HUMAN BEHAVIORAL ECOLOGY SECTION

Modeling Socioeconomic Discontinuity in Southern Alta California

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Abstract The archaeological record in prehistoric southern California exhibits discontinuous socioeconomic change. In the Santa Barbara region over the last 3500 years, archaeological assemblages exhibit high degrees of investment in subsistence technology that increases after the arrival of the bow and arrow at approximately cal A.D. 500, and again during a period of intensification after cal A.D. 1350. the increases in formality are consistent with expectations of an energy maximizing economy. In contrast, archaeological assemblages in the San Diego region over the last 3500 years are characterized by low tool formality; technological investment decreases after the bow arrives and after cal A.D. 1400 during intensification. The San Diego pattern is consistent with expectations of a time minimizing economy. However, several habitation sites appear in the San Diego region from cal A.D. 1400–1700 that have much higher assemblage formality and an apparent focus on high cost, high return resources, consistent with an energy maximizing strategy. I term these "Transitional" sites; precursors to the intensive economy attributed to the ethnohistoric Luiseño. A modified form of the Ideal Free Distribution (IFD) model is used to better explain the appearance of Transitional sites in the San Diego region and the subsequent abrupt shift to the ethnohistoric economy. This research clarifies the conditions under which qualitative differences in hunter-gatherer adaptive strategies can cause socioeconomic divergence.

Resumen El registro arqueológico en el sur de California muestra el cambio socioeconómico discontinua. En la región de Santa Bárbara en los últimos 3500 años, conjuntos arqueológicos muestran un alto grado de inversión en tecnología de subsistencia que aumenta después de la llegada del arco y la flecha de aproximadamente el año 500, y durante un período de intensificación después del

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año 1350. Esto es consistente con las expectativas de una economía de energía máximo. Por el contrario, los conjuntos arqueológicos de la región de San Diego durante los últimos 3500 años se caracterizan por la formalidad herramienta de bajo, la inversión tecnológica disminuye después de la proa y llega después del año 1400 durante la intensificación. El patrón de San Diego región es consistente con las expectativas de un tiempo reducir al mínimo la economía. Sin embargo, varios sitios de vivienda aparecen en la región de San Diego desde el año 1400–1700 que han formalidad mucho mayor de encaje y un mayor hincapié en los recursos de alto rendimiento de alto costo, en consonancia con una estrategia de maximización de la energía. Que yo llamo los "Transición" sitios, precursores de la economía intensiva atribuido a la etnohistóricos Luiseño. Una forma modificada de la Ideal Free Distribution (IFD) el modelo se utiliza para explicar mejor la apariencia de los sitios de transición en la región de San Diego y el posterior cambio brusco de la economía etnohistóricas. Esta investigación aclara las condiciones en que las diferencias cualitativas en las estrategias adaptativas de cazadores-recolectores pueden causar divergencias socioeconómicas.

Archaeological discussions of aboriginal southern California are typically focused on complex hunter-gatherers that over the last 5000 years devised intricate socioeconomic institutions in step with ever intensifying subsistence. The Chumash of Santa Barbara and the Gabrielino of the Los Angeles region, with their circular fishhooks, plank canoes, and shell bead industry, have been the focus of such discourse and much debate concerning the timing and causes for such developments (Arnold 1992, 1995, 1997, 2007; Erlandson 1991, 1997; Erlandson and Rick 2002; Erlandson et al. 2008; Gamble 1995, 2002; Glassow et al. 2007; Jones and Klar 2005, 2007; Kennett 2005; Kennett and Kennett 2000; Raab and Larson 1997). These discussions track a global perspective that all hunter-gatherers gradually succumb to population pressure and/or environmental degradation, becoming sedentary food producers (see Braidwood 1962; Byrd 1998). However, the San Diego region has been conspicuously left out of the discourse, precisely due to the lack of Chumash-like sociopolitical arrangements and complex technologies.

Distinct from the archaeological record of Los Angeles and Santa Barbara, the archaeological record in San Diego exhibits strikingly little change that can be taken as a signal of significant socioeconomic adaptation from 10,000 years ago until just before ethnohistoric times (Hale 2001, 2009, 2010; Hale and Comeau 2009; Warren et al. 2004). The acorn-based economy of the ethnohistoric Luiseño is a departure from the prehistoric record (Hale 2005; True 1980; True and Waugh 1983). This is true despite the mantra that the ethnohistoric economy has its roots in several migrations to the region in the last 2000 years (Bean and Shipek 1978; Kroeber 1925; Rogers 1945).

Substantial compliance-driven archaeological research in San Diego County in the last 30 years has generated a robust database that collectively indicates that the ethnohistoric economy is the late (i.e., post cal A.D. 1700) manifestation of multiple factors both endogenous and exogenous to the local aboriginal population. To be sure, hunter-gatherers were certainly experiencing population growth and deteriorating socioeconomic conditions, implicit in the archaeological record. Such conditions were exacerbated following European contact and the subsequent missionization of local aboriginal groups. However, there is scant evidence, despite direct inquiry into the matter, of the acorn-based ethnohistoric economy extending more than a century or two into prehistoric times. This article does not attempt to explain the precise timing of the ethnohistoric pattern, but rather, to explain how the long-term socioeconomic stability of hunter-gatherer adaptations in the San Diego region was abruptly replaced by a very different, more intensive economy that characterizes the ethnohistoric Luiseño.

Theoretical Context

Behavioral Continua

In the last 30 years or so archaeologists—dissatisfied with stereotypes—have increasingly turned to behavioral continua to explain hunter-gatherer adaptive strategies (see Kelly 1995). Traditional research has focused on finding a definition of pristine hunter-gatherers, i.e., unaffected by contact with foreign societies; of course, this is an impossible venture. Ethnographic work in the twentieth century continued to document societies whose primary mode of production was hunting and gathering, and existing definitions of hunter-gatherers failed to account for an increasing range of behavioral variability. Models of behavioral continua (e.g., foragers-collectors [Binford 1980], travelers-processors [Bettinger and Baumhoff 1982]) emerged with the goal of better understanding the range of behaviors exhibited by hunter-gatherers, rather than coming up with a new definition.

Currently, behavioral continua are some of the most popular models used in hunter-gatherer research, and rightfully so, because they account for most ethnographic cases and are easily adapted to archaeological problems (see Binford 1980). Continua are bounded by dichotomous poles characterizing either extreme, and between these poles are an infinite number of behavioral combinations. Adaptive strategies are described as more or less similar to one of the poles (i.e., forager-like or collector-like) but never completely one or the other.

The purpose of behavioral continua is to provide a range of possibilities for describing combinations of social organization, demography, subsistence, mobility, and other factors that influence hunter-gatherer adaptation. Within behavioral continua, adaptive strategies are optimal solutions to local conditions. As conditions change, adaptive strategies must also change to reach local equilibria. In the forager-collector continuum, a forager-like adaptive strategy might respond to decreased abundance of high-ranked prey by practicing the collector-like strategy of storage, which can be abandoned as soon as conditions favoring storage disappear. This example illustrates the flexibility ascribed to hunter-gatherers in behavioral continua and shows that, in this model, local equilibria are weak and are only as stable as local conditions.

If local hunter-gatherer adaptations are unstable and respond closely to techno-environmental change, as models cast in terms of behavioral continua (i.e., forager-collector) suggest, San Diego hunter-gatherers should have intensified acorn and marine resource exploitation, just as their northerly neighbors did. This is the scenario used explain archaeological patterning among southern California hunter-gatherer groups, the evolution from less intensive foragers to intensive collectors (Byrd et al. 1993; Glassow 1997; Kennett 2005) and from egalitarian foragers to complex fisher-processors (Arnold 1992, 1997; Raab and Larson 1997). In these accounts, subsistence intensification pushes hunter-gatherers from foragers to collectors, or from simple to complex hunter-gatherers, as the result of various combinations of environmental stress, resource availability, and population density. If this were universally true, archaeological patterning should reflect gradual socioeconomic transformation over the late Holocene in the San Diego region as well, but the opposite is true.

The apparent stability of hunter-gatherer adaptive strategies in the San Diego area highlights the limits of models based on behavioral continua; they cannot account for situations in which adaptive strategy does not transform under changing techno-environmental circumstances. Hunter-gatherers in San Diego were exposed to the same technological innovations available in Santa Barbara and Los Angeles, but none of the rapid and substantial changes that occurred in Santa Barbara happened in San Diego. The common solution has been to look for environmental differences to constrain explanations of adaptive change — or the lack thereof.

Environment has always been the stock explanation for adaptive and cultural differences between Santa Barbara and San Diego. Prehistoric socioeconomic development in the Santa Barbara Channel region is typically laid to a combination of topography and marine upwelling that produced a uniquely productive environmental setting vastly more favorable than that in San Diego (Arnold 1997; Kennett 2005; Raab and Larson 1997). Of course, there is some merit to this idea. The south-facing Santa Ynez Mountains terminate abruptly on a narrow Santa Barbara coastal plain, trapping moisture and creating a cool, temperate climate with about 20 inches of annual precipitation. Rock reefs dot the Santa Barbara shoreline, providing superb habitat for shellfish, kelp-dwelling fish, and occasional marine mammal colonies sustained by nutrient-rich deep water upwelling generated by offshore winds, conditions that are replicated on the adjacent Channel Islands.

The coastal mainland further south in Los Angeles, Orange, and San Diego counties is less productive in comparison. The coastal topography of the Santa Monica and Santa Ana mountains and Peninsular Ranges is gentler and receives less annual precipitation (about 10–15 inches), producing a desert-like environment dominated by drought-tolerant chaparral. The availability of marine foods varies, but other than the vicinity of the Santa Monica Mountains where they are steep and rocky, shorelines are generally a mixture of flat, sandy beaches and cliffs interspersed with rocky outcrops and reefs. As a consequence, while pelagic and schooling fishes are widely available in the waters off Los Angeles, Orange, and San Diego counties (Allen 1985; Eschmeyer et al. 1983), sea mammals and kelp-dwelling fish are noticeably less abundant than in the Santa Barbara Channel. The kelp-dwelling nearshore and schooling species that constitute the majority of identified archaeological specimens from the Santa Barbara area (Glassow et al. 2007) were exploited the San Diego area, but in much smaller quantities and were more heavily biased toward schooling species.

This north versus south environmental contrast goes only so far. Certain aboriginally important resources were uniformly abundant along the length of the southern California coast, the most notable being acorns. The coast live oak (*Quercus agrifolia*), so highly preferred because of its oil-rich nut meat (Pavlik et al. 1991), was widely available in inland and coastal settings from Santa Barbara to San Diego (Griffin and Critchfield 1982). The equally valued black oak (*Q. kellogii*) is actually more common to the south, in San Diego County, and decreases in productivity as one moves north, despite increasing rainfall (Koenig 2007).

Prehistoric San Diegans had access to acorn crops at least as productive as those of their neighbors in the Santa Barbara and Los Angeles areas. The intensive, acorn-dominated adaptation present in San Diego after cal A.D. 1700 shows, beyond any doubt, that the region had sufficient terrestrial resources to sustain much denser hunter-gatherer populations earlier in time. In addition, while inferior to that of Santa Barbara, marine environments off San Diego are nearly equal to those of Los Angeles (Goodson 1988), which sustained intensive offshore fishing from plank canoes by the ethnographic Gabrielino. Pelagic and schooling fishes are common to the mild waters of both (Allen 1985; Eschmeyer et al. 1983;

Goodson 1988), their sea bottoms equally broken by reefs supporting stable kelp forests and diverse nearshore fish communities. In comparison to that of Los Angeles, however, the offshore San Diego fishery remained under-exploited.

Considering models of behavioral continua, environment provides a ready-made explanation for regional differences in hunter-gatherer adaptation because they are so clearly tied to their environment, no two of which are ever exactly alike. Environmental explanations may be frequently less convincing when closely scrutinized, however, and the Santa Barbara-San Diego comparison is a good example. It is quite clear that, relative to the Santa Barbara area, San Diego was disadvantaged on the marine side of the equation, which might explain its lesser development of marine resources and offshore fishing. That the intervening Los Angeles area was equally disadvantaged but nevertheless developed an intensive marine emphasis approaching that of the Santa Barbara Channel makes this environmental explanation implausible, however. Because they were on a par with those of Los Angeles, the marine resources off San Diego could have been, but were not, developed into an intensive fishing adaptation akin to that of the Gabrielino.

