

# Risk and Invention in Human Technological Evolution

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A central issue in archaeology is the study of technological change, and yet we have relatively little theory to explain the origin of technological novelty. Most models assume that inventions are generated as needed to solve adaptive problems. Alternatively, some view innovation as a creative and random process capable only of generating variation on which selection operates. This article considers the role of risk sensitivity in the production of technological invention. It is argued that evolutionary ecological models of risk and opportunity cost establish expectations for the contexts in which individuals are likely to stick to conservative technologies and when they are likely to be inventive. Archaeological evaluation of the risk-sensitivity theory of technological change requires attention to components of technological systems and their associated mechanical, operational, and strategic costs. The framework is examined with a case study of technological change from the prehistory of the Kodiak Archipelago in the Gulf of Alaska. © 2001 Academic Press

*Key Words:* risk; technology; invention; innovation; evolution; evolutionary ecology; evolutionary archaeology; Kodiak; Alaska.

## INTRODUCTION

This article considers the problem of technological invention, arguably one of the core issues in the evolution of material culture. Despite longstanding archaeological interest in technology and the “evolution” of material culture and increasing theoretical attention given to understanding the process of technological innovation (e.g., Bamforth and Bleed 1997; Bleed 1997; Oswalt 1982; Pfaffenberger 1992; Renfrew 1978; Shennan 1989; Spratt 1982; Torrence 1983, 1989; Van der Leeuw and Torrence 1989), the evolutionary mechanisms that condition inventive and innovative behavior have gone largely unexplored (Van der Leeuw 1989:300; but see Elster 1983). This article is an attempt to put technological innovation into an evolutionary framework by exploring parameters that are likely to effect the production of inventions. A model developed from microeconomic risk theory is joined with a framework for assessing critical constraints that would affect the utility of technological applications and

put selective pressure on a population of technology users. The model is then explored with a case study of technological change from the Kodiak Archipelago, in the western Gulf of Alaska.

## BACKGROUND

Since the work of Leslie White (1949) and Louis Henry Morgan (1877) before him, anthropologists have recognized a relationship between technology and social evolution. In both cross-cultural (largely ethnographic) and historical (largely archaeological) contexts, a general increase in technological complexity, diversity, and efficiency has been observed or assumed to correlate positively with increasingly complex social and political units of organization (e.g., Adams 1966, 1977, 1996; Boserup 1966, 1981; Fried 1967; Service 1961; but see Oswalt 1982). With varying degrees of sophistication, much of late 20th-century anthropology, and especially “processual” archaeology, was concerned with documenting and explaining this and similar relationships.



Without wishing to reject the generalizing goals of processual archaeology or even the efficacy of many of the models of social evolution it pursued (indeed my own approach is broadly processual and social evolutionary), it is my assertion that many of these models have been of limited explanatory utility because the inferred causal relationships generally have been insufficiently modeled and the mechanisms of change poorly defined. Technological evolution is one dimension of change commonly implicated but poorly specified in processual models (cf. Lemmonier 1992:14–17). The central purpose of this article is to construct a model of technological change that will help to improve our understanding of some of the more important mechanisms involved in technological evolution at the behavioral and archaeological scales.

A number of causal variables have been proposed to account for technological change. One of the most popular is the idea that humans have an inherent capacity to generate technological and strategic innovations under stressful conditions. This view is captured by the hopeful phrase “necessity is the mother of invention” (Rosenberg 1990) and underlies a host of variables commonly articulated in cultural ecological models of evolution (e.g., population pressure, scalar stress, and circumscription; Carniero 1970; Johnson 1982; Keeley 1988).

This perspective has fallen out of fashion in recent years under pressure from two rather different perspectives. First, moves to recognize the socially contingent nature of technological production have emphasized the embeddedness of technology in social structures and the role of material culture as a medium of social agency (e.g., Lemmonier 1992; Pfaffenberger 1992; Sasanman 1993; see also Schiffer 1999). The second critique comes from so-called “evolutionary archaeologists” or “selectionists” in the tradition of Dunnell (1980; see contributions to O’Brian 1996). While the social per-

spective raises important and interesting ideas about the nature of technological change at proximate levels, selectionists seek a materialist and mechanistic science of material culture that can definitively explain technological changes at an ultimate scale. Recognizing the importance of the social perspective, my focus in this article is the more ultimate level of evolutionary argument. I suggest, contrary to current selectionist claims, that Darwinian mechanisms may in fact justify the traditional “mother-of-invention” model, but only if we are willing to consider the role of behavior as a mediator between environmental opportunities and constraints (the social and physical selective environment) and technological production.

A strong reaction against the mother-of-invention model is foundational in selectionist archaeology. Selectionists usually view invention as random and undirected with respect to selection, analogous to mutations in genetic evolution (Dunnell 1978; Neff 1996; Neiman 1995; Rindos 1996). Rindos sees the problem as follows: “Consider a given method for solving problems (e.g., a specific mode of divination, the calculus, or a specific method for surveying land) and call it ‘X.’ Although X serves a desired end, it could not spring into existence simply because a need for X existed. Some other process (be it individual and mental, or social and organizational) had to precede the development of X” (Rindos 1996:161). Furthermore, while humans may invent new tools and techniques to solve perceived problems, the persistence and spread of the innovation among members of a population will depend on the selective environment after the invention was created, not when it was inspired:

No selective advantage may result from solving many mechanical or engineering problems recognized in the present. Conversely, a “chance” innovation that solves no particular mechanical problem in the present may be a key ingredient of some future technological system. . . . The

crucial point here is that problem solving and inventiveness should be viewed as part of the mechanism by which variation, the raw material for selection, arises (Braun 1990; Rindos 1996). Innovation by humans is 'directed' only by individual thought process and cultural context, which are independent of future selective and chance forces that will determine the innovation's success or failure. (Neff 1996:247)

I believe that, without revision, the *mother-of-invention model* (Rosenberg 1990) and the *random variation generation model* (Dunnell 1978; Neff 1996; Rindos 1980) are both insufficient to explain patterns in technological change at an evolutionary scale. The mother-of-invention model requires a mechanism for the generation of adaptive or successful technological variants, since the mere existence of a problem is a poor predictor of the success of a solution (without a feedback mechanism, failure is just as likely as success). To claim otherwise is logically circular. This point is analogous (or homologous, depending on your viewpoint) to the criticism of the adaptationist paradigm in biology levied by Gould and Lewontin (1979) and others.<sup>1\*</sup> It also underlies the primary argument against functionalism in the social sciences (see Elster 1983). The selectionist approach provides a mechanism, selection, for the differential reproduction of technological variation once established (postinvention), but it is blind to important sources of bias (nonrandom forces) in the production of technological variation. In my view, the key to a more satisfactory approach derives from optimal decision theory in evolutionary ecology. Critical to this problem is an evaluation of changing opportunity costs related to technological tinkering or invention. In some cases, investment of time and energy in experimentation would have lower payoffs for individual tinkerers than devoting time and energy to existing technologies (e.g., intensification through increased labor input) or engaging in other activities. In other con-

texts, experimentation should be preferable. Isolating the conditions that would encourage inventiveness (tinkering and experimentation) and predicting the population-level effects of variation in these conditions is the central purpose of this article.

It is worth noting that there are a number of other approaches to the anthropology and archaeology of technology that are not encompassed by the adaptationist/selectionist dichotomy explored here (e.g., Cresswell 1983; Lemonnier 1992; Schiffer 1999; Schiffer and Skibo 1987, 1997; Van der Leeuw and Torrence 1989; Torrence and Summerhayes 1997). Many of these other approaches focus on relatively proximate explanatory levels, sometimes explicitly so (Van der Leeuw 1989:302), and/or on the process of innovation, itself distinct from the question of the conditions that will favor inventiveness (see Renfrew 1978). Proximate and process-oriented approaches are external to the goals of this article, despite important insights they provide toward the building of a general theory of technology. I nevertheless draw useful terminology from this broader field of technological study. Terms such as "performance characteristics" and "constraints" are shared widely in technology studies (Braun 1983; O'Brian et al. 1994; Schiffer 1995, 1999; Schiffer and Skibo 1997; cf. Lemonnier 1992:16). These shared terms and concepts may ultimately assist in the unification of these approaches. However, in this article, I do not attempt to approach a comprehensive and inclusive theory of technology. My concerns are specifically evolutionary and in relating variation in the contexts of human decision making to long-term technological change.

## TECHNOLOGICAL DEFINITIONS

Definition is at the root of concise modeling and theory building. According to the most inclusive definition in Webster's Ninth New Collegiate Dictionary, "technology" is "the totality of the means employed to provide objects necessary for . . . sustenance and

\*See Notes section at end of paper for all footnotes.

comfort" (I have removed the word "human" from this definition to account for the observation of nonhuman use of "technologies").

Buried in this definition of technology, and even more prevalent in colloquial use of the term, are four components: *material*, *practical*, *informational*, and *purposive*. The *material component* pertains to the physical machinery (however simple or complex) or *tools* employed toward some end. Tools in this sense could include both bodily and extrabodily apparatuses.<sup>2</sup> The *practical component* relates to the activities involved in putting tools in motion toward a desired end. This is the active aspect of technology, related directly to its performance. The *informational component* contains the knowledge base and strategy sets underlying technological performance. It is not unreasonable to define all goal-directed behavior as technological, but for the purposes of this article (and consistent with conventional usage), we can constrain the informational component of technology to learned behavior (thereby excluding purely instinctive and predominantly genetic coding). The strategic dimension recognizes that there may be more than one path toward an end and that technological deployment in a variable environment might favor variable strategies. Finally, the *purposive component* recognizes that to be technological, deployment must be goal-directed. While the Webster definition supposes that the goal should be "sustenance or comfort," any goal, however rational or irrational, could be held by technological practitioners.<sup>3</sup>

*Definition 1:* We can now define *technology* more fully as the deployment (*practical*) of tools (*material*), toward some end (*purposive*), according to learned methods (*informational*).

Study of the evolution of technology pre-disposes one to consider how new tools and methods are developed. To do this, we need to refer to the related terms *invention* and *innovation*. In an interesting article that foreshadows some of the issues addressed

here, Renfrew (1978) draws an important distinction between the two. "Invention is the discovery or achievement by an individual of a new process or form, whether deliberate or by chance. Innovation . . . implies the widespread *adoption* of a new process or form, and clearly it must be preceded by the relevant inventions whether by a short or a long period" (Renfrew 1978:90, emphasis in original). Renfrew proceeds then to focus on the latter (innovation/adoption) aspect of technological change in order to problematize the issue of technological diffusion.

Renfrew's definitions make an important distinction between the creation of novelty and its spread, but further distinction is necessary to consider technological change from an evolutionary perspective. Sundbo (1998:1), following Kanter (1983:20), defines innovation as the process of bringing a new problem-solving idea into use, reserving the term invention for the production of the new idea. Thus I restrict the concept of invention to the creation of novelty by an individual or coordinated group *prior to practical testing*. Innovation is a broader concept that includes the research and development necessary to determine the effectiveness of inventions as well as processes of dissemination throughout a population. This distinction is consistent with past usage, where invention and innovation have been isolated.<sup>4</sup> I use these terms according to the following definitions:

*Definition 2:* *Invention* is the development of a novel idea with its attendant material, practical, and informational components, and *an invention* is a novel idea or untested device and/or method. *Inventiveness* is the tendency to produce novel ideas, methods, and devices.

By contrast:

*Definition 3:* *Innovation* is the process of testing and putting into practice an invented method/device, and *an innovation* is an invention that has been "tested" and is therefore no longer novel and unpracticed. *Innovativeness* is the proclivity to experiment with new ideas, techniques, devices, and strategies to make inventions into innovations.

