competing explanations, the most important point to keep in mind is that, having advanced through

plausibility consideration (with the DBM hypothesis being given a free pass) and reached the testing phase of the scientific method, they are considered to be equal. Determining their relative value in explaining past reality will be based entirely on how well they match up with available archaeological datasets. As mentioned earlier, and contrary to the view of Gremillion et al. (2014, p. 6172), they are, in fact, “expected to stand on the strength of available evidence alone.”

Hypothesis testing: Formulation of test implications and comparison of alternative hypotheses with empirical reality

Side-by-side comparison of alternative competing hypotheses to determine which provides the closest match to empirical reality begins with the formulation of “observational predictions” or “test implications” for each of the hypotheses. Such test implications can be either positive (providing support for) or negative (contradicting) specific hypothesis. Test implications are of little value when the causative human behavior patterns identified in alternative hypotheses can be shown to result in the same, or very similar, patterns in the archaeological record. The most valuable type of test implication is one that provides support for one hypothesis while contradicting another. Inferring observational predictions involves two interrelated tasks: actually identifying and explicitly stating them, and also demonstrating a strong cause-and-effect relationship between the hypothesis and each test implication. Demonstrating a logical link or “bridge” between a hypothesis and an observational prediction is often referred to as establishing a bridging argument or argument of relevance (Smith 1977, pp. 611–612), which often draws on analogies considered during plausibility consideration. There is no set of guidelines for identifying any or all of the test implications for a specific hypothesis. Discovering test implications, like formulating theories or hypotheses, is a creative process: “Finding implications, like finding hypotheses, is a problem located in the context of discovery rather than the context of justification” (M. Salmon 1975, p. 462).

Once test implications for competing hypotheses have been identified and explicitly stated, the actual testing of the alternative proposed explanations of past reality is straightforward and involves compiling all available evidence that is relevant to the problem being considered and then comparing test implications with these data to determine how well each hypothesis is supported or contradicted by empirical reality (Smith 1977, pp. 613–614). The hypothesis with the greatest number of true test implications as well as the fewest number of false test implications is judged to provide the strongest explanation.

Comparing the relative values of the diet breadth model and the cultural niche construction theory in explaining plant domestication in the Americas is complicated by the fact that, in spite of a voiced concern with the perceived “erosion of scientific method” by those who have chosen “to abandon the iterative process of hypothesis testing, revision, and retesting that drives incremental advances in scientific understanding” and the call for “a systematic program of theoretically driven hypothesis testing” (Gremillion et al. 2014, pp. 6171, 6172), OFT/DBM proponents rarely offer a presentation or discussion of, or reference to, any test

implications for DBM-derived hypotheses, and none are offered in the regional-scale examples of the diet breadth model considered here—eastern North America (Gremillion 1998, 2004) and the Neotropics (Piperno 2006, 2011). In both examples, “empirical testing” of the diet breadth model consists of a description of the general model, a presentation of archaeological and paleoenvironmental information considered relevant to the question of initial plant domestication, and a concluding summary in which the general model and the archaeological data are discussed. In effect, the specific diet breadth hypothesis and its associated test implications remain imbedded in the general diet breadth model rather than being explicitly stated and examined, and the “testing” of the model, in isolation from consideration of test implications of alternative hypotheses, takes a loose but quite proscribed narrative form.

Given the rigid and formulaic aspects of the diet breadth model, however, and its presentation in the eastern North America and Neotropics case studies, it is possible to develop an initial set of ten test implications for the competing DBM and CNC hypotheses. As mentioned earlier, identifying test implications is not a simple or straightforward process, and there are a variety of additional observational predictions to the ten presented here that could be formulated and employed in additional testing of the two competing hypotheses. The ten initial test implications employed here were selected because each provides support for only one of the alternative explanations, and most are directly linked to one of the most obvious and most significant differences between the DBM and CNC hypotheses for plant domestication in the Americas—the presence or the absence of resource depression.

The DBM hypothesis rests on the concept of asymmetrical adaptation and predicts that initial domestication occurs as a human response to an episode of resource depression—an energy imbalance between supply (optimal diet resources) and demand (human food requirement)—which results in diet breadth expansion and the dietary addition of lower-ranked plant resources. Test implications for the DBM hypothesis would include actual evidence for the causes of resource depression: e.g., population increase as represented by an increase in the number or size of settlements, or evidence of environmental or climate change that could be inferred as resulting in a reduction in the relative abundance and availability of high-ranking food resources. This emphasis on seeking empirical evidence for the actual causes of resource depression is important to emphasize, since OFT practitioners often rely on proxy measures drawn from the list of possible results rather than the causes themselves (Zeder 2012, pp. 254–255).

The CNC hypothesis, in contrast, rests on the higher-level general principle of human behavior centered on active human enhancement of local environments and predicts that initial domestication occurred within a context of stable or enhanced resource availability and utilization in the absence of any evidence of resource depression and energy imbalance. Test implications supporting the CNC hypothesis situate initial domestication within a context of resource abundance as opposed to resource depression and include evidence of low population density as reflected by settlements that are relatively small and few in number, paleoenvironmental evidence for the emergence of resource-rich environments, indicated by archaeobiological assemblages that exhibit human harvesting of a broad and diverse

spectrum of species from biotic communities with no evidence for resource depression, and evidence of human enhancement of local environments (e.g., burning, forest clearing).