The terrestrial side of the equation is even more damaging to the environmental explanation. While the Santa Barbara Channel was somewhat better watered, producing more seeds and roots, acorn resources were similar to those in the San Diego area. Acorns bulked large in the Santa Barbara diet, probably acting as a source of carbohydrates and fat to offset heavy use of protein-rich but fat-poor marine fish (Cordain et al. 2000). From this perspective, intensified fishing in the Santa Barbara Channel had to develop in step with intensive exploitation of terrestrial plants (the acorn in particular). If environment were all that mattered, regardless of whether it was capable of developing an intensive marine fishery, the San Diego region, with its productive acorn crops, should have developed an acorn-intensive adaptation as early as the one that ended up paving the way for intensive marine fishing in Santa Barbara. The hunter-gatherers of San Diego did, in fact, intensify acorn exploitation, but evidence for this is limited to around AD 1700 (Hale 2005; Hale and Becker 2006; also see True and Waugh 1983), and a marine fishery comparable to that in the Los Angeles area never developed.

Environmental explanations for differences in behavior hinge on showing a clear connection between variation in a specific aspect of environment and variation in a specific form of behavior. On this view, there is little merit in the received wisdom that differences in cultural trajectory between the Santa Barbara and Los Angeles regions and the San Diego region can be laid to environment. There are environmental differences, to be sure. The marine fishery of San Diego was surely inferior. But its terrestrial resources were not, and its marine fishery was certainly sufficient to sustain substantial intensification, as the Gabrielino did. In short,

environmental differences cannot provide the crucial link needed to constrain explanation in a behavioral continua model to account for adaptive stability in San Diego.

Time Minimizing and Energy Maximizing

The adaptive stability evident in the archaeological record of the San Diego region is best explained by a model that considers time minimizing and energy maximizing as Evolutionary Stable Strategies (ESS) (Bettinger 1999; Hale 2009). The terms time minimizing and energy maximizing derive from optimal foraging models seeking to explain the relationship between foraging time and energetic yield.

Optimal foraging models have considered time and energy as constraints on fitness in that reproductive success is limited by energy intake and time available to spend in activities that enhance fitness (Smith 1979; Stephens and Krebs 1986). In this view, time minimizing refers to minimizing time spent in subsistence activities to allocate time to non-subsistence goals, and energy maximizing refers to maximizing energetic intake. Belovsky (1987) used linear programming to compare the payoff of plant versus meat foods as constrained by stomach capacity, protein, energy, and time to model !Kung foraging strategies. With an adjustment to account for multiple stomachs requiring satiation, he found that the !Kung practice energy maximizing, rather than time minimizing. Belovsky's (1987) idea was explicitly based on the concept of time minimizing and energy maximizing as ends of a continuum of foraging decisions rooted in general ecological applications of optimal foraging, such as ungulate populations (also see Belovsky 1978). Bergman et al. (2001) considered patch choice and time spent foraging in each patch among bison when evaluating whether these animals practice time minimizing or energy maximizing, concluding that differentiating each is simply a matter of the time scale for observation; bison appear to be time minimizers over a long temporal scale by reducing overall foraging time through maximizing intake in the short term. The concept of time minimizing and energy maximizing as ends of a continuum has been carried over into other anthropological discussions (e.g., Bettinger and Baumhoff 1982; Winterhalder 1983).

Winterhalder (1983) proposed a formal model of time minimizing and energy maximizing based on indifference. He began with the premise that strong preferences for either non-subsistence time or more energy (food) affect the way hunter-gatherers make subsistence decisions. However, his model did not explain the basis for the preferences themselves, and his conclusions, though not deterministic like Belovsky's (1987), were framed in a similar continuum-based perspective. Bettinger and Baumhoff (1982) took a different approach. Assuming that hunter-gatherers are limited by time and energy, they distinguished between time-limited travelers and energy-limited processors. Traveler and processor strategies are adaptive peaks because travelers are time limited and processors are energy limited. Since intermediate strategies are less productive, shifting from one peak to the other (i.e., from traveler to processor) is difficult. Unlike Belovsky (1987), the Bettinger and Baumhoff (1982) model was rooted in the contingency form of optimal foraging theory (diet breadth and patch choice), in which cost and benefits (time and energy) are treated as a ratio (energy relative to time or time relative to energy). This makes it impossible to examine the effect of time or energy independently, and equally impossible to separate time-limited from energy-limited strategies.

Time Minimizing and Energy Maximizing as Evolutionary Stable Strategies

Bettinger (1999) proposed a model that defines time minimizing and energy maximizing as evolutionary stable strategies (ESS). An adaptive strategy encompasses a combination of tactics for subsistence, settlement, organization, and demography developed within an overarching value system (see Bettinger 1999). An evolutionary stable adaptive strategy is one that resists invasion by competing strategies (see McElreath and Boyd 2007). By definition, once established, an ESS cannot be invaded by another strategy. In this context, evolutionary stability is provided by mutually beneficial, and thus self-enforcing, coordination (e.g., driving on the right side of the road) and by value-reinforcing social institutions.

In time minimizing economies, for example, the social institution of tolerated theft works as a disincentive to subsistence intensification (why work hard if lazier individuals will eat just as well?). In the same way, norms valuing leisure time, decorative craftwork, or other non-subsistence pursuits reduce the perceived benefits of foraging, dampening the potential for population growth (Riches 1982; Winterhalder 1996). In energy maximizing economies, on the other hand, privatized resources, positively sanctioned resource hoarding, and punishment for resource theft act as incentives to resource intensification, permitting storage with ensuing population growth (Blurton Jones 1987; Gurven 2004; Winterhalder 1996). The social forces that discourage resource intensification under time minimizing make a shift to energy maximizing impossible absent wholesale social re-coordination—a fundamental shift in values and behavior (see Bettinger 1999).

Bettinger (1999: Figure 5.12) used linear programming to illustrate time minimizing and energy maximizing as ESSs. Bettinger compared the payoff for an individual choosing a time minimizing or energy maximizing strategy, based on the proportion of energy maximizers in the population. The main point of this exercise is that when time minimizers constitute two-thirds of the population, the

payoff is always higher and would be the better choice, while energy maximizing is the better choice when they constitute more than one-third of the population, and the average individual payoff is higher when the population is 100–percent energy maximizers than if it were 100–percent time minimizers. Another important revelation is that average individual payoff is lower for any mixture of time minimizers and energy maximizers than if the entire population were time minimizers. Together, these factors indicate that populations will tend to be either all time minimizers or all energy maximizers. Time minimizing and energy maximizing are stabile equilibria and a shift from one to the other is impossible without a large-scale, coordinated effort to overcome the economic threshold. This same concept is true for daily economic choices as well, including storage and other factors that can disrupt the adaptive stability of time minimizing (i.e., considering storage as an energy maximizing tactic).

Bettinger (1999) further considered the shift to energy maximizing as a function of new technologies and prestige. With the introduction of the bow and arrow and a subsequent increase in the average success of individual hunters, it may have been possible to generate resource surpluses. Bountiful food may have provided more access to mates, associating hunting prowess with prestige. Women, on the other hand, competed for what Bettinger (1999:182) termed "labor-reducing social arrangements," considering the large amount of time they spent processing to meet subsistence requirements.

Hale (2009) presented a formal model for Bettinger's (1999) concept of time minimizing and energy maximizing as ESSs (the algebraic derivation is not summarized here). The model by Hale (2009) is grounded in formal economics and evolutionary theory. The formal economic perspective is that humans have a tendency to make rational decisions about the allocation of scarce resources to achieve desired ends (Robbins 1932). Time and energy are considered the most important scarce resources affecting survival and success. Desired ends are potentially infinite and are both individually and culturally determined. Decisions to allocate resources to specific ends are rational if they match socially defined preferences. Similar to earlier optimal foraging models, evolution by natural selection justifies the assumption that human decision-making is rational, considering that the allocation of scarce resources should be optimized in a way that enhances fitness (see Alvard 1993; Smith 1979; Stephens and Krebs 1986).

Evolution by natural selection is concerned with changes in preference structures inasmuch as they affect the maximization of scarce resources. Hale's (2009) formal model of time minimizing-energy maximizing is based on the assumption that social institutions evolve to stabilize existing preference structures, i.e., a preference for either more non-subsistence time or more energy. Adaptive strategies cannot exist if social rules do not reinforce participation. Changes in local conditions (e.g., technology, environment) elicit qualitatively different responses from each strategy consistent with stable preferences. For example, time minimizers should save more time on subsistence with the adoption of more efficient extractive technologies and energy maximizers should get more energy. Thus, changes in preference structures (i.e., from time minimizing to energy maximizing) are not continuous; they are abrupt, comprehensive changes in social coordination and adaptive mechanisms. In contrast with behavioral continua, the formal model of time minimizing and energy maximizing is based on stabilized preferences, rather than gradation from one strategy to the other. Still, the problem remains of how a shift from time minimizing to energy maximizing can occur since social institutions wield so much influence over daily economic choices.

Hale's (2009) model provides some clarity. Whereas Bettinger (1999) argued that new technology coupled with prestige and access to mates must have provided a new set of opportunities for individuals to indulge in selfish pursuits not typical of time minimizers, Hale's (2009) model considers situations wherein conditions in a time-minimizing economy can significantly deteriorate (i.e., reduction in foraging return rate) to the point that they spend much more time in subsistence than is desired, leaving little opportunity to fulfill non-subsistence needs. At a certain point, energy-maximizing tactics can actually result in less time spent in subsistence, making the shift to energy maximizing both attractive and necessary to fulfill non-subsistence goals. The same time-minimizing social institutions that constrain storage also constrain prestige-based behavior and it is thus just as valid to consider the shift to energy maximizing a function of economic conditions without giving agency to prestige or the influence of new technologies.

Modeling the Transition from Time Minimizing to Energy Maximizing with the Ideal Free Distribution

To better understand deteriorating conditions and the transition from time minimizing to energy maximizing ESSs, Hale (2009) considered time minimizing and energy maximizing as niches in a modified form of the Ideal Free Distribution (IFD). Fretwell and Lucas (1970) originally conceived the IFD to explain why birds congregate in habitats that differ in quality. I employ the basic tenets of the IFD to conceive shifts in population structure across different niches. Certain key assumptions drive the IFD model: (1) individuals have an ideal capacity to perceive variability in habitat quality and select the most suitable habitat, and (2) individuals are free to occupy any available habitat. An individual's decision to occupy any given habitat is thus a behavioral phenomenon.

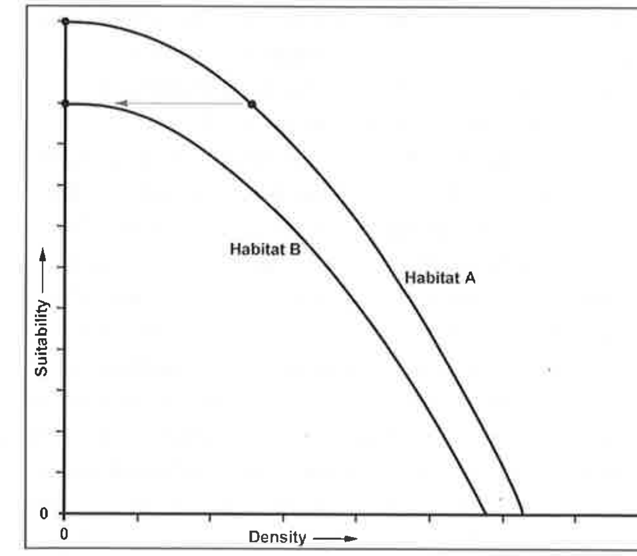

Figure 1. A model of the standard Ideal Free Distribution. Individuals colonize Habitat A first because it has a higher initial suitability, and only populate Habitat B when the suitability in Habitat A diminishes with each additional individual to the point that suitability in Habitat A is equal to Habitat B. Both habitats then have the same mean suitability as habitats are filled evenly.

The availability and distribution of resources vital for survival and reproduction is the intrinsic quality of a habitat that is evaluated by potential colonizing individuals. With each habitat being a discrete area, an individual's perception of habitat quality (or suitability) is a proxy for average foraging return rate, since incremental population growth diminishes food supply. Fretwell and Lucas (1970) provided a simple algebraic derivation of habitat suitability.

