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LITHIC CORE REDUCTION TECHNIQUES: MODELING EXPECTED DIVERSITY

Abstract

We define diversity in core reduction systems as the degree of deviation from the most efficient means to proceed from the start to the end product exhibited in a given core reduction system. Because lithic core reduction systems are often characterized along a continuum of high or low degree of diversity, some archaeologists have suggested that assemblage diversity is linked to raw material availability and quality. In this paper we provide a model that predicts when humans would favor less systematic core reduction techniques as opposed to those that are more systematic. The model incorporates three factors influencing diversity in core reduction techniques: raw material availability, raw material quality, and the ratio of producers to consumers. We provide the model and then estimate where several case examples from different archaeological contexts fit within the expectations. This allows us to generate hypotheses about the relationship of producers and consumers who manufactured the assemblages.

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INTRODUCTION

The process of lithic core reduction is often described as systematic (nearly uniform) or unsystematic (highly variable) (Bleed 2001; Brantingham et al. 2000; Root 1997). For example, some core reduction systems represent human interaction with raw materials that are much more prone to knapping error and failure rates, whereas others appear to follow very specific chains (for an example of each, see Bleed 1996, 101–2). Core reduction systems that are highly uniform usually have less/little sign of rejuvenation due to knapping error, whereas other systems are almost cyclical in nature, indicated by a series of rejuvenation events and techniques that compensate for knapping error and/or raw material failure.

Some core reduction systems are described on a continuum (Shott 1996), ranging from nearly uniform (low diversification) at one end of the axis to unsystematic (high diversification) at the other. Diversity represented within a particular reduction system is likely the result of interaction between human behavior (e.g., social organization or knapping skill) and raw material quality and availability. Subsequently, we equate the *diversity* in reduction techniques to the degree of deviation from uniformity.

Some goals have a potential single most efficient solution. For example, there is always the opportunity to maximize the usefulness of lithic raw material by constraining the reduction sequence to a small degree of diversity around the optimal operation chain. Many times, however, goals can be achieved with less efficient strategies that could produce a high degree of deviation from the optimal operation chain. In light of this, we define *diversity* with respect to core reduction systems as the degree of deviation from the most efficient means to proceed from the start (such as the selection of a cobble to the setup of the core) to the end product (tool blank production) exhibited in a given core reduction sequence. Efficiency is quantifiable with time, energy, and raw material use in relation to the production sequence (Costin 1991: 37). For the purposes of this paper, we are only concerned with the end product of core reduction (tool blanks), not the subsequent negotiations of tool production and maintenance.

Debitage assemblages demonstrate how diversity in core reduction systems is a byproduct of human decision-making processes. Some extraneous factors, such as raw material availability and quality, condition human decision-making with regard to core reduction strategies. Although previous models indicate that the relationship between core reduction techniques and raw material quality and quantity is important, often the relationship between these two variables does not anticipate or fit the diversity that is present in the archaeological assemblage (Andrefsky 1994; Brantingham et al. 2000). This suggests that other variables are influencing the system. One additional variable that can help to explain these situations is the ratio of producers to consumers in the given society.

Drawing upon optimality theory (Foley 1985), we develop a predictive model of core reduction systems that focuses on three aspects influencing the diversity represented in core reduction techniques: raw material availability, raw material quality, and the ratio of producers to consumers. After presenting the model, we turn to several case studies from different archaeological contexts. The case studies demonstrate the continuous relationship between the three variables of interest. This approach departs from previous analyses that use a discontinuous approach or hold several variables constant. This allows us to capture greater subtleties than would have been acknowledged through applying discontinuous or static approaches. The utility of the model is two-fold: (1) it explains the variance in lithic diversity measures not captured in previous analyses and (2) it provides a method for estimating the producer:consumer ratio in particular archaeological contexts.

OPTIMALITY THEORY AND LITHIC REDUCTION

Natural selection has the consequence of optimizing design features for individual gene propagation (Krebs and Davies 1997). Design features that optimize somatic interests (e.g., access to resources such as food and space) have the potential to be converted into individual reproductive success (Krebs and Davies 1997; Smith and Winterhalder 1992). Where resource access is highly competitive, and variation in strategies solving for a particular goal exists, selection should favor the strategy that can solve the problem with the least cost in relation to the other strategies present (Foley 1985). The rationale is that organisms have limited energetic budgets. Individuals that solve particular adaptive problems efficiently can divert energetic surpluses into reproductive or other somatic interests (Kaplan et al. 2000). This is not to say that humans (or other organisms) are optimally adapted to their environment; rather, natural selection tends toward the optimal solution given the range of available phenotypes present in the environment (Foley 1985; Smith and Winterhalder 1992) and contingent on their evolutionary history (Prentiss and Clarke, this volume).