- Test
Implication 1: Evidence of population growth just prior to or concomitant with the initial appearance of domesticates or their wild progenitors in forager diets would support the DBM hypothesis but not the CNC hypothesis
- Test
Implication 2: The absence of evidence of population growth just prior to or concomitant with the initial appearance of domesticates or their wild progenitors would contradict the DBM hypothesis but not the CNC hypothesis
- Test
Implication 3: Evidence of climatic and environmental change reflecting a reduction in the relative biomass of optimum diet species in ecosystems just prior to or concomitant with the initial appearance of domesticates or their wild progenitors would support the DBM hypothesis but not the CNC hypothesis
- Test
Implication 4: The absence of evidence of climatic and environmental changes reflecting a reduction in the relative biomass of optimum diet species in ecosystems just prior to or concomitant with the initial appearance of domesticates or their wild progenitors would contradict the DBM hypothesis but not the CNC hypothesis
- Test
Implication 5: A reduction of high-ranking resources in forager diets just prior to or concomitant with the initial addition of lower ranking resources, including domesticates or their wild progenitors, would support the DBM hypothesis but not the CNC hypothesis
- Test
Implication 6: The absence of evidence for a reduction of high-ranking resources in forager diets just prior to or concomitant with the initial addition of lower-ranking resources, including domesticates or their wild progenitors, would support the CNC hypothesis but not the DBM hypothesis
- Test
Implication 7: Evidence of human niche construction and deliberate and sustained modification of local ecosystems prior to or concomitant with the initial appearance of domesticates would support the CNC hypothesis but not the DBM hypothesis
- Test
Implication 8: The absence of evidence of human niche construction and deliberate and sustained modification of local ecosystems prior to or concomitant with the initial appearance of domesticates would contradict the CNC hypothesis but not the DBM hypothesis
- Test
Implication 9: A rapid transition to agricultural economies following the initial addition of domesticates to the optimum diet of forager societies would support the DBM hypothesis
- Test
Implication 10: The absence of a rapid transition to agricultural economies following the initial addition of domesticates to the optimum diet of forager societies would contradict the DBM hypothesis

The last two test implications are derived from a recent article by Bettinger et al. (2010) regarding the initial domestication of broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) in north China. In their analysis of the initial domestication of these two crop plants in north China, Bettinger et al. argue that once added to the diet, domesticates should quickly move up the resource rank list and fuel a rapid transition to agricultural economies—that the diet breadth model “predicts that once cost differentials favored it at all, agriculture should have been immediately pursued in full; that is, agricultural intensification should have been rapid” (Bettinger et al. 2010, p. 11). Noting that this DBM prediction is not supported by existing archaeological evidence anywhere in the world—domesticates in general play a very small subsistence role for thousands of years subsequent to their initial domestication (Smith 2001b)—Bettinger et al. (2010) draw the same general conclusion regarding the limitations of the diet breadth model and similar optimization models that Jones (1999) reached regarding their use in political science and related fields; that Gray (1987) and others have reached in the biological and evolutionary sciences; and that Levi et al. (2011) reached in regard to human foraging societies: “Part of the difficulty here is that agricultural transitions entail more forces than are recognized in diet breadth” (Bettinger et al. 2010, p. 11). Only 4 years after this forceful and explicit rejection of the basic diet breadth model as having any value in explaining the transition to food production in north China or in any other region of the world, Barton would join Gremillion and Piperno in insisting that DBM provides a framework for understanding this major transformation in human history that is far superior to any “particularist” explanations offered by practitioners of the established paradigm for research on initial domestication.

The initial domestication of plants in the seasonally dry tropical forests of the lowland Neotropics: Comparing the DBM and CNC hypotheses

A DBM-based explanation for the initial domestication of plants in the lowland Neotropics has been presented in two recent articles (Piperno 2006, 2011; see also Piperno and Pearsall 1998). Although this regional-scale case study encompasses a broad area of the Neotropical lowlands, extending from southern Mexico down through Central America and including a large area of northern South America, the explanatory application of the DBM is limited in scope to a portion of northern South America because it is the region that offers the best archaeological record of initial plant domestication in the Neotropics (Piperno 2006, p. 152). Within this region of northern South America, two oval areas are outlined as being of particular interest as potential centers of initial domestication, with Oval D1 identified as a likely area of domestication for four important lowland crop plants (sweet potato—*Ipomoea batatas*, squash—*Cucurbita moschata*, arrowroot—*Maranta arundinacea*, and achira—*Canna edulis*), and a possible area of domestication for three more (sieva bean—*Phaseolus lunatus*, yautia—*Xanthosoma saggitifolium*, and lerén—*Calathea edulis* (Piperno 2006, p. 154; Piperno 2011, fig. 1).

In this northern South America study area, it is proposed that the late Pleistocene-to-early Holocene transformation of vegetation communities set the stage for initial plant domestication. During the late Pleistocene, from about 20,000 BP to

11,000–10,500 BP, the northern South America region, including the D1 Oval, is characterized as being generally covered by savanna/thorny scrub vegetation communities that “*probably* contained dense associations of dry-land cacti and legumes (e.g., *Opuntia*, *Prosopis*, *Agave*), which offered an appreciable high-quality and low-cost, edible biomass, with *little cost* of processing” (Piperno 2006, p. 151, emphasis added). In addition, these open savanna/thorny scrub landscapes “*undoubtedly* were homes to many of the more than 30 genera of now extinct, large and medium-sized grazers and browsers... and hunting in drier and more open areas was *probably* a profitable pursuit” (Piperno 2006, p. 149, emphasis added).

At the Pleistocene–Holocene transition, however, between about 11,000 and 10,500 BP, “the climate rapidly turned warmer and wetter, and elements of seasonal tropical forest moved from their glacial locations and began to replace most of the savanna/thorny scrub floristic associations,” and by “about 10,000 to 9,000 BP, depending on the region, paleoecological records indicate that where a Pleistocene landscape had supported savanna-like vegetation, species rich, seasonal tropical forests now flourished” (Piperno 2006, p. 152). A variety of species of plants are identified as being initially brought under domestication soon after the decline in high-ranking resources, particularly Pleistocene megafauna, took place. This stage-setting shift from a “particularly faunal rich” late Pleistocene savanna/thorny scrub landscape that supported a variety of megafauna prey species, to an early Holocene seasonally dry tropical forest in which “game animals are few in number” and small in size, and “forest plants are poor in calories and widely dispersed in space” (Piperno 2006, pp. 142–144), followed closely by plant domestication, conforms to the OFT/DBM unidirectional or asymmetrical concept of adaptation—that adaptation is a one-way street in which environments change and species adapt.

Changes in return rates of a sufficient magnitude likely to elicit new adaptations can be associated with major, natural changes to the environment, as oscillating climate and vegetation bring changes in resource density and distribution and necessitate a series of new options for humans with regard to the availability, exploitation, and procurement of plants and animals (Piperno 2006, p. 146).

Building on this foundation of major environmental change and loss of megafauna resources at the Pleistocene–Holocene boundary, the DBM-derived explanation for initial plant domestication in the Neotropics employs the standard diet breadth model based on optimization of energy return.

