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Rethinking the Origins of Agriculture

Constraints on the Development of Agriculture

by Robert Bettinger, Peter Richerson, and Robert Boyd

The development of agriculture was limited by external constraints, mainly climate, before the Holocene and mainly by social institutions after that. Population size and growth was important but ultimately did not determine where and why agriculture evolved.

Evolutionary scholars advance two major sorts of hypotheses to explain big events, such as the origin of agriculture. One hypothesis assumes that natural selection is so powerful that organisms are always close to an evolutionary equilibrium with current environment. Thus, any major changes will be a result of *external* processes having to do with the environment. The other camp imagines that evolution is a slow, halting, and biased process that is limited and directed by *internal* obstacles that thwart what natural selection favors, for example, a particular somatic arrangement that is difficult to "engineer" quickly. Both kinds of constraints were probably involved in the trajectory leading to agriculture but perhaps at different timescales.

Climate Change Is Certainly the Major External Constraint

Ice age climates varied at very short timescales (Richerson, Boyd, and Bettinger 2001). Ice core data show that last glacial climate was highly variable on timescales of centuries to millenia (Anklin et al. 1993; Clark, Alley, and Pollard 1999; Dansgaard et al. 1993; Ditlevsen, Svensmark, and Johnsen 1996). There are sharp millennial-scale excursions in estimated temperature, atmospheric dust, and greenhouse gases, right down to the limits of the high-resolution ice core data. The highest-resolution Greenland ice records show that millennial-scale warming and cooling events often began and ended very abruptly and were often punctuated by quite large spikes of relative warmth and cold with durations of a decade or two (e.g., von Grafenstein et al. 1999). Post–Younger Dryas warming (the Pleistocene to Holocene shift) may have occurred in less than a decade (Hughen et al. 2000). In comparison, the Holocene after 11,600 BP has been a period of comparatively very stable climate. Recent work shows that, though driven by the same deepwater cycling process, the climatic variability of the last glacial cycle is greater than those of the previous three (Martrat et al. 2007).

The dramatic Pleistocene climate fluctuations captured in polar ice cores also register at lower latitudes (Allen et al. 1999, 2002; Hendy and Kennett 2000; Martrat et al. 2007; Peterson et al. 2000; Schulz, von Rad, and Erlenkeuser 1998). Mediterranean pollen records show that these changes are reflected in approximately century-scale changes in vegetation (Sanchez Goni et al. 2002).

This picture is not perfect, however. Some records show millennial-scale climate fluctuations during the last glacial cycle that cannot be convincingly correlated with the Greenland ice record (Behling et al. 2000; Clapperton 2000; Cronin 1999, 221–236; Dorale et al. 1998; Richards, Owen, and Rhode 2000; Shi et al. 2000). The ultimate Younger Dryas millennial-scale cold episode at 12,900–11,600 BP, strongly expressed in the high-latitude ice core records, is reported in proxy records from all over the world (von Grafenstein et al. 1999; Werne et al. 2000; West 2001). It is frequently detected in a diverse array of climate proxies from all latitudes in the Northern Hemisphere (Cronin 1999, 202–221). Southern Hemisphere proxies, however, often do not show a cold Younger Dryas period, although some show a similar Antarctic Cold Reversal

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just antedating the Northern Hemisphere Younger Dryas (Bennett, Haberle, and Lumley 2000; Newnham and Lowe 2000).

Some scholars argue that the Younger Dryas was a forcing event that led to agriculture (Bar-Yosef 1998). Dow, Olewiler, and Reed (2005) argue that the Younger Dryas downturn crowded populations that had grown large during Bolling/Allerod amelioration into a few favored places, making agriculture viable relative to traditional hunting and gathering. There is no evidence of agriculture during the Younger Dryas, however, and it seems more likely that, like previous climatic fluctuations, the Younger Dryas simply terminated budding Natufian attempts to intensify plant production (Feynman and Ruzmaikin 2007).

Ice age environments were not only variable, they were demonstrably plant poor. Late Pleistocene plant productivity was limited by lower atmospheric CO_2, which was about 190 ppm during the last glacial cycle, compared to about 250 ppm at the beginning of the Holocene. Photosynthesis is CO_2 limited over this range of variation (Cowling and Sykes 1999; Sage 1995). Phenotypical response to counteract this (e.g., higher stomatal density) resulted in higher transpiration water losses, exacerbating the effect of glacial aridity, and greater susceptibility to cold snaps (Beerling and Woodward 1993; Beerling et al. 1993). As a result, the Pleistocene environment was plant poor. The total organic carbon stored on land as a result of photosynthesis was something like 33% to 60% lower than in the Holocene (Beerling 1999).

In sum, low mean plant productivity and climatically induced greater variance in plant productivity were external constraints that greatly decreased both the efficiency and reliability of plant-based subsistence during the last glacial cycle, ultimately preventing the development of agriculture.