The most basic IFD model considers two habitats (A and B) that vary in intrinsic suitability. Having ideal habitat selection capabilities, individuals colonize the habitat with the highest initial suitability (Habitat A) until, with additional colonizers, suitability in Habitat A decreases to the point that it is equal to the suitability of Habitat B (Figure 1). At this point, individuals evenly populate Habitats A and B since each habitat has the same mean suitability that decreases evenly with increasing population density.

The unmodified IFD does not consider the benefits of congregation, such as spreading the risk of predation over a larger group, access to mates, food sharing, and other social activities. A more useful model includes the Allee effect (Fretwell and Lucas 1970:19; see also Allee et al. 1949), wherein survival and reproduction increase with population size to some population density greater than zero where habitat quality is maximized. In the Allee-based IFD, population density will increase to some optimal size and then decline thereafter with each additional newcomer (Fretwell and Lucas 1970:23–25). When habitat suitability is Allee-based, changes in population structure across alternative habitats are discontinuous because the habitat with higher intrinsic suitability is depopulated until its suitability is equal to the lower quality habitat at its maximum density (see Figure 1).

Other factors can influence perceptions of habitat suitability. For instance, despotism will decrease the perceived suitability of a habitat to newcomers or inferior competitors, having the effect of causing habitats with lower intrinsic suitability to be perceived as better alternatives. Despotic residents may attempt to control access to resource patches to maintain a minimum level of habitat quality. Fretwell and Lucas (1970) referred to such a model as the Ideal Despotic Distribution (IDD).

Quijano and Passino (2007) demonstrated that when the mean population strategy is to achieve an IFD, it can become an ESS. In an IFD structured population, individuals share a mean fitness regardless of whether they are in the habitat with the highest or lowest mean suitability, and colonizing individuals with a different strategy will experience lower return rates—and by extension, fitness. When these conditions are true, the population will be at a Nash equilibrium (see Maynard Smith and Price 1973; McElreath and Boyd 2007), and such an equilibrium could be even harder to disrupt if residents practice despotism as a means of stabilizing habitat suitability.

Modifying the Ideal Free Distribution to Compare Human Economies

Several researchers have successfully applied the IFD in its basic, Allee-based forms, even accounting for despotism (see Kennett et al. 2006; Kennett and Winterhalder 2006; Lessells 1995). These applications take the traditional approach and describe the distribution of human populations over physical habitats. However, the IFD can also describe population dynamics across modes of production or economies of scale if certain assumptions are modified.

The concept of habitat in the IFD, as originally conceived, can be replaced with niche. A niche can be a socioeconomic mode of production as well as a geographically discrete habitat, but niche allows for spatial overlap in economic strategy, whether or not those strategies closely track geography (i.e., deep water fishing). Thus, the original assumption that habitats must be spatially distinct to facilitate an individual's ability to perceive difference in habitat quality is not necessary.

The assumption that individuals are free to occupy any available niche is not universally true. The IDD accounts for some of this, as newcomers may face despotic residents. However, some niches among humans require a minimum number of coordinating individuals for successful colonization, and thus any one individual would not be free to occupy an alternative, density-dependent niche.

Human sociality and economic coordination factors large in decisions to pursue alternative modes of production, and the effects of higher population densities on niche suitability and sustainability are well known. Smith (1991) noted that the overall per capita return rate on certain kinds of hunting increase until an optimal group size is reached based on cooperative efforts, but diminishes thereafter with each additional member to the hunting party. However, these hunting parties allowed additional members to join the hunt, accepting decreased return rates, suggesting that social relationships between group members and promises of future reciprocity strongly affect group size. This pattern holds until the per capita return rate on a hunting party is lower or relatively equal to the returns an individual can achieve on his own (cf. Kelly 1995:219–220; Smith 1991). Other kinds of frequency dependent problems can also affect the perceived suitability of alternative niches, such as skewed sex ratios. If women are the primary processors of acorns, for example, the potential success of attempts to colonize an acorn economy will be dependent on the number of women available to process acorns.

Modeling Time Minimizing and Energy Maximizing as Density-Dependent Modes of Production in the Ideal Free Distribution

Time minimizing and energy maximizing can represent niches in the IFD that are independent modes of production, varying with respect to initial and maximum suitability, return rate, and population density. Hypothetical differences between time minimizing and energy maximizing are outlined in Table 1 and graphically represented in Figure 2.

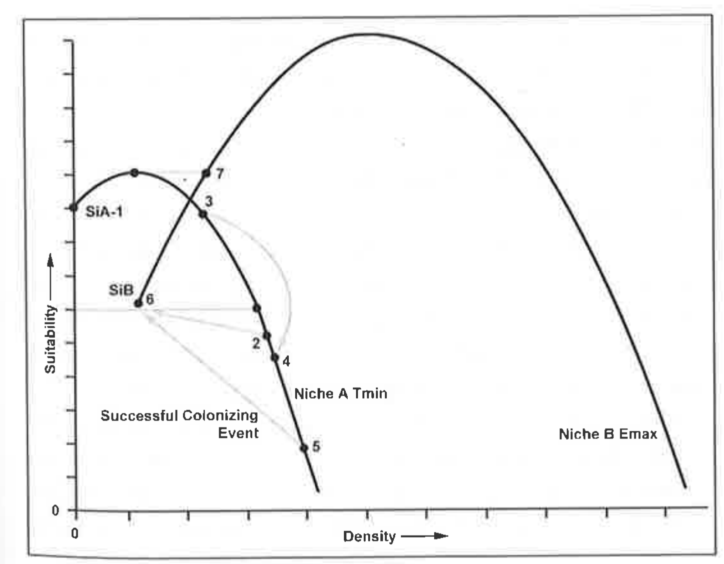

Figure 2. Note the discontinuous population dynamics (highlighted by light gray arrows) that predict cyclical failed colonizing events (Points 2 through 6) before an attempt to colonize the alternative energy-maximizing economic is successful.

Table 1. Expectations of Time Minimizing and Energy Maximizing Economies in the Same Physical Environment.

	Time Minimizing	Energy Maximizing
Initial Suitability (Initial Return Rate)	Higher	Lower
Minimum Density	Very Low	Higher
Allee Effect	Smaller	Larger
Population Density at Maximum Suitability (height of curve)	Lower	Higher
Rate of Diminishing Returns (steepness of curve)	Faster	Slower
Overall Density	Lower	Higher

Setting up the IFD curves to reflect time-minimizing and energy-maximizing strategies requires translation of basic theoretical assumptions for each strategy into variables that affect each curve: initial suitability, minimum density, Allee effect, relative population density at maximum suitability (height of curve), rate of diminishing returns (steepness of curve), and overall population density. To facilitate discussion, it is assumed that the time-minimizing strategy is a basic foraging economy without subsistence specializations, while the energy-maximizing economy is an intensive high-cost, high-yield strategy, such as an intensified acorn-based economy.

Considering initial suitability, a time-minimizing economy is expected to have a higher initial suitability and lower minimum density threshold than an energy-maximizing economy. Time-minimizing economies generally lack subsistence specializations and have a lower population density, translating into higher per capita returns, i.e., foragers are able to pursue higher quality, less abundant resources (Figure 2). In such an economy, individualized or sporadic exploitation of high-cost, high-return resources (such as acorns) is very costly and not expected to occur regularly (see Bettinger et al. 1997). An energy-maximizing economy requires more socioeconomic coordination, resulting in a greater minimum density threshold that has relatively low initial suitability. However, once the energy-maximizing economy starts, greater numbers of individuals coordinating efforts will increase the maximum suitability above that of a time-minimizing economy (Figure 2). Considering an energy-maximizing economy focused on acorns, this high-cost, high-yield resource would provide ample energy and nutrition for a much denser population than an existing time-minimizing strategy. It is also true that an energy-maximizing economy will intensify differently, having a slower rate of diminishing returns overall with population growth than a time-minimizing economy. This is because the primary strategy of a time-minimizing economy is to find ways to discount time spent in subsistence as intensification occurs, whereas an energy-maximizing economy will constantly increase subsistence yield.

With time-minimizing and energy-maximizing strategies modeled as different curves in the IFD, multiple discontinuous changes in population structure occur with incremental population growth. With the time-minimizing economy representing the original niche, as the population grows, the suitability (or return rates) of the time-minimizing economy will diminish to the point that it is equal to the initial suitability of the energy-maximizing economy (Figure 2, Point 2). After this point, conditions in the alternative energy-maximizing economy are better and the minimum number of individuals necessary to colonize such an economy will defect. However, their defection depopulates the original time-minimizing economy, driving suitability of this economy back up. Having ideal niche suitability perception, the colonizers of the energy-maximizing economy will quit and defect back to the time-minimizing economy (Figure 2, Point 3).

With incremental population growth, the model predicts that there will be a cycle of failed colonizing events to start an energy-maximizing economy. The energy-maximizing colonizers will only be successful when their defection from time minimizing to energy maximizing equalizes the suitability between both economies (Figure 2, Points 5 and 6). After this point, newcomers populate the energy-maximizing economy, along with incremental defections from the original time-minimizing economy until the latter is completely depopulated. This occurs because the maximum suitability for the energy-maximizing economy is much higher than that of the time-minimizing economy. Incidentally, a fringe population may develop in the original time-minimizing niche after suitability declines in the energy-maximizing economy to the point that it is equal to the initial suitability of the time-minimizing economy. Note that other factors besides population growth can produce similar effects, such as a dramatic decrease in the suitability of a time-minimizing economy due to the effects of introduced disease or environmental degradation.

This exercise has revealed several non-intuitive predictions. First, conditions in a time-minimizing economy will significantly deteriorate before a socioeconomic shift to an energy-maximizing economy occurs. A proxy for deteriorating economic conditions is declining return rates. Social institutions are expected to stabilize a strong preference for free time so that intensification actually causes time minimizers to allocate a majority of time to subsistence. Second, the shift from a time-minimizing to energy-maximizing economy will be preceded by a series of failed colonizing attempts before the energy-maximizing economy is successfully populated. Hunter-gatherers probably knew the costs associated with mass processing of acorns and other high-cost, high-yield resources, and it is more likely that colonizing attempts would be rare and short-lived before a stable energy-maximizing economy successfully took hold.

Fitting Theory to Data

The archaeological implications of the time minimizing-energy maximizing model, including integration with the IFD, are relatively clear if investment in subsistence technology is used as a proxy for assessing time spent in subsistence. To simplify model evaluation, this research measured response to the introduction of the bow and arrow and to intensification. The bow and arrow complex is a major technological innovation that is superior in accuracy to the atlatl (see Bettinger 1999; Hrdlicka 2004). The atlatl is advantageous when several individuals target animals at close range, particularly large game. The bow and arrow, however, increases the average success of individual hunters at a greater distance than the atlatl (Hrdlicka 2004). Such a technology promises to increase hunting efficiency and should elicit response among time minimizers and energy maximizers.

Based on a strong preference for non-subsistence time, time minimizers should use the time savings afforded by the bow during hunting to save time in traditional subsistence pursuits. The cost of manufacturing the bow and arrow should be offset through saving time in other areas of subsistence, including decreasing the time spent manufacturing other subsistence tools. Conversely, energy maximizers should invest the time saved by using the bow and arrow back into subsistence, whether directly by getting more food or indirectly by formalizing other subsistence tools.

In the same way, time minimizers should respond to diminishing returns through time-saving tactics. Now spending more time in subsistence than is preferred, time minimizers should attempt to save time by reducing tool manufacturing costs. However, time minimizers should specifically avoid manufacturing specialized tools. The opposite is expected for energy maximizers who should respond to decreasing efficiency by producing more efficient, reliable, and specialized subsistence tools, and this may be manifest conceptually in tool decoration as a reflection of the importance of those tools in everyday life.

Considering the modified IFD model, comparing time minimizing and energy maximizing as modes of production reveals that a series of failed energy maximizing colonizing events should appear before a wholesale shift to energy maximizing. The archaeological signature of this is context specific. However, such colonizing

sites should have higher assemblage formality than contemporary time-minimizing habitations. Termed Transitional sites, these should be rare but have a noticeably different subsistence emphasis focusing on high-cost, high-return resources or have an assemblage that indicates as much.