Humans are a cognitively and behaviorally plastic organism (Flinn 2005), suggesting that selection pressures have favored a human phenotype that can adaptively respond to fluctuating social and ecological pressures (Flinn 1996). Additionally, humans are at times aware of diminishing returns that are the product of certain strategies. This allows individuals to adjust investment accordingly (Kaplan and Lancaster 2000). Thus, humans will generally pursue behavioral strategies (for specific goals) that tend to optimize opportunity costs within specific socioecological settings (Smith 2000).

The degree to which optimization is likely to occur is dependent upon the selection pressures surrounding a particular resource (Foley 1985). For resources characterized as having a large impact on fitness (i.e., resources associated with strong selection pressures), individuals can achieve greater fitness returns by selecting strategies that focus attention on the attainment of that resource (Hames 1992; Winterhalder 1983). As a result, optimization of strategies to attain that resource is a likely outcome. Conversely, when a resource has a limited effect on fitness (i.e., resources associated with low selection pressures), selection could tend toward optimization; however, due to the limited energetic budgets of individuals, selection should favor phenotypes that divert their time and energy to the acquisition of other resources that do have high fitness outcomes (Hames 1992; Winterhalder 1983). As a consequence, satisfactory solutions become viable and diversity in strategy sets becomes tolerated for resources that have limited effect on fitness. Winterhalder (1983) provides a graphical model that demonstrates the conditions favoring decisions to invest an additional unit of time and energy into a focal activity (conditions of limited energy) or to divert these scarce resources into other activities (conditions of limited time).

For human populations that rely on lithic resources for access to food or other somatic interests, the nature and access of lithic resources impacts survivorship. Lithic resources approximate a zero-sum game (when one individual accesses the lithic resource, it represents a loss for other individuals in the population). When the lithic resource is proportionally present at high density compared to a hypothetical population, the depletion of the lithic resource may seem inconsequential to individuals within the populace. Thus access to the lithic resource can be conceptualized as having low fitness consequences, as there is little competition. Alternatively, when a lithic resource exists at proportionally low density in comparison to a hypothetical population, its depletion is consequential. Therefore, it can be characterized as having high fitness consequences, as it is likely to be under intense competition.

Optimality reasoning would lead one to conclude that when use of a lithic resource is highly competitive, strategies for converting the lithic resource into a usable end product will be constrained, with the likely solution (or solutions) being the most economical given the range of possible solutions in the environment. A possible outcome is that only a few individuals might specialize in production from the resource, while other individuals consume the few types that are created. If a resource is quickly being depleted, individuals may better redirect their time and energy into other goals or somatic interests. The rationale is that not everyone can effectively engage in an economic enterprise where there are constraints on the resource.

Alternatively, for a lithic resource under low selection pressure, optimality reasoning indicates that strategies for converting the lithic resource into a usable end product will diversify. The rationale is that individuals can maximize opportunity costs by not investing heavily in the manufacture of the resource, but investing in some other arena where high selection pressures exist. Thus, satisfactory solutions are likely to emerge with the manufacture of lithic products. Because the cost of accessing and manufacturing the lithic resource is low, many individuals can access and manufacture its products with few negative repercussions. As a result, a greater proportion of individuals may act as both producers and consumers of the end products.

IMPORTANT PARAMETERS IN CORE REDUCTION DIVERSITY

Arguably, diversity is largely dependent on human decisions in relation to availability, quality, and the ratio of producers to consumers. We now provide our understanding of how this system operates and define the variables presented in our model.

Modeling Diversity and Raw Material Availability

A number of studies argue that there is a link between raw material availability and the constraints on technological design and conformity (Beck et al. 2002; Kuhn 1996). Raw material availability can be modeled as the kcal/hr expended to procure and transport the resource. This would equal the distance one has to travel to the source and the size of the package (Beck et al. 2002).