Clearly, some ambiguity remains between the terms inventiveness and innovativeness, as the two are so closely bound. Nevertheless, the distinction between untested and tested technologies is critical to the ideas developed below. In general, invention refers to the more specific act of creating a technological novelty, while innovation is used more broadly to cover the larger process of realizing technological change. Explicit in Definitions 2 and 3, the targets of invention and innovation are not limited to objects or devices but also new methods (techniques, strategies, and organizational structures; see Sundbo 1998:20; also Schumpeter 1934).

Finally we have:

*Definition 4: Performance characteristics* are the measurable indices of a technology's relative ability to do what it is designed and/or deployed to do.

Axiomatic to the above definitions of invention and innovation, performance characteristics are relatively unmeasured upon creation of an invention, and it is the measurement of performance that converts an invention into an innovation. On an interval scale, performance characteristics could be represented as the mean and variance of multiple deployments, establishing a general expectation about the relative utility of the new device or technique. Research and development (R&D) and diffusion are clearly implicated in the establishment of technological innovations through a population at archaeologically visible scales; however, it is inventiveness that I focus on in this article.

## EVOLUTIONARY ECOLOGY AND TECHNOLOGICAL DECISION MAKING

Evolutionary ecology seeks to synthesize both adaptationist (ecological) and evolutionary theory. It is "the study of evolution and adaptive design in ecological context"

(Wintgerhalder and Smith 1992:3). Behavioral ecology is that subset of evolutionary ecology concerned with accounting for the evolution and adaptive character of behavior. As technological invention, innovation, and application are behavioral, and arguably used for adaptive purposes, behavioral ecology is a reasonable perspective from which to assess the issue of technological evolution.

I take as the starting point of this analysis the evolutionary ecological assumption that decision-making processes are constrained by natural selection to seek fitness-enhancing solutions (see Smith and Winterhalder 1992; O'Connell 1995; Broughton and O'Connell 1999). From this assumption, it is possible to develop testable models about behavior in systematically variable ecological contexts. Evolutionary ecologists predict that behavior will tend in the direction of fitness maximizing within the limits of environmental predictability and available information.

Inventive behavior is costly in time and energy, and given its inherently untested and creative nature, *inventiveness* should frequently result in ineffectual, inefficient, or unintended outcomes, many of which will be less desirable than techniques already in practice. If human inventiveness can have positive and negative fitness consequences under different situations and if humans seek to make adaptive decisions about how to spend limited resources of time and energy, inventive behavior should be sensitive to the costs and benefits of invention and innovation. This should be particularly the case in variable environmental contexts, where the consequences of similar actions can have dramatically different outcomes depending on the circumstance.

Microeconomic models are useful for formalizing fitness maximization problems with respect to divisible resources, such as food. These models all assume a cost-benefit format and seek to account for behavior

by means of economizing principles applied to relevant currencies. Evolutionary ecologists utilize microeconomic models of behavior in which the ultimate currency is assumed to be fitness, but for which proximate fitness-related currencies are substituted in practice (Jochim 1981, 1983; Smith and Winterhalder 1992; Stephens and Krebs 1986; Winterhalder and Smith 1992).

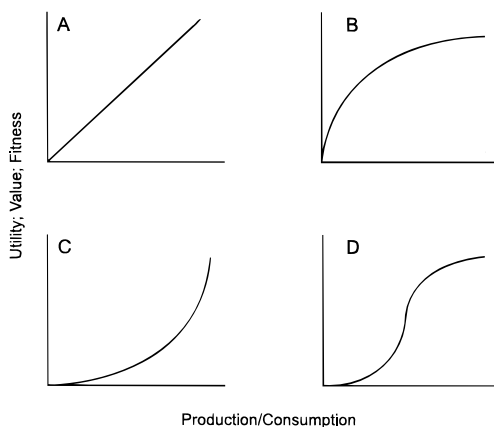
One of the most common forms of microeconomic model in behavioral ecology employs utility functions to estimate consumer choice (Stephens and Krebs 1986: 104-ff; see Mansfield 1982:50-77). Consumer choice (or utility) models try to measure the relative utility or value obtained from a unit of currency. In most economic models, the currency of interest is money, and utility is measured in terms of happiness, health, prestige, or another socially valued variable. Economists have long known that utility rarely has a linear relationship to currency, and utility theory has arisen as a means of describing systematic relationships between these variables. These are often characterized mathematically or graphically in ways that make it possible to predict how much effort or expense economically rational actors would commit in the production or consumption of some good.

Microeconomic models are necessarily proximate in that the relevant currencies are grounded in some system of symbolic value. Behavioral ecologists retool these models to apply to more ultimate issues by defining utility in terms of fitness and fitness-related currencies (Stephens and Krebs 1986:104-ff). While not without controversy or hazard, doing so releases these models from the culture-bound framework of social value, in which utility is inherently tied to ideational systems unique to particular times and places and arguably variable between individuals. If one is willing to suppose that human behavior is at least partially conditioned to seek fitness-enhancing outcomes, fitness-utility models

can be applied heuristically and cross-culturally.

One of the first steps in developing an economic rational choice fitness-utility model is establishing the utility curve associated with incremental changes in the production, control, or consumption of a good.<sup>5</sup>

The functions depicted in Fig. 1 are frequently employed in behavioral ecological modeling (see Blurton Jones 1987; Boone 1992; Stephens and Krebs 1986:130). These curves describe different fitness or utility gain functions. In Fig. 1A, utility increases linearly with respect to increased consumption. An additional unit of consumption is no more and no less valuable than the previous unit. In Fig. 1B utility decreases as consumption increases. This gain function describes marginal utility and is commonly used to characterize the relationship between consumption and satiation. For example, the more food one consumes, the less utility one derives from continued consumption in a given feeding interval. Fig. 1C shows an economy of scale, in which additional units of resource are increasingly valuable as consumption proceeds. In this



**FIG. 1.** Common gains function curves showing different relationships between the production or consumption of a good and its utility, value, or fitness to the producer or consumer. (A) Linear, (B) diminishing, (C) accelerating, (D) sigmoid. (After Boone 1992:321).

case, as one gets more of a commodity, one is able to do more with each additional unit than is possible with each previous unit. Group hunting often takes advantage of economies of scale. For example, for small groups of Inuit ring seal hunters, hunting together at breathing holes generates higher per capita returns than do individual hunters (Smith 1991:325). Likewise, beluga whale hunting (Lucier and Van Stone 1995), bison drives, and net hunting in Africa's Ituri Forest (Noss 1997) all take advantage of the improved efficiency of cooperative hunting. Agricultural production ranging from small family farms to corporate agribusinesses takes advantage of economies of scale, as do modern retail chains, assembly-line factories, and corporate megamergers (see Boone 1992).

Figure 1D combines the diminishing returns (Fig. 1B) and economy of scale (Fig. 1C) functions to give a more realistic model of production/consumption utility. To use the case of consumption, a consumer early in a consumption episode falls on the accelerating portion of the curve. Once a certain amount of resource is consumed, additional consumption generates decreasing marginal utility and by opportunity cost arguments more urgent activities should take precedence. Feeding, for example, is only one of many competing fitness constraints, and the decision to cease consumption should be tied to the potential utility of alternative activities compared with the utility of continued consumption. This is based on the principle of lost opportunity, in which the costs of pursuing one strategy are measured with reference to possible alternatives (Hames 1992:205; Stephens and Krebs 1986:11; Winterhalder 1983).

While feeding behavior is one of the more concise examples of the operation of the sigmoid function (where the shape of the curve is defined by physiologically imposed limits at both ends—minimum energetic requirements and satiation), this shape is logically defensible in all contexts

in which we can expect marginal utility or value to vary across the production/consumption scale. In the context of a market relationship between producers and consumers, production will operate in a sigmoid fashion according to the relative balance of supply and demand. The sigmoid function, however, is not limited to a single concave up/down cycle, and in certain cases it can generate multiple accelerating/decelerating cycles (e.g., under conditions of economic stratification: Boone 1992; Friedman and Savage 1948).

Fitness-utility models are made relevant to technological decisions by the assumption that, at some level, behavioral goals should tend to be fitness-related and by the definitional point that technologies are inherently goal directed. In other words, I assume that technological goals will tend to be oriented toward fitness maximization within the context of available information and environmental constraints (including constraints in anatomy, physical surroundings, and social context). This assumption is founded in the expectation that simple decision rules and predilections are heritable and therefore subject to the effects of natural selection.<sup>6</sup>

Reproductive fitness maximization can be assumed to break down into somatic maintenance/self-improvement and reproduction. In conventional terms and on average, people should be broadly interested in survival and reproduction however these may be pursued (and in the structural complexity of the modern world, the pathways can be remarkably varied and obscure). I note also that the reductionism inherent in fitness maximization assumptions need not dissuade us from the more comfortable notion that our day-to-day behavior follows more cerebral, enlightened, or socially constructed goals. The reduction is methodological in the sense that it should help expose conditions where fitness maximization is the least able to explain behavioral patterns, whereupon more complicated models can be developed.

On the other hand, *assuming* that fitness maximization has no role in the generation of human behavior leaves us in an analytically untenable position should we wish to examine the evolved relationship between biology and culture and perhaps an “emergent” separation between them. This reductionism is also practical for developing models that can be extended cross-culturally and into the archaeological past, where symbolically emergent value systems are less accessible. And of course there are theoretical reasons to believe that a considerable amount of human behavior may in fact be responsive to evolutionary and biological processes.

There are three related aspects to the problem of technological decision making in an evolutionary ecological perspective. These are optimization, risk, and uncertainty. Each must be considered in the technological context with respect to choices between known alternatives and the choice to innovate.

### *Optimization*

Optimization is a basic concept in economic decision theory. It can be defined as the expectation that actors will seek to do as well as possible in the production of a given currency. Optimization is often posed against the concept of satisficing, defined as seeking to do as well as necessary to meet some goal (see discussion in Smith and Winterhalder 1992:54–55). Satisficing has arisen as an expectation of rational decision theory following the realization that simple optimization models are often poor predictors of actual decision-making processes. Nevertheless, satisficing has been rejected as an alternative to optimization on both analytical and theoretical grounds. Analytically it is often almost impossible to determine how much is enough (a threshold of need) in the calculus of decision making. Theoretically, in an evolutionary context, fitness competition between conspecifics is usually assumed to make satisficing an un-

tenable strategy because the individuals that get “more than enough” end up out-competing others in the end (Smith and Winterhalder 1992:54). In general, suboptimal decisions toward one currency can often be accounted for more elegantly within the framework of optimality, where more than one activity or proximate currency is pursued and currency trade-offs are necessary (Winterhalder 1983; Winterhalder and Smith 1992:52).

In the simplest optimization context applied to technology, decision makers can be expected to have some information about the performance characteristics of tried technological solutions, and they should choose that set of solutions that are expected to produce the highest return rate. In a predictable (and deterministic) world with perfect information (certainty) about the productive capacities of different technological options, simple currency optimization models should predict technological choices (see Friedman and Savage 1948:72), notwithstanding the difficulties involved in modeling trade-offs between proximate currencies.

Figure 2 maps the productivity of five alternative technological solutions over a standard gain function. This function illustrates the value of various technologies to a beneficiary measured as a transformation of the average productivity of each solution (in some currency, such as calories) over a fixed interval of time. As an example, these alternatives might characterize different sea mammal hunting technologies, such as clubs, spears, barbed harpoons, toggling harpoons, and nets. For clarity, each technology is spaced evenly along the x axis, so the difference in absolute productivity between each adjacent solution is equivalent.