“Energetic return rates, in fact, are the single best predictor of foraging patterns among modern tropical hunters–gatherers. Energy production and efficiency can therefore be comfortably placed at the heart of a scrutiny of why foraging strategies change” (Piperno 2006, p. 141). “In summary, the single most important factor driving subsistence changes after the close of the Pleistocene probably was the dramatic decline in foraging return rates associated with the demise of glacial-period resources and expansion of forests into regions where open land vegetation had prevailed during glacial times. The removal of many mega- and large- to medium-sized fauna from a resource

set and the need to practice foraging full-time in a tropical forest would immediately force subsistence options in the direction of lower-ranked resources and substantially broaden the diet breadth. Following the diet breadth model, people would have started to cultivate some plants as soon as the net return from subsistence strategies involving plant propagation exceeded those resulting from full-time foraging” (Piperno 2006, p. 152).

While optimization of energy return is identified as *the* essential variable in this DBM-based explanation, risk reduction and resource security are explicitly omitted from consideration as playing a role in initial plant domestication in the Neotropics because small-scale societies in tropical forests rely upon kinship networks in times of resource shortfall.

Because I am exploring the applicability of optimal foraging theory, I largely leave aside the issues of risk reduction and resource security. There is substantial evidence that in simple groups of tropical foragers and horticulturalists, food sharing in the form of extensive household exchange is the most important tactic used to counter risk (Piperno 2006, p. 166).

This represents a significant change in perspective from earlier assessments regarding the relative importance of risk reduction and resource security in the initial domestication of plants in the Neotropics: “It is suggested that the initial domestication of indigenous plants and acceptance of introduced cultivars represented a low-cost strategy to buffer resource variation and unpredictability” (Piperno 1989, p. 539). “I suggest that in these circumstances an economic strategy predicated on some degree of food production would result in a more predictable, secure, and synchronous resource base” (Piperno 1989, p. 544). “In searching for proximal causes of early farming in Panama, I take the view that food production represents a reliable and inexpensive alternative and buffer to the low productivity and periodic shortages of naturally available foodstuffs” (Piperno 1989, p. 550).

The DBM-derived explanation of initial domestication in the Neotropics also lacks any consideration of the potential relevance of environmental enhancement by human societies and only briefly mentions human niche construction during the time frame of initial plant domestication: “Some paleoecological records (e.g., from Panama and Brazil) attest to considerable forest burning and the creation of smaller-scale forest openings between ca. 11,000 and 7000 BP” (Piperno 2006, p. 154); “they frequently manipulated and altered their environments by creating clearings in forests and/or burning them” (Piperno 2011, pp. S456–457).

A number of empirical and theoretical problems with this DBM-based explanatory framework can be identified, particularly in regard to the characterization of the savanna/thorny scrub landscapes of northern South America as supporting a variety and abundance of megafauna, and the assumed importance of these high-ranking species in the diet of late Pleistocene “big-game hunter” societies of the region. As implied by the use of the qualifiers “undoubtedly” and “probably” in the above descriptions of the animal and plant species forming the biotic community of the savanna/thorny scrub environments, no references are provided regarding available faunal or floral datasets that provide information

regarding the actual composition of the vegetation or animal communities of these late Pleistocene landscapes—the biotic community descriptions provided are informed projections. In addition, no well-documented late Pleistocene archaeological sites have so far been identified in the savanna/dry scrub vegetation zones described, and no empirical evidence exists for the subsistence base of the forager groups that are proposed to have occupied them.

Recent research now, in fact, indicates that Pleistocene megafauna were in all likelihood no longer present in northern South America when Paleoindian hunter–gatherer groups first arrived. A comprehensive meta-analysis of megafaunal extinctions, environmental change, and human arrival throughout South America places the last well-dated occurrence of megafauna (species weighing more than 44 kg) in northern South America at 15,000 BP, a full 3,000 years prior to the earliest evidence for Pleistocene hunter–gatherers in the region: “the dates analyzed suggest extinction intensity and timing may have varied across the South American continent, starting in the north long before humans ever arrived” (Barnosky and Lindsey 2010, p. 20, fig. 8a).

The 5,000-year temporal gap opened up by the meta-analysis of Barnosky and Lindsey (2010) between the last occurrence of megafauna and the earliest apparent evidence for plant domestication in northern South America, along with their conclusion that megafauna were never part of the diet of late Pleistocene foragers in the region, presents a serious challenge to the DBM-based explanation. This five-millennia gap and the absence of megafauna from late Pleistocene human diets makes it extremely difficult to cast the loss of megafaunal prey as representing a resource depression that set the stage for a resultant adaptive shift to plant domestication.

The location of the D1 Oval, identified as one of the two centers of plant domestication in northern South America (Piperno 2011, fig. 1), raises another difficulty for the DBM-based explanation in that the D1 oval could not possibly have witnessed the transition from the rich resource base of the late Pleistocene savanna/thorny scrub environments (if it existed) to the impoverished dry seasonal forests of the early Holocene and the associated resource depression that preceded initial plant domestication. The simple reason is that based on environmental reconstructions of the D1 Oval area (Gnecco 2003, p. 14; Gnecco and Aceituno 2006, pp. 91–92; Gnecco and Mora 1997), as well as its placement in the presentation of the DBM-derived explanation (Piperno 2006, p. 154, fig. 7.4; Piperno 2011, fig. 1), the D1 Oval is not, in fact, situated within the savanna/dry scrub vegetation zone but rather encompasses a number of inter-Andean river valleys that supported a dry seasonal forest vegetation cover during the late Pleistocene rather than grasslands and scrub vegetation.