The simplest function between diversity and availability is a linear relationship, where diversity is zero when availability is zero. In this situation, when availability increases, diversity also increases at a constant rate. A slightly more realistic function shows diversity increasing as the square root of availability (*a*). In other words, the function shows a curve where diversity increases drastically with changes in low availability. The slope is less extreme as availability approaches the maximum, but is still increasing (Figure 14.1):

$$d(a) \propto \sqrt{a}. \tag{14.1}$$

Modeling Diversity and Raw Material Quality

Researchers (Andrefsky 1994; Brantingham et al. 2000; Kuhn 1996) have argued that raw material quality affects the degree of diversity in reduction sequences and raw material breakage patterns (Amick and Mauldin 1997). Raw material quality is quantifiable along several dimensions: (1) percent crystallinity, (2) average crystal size, (3) range in crystal size, and (4) abundance of impurities (Brantingham et al. 2000: 257). All four aspects influence fracture mechanics. As noted by Brantingham et al. (2000: 257), "Regardless of quantity, poor quality rocks usually lead to informal technologies." This, however, is not always the case, and systematic reduction sequences have been found in association with poor-quality raw materials (Brantingham et al. 2000).

Raw material quality can also be shown on a continuum. The lowest-quality material would hypothetically be the lowest quality that could still be manipulated by a flintknapper. The highest quality would

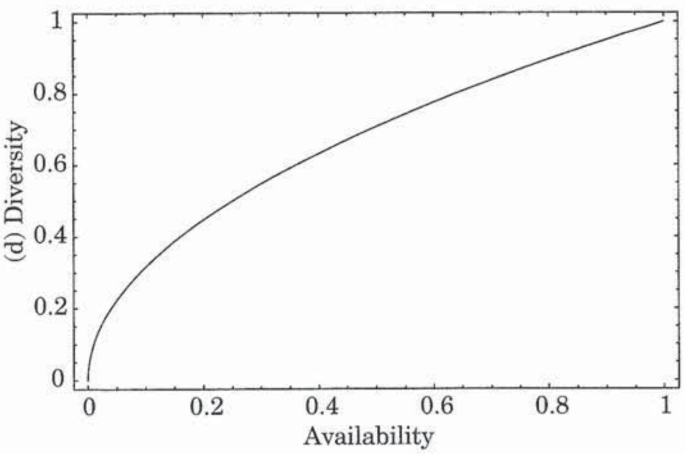

FIGURE 14.1. Functional relationship of diversity (d) to availability (a).

be comparable to a raw material with very low percent crystallinity, on average small crystal size, a small range in crystal size, and low abundance or zero impurities.

We hypothesize that the relationship between diversity and quality is more complex than a simple linear function. Although more data are needed to specifically model this relationship, especially given that it is highly contingent on specific sites and raw materials, the function we used is presented in Figure 14.2 and equation (14.2). With this equation, we propose that diversity scales as an exponentially decreasing function of quality. From this perspective, diversity is highest (or unity) at lowest quality ($q = 0$, the lowest-quality material that can actually still be knapped), and diversity decreases as q increases to the maximum ($q = 1$, the highest-quality material). It is further hypothesized that at low qualities, diversity falls rapidly as q increases, but at higher qualities (smaller grain size, smaller density of inclusions, etc.), diversity does not change nearly as rapidly. The simplest function that meets these criteria is a decaying exponential, where the parameter α controls the rate of the falloff and e is equal to the base of the natural logarithms ($e \approx 2.718$):

$$d(q) \propto e^{-\alpha q} \qquad (14.2)$$

In our model we utilize $\alpha = 3$ as an arbitrary starting point. With further detailed analysis of raw material quality from a given archaeological context, an explicit estimate of α could be obtained.

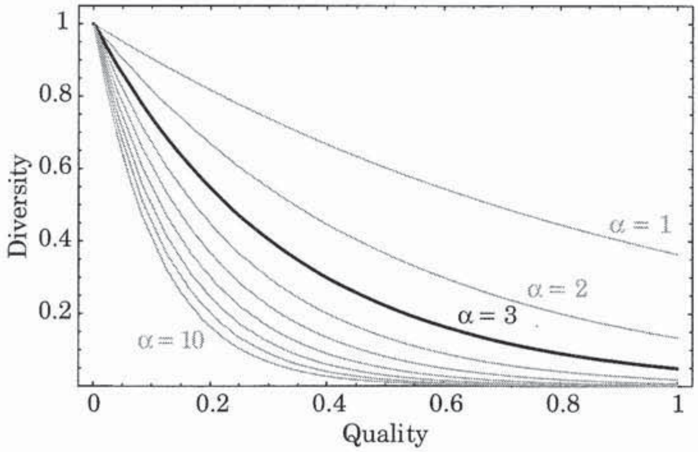

FIGURE 14.2. Functional relationship of diversity (*d*) to quality (*q*).