Notice that the differences in utility between the solutions are far from equal. The difference in utility between A and B and B and C are technically equivalent, but values increase by progressively smaller increments between C, D, and E. Each subse-

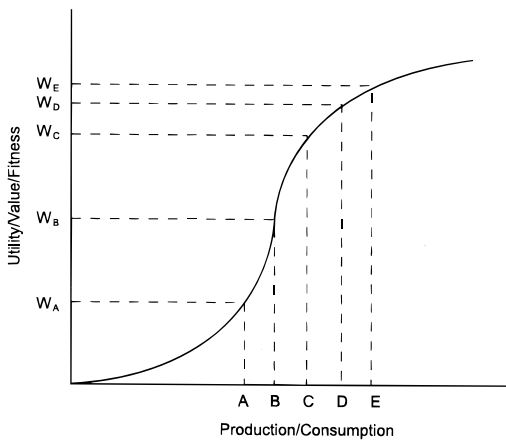


FIG. 2. Variance in utility for constant increases in production/consumption across a sigmoid gains curve.

quent solution is more productive than the previous, so all else being equal, people should adopt the technological solution that has the greatest output (E). However, if there are costs associated with shifting from one technology to another, the most productive solution might not be the most optimal.<sup>7</sup> One implication of this model is that a decision-maker should be willing to pay far more in start-up costs to go from A to B or from B to C than from C to D or D to E. Given the option, improvements, even minor ones, will be more desirable to people lower down on this curve. If technology costs are proportional to improvements in yield, there should be little motivation to change technology when already experiencing diminishing returns. Where start-up and maintenance costs of different technologies are more equal, higher yielding strategies should be utilized more often.

The sigmoid curve is commonly applied to issues of subsistence consumption, based on the parameters set by (1) minimal energy requirements for the act of consumption at the lowest end, (2) absolute energy and nutritive demands for the foraging interval at the inflection point (threshold of self-sustainability to the next foraging interval), and (3) the amount of food an or-

ganism can consume and utilize in a given period of time at the upper end (satiation). The curve is appropriate as well for analyzing technological production, although far less obviously. In the case of technological production (of food or any other fitness-related good), the lower limit can be assumed to be set by the minimal requirements of continued production, the inflection point by the level at which alternative pursuits (trade-offs) begin to outweigh continued production (inflating the costs relative to benefits in continued production), and the upper limit by absolute limits to the productive enterprise. In some cases, as noted above, we are justified in extending the sigmoid curve into additional cycles, characterized by multiple levels of productive utility.

This model has interesting implications, for it suggests an analytical approach to modeling technological choices among alternatives already available. Realism is sacrificed here by the deterministic assumption that these technological solutions have fixed outcomes (which would be true only in a constant and invariable environment) and that decision-makers have complete information about the costs and benefits of the alternative solutions. These conditions will rarely be met exactly (cf. Bateson and Kacelnik 1998; Smith 1988; Winterhalder 1986, 1993), but they may be close enough to make the model interesting.

It is also impossible to model adequately technological invention from this perspective, since inventions are by definition untried and their performance characteristics unknown or at least poorly predicted by past experience. Modeling inventive behavior requires the incorporation of risk and uncertainty.

### *Risk Sensitivity*

Risk theory is a formalized framework for assessing decision-making in a stochastic environment (Bateson and Kacelnik

1998; Stephens and Krebs 1986:128–150; Winterhalder, Lu, and Tucker 1999). In such an environment, adaptive strategies will yield variable outcomes that can be defined (for normally distributed populations) by the average and standard deviation of multiple applications. Decision-makers with experience in the operation of a given technology will have some knowledge of the probability distribution of outcomes and can make choices about its utility compared with other known strategies, as in the case illustrated by Fig. 2 above. In evolutionary ecological usage (following microeconomics), this variance in outcomes due to uncontrolled parameters is termed “risk.”

Many readers will find it tempting to confuse or conflate the definition of risk used in this article (risk = variance) with the more common concept of risk as probability of loss due to unpredictable recurrence of hazard, danger, or hardship (e.g., Halstead and O’Shea 1989; Hiscock 1994; Torrence 1983, 1989). Bamforth and Bleed (1997) have discussed the distinction between *variance* and *probability of loss* definitions of risk. While their treatment clearly exposes ambiguities in the use of the term “risk,” their conclusion that the “probability of loss” definition should take priority is disputed here on two levels.

First, while inspiring advances in our understanding of a whole range of adaptive variation, the analytical problems tackled with the *risk-buffering* models that have followed from the “probability of loss” definition are different from the problem pursued in this article. I am interested here in how a new technological trait might arise, not in the adaptive function that trait may take on after its innovation. Conflating the concept of trait generation and adaptive function generates the form of Lamarckian functionalist argument that has been soundly rejected in both biology and social science (see Elster 1983; contributions in Rose and Lauder 1996).<sup>8</sup> Keeping the two concepts distinct is a key to their collective viability,

and I see potential for complementarity in a theory of technological evolution.

Second, a potentially serious methodological problem with “risk-buffering” approaches is the analytical ambiguity surrounding the concepts of “failure” or “loss.” The difficulties arise when trying to quantify failure. In insurance theory, where the hazard definition of risk originates, failure is an artificially specified threshold value ultimately defined by the expectations and values of consumers. Such a threshold is difficult to operationalize (what is “bad enough” to inspire evasive or “risk buffering” action?). Milton and Savage (1948) use the sigmoid function to illustrate the relationship between insurance seeking (risk aversion) and gambling (risk seeking), showing that the “risk-as-hazard” definition is an incomplete definition of response to stochastic environments. They show that it is clearly misleading to assume that people are always interested in protecting themselves from hazard: Sometimes people put themselves in hazard’s way on the odds that they will actually come out better off. This is in fact the thesis of my risk sensitivity theory of innovation that follows.

In behavioral ecology, risk sensitivity specifies the susceptibility of an agent to unpredictable variance in outcomes. Every actor has risk sensitivity that falls somewhere between fully risk-averse and fully risk-prone. Under normal conditions—that is, when an organism is reasonably well adapted to a given environment—most organisms can be expected to demonstrate risk aversion in most choices (Winterhalder 1993; Winterhalder, Lu, and Tucker 1999). Risk-averse actors seek to make decisions that increase the predictability of outcomes by reducing variance. Risk-prone actors choose to pursue solutions with higher variance on the odds that a higher than average payoff will result. The difference in risk sensitivity can be demonstrated using the sigmoid gain-function curve.<sup>9</sup>

The probability distributions for two strategies are shown in Fig. 3. Both strategies

have normally distributed outcome probabilities. Below the inflection point, the variance above the mean is valued more highly than the variance below the mean, suggesting that individuals in this position would prefer higher variance strategies over lower variance strategies. Above the inflection point, the opposite is true and one should seek to reduce variance and hold outcomes closer to the mean for the given solution.

In reality, organisms move up and down this curve as they accumulate and expend resources and as competing activities become more and less valuable. After a particularly successful hunt or harvest, hunter-gatherers or farmers will be relatively high up on the subsistence curve. The value of continued production should then drop compared to a range of alternative activities defined by greater immediate payoffs. This logic underlies recent models of sharing and tolerated theft (Blurton Jones 1984, 1987; Smith 1988; Winterhalder 1986, 1996, 1997) and helps explain observed egalitarian economic behavior among "immediate return" societies (*sensu* Woodburn 1980,

1982). Intervals of scarcity with the possibility of storage to offset shortfall will increase the utility of producing larger quantities of storable resources, stretching the curve along the x axis.

From the risk sensitivity model, we can infer that individuals may shift between higher and lower variance technologies as their productivity moves up and down the curve in the course of some relevant interval of time. When the productivity of the best available technology (as a function of both average and variance) consistently falls on an accelerating curve, people should be more willing to engage in inventive and innovative behavior. To understand why, we need to consider uncertainty.

### Uncertainty

In an influential article, Frank Knight (1921) argued for a distinction between risk (as variance) and uncertainty. For Knight, uncertainty refers to lack of information or ignorance of probability distributions surrounding one or more activities, a condition that can be rectified only by collecting information (Cashdan 1990; Knight 1921; McCann 1994; Smith 1988; Winterhalder 1983). Given the untested nature of inventions (as defined above), and the attending uncertainties surrounding them, it would be difficult to predict even the stochastic distribution of likely benefits from innovative choices on the basis of the inventions themselves, and the risk-sensitivity model just described would be of little help. From this, we might join selectionist archaeologists and conclude that random variation and selection are the only forces directing technological evolution, since innovators themselves could never predict their successfulness.

However, there are three reasons why the risk sensitivity approach is still a reasonable way to model innovative behavior despite the uncertainty inherent in invention.

First, we can treat untested inventions subjectively as containing within them the

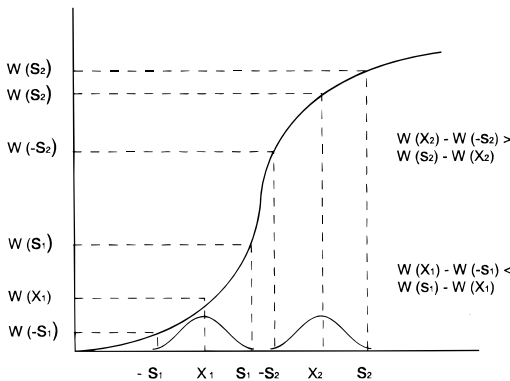


FIG. 3. A graphical illustration of the economic logic behind risk-averse and risk-prone strategies. Decision makers should be risk-averse (variance avoiders) when they experience returns at a level above the inflection point of the sigmoid gains function but risk-prone (variance seekers) when below the inflection point. This follows from the greater average utility to be gained by the latter and lost by the former with increased exposure to variance (see text for elaboration).

potential to yield outcomes anywhere along the production axis, i.e., exhibiting maximum variance. Testing/using the invention (both cognitively and in application) will allow decision makers to continuously recalculate expected probabilities of the innovation.<sup>10</sup> In economics, this use of “subjective probability theory” (McCann 1994; Savage 1972) to operationalize problems of risk and uncertainty has found favor over Knight’s dichotomous view in explaining how decision-makers actually face degrees of uncertainty in the world (Cross 1983:59). Gaining knowledge about a subject decreases uncertainty as individuals continually recalculate their perception of environmental stochasticity (risk).

Second, new strategies involve more or less predictable *research and development costs*, including designing the new technology and sampling its outcome distribution. And third, the decision to invest in something new entails *opportunity costs* measured in the inability to simultaneously practice existing strategies with better known outcome probabilities. Given an idea for an innovation, the first set of costs may be anticipated, e.g., “I will need so much raw material, these secondary tools, this amount of production time, and so many trial runs to see how well it works.” The second set of costs can be anticipated as the worst case scenario cost, e.g., “If I put all of these resources, time, and energy in this experiment, and it fails, how will the potential costs and benefits compare to using a known strategy?”

It should be clear that when the best existing technology produces at a level consistent with an accelerating (upward turning) portion of a utility function (when a person should be risk seeking), inventions (initially presumed to have maximal variance) will be appealing and inventiveness will be favored. The converse should be true when productivity falls on a diminishing utility portion of a utility function, and inventiveness should be avoided in favor of technological conservatism.

Research and development (R&D) and opportunity cost trade-offs act as deterrents to invention and innovation in situations of marginal productivity (at the very lowest levels of production). In all cases, innovations with minimal costs should occur more frequently than more costly ones. All else being equal, however, low-cost innovations should have relatively less power to significantly alter the productivity function (incremental change is less risky and also less likely to generate dramatic consequences for technology). A more complex version of this risk sensitivity model might include a role for the potential of compounded incremental technological innovations to generate more dramatic change, but I do not pursue this topic in this article.

As a final preliminary issue, we need to consider two kinds of uncertainties, *systemic* and *epistemic*, and their relationship in the context of human technological decision making (following McCann 1994). Systemic uncertainty concerns the unpredictability or stochasticity of the environment. It is the objective class of events or relationships that actors and analysts seek to characterize using probabilistic measures. And it is this form of uncertainty that technologies seek to harness. Epistemic uncertainty is lack of knowledge about the deterministic, stochastic, or dynamic nature of the environment. It is a “description of the degree of one’s apprehension and belief” about the variables effecting one’s well-being (McCann 1994:63). In the context of rational decision theory, systemic uncertainty is only relevant in the degree to which it effects decision making, which is operationalized according to epistemic uncertainty. The end results of the subsequent behaviors will be effected in the systemic context—as the behaviors turn out to be more or less effective—and it is the feedback between environment and behavior that is thought to increase behavioral adaptedness. This iterative relationship underlies Jochim’s (1981) use of operant learning as a cornerstone of behavioral ecology.