Along with the 5,000-year gap that separates the last occurrence of megafauna and the earliest report of domesticates in northern South America, there is also a substantial and significant conceptual gap separating the potential explanatory reach and appropriate application of the DBM and how it is actually employed. The DBM is explicitly invoked to explain the initial domestication of plants in the Neotropics: “Following the diet breadth model, people would have started to cultivate some plants as soon as the net return from subsistence strategies involving plant

propagation exceeded those resulting from full-time foraging” (Piperno 2006, p. 152). “Finally, following the DBM, people would have initiated the cultivation of some plants when the net return from this strategy exceeded the return from full-time hunting and gathering” (Piperno 2011, p. S465). As discussed above, however, while the DBM can be used to potentially account for the dietary addition of low-ranked resources in response to resource depression and could be proposed as providing a framework of explanation for the initial dietary addition of the wild progenitors of Neotropical domesticates (if resource depression could be demonstrated), it does not offer any account of the subsequent context or process of domestication. As Winterhalder and Goland (1997, p. 147) point out, the DBM addresses “precursor resource selection decisions which bring foragers into contact with potential domesticates and how these newly encountered potential domesticates enter the diet,” but it provides no potential account of how the domestication process itself proceeds once low-ranking species are actually added to the list of utilized resources. In the words of Gremillion et al. (2014, p. 6172), the diet breadth model “lacks a general theory for human behavior” that can account for the domestication process. The conceptual paradox inherent in the DBM-derived explanation for initial plant domestication is clearly evident in the key phrase: “people would have initiated the cultivation of some plants when the net return from this strategy exceeded the return from full-time hunting and gathering” (Piperno 2011). The obvious question to be raised is how would forager groups have known when to initiate cultivation because it would provide a higher net return from full-time hunting and gathering if they were not already cultivating?

Based on the foregoing discussion, it is not surprising that the DBM-based explanation for the initial domestication of plants in the Neotropics gains no support from any of the 10 test implications presented above and is contradicted by three (T2, T4, and T10). The documented absence of megafauna in late Pleistocene human diets in the region contradicts the claim for a late Pleistocene-to-Holocene environmental downturn and associated resource depression. Recognition of the D1 Oval as supporting a seasonal dry tropical forest ecosystem during the late Pleistocene rather than savanna/thorny scrub vegetation further undercuts the case for environmental downturn and resource depression as setting the stage for initial domestication in the region. There is, in fact, very little archaeological information available that would allow a comparison of late Pleistocene and early Holocene subsistence economies and patterns of resource selection within the savanna/thorn scrub vegetation zone. Finally, there is no evidence of a rapid increase in the economic importance of domesticated plants following initial domestication in this region.

In contrast to the DBM-based explanation for initial plant domestication in the Neotropics, which finds little empirical support in the archaeological and paleoecological records, the CNC is supported by considerable research carried out over the last 25 years on the timing and spatial patterning of initial human colonization of northern South America, and the growing recognition that late Pleistocene and early Holocene forager populations in the Neotropics were actively modifying and managing their local ecosystems. Although environmental modification plays no role in more recent applications of the DBM in an effort to explain

initial plant domestication in the region, evidence of niche construction by late Pleistocene and early Holocene Neotropical foragers was documented more than 25 years ago in Panama by Piperno et al. (1991a, b).

“Pleistocene hunters and gatherers were not passive actors in their landscape.... Here, an anthropogenic disturbance and fire horizon appears suddenly at ca. 11,050 BP. This horizon is characterized by massive increases in particulate carbon and the appearance of pollen and phytoliths from plants of forest gaps, many of which show signs of direct burning and may indicate cultural *maintenance* of forest clearings” (Piperno et al. 1991a, p. 213). “The La Yeguada forests were occupied and modified between 11,000 and 10,000 BP, well before any signs of agriculture in the region. The disturbance patterns here, high and sustained levels of charcoal and invasive taxa...point to exploitation of forests for their subsistence resources” (Piperno et al. 1991a, p. 218). “Over a nearly 11,000-year period, habitat modification, apparently accomplished mainly with the use of fire, was pervasive and systematic” (Piperno et al. 1991b, p. 247).

In their recent synthesis of the now substantial body of archaeological evidence for the initial human settlement of northwest South America, Aceituno et al. (2013) conclude that the first colonization of the major (Magdalena and Cauca) and minor (e.g., Calima, Popayán) inter-Andean river valleys encompassed by the D1 Oval occurred at about the same time as the early evidence of forest management by foragers in Panama (ca. 11,000–10,000 BP), based on numerous well-dated sites: “The increase in the archaeological record starting at the Pleistocene/Holocene transition is associated with an expansion of human groups along the river valleys that cross the Cordilleras of the northern Andes” (Aceituno et al. 2013, p. 31). Although there are no modern analogs for the Pleistocene/Holocene forests of these inter-Andean river valleys, which contained both low- and high-elevation species, they are considered to be generally similar to modern dry seasonal tropical forests in terms of animal biomass and relative abundance of plant species of value for human foragers (Gnecco 2003, p. 14; Gnecco and Aceituno 2006, pp. 91–92; Gnecco and Mora 1997). Based on this similarity between the forest ecosystems of these inter-Andean river valleys during the late Pleistocene and the early Holocene, Aceituno et al. (2013, p. 31) conclude that “*the Pleistocene/Holocene transition was not a dramatic period that required costly adaptive adjustments*” (emphasis added).

Building on the results of much earlier landmark research in Panama (Piperno et al. 1991a, b), a strong case also has been made for the deliberate and sustained human modification of inter-Andean river basin forest ecosystems by late Pleistocene and early Holocene forager groups, beginning from their initial arrival (Gnecco and Aceituno 2006, p. 89; Aceituno et al. 2013, p. 31). More than a decade ago, Gnecco formulated a remarkably prescient alternative to the DBM-based explanation of the late Pleistocene–early Holocene transition and the initial domestication of plants in the region—one that recognized that domestication occurred within a broader context of human niche construction (Gnecco 2003; Gnecco and Aceituno 2006). Piperno and Pearsall (1998, p. 76) offered a similar argument for Neotropical forests in general: “When humans entered the tropical

forest and fired and cleared the vegetation, they unconsciously increased the reproductive fitness of many wild plants and animals most beneficial in their diets and set the stage for control of the reproduction of these plants through cultivation and domestication.”