Archaeological Trends in Coastal Southern California

This research compares the coastal Santa Barbara and San Diego regions. The analytical areas are large enough to characterize the range of variability in aboriginal economies along the coastal plain. The San Diego region is defined as the area south of San Mateo Creek and north of San Elijo Lagoon, extending west of the Peninsular Ranges to the Pacific coast (Figure 3). This region is centered in the area traditionally attributed to the ethnohistoric Luiseño, but it also circumscribes an area that is archaeologically distinct. The Santa Barbara region is defined as the area north of Rincon point, east-southeast of Point Conception, and south-southwest of the Santa Ynez Mountains (i.e., Transverse Ranges). This area was occupied primarily by the ethnohistoric Barbareño Chumash (Glassow 1996).

A sample of archaeological sites in each region was selected for analysis based on chronology and assemblage composition, with the goal of documenting assemblages that generally predate and postdate the arrival of the bow and arrow

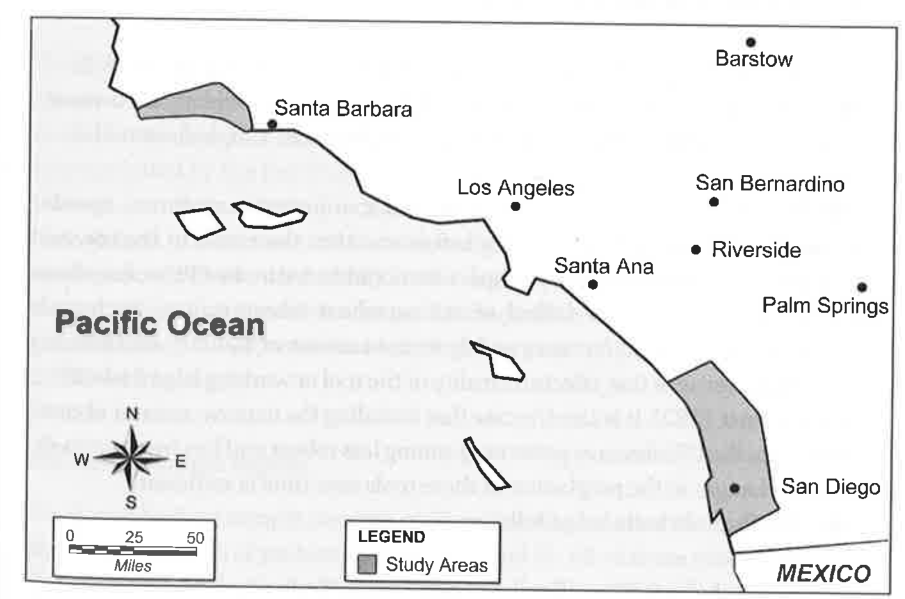

Figure 3. Vicinity map showing the location of the Santa Barbara and San Diego study areas.

(assumed to be at approximately cal A.D. 500), and extending just prior to ethnohistoric times. None of the sampled archaeological sites are free of depositional problems; however, the primary occupation of each site could be assigned to these basic temporal categories. Below is a summary of archaeological patterning presented by region and highlighting assemblage characteristics that can be used to evaluate model predictions regarding assemblage formality. Assemblage data are summarized by region and time period (a more in-depth presentation of data can be found in Hale [2009]). To facilitate discussion, assemblage formality is characterized by formality indices for flaked stone tools (Flaked stone Formality Index, or FFI), lithic waste (Lithic Waste Index, or LWI), and groundstone tools (Groundstone Formality Index, or GFI). Implicit in the formality indices is the expectation that increases in FFI and GFI are representative of more time spent making and refining tools, while decreasing index values reflect the opposite.

Formality indices approximate differences in time invested in subsistence by distinguishing tools that require relatively high amounts of manufacture and maintenance time versus inexpensive (i.e., expedient) tools. Each index is a value that varies between 0 and 1 and is calculated from multiple assemblages (rather than an average value of individual assemblage values). The regional focus of each index is better suited to understanding overarching adaptive strategies (note that individual assemblage index values vary little from the regional value; see Hale [2009]).

The FFI formula is stated as follows:

> *Flaked stone Formality Index (FFI)* = (Total # of formal flaked stone tools: bifaces and formed flake tools) ÷ (Total # of formal and expedient flaked stone tools: bifaces, formed flake tools, retouched flakes, and simple flake tools).

The FFI does not include arrow points, dart points, or projectile preforms, in order to compare non-projectile tool formality before and after the arrival of the bow and arrow. Core/cobble tools and heavy scrapers are not included in the FFI because these tools resist the dichotomous formal versus expedient categorization. Such tools share a fundamental form but vary widely in the amount of initial manufacturing effort and maintenance that affects formality of the tool or working edge (Hale 2001; True and Beemer 1982). It is also the case that including the massive amount of core/cobble tools in the FFI obscures patterning among less robust and less frequent tools. Noting the changes in the proportion of these tools over time is sufficient.

The LWI formula is stated as follows:

> *Lithic Waste Index (LWI)* = (Total # of nondiagnostic shatter) ÷ (Total # of all debitage). This index measures the amount of debitage that was too fragmentary to assign to a particular debitage category in relation to diagnostic flakes.

The LWI approximates the care taken in flaked stone reduction and assumes that, on average, larger amounts of nondiagnostic shatter compared to diagnostic flakes reflects greater expediency in lithic reduction. The LWI is reciprocal to the FFI such that an increase in LWI values implies less care taken in tool manufacture. As more tools are subject to refinement through controlled flaking, there will be a greater number of smaller, diagnostic flakes, reducing the proportion of shatter. There are factors that complicate an accurate measure of the LWI (e.g., assemblage trampling during reoccupation, variation in raw material quality, a dearth of small lithic retooling/repair assemblages in the sample), but these factors were found to have minimal effect (see Hale 2009).

The GFI formula is stated as follows:

> *Groundstone Formality Index (GFI)* = (Total # of formal groundstone tools: all mortars and shaped pestles, millingstones, and handstones) ÷ (Total # of formal and expedient groundstone tools: mortars, and shaped and unshaped pestles, millingstones, and handstones). All mortars are considered formal, given the relatively high cost associated with manufacturing the mortar surface, regardless of exterior condition or whether it is a bedrock feature.

The GFI is similar to the FFI, and it is typically based on a comparison of shaped versus unshaped groundstone tools. All mortars are considered formal/shaped because the manufacture of mortar surfaces requires large amounts of time. The GFI is complicated by the fact that non-mortar groundstone tools can become shaped through use rather than direct intent. However, Hale (2001, 2005) suggested that shaped groundstone tools tend to have intensively used wear facets while unshaped specimens vary widely in the degree of use intensity. Thus, shaping is a good proxy of groundstone formality. Regardless of this problem, intentional shaping was generally easy to observe (i.e., traces of pecked margins on handstones and pestles).

The Santa Barbara Region

The Santa Barbara sample consists of 25 archaeological sites that collectively span the last 9000 years of prehistory (Figures 4 and 5). All of these sites are located on the mainland of the Santa Barbara Channel along the coastal margin, estuaries, and further inland adjacent to major drainages. Each site is considered a residen-

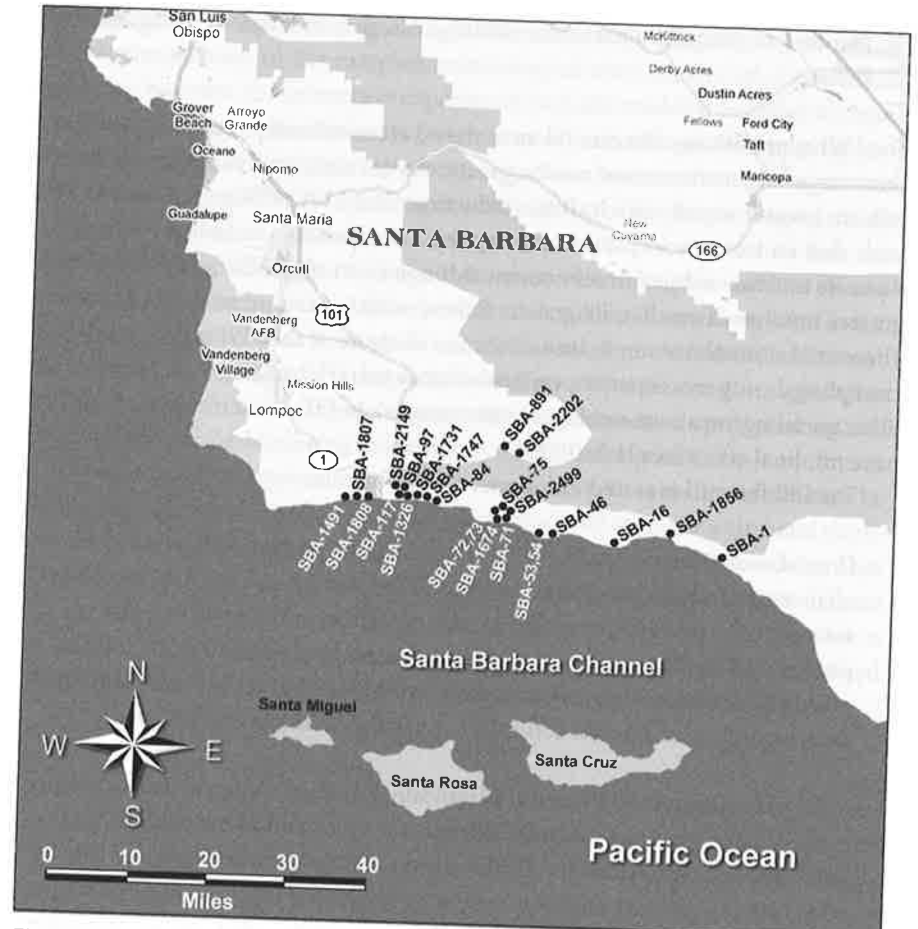

Figure 4. Location map of sampled archaeological sites in the Santa Barbara region.

tial hub, whether seasonally or permanently occupied. Most (if not all) sites consist of an amalgamation of occupations that occurred for different purposes and durations, but teasing such episodes apart can be very difficult given depositional mixing. At some sites more than others (e.g., CA-SBA-46, -71, -73), mixing of very different chronological components inhibits clarification of different economic trends (see Erlandson and Rick 2002; Erlandson et al. 2008; Gamble 1990, 1991). This is especially true when trying to determine the terminus of Millingstone Horizon deposits (Erlandson 1991, 1997). However, within each broad time period, the problem of mixed occupations benefits this research in the sense that a wider range of activities is represented in the assemblages (e.g., task-specific exploita-

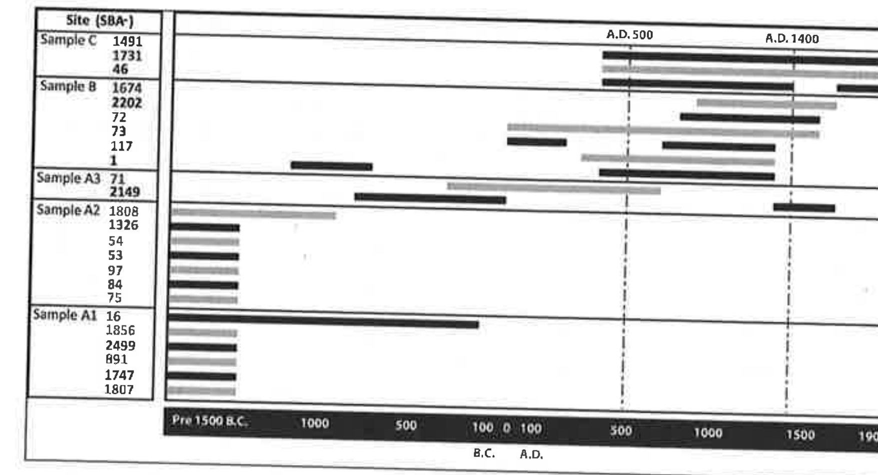

Figure 5. Radiocarbon age for primary occupation of archaeological sites in the Santa Barbara sample. CA-SBA-16, -1856, and -2202 are dated by obsidian hydration and time-sensitive artifacts; CA-SBA-1326 has no direct dates but is spatially associated with CA-SBA-75; CA-SBA-891/2105 has no dates but is nearly a single-component Millingstone Horizon site (Hale 2009).

tion and residential habitation), giving a more complete picture of tool production and use.

The Santa Barbara sample is divided according to the following chronological scheme: pre-cal A.D. 500 (Sample A), post-cal A.D. 500 (Sample B), and post-cal A.D. 1350 (Sample C) (see Figure 5). These categories maximize the contrast between assemblages that date before and after the arrival of the bow and arrow (cal A.D. 500), and to better reflect intensification after cal A.D. 1350. Assemblage data for the Santa Barbara sample is provided in Table 2; a site-specific presentation of assemblage data can be found in Hale (2009).