## A MECHANISTIC THEORY OF TECHNOLOGICAL INNOVATION UNDER ENVIRONMENTAL VARIABILITY

The theoretical discussion to this point situates us to develop expectations about the environmental contexts in which inventiveness/innovativeness would be adaptive; that is, when it should be the preferred strategy for fitness maximizers. Here, I define environment as the collection of physical and social variables that provide opportunities for and constraints on behavior and its outcome.

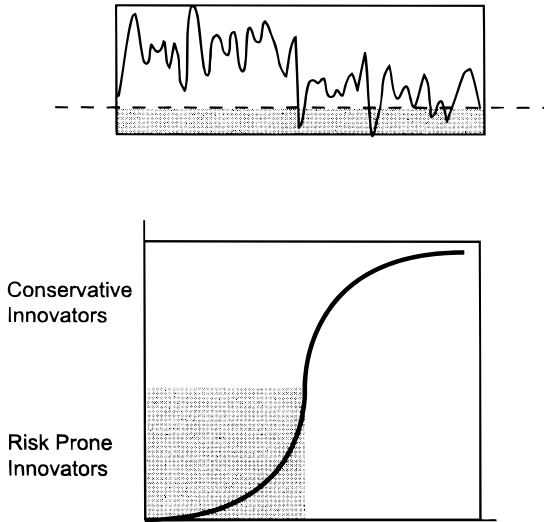
Behavioral ecologists commonly recognize two kinds of environmental variability (Winterhalder and Smith 1992:8-9). The first is *parametric* variability and concerns the changing nature of physical conditions that impose selective constraints and opportunities on survival and reproduction. Parametric variables are independent of any feedback from behavioral responses and are commonly modeled deterministically or probabilistically. Optimal foraging theory, for example, operates in the parametric context (e.g., Kaplan and Hill 1992). The second kind of variability is *strategic* and refers to environmental constraints whose value is conditional of systemically interconnected responses and counterresponses. The social environment is commonly recognized as being strategic in operation because the adaptive value of behavior depends on the actions and reactions of others. In strategic contexts, deterministic and probabilistic models are inappropriate and game theory (or ESS theory in biology) is usually used. While less well-developed in human evolutionary ecological applications than in ethology, microeconomics, and political science, game theory models of strategic variability have been increasing, especially as behavioral ecologists attempt to tackle issues of social dynamics and social evolution (e.g., Boone 1992; Hawkes 1992).

Although a complete behavioral ecological theory of technological evolution requires consideration of both parametric and strategic contexts, I nevertheless limit discussion in this article to the parametric case. A strategic model is a desirable extension of these ideas, should they prove useful in the limited context for which they are developed here.

### *The Theory*

In the context of adaptive decision making with respect to a stochastic parametric environment, we need a way to represent how decisions (subjective/epistemic) vary with changes in physical parameters (objective/systemic). Figure 4 projects variation in a consumer's exposure to environmental variability against a utility function representing that individual's sensitivity to uncertainty. The preference of a decision-maker on this simplified curve will vary as parameters in the environment fluctuate. In particularly bad times, for example, during a drought or an unusually long winter, people will find it difficult to produce subsistence goods to the level of diminishing returns on the utility curve (increasing productivity will continue to have high utility). During these times, higher variance strategies would be chosen, if they were available, and inventiveness would be desirable. During less extreme times, people should spend most of their time on the diminishing returns side of the curve. They should seek to minimize variance in outcomes and would be less inclined to invent or adopt new technologies that would entail both predictable and unpredictable costs and unpredictable benefits.

Put more technically, Fig. 4 illustrates a dynamic feedback between environmental parameters and decision rules directing innovativeness on the one hand and technological conservatism on the other. Environmental parameters (shown in Fig. 4a) send signals to decision-makers by means of



**FIG. 4.** The relationship between environmental variance and risk sensitivity are illustrated here. (a) Shows hypothetical variation in return rates (a function of environmental variation and technological capacity), plotted through time. (b) As productivity remains high, producers remain risk-averse. When productivity drops into the lower portion of the graph, producers are expected to become risk-prone. The decision rule is expected to follow the logic illustrated in Fig. 3 and explained in the text.

variation in productivity that are interpreted according to a utility function (shown in Fig. 4b), which is presumed to be adaptively oriented. Given that the environmental parameters (in Fig. 4a) are themselves an expression of the conjunction of environmental variability and technological efficiency, a change in technological efficiency with invention and innovation will change the relationship of environmental variability to production. This in turn can alter the behavioral response (shift from risk-seeking to risk-avoiding strategies or vice versa). Recognizing that selection is a characteristic of the environment (in this case, the parametric environment), we can treat Fig. 4a as a representation of variation in selective pressure on phenotypes (individuals with given technological abilities). As selection pressure becomes more severe and production drops, it can trigger a change in adaptive strategy. According to the limited case illustrated in Fig. 4b, this change will involve greater inventiveness.

If inventions are produced that subsequently reduce the selection pressure by in-

creasing production or diminishing demand, we can say that technology has evolved adaptively. On the other hand, there is no necessary reason to assume that inventions will work, only that people will be more prone to inventiveness. If inventions are generated that decrease efficiency, they would be abandoned in the innovation/testing process or result in decreased fitness for those who apply them.<sup>11</sup> Thus the theory provides a mechanism for variation in technological stasis and change. Behaviorally motivated change toward decreased efficiency is generally precluded by the omnipresent goal of maximizing fitness, i.e., people should not willingly choose to reproduce a less efficient technology in the absence of compensating trade-offs. Loss of technological efficiency is nevertheless expected under conditions of environmental change.

Because of the investment costs associated with innovation, significant changes should be less likely to occur when decision-makers realize diminishing returns of utility (the concave-down function). By contrast, innovative activity should be more

common when individuals value increased production (the accelerating utility function). Such is the case any time increased income (of whatever currency) will carry the actor to another level of well-being (however defined). A universal example obtains when an individual experiences a deficiency in caloric or nutritional intake to sustain oneself or one's offspring through an anticipated interval of low consumption. When the probability of achieving outcomes at the diminishing returns level is small with known technologies, but when the decision-maker nevertheless has sufficient energetic reserves to pay the anticipated costs of invention and innovation, we would expect people under subsistence stress to become inventive.<sup>12</sup> The costs of failure are assumed to be equivalent to the costs of failure due to persistence in the conservative strategy and can be ignored in this case.

Other cases besides subsistence can be recognized as well. For example, the difference between the strategies of subordinates and elites in the production of wealth in "transegalitarian" societies (Clark and Blake 1994; Hayden 1994, 1995) can be understood as a difference in opportunities for improving well-being (see Boone 1992; Fitzhugh 1999). In this case, the shape of the utility curve is presumed to be concave-down for subordinates (attempts at increasing wealth are going to yield diminishing returns, perhaps through the interference of elites) and concave-up for competitive elites (those who have a reasonable expectation of becoming dominant or particularly powerful with a little more "income"). Symbolic currencies (prestige commodities and money) make it possible for economies of scale to operate at several discrete levels of production above the level of subsistence well-being. In the context of reproductive fitness, there is no necessary upper threshold for "maximal well-being" (as there is for individual food consumption), and in the absence of trade-offs in time allocation and energy expenditure, we would expect no upper limit on the value of productivity.

In simple terms, this model predicts that in situations where individuals have more to gain than to lose by larger variance strategies (i.e., where gambling pays on average), they should be more likely to be innovative. Alternatively, where little is to be gained and much lost with higher variance strategies (when people are risk-averse), technological behavior should be conservative and focused on the most consistent (low variance) and highly productive techniques already practiced.

These predictions find some support in ethnography. Using a similar sigmoid utility curve, Frank Cancian (1972, 1980) finds that low-income Mayan peasants tend to be more receptive to introduced crop varieties and methods than their better-off neighbors. He explains this finding according to the risk sensitivity of his subjects. Cosh and colleagues (1996) likewise find that inventiveness in capitalist firms tends to line up according to a risk-sensitivity model. Struggling firms are much more likely to invent and experiment in an effort to establish themselves, while dominant firms are much more conservative and risk-averse.

Interestingly, biological studies provide some indication of the evolved physiological mechanisms that underlie a risk-sensitivity decision rule (see Bateson and Kacelnik 1998 for comparison of ecological and psychological models of risk sensitivity). For example, a number of studies of both humans and non-human primates have shown that the levels of the hormone serotonin tend to increase in subjects experiencing physiological or psychological stress. This suggests that risk sensitivity, and the ability to shift between risk-averse and risk-prone behavior, was an advantageous trait in primate evolution (Fessler n.d., and personal communication 1999; Raleigh et al. 1984).

Following the above discussion, the risk-sensitivity theory provides a mechanism for the intuitive relationship held between urgency and creative problem solving in the "mother-of-invention" perspective, while embracing the mechanistic strengths of a Dar-

winian theory of evolution. The theory suggests that, while inventions *may* be generated randomly with respect to selection pressure and *may* come to serve adaptive purposes for which they were not designed (Neff 1996; see also Gould and Lewontin 1979), a much higher incidence of innovative behavior and technological change should occur in contexts of enhanced selective pressure. There is no guarantee that any individual invention will be successful; but in a statistical sense, averaged across a population of potential innovators, more inventiveness will increase the likelihood that technological change will be fixed in the population through cultural transmission. This observation provides an opening for archaeological analysis of technological evolution, as archaeology is biased toward the observation of aggregate outcomes over individual behavior.<sup>13</sup>

### TOWARD EMPIRICAL EVALUATION 1: DOMAINS OF TECHNOLOGICAL CONSTRAINT

The theory just described requires further specification before it can be applied to an archaeological context. First, technologies serve a host of purposes and any attempt to compare rates of technological inventiveness

and innovation against environmental parameters (physical and social) necessitates a narrowing of the operational set of given technological systems. For example, innovations in subsistence technology should not be compared to selective constraints best addressed by clothing or shelter. Likewise, military technology would do little to address resource variation directly unless social competition was a derivative of this variation (as is often the case; Kelly 1995).

Second, from a production/output standpoint, technologies have multiple components, including tools, operational characteristics, and strategic variables (cf. Bamforth and Bleed 1997; Torrence 1989). Each component of technology imposes constraints on technological production (Table 1). These constraints can be classified into categories related to tool production (tool constraints), technological deployment (operational constraints), and the social context of invention and deployment (strategic constraints). Tool constraints and operational constraints are both effected by physiological constraints (e.g., anatomy) that make certain inventions more practical than others (Bleed, n.d.).<sup>14</sup> For the purposes of evolutionary patterns in technological change, physiological constraints can be held constant and are not considered further here.

TABLE 1  
Constraints on Technological Application

Constraints	Subconstraints	Examples
Material	Raw material availability	Chert sources, animal bone, hides
	Manufacture and maintenance	Skill development, tool volume, secondary toolkit maintenance, sharpening and repair, retooling
	Technical/mechanical performance	Durability, precision, efficiency
Operational	Deployment skill and knowledge of technology	Facility with tool, experience in application, accuracy
	Knowledge of environment	Optimal deployment
Strategic	Product divisibility	How large and how "lumpy" are the product units
	Group size	Optimal task group, members' and joiners' interests
	Variance in skill	Competence of potential participants

Tool constraints include (among other things) raw material availability, manufacturing efficiency (learning costs, maintenance of manufacturing tool kits, etc.), and technical performance efficiency (e.g., edge angles related to cutting ability or fiber strength in rope technology). Operational constraints relate to the deployment of a technology in a given environment to produce a desired effect and include information about the best articulation of a technology in an environment and the level of skill developed by a "technician." Strategic constraints relate to the social context of technological implementation, particularly competition and cooperation over materials and products and rights to participate in or benefit from technology. Some strategic issues include divisibility of the product and its desirability across a population of potential collaborators/consumers, competition over materials and labor, production scale issues (such as variation in effective task group size; Bleed 1997:98; Smith 1981), and variance in skill across a group of potential collaborators.