Rejecting the concept of asymmetrical adaptation (i.e., “if no environmental change occurs adaptation is unnecessary; that is, without external stimuli adaptation does not occur,” and that “culture is essentially passive, waiting for environmental changes to start working”), Gnecco questioned “the stereotype of hunting-gathering as an exploitative, nontransformative strategy,” argued that “early hunter-gatherers were already impacting the environment in the Neotropics through forest clearing, burning, and cultural selection of key vegetal resources,” and cited evidence of “humanly induced forest disturbance and resource manipulation and intervention since the late Pleistocene” (Gnecco 2003, pp. 13–14). Based on information from inter-Andean river basin sites, Gnecco proposed that late Pleistocene and early Holocene foragers in northern South America “not only gathered and hunted but ...also altered to their benefit the natural productivity of resources” (Gnecco 2003, p. 14). Ecosystem engineering or niche construction by forager groups in the region involved clearing over-story canopy to create “a space open enough for allowing the growth of pioneer species” and allow “prior to domestication and fully established agriculture... the artificial concentration of useful, otherwise dispersed plants. The artificial concentration of favored species may have required planting and tending, including forest clearing, and weeding” (Gnecco 2003, pp. 14–15). Gnecco (2003, p. 15) also notes that “such forest clearing and/or tending not only favored useful plant species but also animals” and concludes that “(e)vidence from the neotropics indicates early human management of vegetal and, likely, animal resources by 11,000 BP, including forest clearing or utilization and maintenance of natural openings by burning, and the cultural selection of useful species through protection and planting” (Gnecco 2003, p. 19, see also Gnecco and Aceituno 2006, pp. 92–93).

In contrast to the DBM-based explanation, which gains no support from any of the 10 test implications presented above and was contradicted by three, the CNC hypothesis is supported by all three of the test implications that apply to it (T6, T7, and T10), and it is not contradicted by any test implications, indicating that it provides a much better framework of explanation for initial plant domestication in the Neotropics than the DBM account. In summary, there is the absence of any supporting evidence from the Neotropics for the DBM-based explanation of plant domestication, and serious flaws in how the DBM is applied. At the same time, there is strong support for the CNC theory in the form of abundant evidence and compelling synthesis arguments for the initial domestication of plants having taken place within a larger context of extensive human niche construction and broad-based management and enhancement of tropical forest ecosystems.

The initial domestication of plants in eastern North America: Comparing the DBM and CNC hypotheses

The diet breadth model is acknowledged as not providing an explanation for the initial domestication of plants in eastern North America. It is presented, however, as

providing a powerful case study of how the DBM can lead to a deeper understanding of the process of domestication, even when it fails: “The criticism that HBE models sometimes fail to yield accurate predictions when tested misses the point that the exploration of the model’s vulnerability can itself be a source of insight. Models are productive means for “eliminating problematic answers and identifying and pursuing more promising ones”.... In other words, “failure is an option” (Gremillion et al. 2014, p. 6174).

Given this profile of failure, the eastern North America case study offers the opportunity to address a key question raised earlier—did the initial failure of the DBM to provide an explanation of plant domestication in one of the world’s independent centers of domestication, in fact, lead to a subsequent consideration of alternative competing hypotheses through the “iterative process of hypothesis testing, revision, and retesting,” which is identified as a central strength of the OFT/DBM approach (Gremillion et al. 2014, p. 6172). Or, on the other hand, is real-world failure of DBM-derived hypotheses in archaeology instead a boilerplate “heuristic” prelude that is followed not by consideration of alternative hypotheses, but rather by informal “post hoc” theorizing that is constrained within the parameters of DBM theory and centered on considering other OFT/DBM-derived variables that might account for deviations from initial model predictions (see Green and Shapiro 1994; Jones 1999 for discussion of the prevalence of such post hoc theorizing by practitioners of comprehensive rationality and expected-utility approaches in other social science disciplines). Along with considering what occurs post-failure of the DBM in eastern North America—whether it involves revision, retesting, and consideration of alternative hypotheses or “post hoc” theorizing—the DBM and CNC hypotheses also are compared in terms of which is best supported by the available empirical evidence from the region of eastern North America that actually witnessed initial plant domestication.

This comparison of DBM and CNC hypotheses within the area in eastern North America that actually witnessed initial plant domestication is necessary because it is not encompassed by Gremillion’s (1998, 2004) application of the DBM in the region. The DBM-based case study is situated in the rugged eastern Kentucky uplands of the Cumberland Plateau, located at the extreme eastern edge of the Oak Savanna and Oak Hickory forest regions within which initial plant domestication took place in eastern North America (Fig. 2), hundreds of miles distant from the archaeological sites in Missouri, Illinois, and Tennessee that have yielded the earliest domesticates. The DBM study area is also environmentally quite distinct from the river valley habitats in which the archaeological sites that have yielded the earliest evidence of domesticates are located; are all situated in first-through third-order tributary river valley corridors of the Mississippi River catchment (Smith and Yarnell 2009), quite different from the upland environments surrounding the higher-elevation rockshelter site assemblages that are the focus of the DBM-centered studies. Finally, all of the rockshelter occupational episodes and archaeobotanical assemblages included in the analyses post-date by ca. five centuries the initial appearance of domesticates in river valley settlements quite distant from the eastern Kentucky subregion that is the focus of Gremillion’s research (Smith and Yarnell 2009).

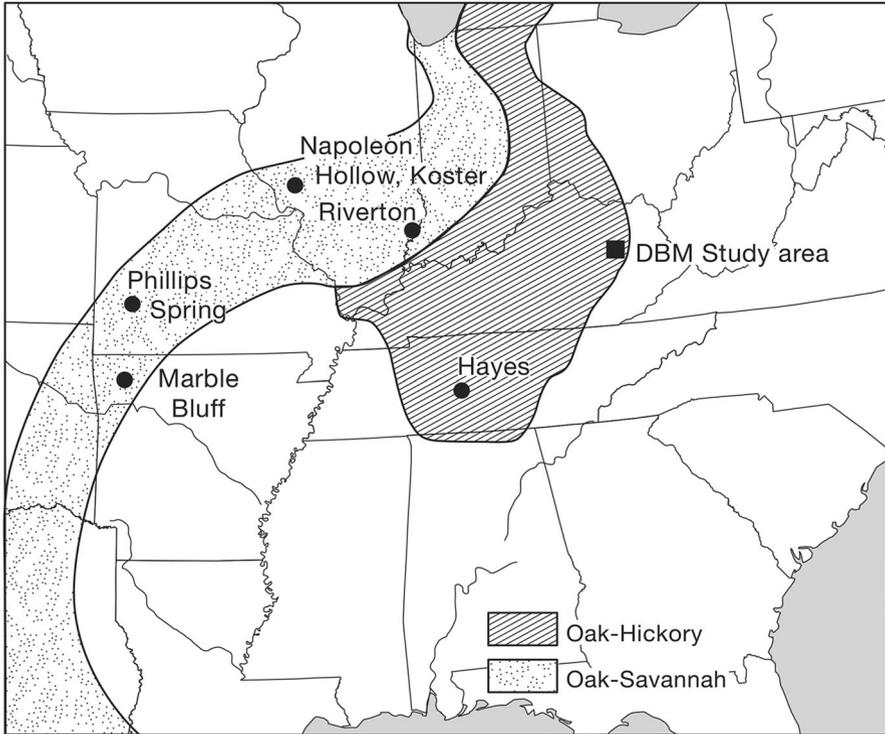


Fig. 2 The location of Gremillion’s (1998, 2004) diet breadth model study area in the Cumberland Plateau, at the eastern margin of the mid-latitude interior riverine area that witnessed the initial domestication of plants in eastern North America. Sites that have yielded the earliest evidence of domesticates are shown