We chose this value for α because it provides an expectation that diversity will increase substantially with increases in poor-quality material but will also have a slope that is less steep with higher-quality material. We also assume that this curve will never reach zero diversity, because the model is built for a reductive technology (core reduction), and that human interaction with reductive technologies will always produce some degree of diversity.

Ratio of Producers to Consumers

The ratio of producers to consumers is a remarkably complicated variable to explain in mathematical terms. It is not clear how the relationship between diversity in core reduction systems and the producer:consumer ratio would actually pattern under specific conditions. Adopting a conservative approach, we have chosen the simplest linear model (Figure 14.3). We define μ to be the ratio of producers to consumers, $\mu = P/C$, where diversity increases at a constant rate as the ratio of producers to consumers increases. We recognize that this is largely based on parameters guiding knowledge transmission in different contexts. However, we believe that this allows a starting point that we and others can test to model human behavior and the diversity of core reduction techniques:

$$d(\mu) \propto P/C. \tag{14.3}$$

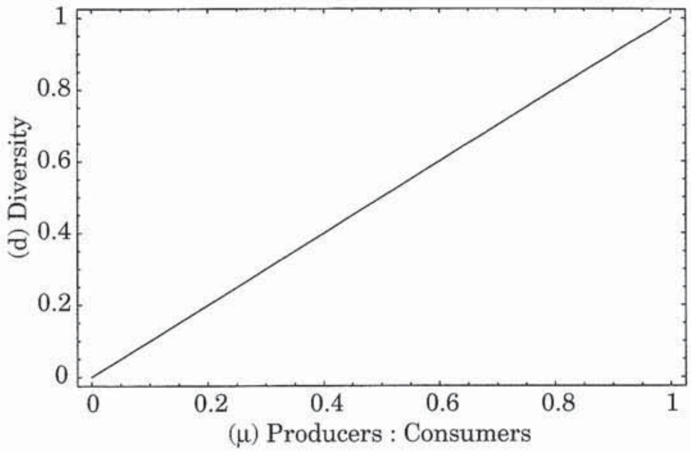

FIGURE 14.3. Functional relationship of diversity (*d*) to the ratio of producers to consumers (μ).

A MODEL OF CORE REDUCTION DIVERSITY (CRD)

The CRD model is based on the three parameters discussed above. In the following equation,

$$d(a, q, \mu) \propto \mu\sqrt{a}\,e^{-\alpha q}, \tag{14.4}$$

diversity is proportional to the ratio of producers to consumers (μ), the square root of availability (a), and the base of the natural logarithms (e) to the negative power of α times quality (q). The equation is presented in Figure 14.4. In this plot, quality changes in increments of .1 in each graphic from 0 (the lowest-quality raw material) to 1 (the highest-quality material).

This model provides a technique that can estimate the ratio of producers to consumers (μ). Therefore, we can solve for μ by inverting the last expression (eq. (14.4)) and writing it as

$$\mu(a, v, q) \propto \frac{d}{\sqrt{a}}e^{\alpha q}. \tag{14.5}$$

This equation is plotted in Figure 14.5, where availability changes in each plot by increments of .1 from very costly to attain ($a = 0.1$) to readily available ($a = 1.0$). As seen in Figures 14.4 and 14.5, case examples can be explicitly plotted on the graphs based on the quantifiable variables: raw material quality, raw material availability, and diversity in core reduction techniques. If the relationships between the variables are an accurate estimate of data sets, then one should be