Clearly an exclusive focus on archaeologically recovered tool parts (projectile points, knives, net weights, fish hooks, bowls, pots, etc.) will be insufficient for assessing the relative costs and benefits of prehistoric technologies. At a minimum, archaeologically recoverable tool parts should be situated analytically in the larger technological system in which they would have been used (Bleed 1997; Bamforth and Bleed 1997:111).

The classification of technological components and associated constraints in Table 1 is similar to previous classifications (e.g., Bleed 1997; Hayden et al. 1996; Shott 1996), and for clarity, it is important to explain why a new classification is offered here. Hayden and colleagues (1996) have recently presented a Design Theoretic approach to lithic technology, which shares a basic organizational structure with that presented above and in Table 1. As they note, design theory examines constraints on tech-

nological problem solving. Common constraints are divided into adequate task performance, material availability and cost, available technologies, and the relative values of alternatives to production and use (Hayden et al. 1996:10 and references). Differences between the scheme of Hayden and colleagues and the one employed here derive from differences in analytical goals. Where the former seek to put lithic tool categories into a hierarchy of design for the analysis of technological assemblages, I am interested primarily in the relative opportunity costs of functionally similar technological systems.

My classification also shares similarities with a general technological scheme used by Shott (1996). Shott considers causes of artifact variation within a single class of artifacts, projectile points. He lists a number of what might be called "random" sources of variation (style, individual variation, laziness in conformity, time/space drift, raw material variation, and measurement error) and then turns to what Dunnell (1978) would call "functional" characteristics, divided into manufacture and performance criteria. While I recognize that random sources of variation exist, my purpose here is to argue that adaptive decision making is a more important mechanism driving variation in rates of technological change. Shott's concern with the manufacture and performance of hunting tools is comparable to the one offered here. His scheme, however, is not designed to compare technological systems so much as tools and tool components, and he does not consider strategic variables as defined here.

Finally, Bleed (1997; see also Bamforth and Bleed 1997) presents a behavioral classification of technology that focuses on technological content (behavioral) and technological results (archaeological). The articulation of results with the environment has a feedback on subsequent technological content. Bleed includes material culture, environmental modifications, social arrangements, and

adaptive success in the “results” category. He puts knowledge, applications, and standards in the “content” category. Bleed’s model adds conceptual clarity to aspects of technological practice and comes closest to the goals of this article in attempting to specify costs affecting technological production and application (see especially Bamforth and Bleed 1997). The scheme presented here differs from Bleed’s in its attempt to focus on the causes of technological change in an evolutionary ecological framework.

## **TOWARD EMPIRICAL EVALUATION 2: PREDICTING TECHNOLOGICAL CHANGE IN HUNTER-GATHERER SUBSISTENCE SYSTEMS**

In the remainder of this article, I limit the discussion to technological change in hunting and gathering subsistence economies. This specificity has three advantages, one theoretical and two practical. First, by limiting focus to social contexts that are, for the most part, socioeconomically nonhierarchical, we are justified in using a simple single-cycle sigmoid function to characterize economic valuation and risk sensitivity.<sup>15</sup> Second, limiting our focus to a rather specific economic domain reduces the number of variables at play. And third, focusing on hunting and gathering systems facilitates assessment of predictions against an accumulated record of 7000 years of prehistory on the Kodiak Archipelago in southern Alaska, with which I have been working for a number of years. Despite this focus, the risk-sensitivity model should be sufficiently general to apply to other classes of technology and systems of economic production (e.g., agriculturalist, market-exchange, and capitalist) where microeconomic models have more traditionally been applied.

For a variety of reasons, the case study that follows cannot be considered a rigorous “test” of the risk-sensitivity model, as I make clear below. Instead, it is put forward (1) to better ground the model in an archaeological context and (2) to suggest productive av-

enues for future modeling and research. Additional lines of evidence are needed to put the risk-sensitivity model on more solid empirical footing, and some of these are discussed near the conclusion of this article.

The risk-sensitivity model as developed in this article suggests that, in nonhierarchical contexts (where risk sensitivity can be concisely described according to a single accelerating/decelerating sigmoid utility function), technological inventiveness should be most prevalent when traditional technologies become more difficult to implement due to increased costs and/or decreased payoffs (measured in proximate currencies such as time and energy).

Different kinds of costs are expected to motivate different kinds of innovations, suggesting testable predictions concerning the nature of technological change. These are tooling costs, operational costs, and strategic costs.

### *Tooling Costs*

Increased difficulty in procuring familiar raw materials for the manufacture of tools will impose selective pressure for raw material change with (1) increased distance from known raw material sources, (2) depletion or exhaustion of known and favored sources (including reduced raw material quality and declining availability of material for second order tools, e.g., antler billets), (3) lack of experience with local sources and the functional properties of local materials, and (4) competitive exclusion from traditional sources or trade routes.

The nature of mobility practiced by a hunting and gathering group will effect access to raw materials as it does with other resources. High mobility within a fixed range reduces the effects of distance on raw material accessibility for sources within the range. Reduced mobility (smaller range) or emigration (range relocation) away from source areas, however, should lead to increased difficulty in material procurement in the absence of compensating trade networks.

Material depletion depends on the rate of exploitation relative to the size and distributional properties of sources. A large stone quarry might impose no practical limitation for small-scale collectors with minimal stone needs, while intensive exploitation for trade could quickly reduce the availability of higher quality materials.

For renewable resources, we must also consider the rate of replenishment relative to exploitation. On the North American arctic coast, driftwood is the only wood for manufacturing tools, and it is often extremely rare and unpredictably located. Most tool parts, which elsewhere are made of wood are, in the arctic, commonly designed from animal bones reinforced with other animal parts such as sinew (e.g., the composite sinew-backed bow). On the Alaskan subarctic coast where driftwood is still the primary source of workable wood, driftwood is commonly much more abundant than in the arctic but still potentially vulnerable to heavy exploitation (Fitzhugh 1996:228–236).

And for all resources (technological and subsistence), we must consider predictability in time and space. Fixed resources once identified are geographically predictable, although they may be periodically inaccessible (blocked by snow in winter, isolated at high tide, etc.). Mobile resources (e.g., caribou antler, walrus ivory, and sea mammal hide) vary in spatiotemporal predictability, and their availability is conditioned by ecological factors that can impose more stringent scheduling conflicts on procurement. In many cases, these animal-derived raw materials can be acquired in the process of subsistence pursuits, but in others, technological demands conflict with optimal subsistence pursuits. Change in the ecological parameters underlying availability of these resources could have exaggerated effects on the technological system, potentially forcing technological (or subsistence) change or collapse.

Raw material change, while not necessarily implicating change in other dimensions of the technological system, could sometimes lead to secondary change in manufac-

turing and in applications themselves. New raw materials with novel characteristics will inevitably require modifications in manufacturing technique, for example, as a result of differences in tensile strength, crystal structure, hardness, or porosity. New manufacturing strategies and new secondary tools might be developed in an effort to overcome unprecedented challenges in manufacture. We can thus predict that raw material change will lead to manufacturing change to the degree of difference in the workability of the two materials (old and new). For example, substitution of one kind of chert for another should impose fewer secondary changes than a shift from obsidian to chert, chert to slate, or bone to stone. Likewise, a change in grass varieties in basketry would be less significant than a change from grass to spruce root, or from stone to clay in pot manufacture.

In turn, distinct characteristics of new tools will have some effect on the performance of technological application, potentially effecting change in methods of deployment or even modes/targets of production. Such effects would derive from modification in the operational costs of technological deployment discussed next.

### *Operational Costs*

Operational costs are likely to be inversely related to experience with a technology in a given environment. Technological efficiency will be lowest in newly colonized or substantially altered environments and should improve as familiarity increases. “Blind” colonization of a new area (for example, by accidental or exploratory boat voyaging) should generate higher operational costs than gradual niche expansion, just as colonization of unfamiliar habitats will involve more operational costs than colonization of familiar habitats.

Operational costs should increase as well with subsistence resource depletion, as existing technological strategies yield increasingly lower return rates. Optimal foraging

theory contains a suite of models appropriate to evaluating changes in costs and benefits of alternative subsistence pursuits (Charnov 1976; Charnov and Orians 1973). The prey choice model (Kaplan and Hill 1992; Stephens and Krebs 1986) is particularly important for predicting when a population might become *invention prone*. This model predicts that foragers rank resources according to their postencounter return rates and that the only resources included in the diet will be those with greater return rates than the average of all ranked resources (taking below the average would reduce foraging efficiency). As high-ranking resources decline in availability, optimal rankings expand to include lower ranked targets or people move to more profitable locations (Kaplan and Hill 1992).

The Patch Choice model (Kaplan and Hill 1992:178–185) considers foraging practices in spatially heterogeneous environments. Where resources are located in relatively discrete patches, they are often characterized by diminishing returns. Over time as the patch is utilized, it becomes increasingly depleted. Patch depletion is inversely related to patch size and occurs most rapidly for large bodied prey with low reproduction rates (Broughton 1994a, 1994b, 1995; Cannon 2000; but for caveats see Rick and Erlandson 2000). Because large bodied prey generally offer the highest return rates to hunters, they often top hunter-gatherer prey rankings. The result is a tendency to diminish large-bodied prey species (Broughton 1994b, 1995), as they are simultaneously the resources most attractive to hunters and most vulnerable to depletion.

The most likely forager response to patch depletion caused by harvest pressure is to move to a less depleted patch (following the Patch Choice model). When the costs of mobility increase (e.g., social circumscription) or where moving fails to improve the foraging situation (e.g., seasonally synchronized patch impoverishment), diet breadth should expand. Without technological or strategic change, however, the total foraging return rate falls as

diet breadth expands and foragers become increasingly exposed to stochastic variation and unpredictable returns. Vulnerability to resource variation increases the costs of foraging with known technologies and should make technological invention and experimentation more attractive. Such invention and experimentation is most likely to focus first on the larger bodied prey species in attempts to increase yields in these higher utility resources. Then, as these resources are pushed farther into decline by increasingly effective harvesting technologies, inventiveness should gradually turn to more reproductively stable (r-selected and typically small-bodied) resources. Thus, technological innovations in hunting and gathering societies should focus increasingly on r-selected species through time (cf. Hayden 1981) until or unless larger bodied species gain in productivity due to dramatic change in ecological conditions (e.g., major decline in predation due to human population crash).

### *Strategic Costs*

Strategic costs will increase with competition over raw materials, labor, and products. Competition will increase with scarcity and defensibility/exclusivity of any of these variables. Competition is likely to be least acute for unpredictably captured, large, bulky prey, with little long-term storage potential. Sharing is commonly observed for such resources among ethnographically studied hunter-gatherer societies (Blurton Jones 1987; Lee 1979; see Winterhalder 1997). If subsistence foci shifts to increasing use of stored foods, competition is likely to increase as store owners seek to conserve a predictable and extendable food supply (cf. Testart 1982; Woodburn 1982). Such competition would increase incentives for innovation in defensive technologies at various scales (e.g., protected storage facilities, weapons, and fortifications), and it would increase the attractiveness of aggressive technologies and strategies.

Competition between laborers can be expected anytime a group is involved in co-

operative productivity. The larger the group involved in production, the greater the potential for competition. Smith (1981) has illustrated the conflicts of interest between members and potential joiners in establishing productive task groups in acephalous societies. Boone (1992; following Vehrencamp 1983) has extended this model to consider conflicts between leaders and followers in nonegalitarian groups. For the purposes of this article, conflicts of interest between task members can be expected to increase with larger task groups and greater asymmetry in the benefits of production. Competition *over* labor is only likely under conditions of institutionalized socioeconomic inequality, when the products of labor are differentially controlled by competing elites (Fitzhugh 1999).