Rather than addressing the initial domestication of indigenous seed plants in eastern North America, the DBM-based case studies instead consider a quite different but still interesting set of questions centering on how already domesticated species are subsequently added to the diet of forager societies situated in upland environmental settings. As is explicitly conceded, the initial application of the DBM in an effort to explain the adoption of already domesticated plants by upland forager societies in eastern Kentucky finds no support in the archaeological record. None of the ten test implications listed above are supported by the available archaeological, archaeobotanical, or environmental evidence. There is no evidence of human population pressure on resources in the upland study area, nor is there any indication of environmental or climatic deterioration (Gremillion 2004, p. 227) or any indication of resource depression: “There is no independent evidence in eastern Kentucky of the kind of food shortage that would make a broad-based diet including small grains economically advantageous. The patch and diet choice models thus do not explain why small grains, whether naturally available or cultivated, were exploited in the region prehistorically” (Gremillion 2004, p. 229).

While the absence of any evidence of resource depression that precedes or is concomitant with the initial appearance of indigenous seed crops in the eastern Kentucky Cumberland Plateau study area is readily acknowledged, clear evidence for human niche construction is mentioned (Delcourt et al., 1998; Gremillion 1998, p. 140; 2004, pp. 227, 229). The pollen record from Cliff Palace Pond (Delcourt et al. 1998), located 15 miles from Gremillion's study area, is cited as documenting "an increase in fire frequency, forest opening, and a shift in forest composition in favor of fire-resistant species (including oaks and chestnut) around 3000 BP," indicating that "at least some of the major sources of plant calories—including oak and chestnut trees—probably became more abundant rather than less" (Gremillion 2004, p. 227). Similarly, "macrobotanical data suggest that the shift to a more prominent role for seed crops was accompanied by increased anthropogenic environmental disturbance"; "[e]cological analysis of seed data also supports a general increase in anthropogenic habitats such as gardens and clearings near the shelter, or at least in the utilization of such habitats"; and "[t]he spatial scale of the disturbance created by agricultural clearing may have been relatively small, but was sufficient to create new habitats for plants that thrive in open, disturbed areas" (Gremillion 1998, pp. 140, 146, 148). Evidence of anthropogenic fire-induced ecology producing forest opening and increased edge vegetation is also seen in archaeobotanical assemblages recovered from Carlston Annis and Bowles—two river bottom shell mound settlements in the middle Green River region 50 km west of Gremillion's study area, which were first occupied around 4,000 BP (Crawford 2005). Plant food remains at the two sites were dominated by nuts and mast (e.g., hickory and acorn) and the seeds of fleshy fruits (e.g., strawberry, blackberry, grape, honey locust, persimmon), with lesser amounts of seeds of other species. No domesticated plants were recovered from the assemblages (Crawford 2005).

This clear empirical record of deliberate and sustained human modification of the forest environment in ways that would have increased the abundance and predictability of food resources, occurring in the same time frame that eastern domesticates were first introduced into the upland environment of the Cumberland Plateau, represents strong support for the CNC hypothesis. The initial addition of small-scale cultivation of eastern crop plants into the subsistence systems of upland forager societies occurred in the absence of resource depression, and within a larger context of general efforts by upland small-scale societies to enhance local environments and increase the productivity and predictability of food resources: "such forest opening did in fact occur around 3000 BP in eastern Kentucky as a result of burning, perhaps by human populations to increase yields of food resources" (Gremillion 2004, p. 229). Small-scale burning to create forest opening mosaics would have increased the abundance of many early successional species of plants that were food sources both for humans and their primary prey species (e.g., white-tailed deer), while also encouraging fruit, nut, and mast-bearing tree species (Smith 2009, 2011a). In summary, while the DBM-based hypothesis for the initial adoption of domesticates in the Cumberland Plateau is not supported by any of the ten test implications listed above and is contradicted by three, the CNC hypothesis is supported by all three of the test implications relevant to it, and it is not contradicted by any.

Rather than considering this quite viable alternative explanation, however, the focus instead shifts to finding a scenario for the addition of seed crops into the diet of upland forager societies that is compatible with the diet breadth model and the optimizing assumptions embedded within it. Avoiding consideration of the possibility that the initial resource selection and optimization assumptions of the DBM are false, the argument is instead presented that previous assessments of small-seeded plants as being low value must be in error. If eastern crop plants were dietary components of Cumberland Plateau foragers in the absence of any evidence of resource depression, then based on OFT/DBM principles, their long-standing characterization as low-ranking resources that are only utilized when the optimum diet line has been pushed down must be incorrect. It is argued that contrary to DBM expectations, small-seeded plants actually should be ranked above the optimum diet line. Noting that the low ranking of small-seeded plants in DBM approaches is primarily due to the substantial time and energy costs involved in their processing, rather than in their collecting, it is proposed that such processing costs are actually much lower than previously estimated. This is because, it is suggested, in temperate regions with pronounced cold seasons, the processing of small seeds following fall harvest (when demands on time are high) might have been delayed until the winter, thereby substantially reducing their “opportunity costs—the costs of neglecting other needs that cannot be met simultaneously,” and that “if processing could be deferred until other tasks had been completed or curtailed, its costs would represent little or no lost opportunity” (Gremillion 2004, p. 228).