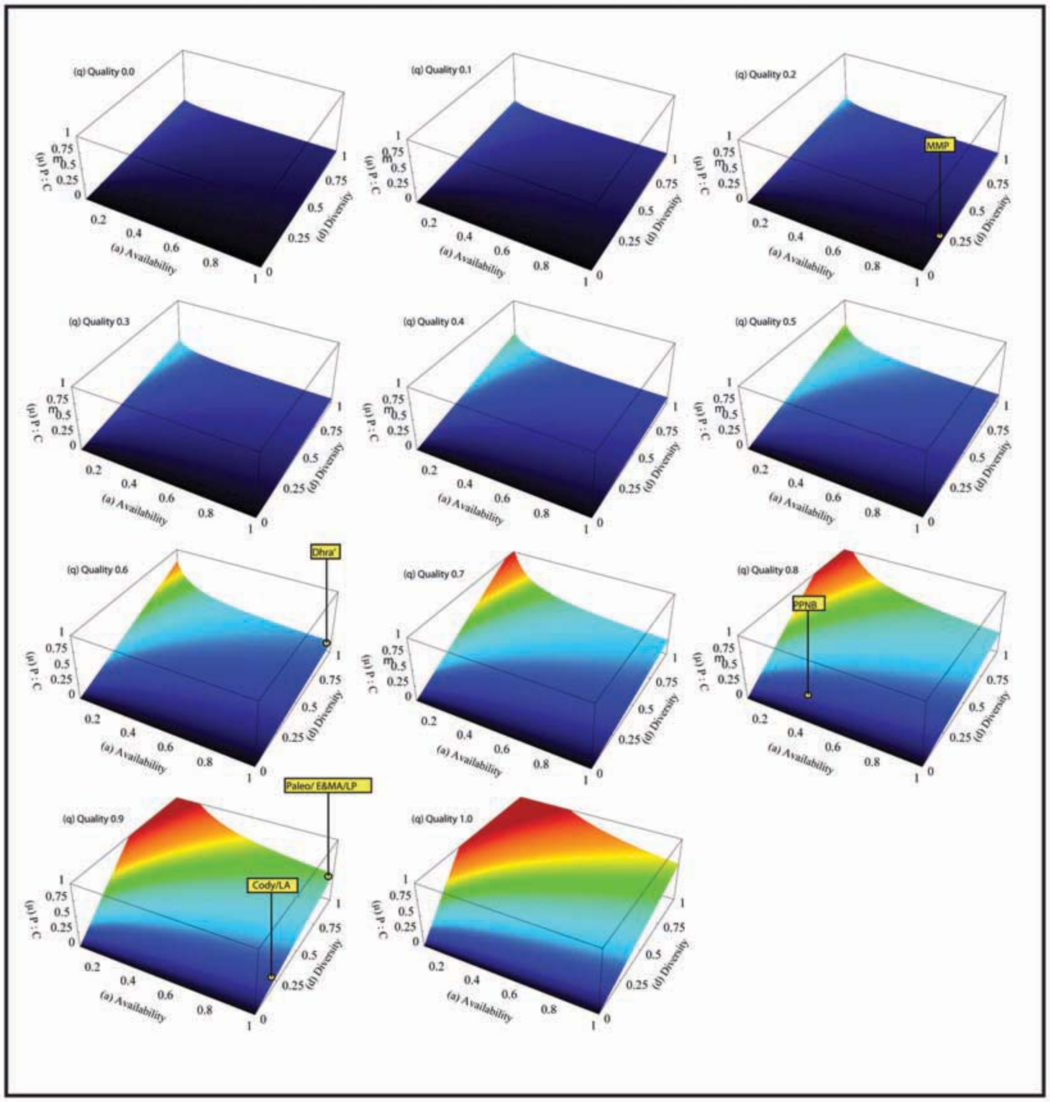

FIGURE 14.4. Plot of equation (14.4), where quality is decreasing by increments of .1 in each graph. Case examples discussed in text are labeled as (1) MMP = Mongolian Middle Paleolithic (Brantingham et al. 2000), (2) Dhra' = Dhra' Early Neolithic (Goodale et al. 2002), 3) PPNB = Middle Pre-Pottery Neolithic (Wilke and Quintero 1994), and (4) Paleo/E&M A/ LP = Paleoindian, Early and Middle Archaic, Late Prehistoric (Root 1997).

able to approximate the ratio of producers to consumers in a given community. We have plotted several cases in Figures 14.4 and Figures 14.5 where we would expect them to be a best fit in the model.

CASE EXAMPLES

To evaluate the potential utility of this model, we now explore several case studies from different archaeological contexts around the world