## PREDICTIONS

Inventions motivated by tooling costs should involve changes in the way tools are made (raw materials used and methods of manufacture) and less so the functional characteristics of technological deployment, although change in one could precipitate change in the other, as discussed above. Operational costs should more directly influence innovation in the kinds of tools made, the way they are deployed, and in the nature of technological output (subsistence resources in examples discussed in this article). Strategic costs could influence both technological materials and products. Competitive exclusion from raw material or subsistence resources and changes in the nature of cooperative subsistence procurement, sharing, and storage (hoarding) will all have implications for technological practice.

A few specific predictions:

1. Movement into unfamiliar environments/away from familiar environments should generate inventive behavior in raw material use: conservation of traditional (nonlocal) raw materials and experimentation with the technological properties/effectiveness of new materials.

2. Movement into unfamiliar ecosystems should lead to greater technological innovation (qualitative changes in technology leading to novel tool classes and new deployment methods) compared to moving into familiar environments. Rapid environmental change (such as a major climate change event) should have a similar effect, making traditional approaches more difficult to sustain and encouraging invention and innovation.

3. Change in foraging technology should occur first, if at all, in technologies for capturing large, high-utility species and then shift to more sustainable r-selected species.<sup>16</sup> Long-term technological change under environmental stability should trend toward increasing efficiency, but the most rapid and dramatic changes are expected under environmental change. However, there can be no guarantee that the new technology in the new environment will be better than the old technology in the old environment (increased efficiency or decreased exposure to hazard are predicted only within the selective constraints of a given environment as it influences technological decision making).

4. When population density increases in an area and raw materials or subsistence patches become circumscribed, hunter-gatherers should find it more difficult to employ the range of adaptive strategies that had previously allowed them to negotiate unpredictable shortfalls. In this context, one of the remaining adaptive strategies is heightened competition. With increased competition we should see technological changes that emphasize locally available materials and species requiring lessened dependence on resources controlled by other groups. Intergroup exchange should become more formalized and canalized as hierarchical resource control increases. By decreasing the number of nodes and vectors of exchange, formalized elite exchange partnerships should result in decreasing diversity in nonlocal resources

recovered archaeologically. The end result of this trend, where sustainable, would be formalized exchange between individuals or groups with complimentary resources. Noncompetitive groups could be entirely excluded from these exchange systems or included at significant disadvantages as economic inequalities emerge. The development of prestige economies and exchange of more strictly symbolic currencies will augment this emerging economy (Fitzhugh in press-a).

### METHODOLOGICAL ISSUES

The model just elaborated requires the ability to measure two separate phenomena in the archaeological record: risk and technological change. As specified in an earlier section of this article, risk is related to individual vulnerability to unpredictable environmental variation through a filter of knowledge, skill, and technological prowess evaluated against a host of possible trade-offs: i.e., risk is a subjective/epistemic variable. It is reasonable to assume that basic biological goals frequently dominate decision making (e.g., food, shelter, and reproduction). This assumption is supported by a variety of cross-cultural ethnographic studies of human behavior (see Smith and Winterhalder 1992; Winterhalder, Lu, and Tucker 1999). Archaeologists often measure risk by quantifying environmental variability in single parameters that effect such variables, such as rainfall or temperature, evident in prehistoric data sets (tree rings, pollen, and ice cores). These indices generate proxy measures of environmental productivity, but are not themselves direct measures of risk as experienced by decision-makers.

Proxy records of environmental variability have received their greatest use in the "risk-buffering" theory of cultural ecology/processual archaeology (e.g., Halstead and O'Shea 1989). I have already noted above that these models utilize a slightly

different concept of "risk" than the one used here and in behavioral ecology. Most applications of this approach display time-series proxy data (usually from the recent past) to show how different cycles of unpredictable shortfall require targeted coping strategies if people are to successfully occupy a given environment. In other words, these applications seek to establish the *need* for adaptations to unpredictable shortfall that will carry populations through crises at different scales. Having identified an adaptive problem, the technological (including social) organizations under examination are then considered justified as adaptations (e.g., Minc 1986). Rarely do these applications actually demonstrate *changes* in the state of the environment (average and variance) that would *promote* the change observed. Given the difficulty of projecting high-resolution proxy measures of environmental variation into the prehistoric record in parallel with archaeologically observed changes, we are forced often to consider more qualitative predictions. Improving on this will necessitate application of paleoecological measures that track the environment changes that should directly relate to changes in the matrix of adaptive decision making and hence technology (in the broadest sense).

Even with more focus on actual paleoecological variability, we must acknowledge that the proxy measures are only indirect indices of the selective environment. What we really want to measure is variance in technological effectiveness. Evidence of increased environmental stress—mean and range of variability (e.g., with climate change)—would have little effect on survival and reproduction if available technologies could already handle the new environmental regime (e.g., keeping productivity above the dashed line in Fig. 4a).

Qualitative or indirect measures, such as immigration into unfamiliar environments, resource depression, and circumscription, each impose constraints on technological

production and may actually be more relevant to technological change (they may prove more accurate even if less precise). Similarly, technological change itself alters the relationship of a population to its external environment (although to invoke it as a primary mechanism of change in this argument would be logically circular). With each qualitative change examined here, decision-makers face new challenges, presumably experienced as increased exposure/vulnerability to unpredictable fluctuations in resource harvests (more frequent and/or more intense shortfalls). While the following study does not address decision making in terms of time cycles of shortfall ("risk" in the hazard definition), I view technological change to follow from exposure to just this sort of negative trend in technological effectiveness.

The model predictions above specify circumstances (colonization, resource depression, environmental circumscription, and intraspecific competition) where individuals should experience increased risk and uncertainty in technological productivity and therefore greater tendency toward technological invention and experimentation. These predictions can be examined irrespective of data on external variability, which may in some cases be the precipitating factor in the immigration, resource depression, circumscription, or competition that then leads to technological changes. The case study outlines a sequence of technological changes that can be fit to these predictions.

The second requirement of the above model, measuring technological change, is even more difficult than measuring risk or specifying more and less risky situations. While identifying aspects of technological changes in the archaeological record is often relatively straightforward, measuring rates of technological change or otherwise quantitatively specifying the significance of technological changes is a considerable challenge. For example, should we measure

the rate of new (archaeologically visible) tools entering a cultural system or the rate of turnover in tools (as a function of tools entering and exiting the system)? Also, how shall we distinguish between incremental and quantum changes in technologies or their components? These are critically important issues for the testing of the model elaborated above, and ones that require greater elaboration than I can provide in the remainder of this article. Here, technological change is treated qualitatively rather than quantitatively as a function of novelties introduced into the archaeological record of the Kodiak Archipelago.

### PREHISTORY ON THE KODIAK ARCHIPELAGO

With a record of significant technological change that extends back 7500 years, the prehistory of the Kodiak Archipelago provides a useful case against which to cast the above predictions.

The Kodiak Archipelago is a mountainous set of islands in the northcentral Gulf of Alaska about 40 km southeast of the Alaska Peninsula (Fig. 5). While the coastal and marine ecosystems are fairly productive during warmer seasons of the year, the terrestrial flora and fauna are relatively sparse. Indigenous terrestrial mammals are limited to the northern vole, ground squirrel, red fox, ermine, land otter, and the legendary Kodiak brown bear. Archaeological fauna suggest that some of these species were occasionally hunted, but in relatively low proportions when compared to species found in the littoral and maritime zones (e.g., Amorosi 1987, 1988; Clark 1974a; Partlow 1998; Yesner 1989). Primary subsistence throughout prehistory and into the post-contact era derived in various proportions from sea mammals (seals, sea lions, sea otters, and whales), pelagic fish (halibut, cod, and flounder), schooling fish (salmon, herring, and dolly varden), migratory waterfowl, marine birds, and shellfish. Ethnohis-

toric evidence records the use of edible roots, leaves, and berries in warmer months. These were sometimes preserved in sea mammal oil for winter consumption (Davydov 1976:16; Haggarty et al. 1991; Russell 1991).

Kodiak prehistory is divided into three periods: Ocean Bay, Kachemak, and Koniag. Each is subdivided into two phases. The resulting six prehistoric phases are defined by significant technological changes, allowing us to use these phases as benchmarks in technological evolution if we can assume evolutionary continuity throughout the sequence.

A strong case for cultural continuity between Ocean Bay, Kachemak, and Koniag periods has been made by several archaeologists in recent years (Clark 1996, 1997; Jordan and Knecht 1988; Knecht 1995; see also Fitzhugh 1996). These arguments have been challenged by others on the basis of folkloric and linguistic data (e.g., Desson 1995;

Dumond 1998; see also Hrdlicka 1944). All that can be claimed against continuity, however, is that the contemporary Alutiiq people of Kodiak share a heritage with Bering Sea Yupiq. Given the inadequacy of historical linguistics to accurately measure time since divergence and the effects of continued linguistic interaction between populations speaking related languages (Grayson 1993), the antiquity of this relationship cannot be determined and could extend to the original colonization of Kodiak prior to 7500 years ago. Biological analysis of Kachemak, Koniag, and Alutiiq populations remains inconclusive regarding relationships between prehistoric periods and modern populations. Despite greater linguistic affinity with Bering Sea populations, Kodiak skeletal samples from the Koniag period are often found to be more closely related to Northwest Coast Indian groups (see Scott 1991, 1992, 1994; Turner 1988a, 1988b). I take this ambiguity to indicate considerable gene flow and sharing of traditions throughout coastal Alaska throughout prehistory and particularly in later periods. Acknowledging the unsettled character of this debate, I proceed with the assumption that the Kodiak sequence is culturally continuous, notwithstanding considerable interaction with a broader region.

Beyond continuity, the issue of technological diffusion deserves comment, as it is traditionally posed in contrast to innovation in archaeological writing (but not in the economic literature on technological change, e.g., McCardle 1985; Teubal and Steinmuller 1987; Thirtle and Ruttan 1987; see Renfrew 1982). Despite important differences in the processes of invention and diffusion/adoption, from an evolutionary/adaptive perspective risk and uncertainty are recognized in either pathway. Pure invention should involve greater uncertainty than borrowing because the latter path contains an opportunity for transmission of information about manufacture and

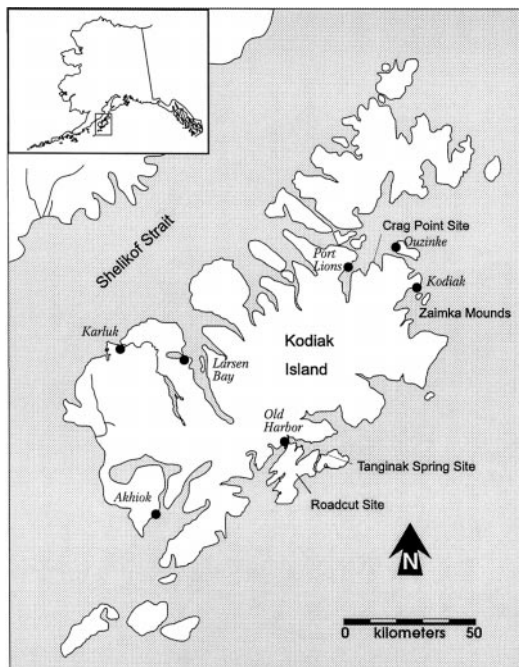


FIG. 5. Map of the Kodiak Archipelago showing key sites discussed in the text.

performance features of the new technology. Nevertheless, borrowing should normally be more costly than continuing to use an established technique for which the requisite skills are established and the probability distribution better understood. Thus the same logic is appropriate to model both processes. In any event, as Clark (1982:118) has pointed out, the spread of an innovation from the individual inventor to the larger population is itself diffusion (see Thirtle and Ruttan 1987). At an archaeological scale, invention and diffusion may be largely indistinguishable.

**KODIAK TECHNOLOGICAL CHANGE**

*Colonization and Ocean Bay I*

Table 2 details the Kodiak technological sequence. The archaeological record begins about 7500 cal. BP in the early Ocean Bay I phase. Only a few archaeological sites have been systematically investigated from this time period.