The Millingstone Horizon is one of the few commonalities between the Santa Barbara and San Diego regions (Glassow et al. 2007; Hale 2001; Owen 1964; Rogers 1945; Wallace 1955; Warren 1968; Warren et al. 2004). Its earlier termination in Santa Barbara signifies fundamental shifts in settlement and subsistence that did not occur in San Diego. These differences are most visible in the last 3500 years. By 1500 BC, Santa Barbara assemblages have large numbers of shaped mortars and pestles relative to the older millingstone and handstone forms (see Erlandson and Rick 2002; Glassow et al. 1988). The growing number of shaped mortars and pestles likely reflects greater use of acorns relative to small seeds and tubers. Alternatively, Glassow (1996) suggested that the observed increase in the more costly-to-make mortars and pestles simply reflects more intensive plant process-

Table 2. Relative Proportion of Assemblage Constituents by Sample for the Santa Barbara Region.

Artifact	Sample A pre-cal A.D. 500		Sample B cal A.D. 500–1350		Sample C post-cal A.D. 1350	
	N	%*	N	%*	N	%*
Points	183	4.3	227	11.8	144	12.5
Point preforms	24	0.6	157	8.2	90	7.8
Bifaces	319	7.6	280	14.6	192	16.7
Formed flake tools	501	11.9	381	19.8	398	34.6
Retouched flakes	152	3.6	47	2.4	37	3.2
Simple flake tools	810	19.3	388	20.2	140	12.2
Core/Cobble tools	265	11.8	151	11.6	40	3.7
Hammers	230	8.5	72	2.4	2	4.1
Mortars	359	2.4	46	3.4	47	2.2
Pestles	102	2.0	66	2.9	25	1.0
Millingstones	86	7.3	56	0.8	12	0.6
Handstones	307	20.7	16	1.9	7	1.4
Total stone tools	4207	100.0	1924	100.0	1150	100.0
Simpson Diversity Index	8.10		7.53		5.29	
Evenness	0.62		0.58		0.41	
Bone tools	176		269		117	
Hooks	15		152		60	
Grand Total	4398		2345		1327	

Note: *, percent of grand total. The Shannon Diversity Index is based on: [SUM : $(n_i(n_i-1))$]/N(N-1), where n_i = # artifacts in a category and N = total # of stone artifacts.

ing in general, i.e., of acorns, roots, and small seeds, collectively. However, intensive, broad-spectrum plant processing is already apparent in Millingstone Horizon sites, such as Glenn Annie Canyon (CA-SBA-530), which predates 1500 BC (Hale 2001). Since millingstones and handstones never disappear, this suggests that the growing fraction of mortar-pestle technology reflects a processing specialization on high–cost, high-yield resources, probably acorns.

Once a high-cost processing economy became evident in Santa Barbara, several technological innovations appeared, including the j-shaped fishhook (600 BC), plank canoe (cal A.D. 400), bow and arrow (cal A.D. 500), circular fishhook (cal A.D. 1300), and microlithics (cal A.D. 1300) (Arnold 1992, 1997; Gamble 2002;

Glassow 1996; Kennett 2005; King 1990; Rick et al. 2002; Strudwick 1986). Dates of arrival for each of these technologies are more or less certain. Rick et al. (2002) developed a strong chronology for single-piece fishhooks, drawing on a number of direct radiocarbon dates. Microlithics are also reliably dated from contexts on Santa Cruz Island (Arnold 1986). However, the plank canoe and bow complex are less reliably dated. The plank canoe is known ethnographically and from pieces of wood planks (Gamble 2002), but its early arrival date is also based on inferences from changes in subsistence remains. Likewise, inception dates for the bow complex are complicated, its cal A.D. 500 arrival being somewhat tenuous. Glassow (1996) presented a strong argument for small leaf-shaped points as the first arrow tips, appearing at around cal A.D. 500, then transitioning to the Canalino (i.e., Cottonwood Triangular) tips later in time, at around cal A.D. 1300 or so.

Subsistence appears to have changed gradually and in step with the arrival of new technologies, as evidenced by an increase in fish remains beginning after 1500 cal B.C. and rapidly accelerating after cal A.D. 1350 (Kennett 2005), a shift in shellfish exploitation to emphasize California mussel (Glassow et al. 1988), and higher frequencies of traditional resources including terrestrial game and seeds. Settlement also changes at 1500 cal B.C., becoming characterized by large coastal and interior villages with multiple semisubterranean houses and large communal features (Erlandson 1997; Gamble and Russell 2002). Reconstructions of settlement and subsistence for the Santa Barbara region are based on archaeological data from sites on the mainland and from several of the Channel Islands, especially Santa Rosa and Santa Cruz islands (see Kennett 2005). Island occupation may have been episodic prior to 3500 years ago, but after this time, evidence for stable island occupation (even if seasonal) and a strong economic relationship with the mainland is apparent from various archaeological sites.

Turning to assemblage composition, several important shifts occur after the bow and arrow arrives (cal A.D. 500), and after cal A.D. 1350 when subsistence intensified. Comparing Samples A (pre-cal A.D. 500) and B (cal A.D. 500–1350), projectile points more than double in frequency from 5.0 percent in Sample A to 13.0 percent in Sample B, accompanied by a more modest, yet still large increase in bifaces from 8.0 percent in Sample A to 16.0 percent in Sample B (see Table 2). Formed flake tools nearly double in proportion from 13.0 percent in Sample A to 21.0 percent in Sample B, while their expedient counterparts—retouched flakes and simple flake tools—remain stable, together comprising an average of 25.0 percent. Crude core/cobble tools and hammers decrease in combined proportion by more than half, from 15.0 percent in Sample A to 7.0 percent in Sample B. The drop in the overall proportion of groundstone tools is due to the sharp increase in arrow points combined with a decrease in the absolute frequency of handstones

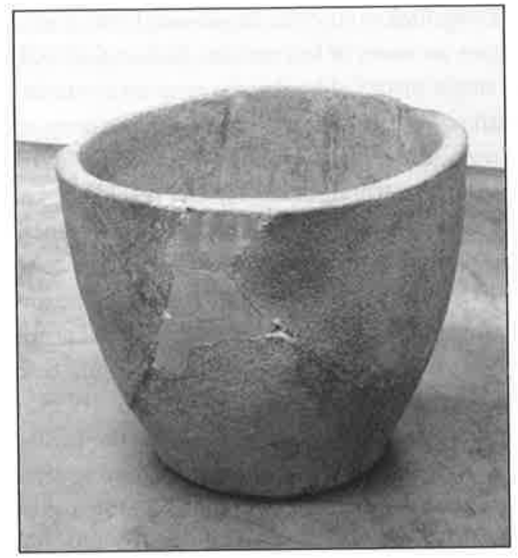

Figure 6. Flower pot mortar from the Santa Barbara region (curated at the University of California, Santa Barbara).

and millingstones. However, an important shift in groundstone proportions is clear. In Sample A, the ratio of mortars to millingstones is 1:3, and in Sample B this ratio shifts to 4.1:1. This signals an important shift in the economic significance of intensive processing. Finally, there is a large increase in bone tools and shell fishhooks from a combined proportion of 4.0 percent for Sample A to 19.0 percent for Sample B (see Table 2).

A comparison of Samples B and C is intended to gauge further shifts in tool manufacture in response to subsistence intensification. While projectile points remain stable between Samples B and C at approximately 21.0 percent, the proportion of bifaces increases slightly while formed flake tools are much more prevalent, increasing from 21.0 percent in Sample B to 36.0 percent in Sample C (see Table 2). On the other hand, expedient simple flake tools drop from 22.0 percent in Sample B to 13.0 percent in Sample C. The slight decline in proportion of mortars and pestles is due in part to the large proportion of formed flake tools. Regardless, highly shaped and decorated mortars and pestles are a hallmark of assemblages that postdate cal A.D. 1350, such as flower pot mortars (Figure 6).

The appearance of the circular fishhook after cal A.D. 1350 is evidence of increasing technological specialization. The circular hook—often with a grooved shank—is considered more refined in form and was probably more efficient in terms of reducing loss once a fish was hooked (see Glassow et al. 2008; Kennett 2005; Salls 1988). Kennett (2005) suggested that variability in earlier hook forms

could relate to the targeting of a wider variety of fish, indirectly implying that the circular grooved shank hook is intended for a narrower range of fish.

Another unique characteristic of Sample C sites is the commonality of microdrills used to manufacture beads. These formal tools are small bladelets that have been retouched on the distal end to form a narrow drill bit typically less than 1.0 mm in diameter. Arnold (1992) discussed the microblade industry on the Channel Islands, and it is likely that the presence of these items signifies bead manufacture at mainland sites. Regardless, it is further direct evidence of technological specialization.

Changes in assemblage composition are better characterized by the Simpson's diversity index and assemblage formality indices. The Simpson's diversity index (D) is the inverse of the sum of the squared proportions for each artifact class:

$$D = 1/[\Sigma(n_i/N)^2]$$

where n_i = the number of specimens in a particular artifact category and N = the total number of specimens for all categories (see Bettinger 1980). Larger Simpson values reflect greater diversity, with the maximum value being equal to the maximum number of artifact categories. Since all assemblages have the same number of artifact classes (i.e., richness), the Simpson index is only measuring variability in evenness because richness is the same. To better estimate evenness across all samples, the Simpson's index value was divided by the maximum number of tool classes present. For the Santa Barbara assemblages, Sample A has the highest Simpson values (8.10), Sample B (7.53) is slightly less diverse than Sample A, and Sample C is dramatically less diverse (5.29) (Figure 7). Likewise, evenness drops from 0.62 in Sample A to 0.58 in Sample B, and 0.41 in Sample C.

While seemingly counter-intuitive, the trend of decreasing assemblage diversity and evenness is due to a shift toward more specialized technologies at the sacrifice of generalized processing and cutting tools. This is supported by substantial increases in the FFI and GFI values. The average FFI value for Sample A is 0.46 (see Table 2, Figure 8). In contrast, Sample B has a much higher FFI value of 0.60. This higher value is due to the increase in bifaces and formed flake tools from a combined proportion of 20.0 percent in Sample A to 35.0 percent in Sample B. A drop in the LWI value from 0.50 for Sample A to 0.46 for Sample B indicates that greater care was taken in finishing flaked stone tools (i.e., larger amounts of finishing flakes relative to nondiagnostic shatter).

Regarding groundstone, the GFI value for Sample A is 0.58, increasing to 0.82 for Sample B (see Table 2, Figure 8). This is due to the higher proportion of shaped mortars and pestles in Sample B and a decline in the abundance of handstones.

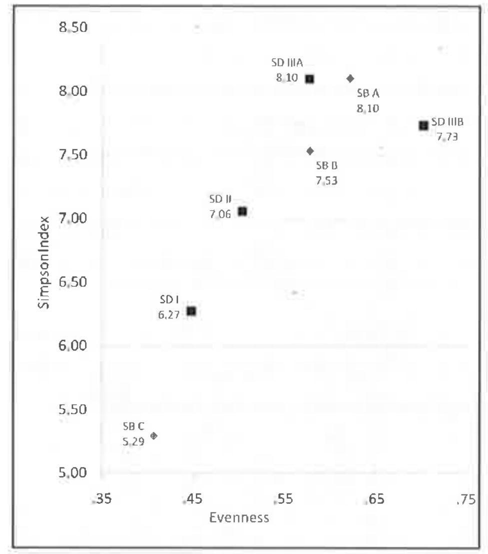

Figure 7. Simpson's Diversity Index and evenness values for the San Diego and Santa Barbara regions.

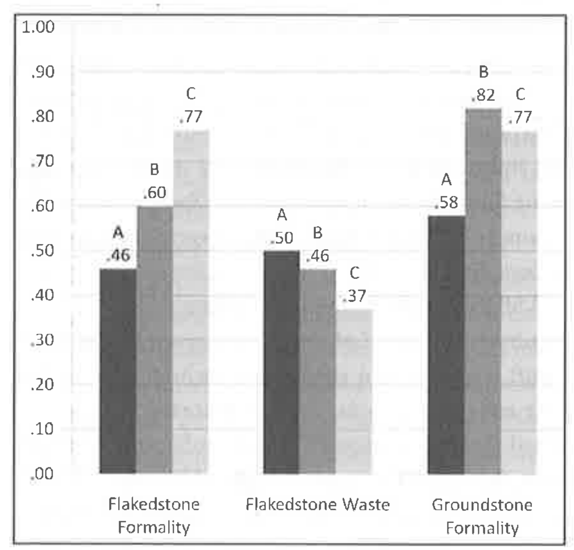

Figure 8. Assemblage formality index values by sample for the Santa Barbara region.