This effort to elevate small-seeded crop plants above the optimum diet line by recalculating their opportunity costs clearly qualifies as post hoc theorizing as opposed to the “iterative process of hypothesis testing, revision, and retesting” (Gremillion et al. 2014, p. 6172). Although this redefining of small-seeded plants as optimum diet species is variously identified as a “model” and a “hypothesis” for explaining their utilization by forager societies in the absence of resource depression (Gremillion 2004, pp. 216, 229), consideration of this model or hypothesis does not progress beyond the initial step of hypothesis formulation. It remains an untested proposition. There is no plausibility consideration, no attempt to present a reference class of case studies demonstrating the prior probability of delayed processing by forager societies as a way of reducing opportunity costs. There is no development of test implications or actual testing, just the assertion that “(t)here is reason to believe...that postponement of consumption may entail benefits that counterbalance its added costs” (Gremillion 2004, p. 228). Far from providing an example of rigorous application of the scientific method and an “iterative process of hypothesis testing, revision, and retesting” (Gremillion et al. 2014, p. 6172), the application of the DBM in eastern North America illustrates the strong tendency by OFT/DBM practitioners to stay within the bounds of their theoretical perspective rather than considering non-OFT/DBM alternatives; it also highlights the relative ease with which variables such as resource ranking can be recalibrated in order to conform to DBM expectations.

In contrast to the DBM analysis situated in the Cumberland Plateau, no effort has been made to apply the DBM to the mid-latitude interior riverine region of eastern North America that actually witnessed the initial domestication of indigenous seed

plants, or is it likely that any future effort will be made to do so. While there is a well-documented complete absence of evidence for resource depression preceding initial domestication in the region, there is at the same time strong support for the CNC hypothesis (Smith 2012; Smith and Yarnell 2009). All three of the test implications relevant to the CNC hypothesis listed above are satisfied in eastern North America, and many of the general test implications listed for the CNC theory (Smith 2012; Zeder and Smith 2009) also are met: initial evidence of domestication occurs in resource-rich ecosystem settings rather than more marginal environments; settlements are small; there is evidence of utilization of a broad spectrum of resources with no indication of declining access to high-ranking prey or any evidence of population packing; and there is evidence of ecosystem engineering and multigenerational corporate ownership of established resource-catchment territories (e.g., corporate burial features). In summary, the CNC hypothesis for initial plant domestication and the incorporation of domesticates into the forager diet is well supported in both Gremillion's Cumberland Plateau study area and in the mid-latitude interior riverine area in which eastern seed plants were actually first brought under domestication, while the DBM-based hypothesis finds no support in either area.

Discussion and conclusions

In this article, I have offered a side-by-side comparison of two alternative explanatory frameworks (CNC and DBM) for the initial domestication of plants and animals, following both through the successive general steps of the scientific cycle—hypothesis formulation, plausibility consideration, development of test implications, and hypothesis testing—and using two regional case studies—eastern North America and the Neotropics—to frame the comparison. This analysis has exposed a wide range of flaws and shortcomings of the diet breadth model as it has been applied to the evolutionary question of initial domestication.

The most obvious and basic flaw of the diet breadth model is that rather than providing a potential explanation for initial domestication, DBM only addresses the question of how and why low-ranking resources may have been initially added into the diet of hunting and gathering societies prior to domestication. No higher-level general principles of human behavior are invoked as a foundation for the subsequent initial domestication of species once they enter the diet of hunter-gatherer societies, other than the implicit but unstated assumption that domestication somehow results from a continuation of the adaptive response to resource depression.

The characterization of OFT and DBM as being nested within a hierarchy of evolutionary theory and derived from and informed, supported, and reified by well-established higher-level schools of evolutionary thought also remains very much in question. The concept of optimization on which OFT and DBM are based was introduced into biology from microeconomics in the mid-1960s as an untested hypothesis, and it has enjoyed a quite checkered career over the last four decades, with numerous case study applications in biology and across a range of other disciplines documenting its failure to account for real-world situations (e.g., Gray

1987; Jones 1999; Levi et al. 2011; Pierce and Ollason 1987; Sih and Cristensen 2001; Simon 1999; Smith 2012; Zeder 2012). Although optimization, OFT, and DBM are presented as being accepted as modern biological principles and standard approaches in biology (Gremillion et al. 2014; Piperno 2006, 2011; Winterhalder and Kennett 2006), they are far from being embraced as established and widely employed approaches in any discipline. A number of the studies proposed by Gremillion et al. (2014) in support of the successful application of DBM in general, ranging from case studies of human foraging to synthesis assessments of political science and economics, in fact, provide clear documentation of the failure of OFT/DBM and the principle of optimization to account for empirical reality.

If, however, for the sake of discussion, the tenuous link between OFT/DBM and higher-level evolutionary theory is granted, a set of questions centering on the neo-Darwinian perspective of OFT/DBM comes into clearer focus. While neo-Darwinism serves as the overarching evolutionary theory for OFT/DBM, macroevolutionary theory has posed a clear challenge to neo-Darwinism over the past 35 years. Macroevolutionary theory represents a more viable and more appropriate theoretical perspective for addressing the initial domestication of plants and animals worldwide, and major evolutionary transitions in general. Similarly, NCT and cultural or human niche construction, which is directly antithetical to OFT/DBM and directly derived from macroevolutionary theory, provides an alternative and long-established approach within HBE. The CNC theory of initial domestication has been recently characterized as lacking “a general theory for human behavior,” “relying on diverse and often conflicted principles to account for the decision-making behavior of human agents,” exhibiting “creative or arbitrary combinations of a ‘bounded rationality’... drawn opportunistically from ethnographic or contemporary observations” that are seldom made explicit, and employing “undefined or vaguely conceptualized properties or goals” (Gremillion et al. 2014, pp. 6172, 6173). Contrary to this characterization, the CNC theory of domestication, as outlined here and presented in detail in earlier articles (Smith 2007b, 2011a, 2012), is directly derived from NCT, which in turn emerged out of macroevolutionary theory. Along with macroevolutionary theory, NCT and CNC provide a significantly more current, robust, and relevant theoretical approach in efforts to gain a better understanding of initial domestication.