Social Institutions Are a Dominant Internal Constraint

The transition to agriculture was certainly limited by internal constraints. Assuming that Pleistocene agriculture was impossible, the earliest occurrences of agriculture after the Younger Dryas suggest that it takes on the order of 1,000–2,000 years to overcome the internal constraints preventing agricultural development once climate ameliorates and stabilizes, most of this probably having to do with developing the requisite behaviors, technology, and know-how (Feynman and Ruzmaikin 2007; Richerson, Boyd, and Bettinger 2001). This is roughly the pace of the massive reorganizations of atmospheric circulation that account for rapid Pleistocene climate change, which operate on 1,450-year cycles (Mayewski et al. 1997). In any case, 1,000–2,000 years is a minimum figure. Agricultural innovations, after all, have continued right down to our day. Internal constraints frequently prevented agriculture from evolving for thousands of years—or even at all. That perhaps 20% of the world remained as hunters and gatherers until nineteenth-century European expansion suggests that even when climate is permissive, the transition to agriculture often takes more than 10,000 years (i.e., more time than has lapsed since the end of the Younger Dryas), even in regions perfectly suited to agriculture—places like Argentina, California, and the Great Basin (Porter and Marlowe 2007). A variety of external constraints—unfavorable geography (Diamond 1997), absence of suitable domesticates (Blumler and Byrne 1991), and resources supporting populations too small to sustain the necessary pool of cultural knowledge (Henrich 2004)—surely slowed the process some, but not enough to account for the 10,000-plus-year lag observed in Argentina, California, and the Great Basin, probably reflecting strong internal constraints. Social institutions seem a likely source of such internal constraints, ones strong enough to prevent or greatly slow the evolution of agriculture, because human subsistence behavior is always part of a larger adaptive strategy that is as much social as economic, as the substantivists used to remind us.

We can think of four reasons why the evolution of social organization is a strong internal constraint on the evolution of subsistence systems. First, social organization is not particularly observable by outsiders. Social institutions are enacted in a diffuse network of everyday interactions, punctuated by public rituals and ceremonies of uncertain meaning to outsiders. Second, institutional innovations are more difficult to try out than technical ones. At least some minimum number of individuals must understand and subscribe to an institutional innovation for it to begin operating. Its success or failure may take a generation or more to evaluate. Compare this to trying out a new annual crop. Curious individuals can plant a small trial plot and get a rough idea of success or failure in one season. For these two reasons, successful institutions spread slowly beyond the societies that innovate them. Third, game theorists tell us that repeated games have many equilibria. Most likely, social systems tend to be locally stable, and when events destabilize one equilibrium, the search for a new one will be heavily constrained by history (Greif 2006). Thus, cultural evolution will be relatively inefficient at quickly finding globally optimal social institutions. Fourth, to the extent that institutions evolve by a process of cultural group selection, rates of change will tend to have millennial timescales (Soltis, Boyd, and Richerson 1995). Further, the type of group selection investigated by Soltis, Boyd, and Richerson (1995) prevents "recombination"; superior institutions have to evolve independently in each lineage rather than being borrowed. A fast form of group selection is possible (Boyd and Richerson 2002). However, this mechanism will work best for features of social organization that are observable, subject to trial, and not affected by forces that stabilize local equilibria. Hence, cultural evolution in the Holocene has involved apparently progressive changes over the last 10 or more millenia. Most likely, the main rate limiting step over this period has been the evolution of more sophisticated social organization.

There are at least two dominant hunter-gatherer equilibria in the Holocene, and the dichotomy is variously styled as complex versus simple, immediate versus delayed return, and so forth. We prefer a contrast in standard ecological parlance, between *energy maximizing* and *time minimizing* hunter-gatherers, terms that refer to the two quantities that dominate quantitative treatments of foraging behavior (Bettinger 1999, 2001). The easiest way to see the difference is with respect to constraints: energy maximizers spend as much time as possible harvesting resources, maximizing energy up to limits imposed by available time. Time minimizers spend as little time as possible harvesting resources; they minimized harvest time up to limits imposed by basic energy requirements. The differences in strategy play out in a number of interesting ways. For example, time minimizers favor alternatives with more variable return times and in that sense seek risk.

For a variety of reasons, time minimizing is inimical to plant intensification, and by extension, agriculture, while energy maximizing, is not (Bettinger 2006; Bettinger et al. 2007). It is always dangerous to model Pleistocene hunter-gatherers after their Holocene counterparts, but the differences between these two strategies are general enough to warrant extrapolation to the terminal Pleistocene, leading to the argument that energy maximizing probably evolved during the Bolling/Allerod/Younger Dryas, permitting agriculture to evolve within 1,000 years after climate amelioration. On that logic, the shift to energy maximizing among later Holocene hunter-gatherers (Bettinger 1999) should repeat changes observed in the Bolling/Allerod/Younger Dryas. Further, that some Holocene energy maximizers remained hunter-gatherers until European contact (California is the best example) suggests that while the Holocene adaptive landscape probably made agriculture mandatory in the long run (the world is now wholly agricultural), it contained substantial room for continuing hunter-gatherer evolution, as replacements of agriculturalists by hunter-gatherers in the North American Great Basin and Southwest show.

Conclusion

We think that progress will be made on macroevolutionary problems like the rise and development of agrarian societies by paying attention to the concept of rate-limiting processes. For example, population pressure is no doubt an important component driving the evolution of technology and social organization. But we have argued (Richerson, Boyd, and Bettinger 2001) that it is unlikely to be the rate-limiting step in macroevolutionary scenarios. The essential insight is due to Malthus. Unconstrained populations of humans can approximately double in every generation, leading to the very rapid generation of population pressure. What Darwin took from Malthus was the insight that population pressure is almost always significant; only under extraordinary, short-lived circumstances is it weak. Thus rate-limiting processes in evolutionary trajectories are almost always going to be something else. We have proposed a simple two-part hypothesis to explain the origin and subsequent development of agriculture. In the last ice age, climate fluctuations and low CO_2 concentrations made agriculture impossible. In the climatically quiet Holocene, the competitive advantage of agricultural subsistence led to its dominance everywhere, albeit after thousands of years of cultural evolution. We propose that the most important limiting factor in the rise of agricultural societies has been the slow evolution of social innovations that permitted ever larger and better-organized agrarian societies.

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