However, millingstones and handstones remain common, implying continued use of more generalized processing equipment.

Assemblage formality increases sharply among post-cal A.D. 1350 assemblages. The FFI value for Sample C is 0.77, up 17.0 percent from the 0.60 FFI value for Sample B. The much higher FFI value is due to further increases in bifacial tools and formed flake tools, including both large and small drills. Fishhooks were probably made with larger, less-refined drills, while beads were manufactured using small microblade drills (see Bamforth 1991)—both circular fishhooks and shell beads are abundant in Sample C.

A decline in the LWI value from 0.46 in Sample B to 0.37 in Sample C is evidence that investment in tool finishing was a priority. This drop in nondiagnostic shatter occurs despite increased use of lower quality Monterey chert that would produce more shatter than higher quality Franciscan chert, especially since the latter had to be imported.

There was limited access to Sample C collections, resulting in a relatively small number of groundstone tools that could be examined for shaping. Nevertheless, the GFI value for Sample C is 0.77. A larger sample may increase this GFI value, as is implied by several pieces of "flowerpot" mortars (see Figure 6) and decorated pestles. These decorated items are the result of investing ideology in the manufacture of subsistence tools—an indirect symbol of their economic significance. Nevertheless, mortars and pestles are more common than millingstones and handstones in Sample C. The ratio of mortars to millingstones in Sample C is 3.6:1, similar to the 4:1 ratio for Sample B. A larger sample size may clarify the pattern further.

Collectively, Simpson's values and formality index values for Santa Barbara region assemblages indicate that as technological specialization increases, the diversity of artifact classes decreases, i.e., expedient tools become less common, replaced by formal tools. Specifically, overall assemblage formality increases after the introduction of the bow and arrow at approximately cal A.D. 500 and after cal A.D. 1350 when subsistence intensifies.

The San Diego Region

A total of 55 archaeological sites is included in this sample, cumulatively spanning the middle and late Holocene. Given that the long-term stability of early and middle Holocene assemblages (i.e., Millingstone Horizon, Encinitas Tradition, or La Jolla assemblages) is widely known and documented, the goal of this sample was to best characterize assemblages over the last 3500 years when most purported adaptive changes have occurred (see Warren et al. 2004; Hale 2001, 2009) (Figures 9 and 10).

The sampled assemblages were separated into three main time periods: pre-cal A.D. 500 (Sample I), post-cal A.D. 500 (Sample II), and post-cal A.D. 1400 (Sample III). The cal A.D. 500 and cal A.D. 1400 separations were used to maximize the contrast between assemblages and in fitting with traditional separations after

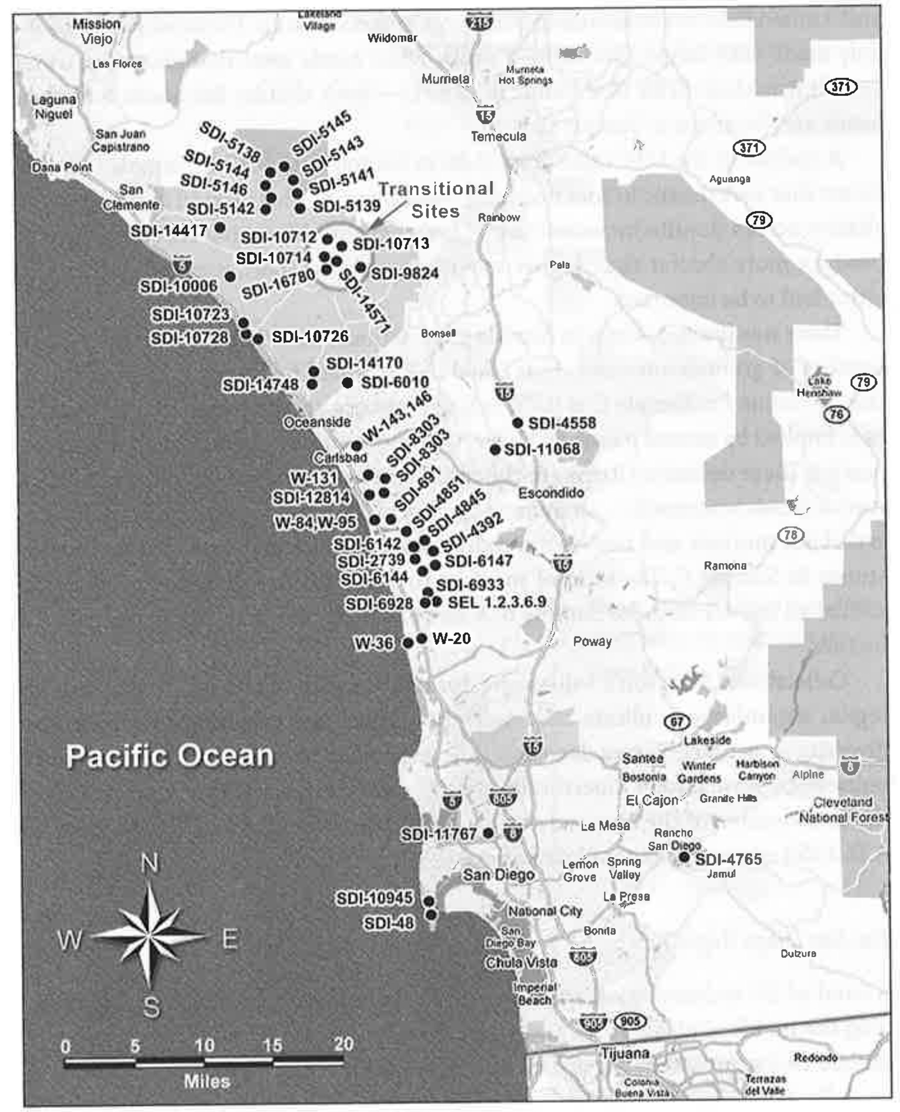

Figure 9. Location map of sampled archaeological sites in the San Diego region.

the introduction of the bow and arrow (available after cal A.D. 500), and after the onset of intensification (cal A.D. 1400) (Hale 2009; see also Warren et al. 2004). A subset of four sites (CA-SDI-10712/10713, -10714, -14571, and -16780) from Sample III counter the main trend (see Hale and Becker 2006; Reddy 2000; Reddy et al. 2006). These sites are subdivided as Sample IIIB, and are small, dense mid-

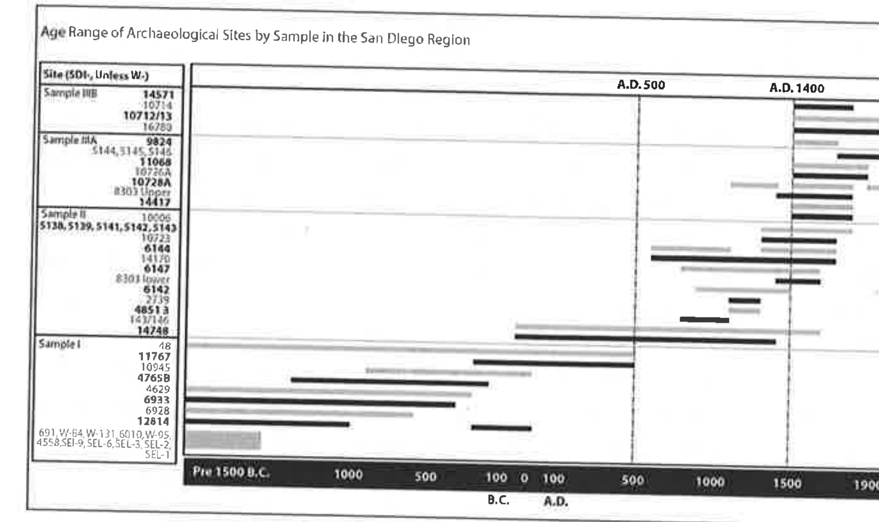

Figure 10. Radiocarbon dates for the primary occupation of archaeological sites in the San Diego sample. Sites W-84, -88, -97, -131, and CA-SDI-4392 are uncalibrated dates from marine shell, but still date to the middle and early Holocene; CA-SDI-6142, -6144, and -6147 are uncalibrated dates from shell, but calibration would not change the main occupation to predate arrival of the bow and arrow.

dens (no more than 30–50 cm thick) that are rich in organic remains and ceramics and have large proportions of formal flaked and groundstone tools, including large proportions of bedrock mortars (see below). Sample IIIB sites are short-lived, dating between about cal A.D. 1400 and 1700 (see Figure 10).

The archaeological record of the San Diego region is strikingly different from the Santa Barbara region. San Diego assemblages, dating from before 1500 cal B.C. until cal A.D. 1700, are characterized by a generalized processing and gathering economy (see True and Waugh 1983; Warren et al. 2004). Although much debated, the terminus of the San Diego Millingstone Horizon is usually equated with the disappearance of lagoon and estuary sites at around 3500 years ago, when erosion and flooding destroyed or decreased the bioproductivity of many lagoons (see Warren 1968; Warren et al. 2004). However, there are coastal and inland sites with Millingstone-like assemblages (i.e., dominated by ground and battered stone tools) postdating 1500 BC (see Gallegos and Kyle 1998; Yohe and Chase 1995), indicating that the Millingstone pattern in the San Diego region was not specifically a lagoonal/estuarine adaptation. Indeed, True's (1958) Pauma Complex is an inland expression of the Millingstone pattern. Subsistence throughout the late Holocene continues to feature generalized processing without specializations, despite regional variance in specific kinds of resources used, i.e., more fish were taken in southern San Diego County.

With the exception of the bow and arrow, other novel technologies used in Santa Barbara were largely ignored in San Diego. With the availability of the bow and arrow, traditional settlement shifts slightly, with large habitation sites being positioned with direct access to the most productive seasonal resources. This is accompanied by an increase in small, temporary camps (see Hale and Becker 2006). No formal residential or communal structures are known from either kind of site in the San Diego region. An intensive acorn economy did not take hold until around cal A.D. 1700, when ceramics also appeared in massive quantities (Griset 1996; Hale and Becker 2006; True and Waugh 1983). Acorns were most likely used intermittently during the late Holocene, but they were not as paramount in the local economy as they were in the Santa Barbara region, implying that San Diego hunter-gatherers did not incorporate the social organizational imperatives of an acorn economy (pronounced division of labor) (see Warren et al. 2004:96).

Summarized assemblage data for the San Diego region show a trend of decreasing tool formality over time (Table 3). In general, all assemblages are dominated by ground and battered stone tools with formal tools, such as bifaces and formed flake tools, being notably rare. After the bow and arrow became available, shifts in assemblage composition reflect a time-saving response in tool manufacture. Aside from the obvious increase in projectile points and fragments thereof, bifaces increased from nearly zero to 5.3 percent of the tool assemblage (see Table 3). Most of these bifaces, however, are not tools in their own right but were discarded during the process of arrow point manufacture (Hale 2009). Interestingly, formed flake tools drop from 8.0 percent to 1.6 percent, while their expedient counterparts—retouched flakes—double in relative proportion. Retouched flakes represent an expedient manufactured edge that was used to perform the task of formed flake tools that were maintained for longer periods of time. This simple shift in flake tool production is seen as a time-saving tactic to offset the cost of investing in bow and arrow technology. These same trends are more pronounced after cal A.D. 1400.

When comparing Samples II (cal A.D. 500–1400) and IIIA (cal A.D. 1400–1700), there is continued focus on arrow point production, as formed flake tools are essentially absent with retouched flakes and simple flake tools (both expedient, limited-use implements) continuing to define lithic tool kits. A reversal in the relative proportion of retouched flakes and simple flake tools—the former decreasing, the latter increasing—is further evidence of time-saving tactics in tool manufacture as unmodified flakes take over the majority of cutting and scraping tasks. Interestingly, the bulky cobble-based tools (including scraper planes and heavy scrapers) that are so common for well-known Millingstone Horizon sites

Table 3. Relative Proportion of Assemblage Constituents by Sample for the San Diego Region.