The Tanginak Spring site, currently under analysis by the author, is probably the most extensively investigated of these early sites. Two radiocarbon dates (one from the base of the site and the other from close to the top) suggest that the site was occupied intermittently from 5950 BC<sup>17</sup> (6660 ± 230 years BP, Beta-76738) to 4535 BC<sup>18</sup> (5710 ± 70 years BP; Beta-134789).<sup>19</sup> On the basis of preliminary analysis of material from a stratified sequence of five occupation layers, this site contains an in situ evolution from large prismatic blades (“macroblades”) in the basal occupation to a predominantly bifacial/flake technology higher in the site.<sup>20</sup> The lithic tools in the initial occupation are notably dominated by macroblades, commonly made from Alaska Peninsula basalt, and a pair of projectile points seemingly produced on blade blanks of nonlocal silicified slate or banded chert.<sup>21</sup> No cores have been found that would match these tools. Artifacts from higher occupation levels are dominated by tools shaped through heavy bifacial retouch as

**TABLE 2**  
**Kodiak Prehistory, Emphasizing Significant Changes**  
**in Archaeologically Observed Technology**

Periods Phases Years BP	Ocean Bay				Kachemak		Koniag	0
	I 7500	I 6500	II 5500	II 4500	Early 3500	Late 2500	1500	
Manufacture techniques:								
core and blade	[Bar from 7500 to 5500]							
chipped stone	[Bar from 7500 to 0]							
ground slate	[Bar from 4500 to 0]							
Tools:								
burins	[Bar from 7500 to 7000]							
macroblades	[Bar from 7500 to 7000]							
microblades	[Bar from 7500 to 5500]							
triangular stemmed points	[Bar from 7500 to 5500, with '??' and '.....?']							
bipoints	[Bar from 7500 to 5500, with '.....?']							
bayonet-style lances	[Bar from 4500 to 3500]							
double edged slate knife	[Bar from 4500 to 3500]							
plumett style sinker	[Bar from 4500 to 3500]							
barbed harpoons	[Bar from 7500 to 0, with '?' at 7500]							
togglng harpoons	[Bar from 2500 to 0]							
composit fishhooks	[Bar from 7500 to 0, with '?' at 7500]							
notched shingle net sinkers	[Bar from 4500 to 2500]							
semilunar (ulu) knife	[Bar from 2500 to 0]							
diamond cross-section point	[Bar from 1500 to 0]							
riverine fish wiers	[Bar from 2500 to 0, with '?' at 2500]							
composit fish harpoons	[Bar from 2500 to 0, with '?' at 2500]							
gravel tempered pottery	[Bar from 1500 to 0]							

well as microblades and cores all of predominantly local cherts (especially those from a source less than 3 km distant). Microblade cores from this site are considerably variable in form, as is common for coastal microblade sites around the American North Pacific (see Jordan 1992; contributions in West 1996a). One core is somewhat similar to the wedge-shaped, single-faceted cores of the Denali/Diuktai (Paleoarctic) traditions (Dumond 1977: 36–46; e.g., Powers 1996:350; West 1996b, 1996c:338). Burins, while uncommon, have been recovered from the site.

A related assemblage has been isolated at the base of the Crag Point site (KOD 044) in northern Kodiak (Jordan 1992). There, Jordan identified what he believed was a pre-Ocean Bay assemblage sharing affinities with the Paleoarctic tradition of the Alaskan Interior. On the basis of 39 lithic artifacts (plus debitage) and a charcoal date from an exceedingly small sample, Jordan argued that he had uncovered a “Maritime Paleoarctic” tradition on Kodiak, dating to  $7790 \pm 620$  rcybp (Beta-20123). The assemblage included a wedge-shaped microblade core, microblades, burins, a bifacial bipoint, a cobble scraper, and an abrader. A ground slate knife common to later traditions was found as well, indicating a degree of mixing with later cultural deposits at the site. Similar to materials from the base of the Tanginak Spring site, several of the Crag Point artifacts were manufactured on basalt and other raw materials from Alaska Peninsula sources (Jordan 1992:130–131). Most archaeologists reject Jordan’s date for this assemblage due to the small sample of charcoal dated, the use of quadrupled counting time, and the large error factor (Mills 1994). With the large error term, the Crag Point date overlaps the Tanginak dates and could reasonably indicate an occupation of similar age, as the assemblages suggest.

Other sites of comparable age have been examined cursorily around Kodiak. The Sitkalidak Archaeological Survey identified

one other early Ocean Bay site (Fitzhugh 1996) and an Alutiiq Museum project dug into an early Ocean Bay component below a Kachemak deposit near Kodiak at the Cliff Point/Zaimka Mound site in 1998. Excavators at the latter site found a boat-shaped stone lamp of comparable form to one found on the basal level of the Tanginak Spring site and have a radiocarbon date fitting into the same age range (Amy Steffian and Patrick Saltonstall, personal communication 1998, 1999).

On the basis of current evidence, the earliest archaeological record on Kodiak suggests a colonization of the archipelago by people from the coasts of the Alaska Peninsula and exhibiting residual technological affinity with populations in the Eastern Aleutians roughly 1000 years earlier (Aigner 1977; McCartney 1984).<sup>22</sup> These colonists arrived with a core-and-blade technology suited to the fine-grained cryptocrystalline rocks of the volcanic Aleutian Chain and Alaska Peninsula. When they arrived on Kodiak, they were confronted with decreased access to traditional raw material sources and would have taken time to locate alternative sources around Kodiak. Bedrock outcrops and associated beaches around Kodiak contain variable quality cherts, metatuffs (metamorphosed volcanic tuff), and siltstones that were incorporated into traditional technologies. None of these materials appear to have been well-suited to the production of large prismatic macroblades. As a result technological focus quickly shifted away from the production of macroblades toward bifacially flaked tools, albeit with continued reliance on microblade technology. At the Tanginak Spring site, local sources (< 3 km) were tapped for microblade production despite inferior workability and durability.

This scenario suggests that colonists to Kodiak experienced increased technological costs associated with increased distance from known raw material sources (on the Alaska Peninsula) and increased uncertainty about

Kodiak material location and quality. The shift from production of macroblade technology to bifacial flaking technology appears to occur rapidly. Almost all large blades and tools from blades at the Tanginak Spring site are made from nonarchipelago materials (principally basalt). In an artifact inventory of several thousand pieces (and excluding additions from the 1999 excavation, not yet tabulated) we have 55 intact blades, of which 9 are larger than 50 mm in maximal length. In contrast we have 46 bladelets and "microblades."<sup>23</sup> Most microblades and cores are of raw materials available in the immediate vicinity of the site. A few examples come from more distant Kodiak materials. This implies that macroblades were imported to Kodiak (or at least to the Tanginak site) as blades and that the cores were left behind. Whether this is a signal of initial colonization, periodic travel to the Alaska Peninsula, or trade will be difficult to determine; nevertheless, the early Ocean Bay I record supports the prediction of rapid technological change following a colonization event. Stone tool technologies then appear to stabilize for almost 3000 years.

### *Ocean Bay II*

The next major change in Kodiak lithic technology relates to the development of a ground slate industry leading up to 4500 cal BP and the beginning of the Ocean Bay II phase. Ocean Bay I assemblages were defined initially by Clark (1974b, 1980) to contain a predominance of flaked chert and the near absence of ground slate until late in the phase.<sup>24</sup> Ocean Bay II, by contrast, takes its inception from the shift to a predominantly ground slate lithic industry. Clark (1982) has argued that this was an independent invention within the Ocean Bay culture, derived largely from the transfer of ancestral sawing, scraping, and grinding techniques from bone to stone.

Ocean Bay II assemblages are characterized by long lances, projectile points, and

double-edged knives, all of ground slate. These tool components appear to supplement or replace hunting and processing components of flaked stone and microblades after 4500 BP. Clark (1982) suggests that this technological change occurred by accident as artisans applied bone-processing methods to locally available beach shingles. According to Clark, these artisans would have quickly recognized the manufacturing advantages of slate over chipped stone and soon discovered its utility in sea mammal hunting over water. Slate is readily available in most parts of the Kodiak Archipelago, and it is easily cut to the form of point or knife blanks by sawing and snapping slabs or beach shingles to appropriate dimensions. Slate is relatively easy to grind to a fine edge, and while softer than chert, it can be resharpened more easily, economically, and predictably.<sup>25</sup> Finally, ground slate points may be more effective than flaked stone or microblade inset bone points in maritime contexts, as slate tends to shatter in the wound (Clark 1982; cf. Hayden 1981).

Clark's (1982) model of innovation in Ocean Bay II slate grinding does not seek a motivation for the innovation process he sketches. He rejects the idea that raw material availability would have precipitated this change and prefers an accidental discovery combined with a readily understood bone-working technique. As populations expanded throughout Ocean Bay times, and as sea mammals were targeted more heavily, it is reasonable to infer that resource depression within patches would have become more common. Reduced patch productivity (e.g., size of a sea lion rookery) due to increased harvest pressure would increase foraging costs and increased the attractiveness of invention and experimentation. Slate bayonets, points, and processing tools may have been successful innovations brought about by resource depression. This interpretation will remain speculative until the prediction of resource depression in Ocean Bay II times

can be investigated in the archaeofaunal record. Alternatively, it is reasonable to see the gradual development and ultimate ascendancy of ground slate hunting technology over 3000 years as a result of microscale innovations, precipitated by the lack of high-quality cryptocrystalline material sources in most parts of the archipelago compared to abundant slate sources. Testing this suggestion will be difficult.

### *The Kachemak Period*

The Early Kachemak phase remains the least documented of the Kodiak sequence. Ongoing research by Donald Clark in the Afognak River region and by the Alutiiq Museum along the Kodiak road system are beginning to improve our understanding of early Kachemak lifeways (Clark 1996, 1997; Steffian et al. 1998; Steffian and Saltonstall personal communication 1998, 1999, and 2000).

The Early Kachemak phase marks several notable technological changes between 4000 and 3500 BP. Clark (1996) has reported one Ocean Bay II/Early Kachemak transitional assemblage at the Afognak River site (AFG-088). Other Early Kachemak sites are temporally and technologically distinct from late Ocean Bay assemblages, despite continuity of some technological elements such as slate scraping and the serrated-stemmed, ground slate knife. Regardless, there is little reason to believe that Early Kachemak reflects an influx of new people to the Gulf of Alaska and Kodiak, as there is no better antecedent to this phase in the adjoining regions.

The Early Kachemak tool kit includes a toggling harpoon form, which supplemented existing barbed harpoons carried over from Ocean Bay times. In contrast to Ocean Bay II, Early Kachemak people used relatively short ground slate points and did not use bayonet-sized slate lances. They developed a uniquely Early Kachemak plummet-style, end-grooved cobble, presumably

used as a weight for line fishing. Bilaterally notched beach shingles found in small numbers in late Ocean Bay II assemblages became ubiquitous in this and the following Late Kachemak phase to the point where beaches in front of some sites are littered with hundreds of notched stones. These are commonly interpreted as net-sinkers. The semilunar ground slate knife, or *ulu*, also makes its first appearance in this phase. In addition, Early Kachemak is the first phase in Kodiak prehistory with clear evidence of sod house villages.<sup>26</sup> Sod houses had replaced or supplemented skin tents by no later than late Ocean Bay II times, and red ochre-coated floors disappear by the beginning of the Kachemak period (Fitzhugh in press-a).