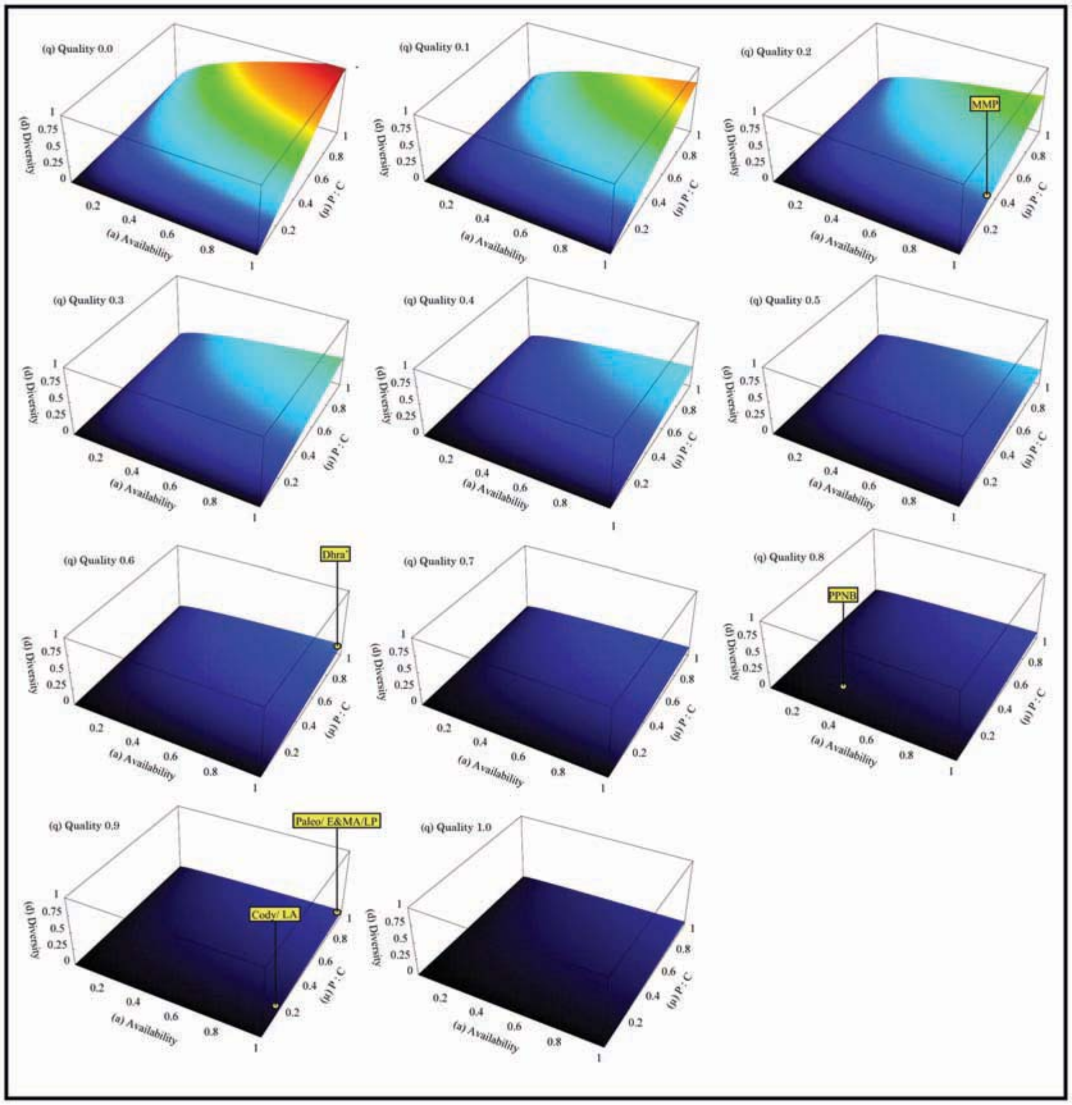

FIGURE 14.5. Plot of equation (14.5), where availability is decreasing by increments of .1 in each graph. Case examples discussed in text are labeled as (1) MMP = Mongolian Middle Paleolithic (Brantingham et al. 2000), (2) Dhra' = Dhra' Early Neolithic (Goodale et al. 2002), (3) PPNB = Middle Pre-Pottery Neolithic (Wilke and Quintero 1994), and (4) Paleo/E&M A/ LP = Paleoindian, Early and Middle Archaic, Late Prehistoric (Root 1997).

that reflect different occupational histories. Each case is plotted in Figures 14.4 and Figures 14.5 for reference. Cases act as working hypotheses about the ratios of producers to consumers reflected by the given assemblages. Each case provides the quality, availability, and diversity reflected in each assemblage, allowing an estimate of the producer:consumer ratio.