Artifact	Sample I pre-cal A.D. 500		Sample II cal A.D. 500–1400		Sample IIIA cal A.D. 1400–1700		Sample IIIB Transitional cal A.D. 1400–1700	
	N	%	N	%	N	%	N	%
Arrow points	2	0.0	58	4.8	40	7.5	20	12.7
Darts	32	0.6	1	0.1	1	0.2	0	0.0
Point preforms	21	0.4	40	3.3	33	6.2	4	2.5
Bifaces	46	0.9	64	5.3	31	5.8	16	10.1
Formed flake tools	432	8.0	19	1.6	5	0.9	14	8.9
Retouched flakes	294	5.4	162	13.3	28	5.2	2	1.3
Simple flake tools	962	17.8	85	7.0	72	13.5	13	8.2
Cobble tools	658	12.2	122	10.0	35	6.5	6	3.8
Heavy scrapers	478	8.8	67	5.5	2	0.4	0	0.0
Hammerstones	562	10.4	114	9.4	61	11.4	5	3.2
Millingstones	5	6.5	19	9.3	14	23.4	29	19.6
Handstones	31	28.4	4	28.6	21	12.5	0	11.4
Mortars	350	0.1	113	1.6	125	2.6	31	18.4
Pestles	1537	0.6	348	0.3	67	3.9	18	0.0
Total stone tools	5410	100.0	1216	100.0	535	100.0	158	100.0
Simpson Diversity Index	6.27		7.06		8.10		7.73	
Evenness	0.45		0.50		0.58		0.70	
Ceramics	51		262		1419		194	
Bone tools	60		29		26		12	
Beads	129		42		15		1	
Grand Total	5650		1549		1995		365	

Note: Millingstone and mortar categories include bedrock features. Much of the Sample IIIA ceramics likely derive from later, post-AD 1700 components at two key sites, CA-SDI-11068, and -8303. The Shannon Diversity Index is based on: [SUM (ni(ni-1))]/N(N-1), where ni = # artifacts in a category and N = total # of stone artifacts.

sharply drop in relative proportion after cal A.D. 1400 (Sample IIIA), while bedrock milling elements become abundant. This likely signals a shift in processing to focus on the more productive and traditionally exploited plant foods as a response to diminishing returns, for which there is some supporting ethnobotanical evidence (see Hale 2009; Reddy 1996, 1997, 1999, 2000).

Toolkits from Sample IIIB differ markedly from those in the contemporary Sample IIIA (see Table 3). Sample IIIB assemblages are generally smaller than those from Sample IIIA and have a limited temporal span, with reliable radiocarbon dates placing the sites roughly between cal A.D. 1400 and 1700. In Sample IIIB, projectile points and preforms show a modest 1.5 percent gain reflecting the continued importance of bow technology, but higher assemblage formality is reflected in greater proportions of formed flake tools, increasing from almost zero to 8.9 percent of Sample IIIB assemblages. Expedient retouched flakes are nearly absent and simple flake tools are 1.5 times less common than in Sample IIIA. Bifaces (including those produced for the manufacture of non-projectile tools) double in proportion, the greatest proportion of any sample (see Hale 2009). In addition to the shift to formal implements in the light lithic categories, decreased reliance on cheap tools is also evident as cobble tools drop to negligible levels and bulky scrapers disappear from Sample IIIB assemblages (see Table 3).

Groundstone also shows a shift toward relatively expensive implements. Including bedrock milling surfaces, mortars account for more than 18 percent of Sample IIIB assemblages, despite the continued commonality of millingstones. As I have argued elsewhere (Hale 2001, 2005, 2009), mortar surfaces are exceptionally costly to manufacture compared to flat, concave, or basined milling surfaces, and must indicate greater investment in technology to handle more intensive processing.

At first glance, ceramics sherds from Sample IIIB sites comprise a smaller proportion of the overall assemblage (53.2 percent) compared to 71.1 percent for Sample IIIA sites (Table 3). However, ceramic density at Sample IIIB sites is actually higher. Comparing the ceramics from control units (i.e., not including shovel test pits [STPs] or surface artifacts), Sample IIIB sites have an average ceramic density of $88/m^3$ (n = 168, volume = 1.914 m^3). In contrast, Sample IIIA sites have an average ceramic density of $55/m^3$. Sample IIIB sites have more than 1.5 times the ceramic density than contemporary Sample IIIA sites, indicating evidence of additional investment in technology and a shift in processing and storage techniques. Moreover, there is strong reason to believe that the bulk of ceramics in Sample IIIA derives from post-cal A.D. 1700 occupations at CA-SDI-11068 and CA-SDI-8303. Considering only CA-SDI-11068, it can be argued that approximately 75.0 percent of the 877 ceramic sherds present in strata assigned to Sample IIIA likely derive from post-cal A.D. 1700 occupations but have been transported to lower levels due to post-depositional processes. More than 10,000 pieces of ceramic vessels were recovered from the site, 91.0 percent of this from the upper 40 cm that postdates cal A.D. 1700 (see Schroth and Gallegos 1991). If only 25.0 percent of the ceramics from CA-SDI-11068 are included in Sample IIIA, the overall assemblage proportion of ceramics drops to 53.0 percent.

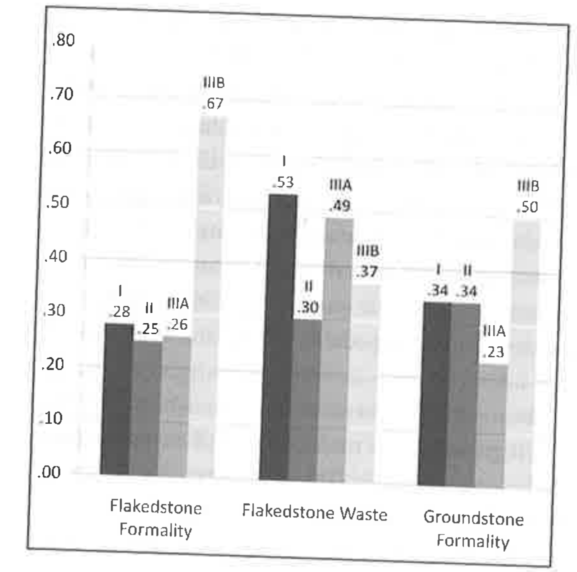

Figure 11. Assemblage formality index values for flaked stone, debitage, and groundstone by sample for the San Diego region.

Simpson's index values increase in step with evenness from Sample I to Sample IIIA, indicating an increase in diversity (see Figure 7). Simpson's index values increase from 6.27 in Sample I to 7.06 in Sample 2 and 8.10 in Sample IIIA. Similarly, evenness increases from 0.45 in Sample I to 0.50 in Sample II and 0.58 in Sample IIIA. The increasing diversity is related to an increase in the use of multiple kinds of expedient tools across the board (see Hale 2009). However, Simpson's index decreases for Sample IIIB to 7.73, while evenness increases further to 0.70. The drop in diversity in Sample IIIB is due to the decreased reliance on heavy cobble-based pulverizing and chopping tools, decreases in expedient flake tools, and increased use of formal task-specific tools (i.e., technological specialization).

Formality indices clearly show a trend of stable or decreasing assemblage formality for the San Diego region over time. Comparing Samples I and II, there is a slight shift from an FFI value of 0.30 characterizing Sample I assemblages to 0.27 for Sample II (post–cal A.D. 500) (Figure 11). The approximate 3.0 percent drop in assemblage formality is not large or significant, but it is a good indicator of stability in the amount of time invested in manufacturing flaked stone tools. The shift in FFI is due to a sharp drop in the proportion of formed flake tools in Sample II assemblages, as well as the scarcity of dart points. The LWI drops by 23.0 percent from 0.53 in Sample I to a value of 0.30 in Sample II. The decreased LWI value is related to an increase in the amount of late-stage finishing flakes produced during arrow point manufacture, dropping the proportion of nondiagnostic shatter that is typically produced during the earlier stages of reduction. Finally, the GFI value in Sample I is 0.34; this value is slightly less for Sample II (0.32).

This slight decrease of two percent is clarified when regional variation is considered. For Sample II, groundstone formality is highest in upland regions (GFI = 0.42) that witnessed substantial residential occupation after the bow arrived. Upland areas lack ample sources for groundstone raw material, and most handstones in upland areas were imported from the coast and were intended for reuse. Thus, upland milling tools are more formalized as a result of extensive reuse and intentional shaping to facilitate transport (see Hale and Becker 2006). Conversely, coastal habitation sites have large amounts of expedient groundstone, with a GFI of 0.22. Coastal locales have easy access to cobbles eroding from drainages and beaches that can be used as handstones. The contrast is greater when considering that less than 10.0 percent of all groundstone tools from all of Sample II were derived from upland sites. Nevertheless, the stable GFI value after the bow is adopted is evidence that traditional processing prevailed.

Comparing Samples II and IIIA, already low assemblage formality is maintained, with the FFI value remaining constant at 0.27 (see Figure 11). Low flaked stone formality in Sample IIIA is due to the fact that nearly all flaked stone tools are arrow points or arrow point preforms. The LWI value increases from 0.30 in Sample II to 0.49 in Sample IIIA. That half of all debitage is nondiagnostic shatter is related to the idea that less care is taken in the initial stages of flaked stone reduction, producing large quantities of shatter while breaking cobbles open. Given the large number of arrow points in Sample IIIA, an increase in shatter is likely due to more frequent assaying of cobbles to produce one or two flakes suitable for arrow point production. In this sense, more frequent quarrying of cobbles for a decreased number of tools made from each cobble should produce greater proportions of shatter relative to finishing flakes. Important here is the fact that debitage does not reflect increased production of fine lithic tools or prolonged maintenance.

Turning to groundstone, there is a slight increase in the GFI value from 0.32 in Sample II to 0.33 in Sample IIIA. Unlike the transition from Sample I to Sample II in which large amounts of expedient groundstone tools were found at coastal locales, these same locations witnessed greater regularity and intensity of groundstone use in Sample IIIA, leading to a slight increase in the overall GFI value, although traditional processing techniques continues.

The stable trend of low assemblage formality, if not decreasing, is countered by a handful of sites comprising Sample IIIB. The most striking attribute of Sample IIIB is the high FFI value of 0.67—more than twice the value of any other time period, including contemporary Sample IIIA sites (see Figure 11). The larger FFI value for Sample IIIB is due to a sharp increase in formed flake tools and bifacial

tools (i.e., knives and other cutting implements). Supporting increased production of finely made lithic tools is the drop in the LWI value to 0.37. Since more effort is being placed on finishing flaked stone tools, small diagnostic flakes increase in proportion to shatter. Another unique attribute of Sample IIIB is the high GFI value (0.49), which is much higher than contemporary Sample IIIB or earlier samples. Sample IIIB has a much higher GFI value partly because of the large number of mortar surfaces. However, it is also true that Sample IIIB handstones exhibit higher degrees of shaping than those from other samples.

Overall, formality indices in the San Diego region show a trend of decreasing assemblage formality after the arrival of the bow and arrow at about cal A.D. 500 and during intensification after cal A.D. 1400. Sample IIIB sites (ca. cal A.D. 1400–1700) are an exception to this rule, having high assemblage formality and an apparent shift in processing technique implied by large numbers of mortar surfaces and high ceramic sherd densities.

Summary

The San Diego region is characterized by low assemblage formality that generally declines after the bow arrives (ca. cal A.D. 500) and during intensification after cal A.D. 1400, with most tools becoming more generalized over time. The Santa Barbara region, however, exhibits high assemblage formality in all samples, increasing after the bow arrives and during subsequent subsistence intensification. The technological divergence evident between the two regions reflects fundamentally different time-allocation strategies related to subsistence.

Time Minimizing-Energy Maximizing: Socioeconomic Divergence in Southern California

The relative degree of investment in the manufacture and maintenance of subsistence tools can be used as a proxy for time spent in subsistence. From this perspective, predictions regarding a time minimizing or energy maximizing response to the introduction of a new technology or to diminishing returns can be measured in the archaeological record.