Turning to the proper use of scientific reasoning, any call for the rigorous employment of the hypothetico-deductive version of the scientific method in addressing the general research domain of initial domestication is inappropriate. Four decades ago, a respected philosopher of science described the hypothetico-deductive method as an oversimplified and incomplete account of scientific reasoning, and determined it to be inapplicable in archaeological inference (M. Salmon 1975, 1976). The form of inference that is actually employed in archaeological reasoning—the hypothetico-analog method, was described in detail more than 35 years ago (Smith 1977). In addition, the proposal that hypotheses must be initially derived from and informed by higher-level evolutionary theory rather than formulated through induction based on observation of empirical reality is incorrect. In archaeological reasoning the process of hypothesis formulation is always inductive in nature, and all hypotheses, no matter what their source, are all

equal in standing prior to the second step in the scientific process—plausibility consideration. While higher-level evolutionary theories do represent a valuable source for hypothesis formulation, as exemplified by the development of NCT from macroevolutionary thought, the actual explanatory strength of any hypotheses generated from a consideration of evolutionary principles can be established only through empirical testing. Similarly, the belief that a hypothesis can be rejected prior to plausibility consideration on the basis of its origin and context of its formulation—if it is not sufficiently informed by overarching evolutionary theory but rather has been inductively developed from observation of the real world—is incorrect and runs counter to the logical structure of the scientific method. Since hypotheses originating from initial consideration of higher-level evolutionary theory have no higher standing or support than any other hypotheses prior to plausibility consideration, the suggestion that researchers must explicitly identify their theoretical perspective and evolutionary credentials is misplaced. The theoretical position of a researcher, either explicitly announced or implicit, has no bearing on the relative explanatory value of any hypothesis they formulate. I think it is safe to reasonably assume that the vast majority, if not all, geneticists, biologists, archaeobiologists, and archaeologists actively conducting research on initial domestication and agricultural origins under the current established paradigm have a solid background in evolutionary theory and fully appreciate its central role in gaining a better understanding of these major evolutionary episodes in human history.

Optimal foraging and DBM approaches also omit any consideration of the prior probability of DBM-based hypotheses, an indispensable step in the scientific method, substituting instead a simple appeal and linkage to higher-level theory. This omission further calls into question OFT/DBM understanding of the structure of scientific inference in archaeology and undermines the call for researchers operating under the established paradigm to emulate OFT/DBM and become more rigorous in their implementation of the scientific method. The failure to define and present a specific reference class of human or nonhuman real world analogs that demonstrate the actual existence of a cause and effect relationship between resource depression and initial domestication means that there is, in effect, no bridging argument, and without such a bridging argument, the cause and effect link remains firmly in the realm of untested assumption. The rejection of a side-by-side comparison of competing hypotheses, both during plausibility consideration and empirical testing, in favor of considering a single, invariably DBM-derived, potential explanation for initial domestication, provides an additional significant departure from standard scientific practice. The sequential, or one at a time hypothesis consideration involving a cycle of revision and reassessment could be a viable alternative to side-by-side comparison, depending on the robustness with which such revision and retesting is carried out and the relative inclusiveness of consideration of alternative explanations. DBM approaches to explaining initial domestication fall far short of demonstrating any willingness to pursue serial revision and retesting of hypotheses.

Turning to the actual comparison of DBM-derived and NCT-based hypotheses for initial domestication with available empirical datasets from two independent centers of domestication in the Americas, the CNC is much better supported by the

archaeological and paleoecological datasets currently available. The DBM-based explanation of initial plant domestication in the Neotropics is not supported by currently available archaeological or paleoenvironmental evidence. A 5,000-year gap now separates the last occurrence of megafauna from the earliest indication of domesticated plants, effectively removing the proposed cause of resource depression that was hypothesized to lead to subsequent plant domestication. The DBM-based explanation of initial plant domestication in the Neotropics also is considered in isolation, with no discussion of alternative explanations, even though substantial evidence in support of a CNC explanation has been available for several decades, and a strong argument for initial domestication having occurred within a broader context of human niche construction was proposed more than a decade ago (Gnecco 2003). The DBM-based explanation of initial plant domestication in eastern North America, acknowledged to be a failure, is confined to consideration of the subsequent initial adoption of domesticated plants by forager groups occupying upland areas that are on the eastern margin of the mid-latitude interior riverine region that actually witnessed the more important and earlier transition to low-level food production in the eastern woodlands. In both the eastern margin upland DBM study area and the resource-rich river valley settings that supported the human societies that initially brought indigenous plants under domestication, however, NCT and the CNC theory of domestication are better supported by the available empirical evidence. In addition, rather than demonstrating how the DBM, even when it fails, can lead to a subsequent worthwhile consideration of alternative hypotheses, the case study application of DBM in eastern North America instead clearly follows the path of “post hoc” theorizing that is constrained within DBM theory, with no follow-up assessment of the strength of alternative scenarios beyond the initial step of informal hypothesis formulation.

Given the DBM’s long list of conceptual and logical flaws, and the continuing empirical failures of the DBM to provide a viable explanatory framework for initial domestication, it is not surprising that over the past several decades, few researchers operating under the established paradigm have been drawn to adopting OFT as an alternative approach. It is also unlikely, in my opinion, that the recent overarching synthesis of the OFT/DBM “paradigm” (Gremillion et al. 2014) will attract any new converts to what is a quite limited theoretical perspective. This does not, of course, mean that the CNC-based theory provides a final, comprehensive, and compelling explanation of initial domestication, only that when compared side-by-side to DBM-derived scenarios, it is better supported by the currently available and relevant archaeological, archaeobiological, and paleoenvironmental evidences. The CNC framework of explanation, however, does bring us closer to a better understanding of the initial domestication of plants and animals, and I hope that researchers working in different regions of the world will be encouraged to look more closely for evidence of human niche construction within the larger cultural and environmental context of domestication and the transition to food production.

Over the next decade, at least, I fully expect the increasing number of geneticists, biologists, archaeobiologists, and archaeologists who are addressing an ever-expanding range of questions within the general research domain of initial domestication and agricultural origins will be working primarily at the first three

levels of analysis briefly outlined in the introduction of this article. The reason for this is obvious. Under the existing paradigm, and within the context of normal science, there are simply too many interesting research questions at multiple levels of complexity available for investigation. As empirical information regarding the initial domestication of a diverse array of different species across an expanding number of world regions continues to increase in quantity and quality, more sophisticated and nuanced general explanatory frameworks with global applicability will certainly also be formulated and tested, and the role of general strategies of niche construction in domestication will come into clearer focus.

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