Near East Early Neolithic

The early Neolithic Site of Dhra', Jordan, exhibits a very large lithic assemblage composed of over one million pieces of debitage, tools, and cores (Finlayson et al. 2003; Goodale et al. 2002). The lithic assemblage is so large that a specific study of lithic core reduction techniques has been difficult. However, we have observed debitage elements that can provide the basic and most efficient means of how Pre-Pottery Neolithic A (PPNA) knappers produced the final product or tool blanks. We have also observed a number of diagnostic by-products that suggest that the knappers at Dhra' had to overcome a number of production errors and raw material failures.

The knappers at Dhra' primarily exploited one type of raw material (although there is some variability in the assemblage, the use of other nonlocal raw materials equates to less than 1%). The raw material, flint, is found in an outcrop approximately 50 m from the site (Goodale et al. 2002). It can be described as medium-quality, with small to medium crystallinity, but with frequent impurities and random planes subsequent to the formation processes.

In the case of Dhra', the raw material is readily available with low procurement and transport costs and is characteristic of medium quality. As shown in Figure 14.6, the debitage indicates that there were often circumstances where the knappers at Dhra' adjusted for knapping error and raw material failure. This likely facilitated a situation where it was not necessary for any knapper at Dhra' to be highly proficient and also allowed anyone in the community to participate as both producer and consumer. In this example, we see highly available raw material, a medium quality that we would approximate at .6 in our model, and a high degree of diversity in the core reduction system, where knappers often had to negotiate production errors or raw material failure. The hypothesis is that Dhra' is best characterized as reflecting a high ratio of producers to consumers.

Near East Middle Neolithic

During the Middle Pre-Pottery Neolithic, something quite different appears to happen in terms of uniformity in core reduction sequences. We see the advent of a highly systematic type of core

FIGURE 14.6. The highly variable reduction system exhibited in the Dhra' debitage and core assemblages.

reduction referred to as the naviform technique (Quintero and Wilke 1995). This type of core reduction has more specific operational chains (Wilke and Quintero 1994) that were hypothetically selected for under the social requirement for standardized long and straight blade tool blanks (Quintero and Wilke 1995). Naviform core technology utilized specific, high-quality raw material, which was not locally available (Quintero and Wilke 1995: 20). The naviform technique allows a higher degree of control over blade morphology than was previously possible with other core reduction technologies (such as that exhibited in the Dhra' assemblage). In comparison to the early Neolithic knappers at Dhra', who were producing highly variable products, middle Neolithic naviform producers were able to maximize the end product in the form of long and thin blades. Quintero and Wilke (1995) note the important manner in which knappers prepared their naviform cores with a consistent length of 12–15 cm and a width of 1.5–3.5 cm. They go on to suggest (1995: 26) that the socioeconomic conditions that accompanied the development of specialized blade-making flourished with demographic and economic growth. This would also hypothetically correlate with a greater degree of roles in the community, where select individuals were rewarded for flintknapping skills. Our hypothesis is that the process of naviform core reduction is characterized by expensive raw material acquisition, high quality, and a low degree of diversity, emphasizing a low producer:consumer ratio.

Mongolia Middle Paleolithic

Brantingham et al. (2000) provide a very interesting case of core reduction techniques from the Middle Paleolithic of East Asia. The raw material primarily exploited at the site is locally available and is on average of very poor quality. There are a few examples of core reduction that appear highly unsystematic, where the knappers negotiated the failures of the raw material, producing highly diversified core reduction techniques. However, they focus on another example of reduction technique that appears highly systematic and demonstrates that knappers focused on the most efficient chain that the raw material would allow. Brantingham et al. (2000) are unsure why this strategy was favored. Based on our model, we suggest that the highly uniform core reduction technique is representative of a low ratio of producers to consumers and that select individuals in the community paid the cost to learn how to negotiate the poor-quality material. Our hypothesis for the highly systematic core reduction technique is representative of poor quality and highly available raw material with a low degree of diversity, emphasizing a low ratio of producers to consumers.

North America Paleoindian to Late Prehistoric

Drawing on the Paleoindian to Late Prehistoric occupations of the Benz site in North Dakota, Root (1997) makes a compelling argument linking the ratio of producers to consumers to the efficiency of biface production. The site contained several "features" composed of clusters of lithic debitage that "likely mark the places where individual knappers made tools (Root 1997: 35)." The knappers at the Benz site exploited locally available and abundant high quality Knife River Flint. In his analysis, Root (1997: Table 7) provides estimates for the number of tools made in each feature by dated occupation. He concludes that the periods of highest efficiency are the Cody Complex and Late Archaic occupations. In opposition, the Paleoindian, Early and Middle Archaic, and Late Prehistoric occupations have the lowest scores for efficiency in biface reduction. This is an interesting pattern and we suggest that it may be linked with fluctuating social systems and changes in the ratio of producers to consumers through time. Root (1997: 42) also suggests that in the periods of highest efficiency, knappers were producing bifaces for exchange in the area, which was likely negotiated by shifts in social organization enabling an expansion of the number of community roles. In essence, Root's hypothesis (1997: 42) is similar to ours by suggesting that participation in production and consumption was no longer equal.