To review, in the time minimizing-energy maximizing model, a time-minimizing strategy minimizes the time spent on subsistence in exchange for more nonsubsistence time, and an energy-maximizing strategy maximizes energetic yield at the expense of free time. Time and energy are treated as independent variables that require maximization. Thus, the optimal solution in allocating these resources will depend on social preferences. Value-reinforcing social institutions stabilize

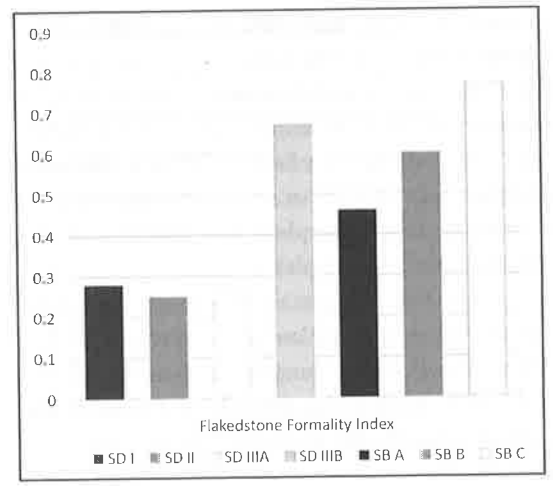

Figure 12. Flaked stone Formality Index (FFI) values by sample for the San Diego and Santa Barbara regions.

preference structures, i.e., a time-minimizing preference for more free time and an energy-maximizing preference for more food. In this way, time minimizing and energy maximizing are stable socioeconomic adaptive strategies that respond differently to factors affecting the utility of time spent in subsistence.

The time minimizing-energy maximizing model predicts that time minimizers and energy maximizers will differ in their response to new technologies and to subsistence intensification. Time minimizers will use a new technology to save additional time during subsistence. In the same way, time minimizers should decrease the overall time spent during subsistence to maintain return rates during intensification. Archaeologically, the time spent making subsistence tools (assemblage formality) should decrease after the bow arrives and during intensification. The archaeological record of the San Diego region generally fits these predictions, implying that hunter-gatherers there practiced a time-minimizing adaptive strategy until ethnohistoric times (Figures 12, 13, and 14). San Diego region sites already had low assemblage formality prior to the arrival of the bow and arrow, but its adoption was met with decreased time spent making non-projectile tools to offset the time required to manufacture bow and arrow equipment. Likewise, a steep increase in nondiagnostic flaked stone tool production waste during intensification reflects less care taken in tool manufacture, as does decreased groundstone formality; both are time-saving tactics that offset diminishing returns.

On the other hand, since the main preference for an energy-maximizing economy is for more food, energy maximizers should use a new technology to increase subsistence yield. Additionally, energy maximizers should invest more time in subsistence to increase energetic yields during intensification, pursuing increasingly high-cost, high-yield resources. This results in higher assemblage formality after the bow arrives and during intensification. The trajectory of increasing assemblage formality and technological specialization in the Santa Barbara region fits with expectations of an energy-maximizing economy (see Figures 12, 13, and 14). In contrast to San Diego, Santa Barbara assemblages were composed of formal flaked and groundstone tools prior to the arrival of the bow and arrow, having large numbers of bifaces, finely made flake tools, and mortars. After the arrival of the bow, the proportion of these items increased and several technological specializations were emphasized (e.g., fishhooks, various drills, plank canoe). This trend is continued after cal A.D. 1350 in response to intensification, and decorative craftwork is more visible (e.g., beads, decorated groundstone tools).

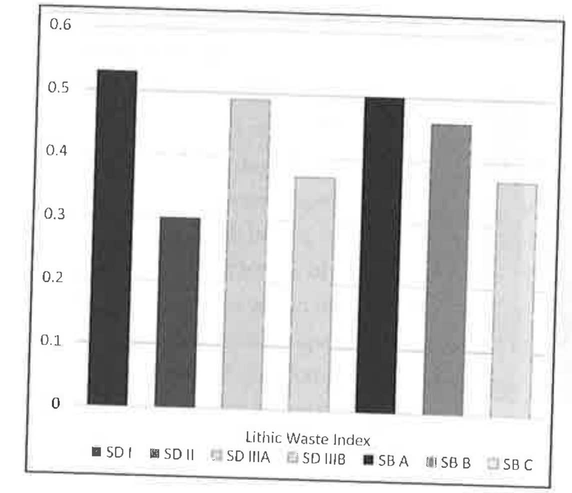

Figure 13. Lithic Waste Index (LWI) values by sample for the San Diego and Santa Barbara regions.

In the time minimizing-energy maximizing model, shifts in preference structures are abrupt rather than gradual, because adaptive strategies are stabilized by social rules that co-evolve with preferences, culling economically irrational behaviors. Such strategies should inherently resist change, thereby stabilizing a time-minimizing economy until economic behavior is no longer rational, i.e., when economic decisions fail to satisfy minimum requirements for free time. For this reason, a shift from time minimizing to energy maximizing is difficult to conceive. A modified form of the IFD model was used here to clarify the shift. Comparing time minimizing and energy maximizing as density-dependent modes of production, the modified IFD model predicted that a series of attempts to start an energy-maximizing economy should occur prior to a successful adaptive shift. Additionally, a successful shift to energy maximizing should only occur after conditions in the time-minimizing economy significantly deteriorate to the point that

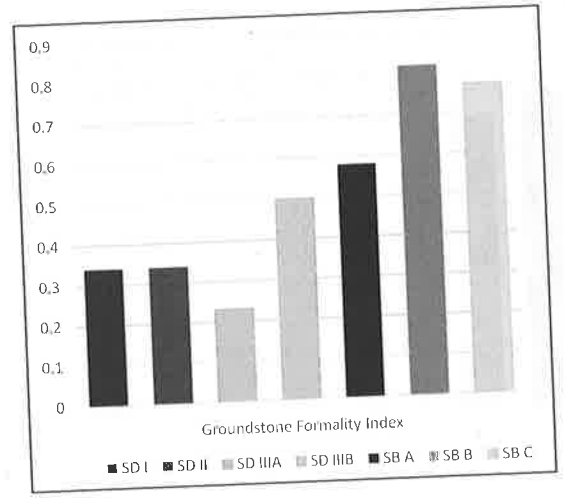

Figure 14. Groundstone Formality Index (GFI) values by sample for the San Diego and Santa Barbara regions.

time-minimizing tactics to maintain subsistence efficiency fail to satisfy minimum levels of free time. The archaeological implication of the IFD model is that the colonizing events should produce assemblages that reflect energy maximizing behavior, i.e., higher assemblage formality. In the San Diego region, four such Transitional sites (Sample IIIB) were found that date just prior to the ethnohistoric pattern. Transitional sites have higher assemblage formality than any other sample in the San Diego region (Hale 2009; also see Hale and Becker 2006; Reddy 2000; Reddy et al. 2006) (see Figures 12, 13, and 14).

Was the transition to energy maximizing inevitable for hunter-gatherers in the San Diego region? Archaeological evidence suggests as much, with the appearance of Transitional sites prior to European contact. Resistance to encroaching energy maximizers from the north was clearly successful for at least the last 2000 years or more. Several sites with assemblages strikingly similar to Gabrielino or Chumash sites are known, including one in the Las Flores Creek drainage that included a more than 2000–year-old burial covered with a whale scapula, along with a handful of formal lithic tools (CA-SDI-1436; Ezell 1975). Another site (CA-SDI-5353) includes a range of occupational debris from local inhabitants that span the last 1500 years of prehistory, but the site also includes a steatite comal and pieces of an abalone shell circular fishhook, as well as several unique formal lithic tools that are seemingly out of place for the San Diego region (see Koerper et al. 1996). Yet another site near San Onofre Creek (CA-SDI-1076) purportedly contained more than 50 circular shell fishhooks (though none can be relocated). Such sites may reflect incursion of energy maximizers but, as is evident from the record, the practices associated with the inhabitants of these sites did not have a noticeable effect on local populations.

The earliest confirmed evidence for energy maximizing on the California coast comes from Santa Barbara, where large quantities of mortars and finely made flaked stone tools are common as early as 5000 years ago (e.g., Hale 2009; Harrison 1964; Levulett et al. 2000). Subsequent patterning there shows a continuation of relatively high degrees of investment in subsistence technology, including the development of several specializations, such as single piece and circular fishhooks, plank canoes, shell beads, highly formal lithic tools, specialized mortars, and tools used in the manufacture of these items. Identifying Transitional sites in the Santa Barbara region has yet to occur and is made difficult by modern development and sometimes inadequate reporting of assemblages from key sites there.

The spread of the Santa Barbara energy-maximizing strategy into the Los Angeles region was largely uninhibited, although it seems to have lagged, probably due to adjustment of the strategy to a different environment and population, since the original energy-maximizing economy was finely tuned to the Santa Barbara region. This being the case, the resistive time-minimizing economy in the San Diego region may have been overrun by energy maximizers from the north as that economy adjusted to terrestrial and marine environments very similar to the San Diego region. Transitional energy-maximizing sites in the San Diego region are a signal that an endogenous shift to energy maximizing was underway, but more time would have been needed to develop stabilizing social institutions unique to local inhabitants, making them susceptible to population overrun from the north.

I have speculated that the ethnohistoric Luiseño practiced an energy-maximizing economy. This is based largely on the fact that the Luiseño were heavily reliant on acorns (Bean and Shipek 1978; Shipek 1991), and that an acorn-based economy requires large-scale coordination and time investment unexpected of a time-minimizing economy (Hale 2009; also see Bettinger 1999; Bettinger et al. 1997). Without being invaded by the Gabrielino, and given the presence of Transitional sites, the Luiseño energy-maximizing economy was probably forming just prior to missionization. Signatures from village sites, such as Topamai on Camp Pendleton in northern San Diego County, suggest as much (York et al. 1999), as does True's (1980; True and Waugh 1983) early work on the San Luis Rey Complex. However, much work remains to truly define the ethnohistoric archaeological record in the San Diego region without carrying forward the assumption that associated adaptive strategies extend into the distant past. In this sense, defining the time during which acorn exploitation became the focus of subsistence is paramount. Additionally, extensive research on Peninsular Range sites will undoubtedly provide more evidence and more clarity on the nature of adaptive shifts during the last 500 years.

Conclusions

The archaeological record in the San Diego region is characterized by low tool formality for much of the Holocene until just prior to ethnohistoric times. Tool formality there decreases after the bow arrives (ca. cal A.D. 500) and during intensification after cal A.D. 1400. In contrast, assemblages from the Santa Barbara region have high tool formality for much of the Holocene, with even greater technological investment seen after the bow arrives and during intensification after cal A.D. 1350.

In this overview, I argue that hunter-gatherers in San Diego were characterized by a time-minimizing economy that abruptly shifted to an energy-maximizing economy evident among the ethnohistoric Luiseño, while the Santa Barbara region has been characterized by an energy-maximizing economy for at least 5000 years. Archaeological patterning in each region exhibits divergence: San Diego assemblages become less formal over time and those in Santa Barbara become more formal. Such divergence is predicted by the time minimizing-energy maximizing model. A small set of sites from the San Diego region, however, have high assemblage formality, consistent with energy maximizing. These Transitional sites date just prior to the ethnohistoric pattern and are considered precursors to the ethnohistoric energy-maximizing economy. The appearance of these Transitional sites is predicted by a modified form of the IFD that compared time minimizing and energy maximizing as density-dependent modes of production. While the endogenous shift to energy maximizing appears to have been underway in the San Diego region prior to European contact, the economy recognized during ethnohistoric times more likely resulted from the influence of European contact and missionization that effectively truncated local adaptive processes. This research begs reconsideration of existing collections to tease apart potentially important transitions hiding in traditional artifact classifications and glossed over by the assumption that ethnohistoric lifeways characterized all of the last 1500 years or more of prehistory in southern California.

The divergence between hunter-gatherer strategies in the Santa Barbara and San Diego regions means that not all hunter-gatherers are cast from the same mold. Such qualitative differences among hunter-gatherer adaptive strategies cannot be explained using behavioral continua, i.e., the forager-collector model (see Binford 1980; Kelly 1995). It is rare for current archaeological explanations to find disagreement with the forager-collector model since it offers an infinite number of behavioral combinations to explain hunter-gatherer behavior. Adaptive strategies in the forager-collector model closely track technological and environmental conditions to approximate optimal subsistence behavior. However, such a perspective cannot account for adaptive stability when conditions change, providing no justification for the socioeconomic divergence between the Santa Barbara and San Diego regions. The time minimizing-energy maximizing model does just that, showing that behavioral continua models are not universal representations of human behavior.

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