DISCUSSION

The case studies presented highlight the flexibility of human behavior negotiating the constraints of resources (or lack thereof) and the ability of humans to produce a range of diversity in reduction techniques. This range of diversity may be predicated on a number of factors, including how humans interact with their social and natural environments. Natural selection has favored a human phenotype that is behaviorally and cognitively flexible (Flinn 1996). Humans are aware of strategies that produce diminishing marginal returns on investment (Kaplan and Lancaster 2000). As a result of these propensities, humans can alternate strategies toward specific goals as social and environmental circumstances fluctuate (Kaplan and Lancaster 2000). The cost–benefit structure of engaging in any economic activity is shaped by the level of skill required for involvement and the competitiveness of the particular context (Kaplan and Lancaster 2000). This structure helps negotiate whether an individual engages in the production of a lithic core reduction technology or spends time and energy in other arenas. Linked to this is the availability of resources in the environment, the quality of the resources available, and the number of other individuals already engaged in the enterprise. The balancing of these three conditions affects the diversity (or lack thereof) in production techniques. If competition is high, costs will be high to engage in the economic activity, which leads to fewer individuals engaged in production. As a result, the diversity of lithic reduction techniques will be constrained. However, if competition is low, costs in engaging in the economic activity will be low, leading to more individuals engaging in production. As a result, diversity in reduction techniques should expand. Since researchers can estimate lithic availability, indices of lithic quality, and indices of diversity in reductive techniques, it is possible to extrapolate the producer:consumer ratio (at least in terms of our general model).

When lithic quality is low, availability of resources is low, and diversity in technique is low, one can expect a low ratio of producers to consumers. This is due to the fact that poor-quality resources require a greater degree of skill to manipulate in an efficient manner. To gain such a high degree of skill, one must go through a learning process. The time and energy required to learn such a technique would have been high. In an environment such as this, a tradeoff is present: (1) does one invest the time and energy in learning the lithic reduction craft; or (2) does one allocate energy into other arenas where time and energy produce greater returns from investment. In an environment of high stress, the strategy of learning lithic reductive techniques may be frequency-dependent. In other words, as the number of individuals learning and investing in lithic reduction techniques increases and the quantity of the resource decreases, the value of the time and energy expended on the craft decreases. Human behavior should be sensitive to this relationship, and people will hypothetically tend to allocate their time and energy into other arenas where they may receive a greater return on investment. Consequently, few producers will be favored in proportion to the number of consumers.

A high ratio of producers to consumers is consistent with conditions where lithic quality is high, availability is high, and diversity in reduction technique is high. This is due to the fact that the resource is relatively inexpensive (in terms of energy expended for access and in terms of investment required for learning how to manufacture the resource). With low costs, there is less incentive to invest heavily into learning skills associated with the lithic technology. As a result, more individuals are likely to be producers. Included in this expansion of the individuals in the production phase may be a younger age bracket, which also shapes the level of diversity witnessed in reduction techniques. As argued by Bock (2005), younger individuals have less motor control (which is a function of time involved in the production of the craft), resulting in greater degree of variability in production techniques within and between individuals.

CONCLUSIONS

Understanding the social, economic, and technical constraints for different chipped stone reduction pathways helps us examine differences in human behavior. The ability to estimate the producer:consumer ratio contributes toward this goal. It deals with a question that has been associated with studies of craft specialization throughout the study of anthropological archaeology (Costin 1991). The model and mathematical estimate focus on several independent, nonconstant parameters that scale along a continuum rather than holding several of them as static (for example, Beck et al. 2002).

Although we have not directly tested the model, we have presented case studies as hypotheses. By adding a third variable that is articulated with a well-supported principle in evolutionary analyses (optimality), it is possible to explain some of the diversity in the archaeological record. As an example, it explains the anomalous occurrence of low diversity despite low quality and high availability in the Middle Paleolithic of Mongolia. In future studies, if we can determine the relationship between population size and the producer:consumer ratio, we may be able to directly test this relationship.

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