While archaeologists must be cautious inferring functions and behavioral patterns from artifacts and archaeological patterns, multiple lines of evidence in the Early Kachemak material suggest a significant change in subsistence technology. This development parallels a change in social organization and settlement pattern at this time (Fitzhugh in press-a, in press-b). The introduction of the toggling harpoon would have allowed for greater recovery of sea mammal prey, perhaps compensating (at least temporarily) for losses in foraging efficiency due to patch depletion or exhaustion as human populations grew around the Kodiak landscape. This can be speculatively coupled with the reduction in slate point size to infer that direct spear hunting of sea mammals at rookeries and haul-outs had become more difficult and hunting was accomplished increasingly on open water.<sup>27</sup>

Emphasis on notched net-sinker stones and the semilunar slate knife implies increased attention paid to the mass capture and processing of aggregated resources. Herring and salmon are the most likely targets of net fishing around Kodiak, as they school close to shore and in rivers in the late spring, summer, and fall months. Other resources, such as birds and seals, have been

captured in nets in recent centuries (S. Haakanson, Sr. personal communication 1993) and also may have been targeted by this prehistoric technology.

As discussed above, decreased foraging efficiency in higher ranked, large-bodied resources (due to patch depletion) will often result in greater attention paid to smaller bodied resources. Without technological change, the result is a more variable diet but an overall decrease in foraging efficiency compared to earlier times. However, technologies that take advantage of reproductively stable populations (more "r-selected" and generally smaller bodied resources) by decreasing the costs involved in their capture and processing can restructure the rank order of resources in the diet and potentially increase foraging efficiencies.

Mass capture technologies apparently accomplished just such a restructuring of Kachemak subsistence priorities. Nets would have assisted in the capture of schooling resources such as salmon and herring, available for short periods. However, simultaneous improvements in processing technology were required so that the high volume of food captured could be extended into the winter period when few economically important species could be found. The semilunar knife would have reduced wrist strain and improved efficiency in fish (especially salmon) processing. As fish meat can spoil if not processed rapidly after capture, the ability to process these resources quickly with minimal strain would have directly increased the volume of food reserves put up for winter. As the changes noted here are expected to follow resource depression of large-bodied prey species, such as sea lions and seals, evaluating this scenario will require faunal analysis for evidence of resource depression in large prey and subsequent increase in the relative proportions of smaller, more r-selected, and mass-harvestable resources, such as herring and salmon. Robert Kopperl is currently pursuing this problem at the University of

Washington as part of his dissertation research.

Restructuring of subsistence priorities through technological change at the inception of the Early Kachemak had significant consequences for subsistence scheduling, settlement patterns, coresidential group size, and social organization. Some settlements (presumed to be winter villages) became more permanent and grew larger. Other sites became more specialized for seasonal resource harvesting and may have been outposts for spring, summer, and fall resource harvests (see Fitzhugh in press-b). Whereas Ocean Bay groups around southeast Kodiak camped in central locations for the greatest flexibility in logistical foraging, in Kachemak times, semipermanent camps were established near the mouths of small streams and on the lower courses of rivers (Fitzhugh 1996). Increased population density in the Kachemak period would have made it more difficult to survive winter without significant food stores, and focused harvesting of salmon from these camps facilitated the production of the necessary stores.

By Late Kachemak times, there is evidence of increasing political competition within and between communities. This competition is evident in an elaborate mortuary tradition (Simon and Steffian 1994; Urcid 1994; Workman 1992), the use of exotic raw materials and regionally specific styles of personal decoration (Steffian 1992; Steffian and Saltonstall 1995), and the establishment of small defensive sites on cliff-faced islands and promontories (Fitzhugh 1996). On the basis of settlement pattern studies in Southeast Kodiak, a significant whaling industry appears late in this phase (Fitzhugh 1996). Whaling would have contributed greatly to subsistence, when successful, but given the hazards and variability in success rates, whaling was probably as much a vehicle for status competition within communities as it was an economic pursuit. Ethnohistoric evidence supports this view for the protohistoric period

(Crowell 1994) and ethnographic reports from elsewhere show that whaling is often linked to rank competition (Sheehan 1985; Drucker 1951), probably because of the danger involved.

### *The Koniag Period*

Hunting technology goes through another transition at the break between Late Kachemak and Early Koniag. Early Koniag has a unique ground slate lance form with a thick diamond cross section. These points may have armed spears for whaling, sea mammal hunting, or warfare. Whatever the specific use of these points, the thickened cross section would have increased their effectiveness and durability as thrusting weapons over the typically thin and flat Late Kachemak point forms.

Sometime in the Kachemak or Koniag period, riverine weir fishing was established and, by Koniag times, fish were being harvested out of weirs with composite fish harpoons (Jordan and Knecht 1988:268–269; Knecht 1995:198–219). Pottery with Bering Sea antecedents shows up on Kodiak during the Koniag period (Dumond 1984, 1994). Residue of burned sea mammal oil on the surfaces of this coarse, gravel-tempered pottery and its uneven distribution around the archipelago suggest an association with the processing of whale blubber into oil. The “ceramic Koniag” (Clark 1974a) appear largely limited to the southern half of the archipelago. Mass production of whale oil could have fed a developing trade network across the island and beyond, in which salmon from more productive Karluk and Ayakulik rivers was traded for oil (Knecht, personal communication 1993; cf. Speth and Spielmann 1983). Whale oil was a commodity of significant value traded along the Northwest Coast at European contact (Burch 1988a:236–237; Davydov 1976:3; de Laguna 1990:209), and it is reasonable to look for the development of this tradition in the preceding interval,

when pottery and evidence of sociopolitical complexity emerge along with exploding population densities (Fitzhugh 1996).

In Southeast Kodiak, Koniag period settlement patterns indicate a shift in winter villages from semiprotected outer bay locations to exposed coasts with greater visibility and better access to whales. These villages, which are also considerably larger than Kachemak villages, were commonly associated with defendable islet refuges. In contrast to Late Kachemak refuges, Koniag defensive sites had facilities for housing entire villages. As many as 50 house pits have been observed on some of these sites (Fitzhugh 1996).

Analysis of house sizes from the Kachemak and Koniag periods shows a dramatic change in coresidential patterns between these two phases. Kachemak houses have a single room and tend to be relatively small (avg. 15 m<sup>2</sup>), while Koniag houses include multiple side rooms and more than double in average size (39 m<sup>2</sup>) by late Koniag (Fitzhugh 1996:301–317).<sup>28</sup> Koniag side rooms are known ethnographically to have served as sleeping and bathing areas (Davydov 1976; Holmberg 1985; Lisianskii 1814). Considerable variation is witnessed also in Koniag house size data compared against a more homogeneous Kachemak sample. This increase in house size variation suggests an increase in social asymmetry toward the ranked and stratified political organization recorded ethnohistorically (Townsend 1980; see also Fitzhugh 1996). The growth of social ranking within villages in the Koniag period clearly parallels an expansion in interregional alliances and warfare as indicated by the size and locations of defensive sites (Fitzhugh 1996).

If social asymmetry is linked to differential success in resource control, as is often argued (e.g., Boone 1992; Carniero 1970), the Koniag pattern implies considerable territoriality of resource patches and discrepancies in access to long-distance trade networks. According to the technological

model established above, this should result in increased heterogeneity in the distribution of quality resources (raw materials, subsistence foods, and trade goods) as some people are better able to control access to resource patches and trade partners. Currently, archaeological data to address this prediction have not been compiled. However, ethnohistoric documentation of late Koniag lifestyles strongly supports exclusive rights to resource patches, inequality in access to distant trade partners, and the accumulation of wealth (Holmberg 1985; Townsend 1980). Conditions were thus present to expect competitive constraints on raw material availability, technological production, and access to tradable commodities. We would expect commoner households to contain fewer nonlocal materials than elite households and greater emphasis on technologies that could be locally supported and deployed with low labor inputs. Their middens should contain a higher concentration of free-ranging (nonexcludable) or low-quality resources and low-utility components of shared resources. The Koniag case, with the emergence of socioeconomic and political inequality, begins to transcend the focus of the model developed in this article and is discussed in more detail in a subsequent publication on technological change in egalitarian and nonegalitarian contexts (Fitzhugh 1999).

Traditional technology was maintained for several generations after Russian conquest in 1784 AD. Ground slate points, *ulus*, skin boats, and sod houses were continued into the early 20th century along side iron, porcelain, firearms, and other imports. Significant technological shift occurred only with the development of the commercial fishing industry at the end of the 19th century.

## DISCUSSION

Technological change on Kodiak is consistent with the predictions generated for the

risk sensitivity theory of technological inventiveness. Early in prehistory, we see conservation of nonlocal resources from the inferred staging area of colonization (Alaska Peninsula/Aleutians). Experimentation with local raw materials led quickly to an abandonment of macroblade production and a shift to bifacial/flake tool industries. Tinkering with slate is evident from the earliest site, but its benefits were only significantly expressed in hunting technology after almost 3000 years of Kodiak residency.

Resource depression for sea mammals is expected intermittently from Ocean Bay II times on, but this prediction has not yet been evaluated with faunal data. Technological changes clearly shift from the procurement of large but reproductively unstable populations to smaller but more aggregated and reproductively stable resources through time. Sea mammals and large fish continue to be important throughout prehistory, but their relative importance in the annual economy and settlement round appears to decline.

Predictions related to competition over resources and its affect on technological change have not been thoroughly evaluated here. Nevertheless, social competition and the emergence of rank and stratified society in later prehistory suggest avenues for future technological analysis. For reasons to be explored in a subsequent article (cf. Fitzhugh 1999), political inequality should stimulate technological change, and we would expect to see an increase in the rate of change in the Koniag period. Reduced competition following Russian colonization and the decimation of the local population by disease and conscription is consistent with the low level of indigenous technological change observed throughout the Russian American phase. It was not until the advent of the commercial salmon fishery that Alutiiq people found themselves competing again for economic advantage, this time with outsiders, and this is the time when technological changes once again increase.

Despite general correspondence between the model predictions and the case study, more research is necessary to better evaluate the risk sensitivity model. It is not yet possible to demonstrate that technological changes were actually precipitated by increases in the risks associated with traditional methods, and we still need improved methods for quantifying technological change itself. Higher variance and lower average yields in hunting, fishing, and gathering are expected as populations become more dense and patches are more intensively harvested. Population growth is characteristic of much of Kodiak prehistory, although there is one period (Early Kachemak) for which populations might have fallen substantially (Fitzhugh 1996). Detailed analyses of faunal data, raw material sources, and the frequencies of local and nonlocal materials in assemblages of different ages are critical to the fine-grain testing of the hypotheses proposed in this article.

## CONCLUSION

Throughout this article, I have sought to provide a theoretical framework capable of explaining the empirical generalization that technological changes are commonly precipitated by necessity. I have done so utilizing the mechanistic principles of Darwinian evolution, within the framework of evolutionary ecology and microeconomics, by examining the circumstances under which decision-makers should be inclined toward risk taking in invention. I reiterate that the risk-sensitivity model elaborated here provides no guarantee that inventiveness will be successful. Innumerable unsuccessful inventions must have been common throughout prehistory and many inventors surely suffered the consequences of these failures. The principle difference between the model proposed in this article and many processual (e.g., “mother-of-invention”) models of technological evolution concerns the mechanism provided here for individual decisions between con-

servative and innovative strategies. Processual models tend to assume that evolution is progressively guided and that individuals are generally able to address crises with novel and effective improvements, pulling themselves out of danger as necessary. These kinds of models are appealing because they seem to account for the empirical record at the resolution of temporally aggregated archaeological data.

Selectionists have been quick to counter that evolution could not have generated such effectively “preadapted” populations. Absent is a mechanism for the generation of adaptive change. Unfortunately, random variation, the preferred mechanism of selectionist archaeologists, fails to account for the generally “directed” nature of technological variation in archaeological and historical sequences around the world (notice I did not say “unilinear”). Evolutionary ecology, with its assumption that humans have the evolved cognitive ability to seek adaptive solutions to perceived problems, provides a mechanism previously hidden in the processualist’s black box. At the same time, this approach is consistent with the mechanisms of Darwinian evolution. The above model of technological change simply requires that individuals have the cognitive flexibility to assess their risk sensitivity and modify their technological behavior accordingly. The relative success or failure of a novelty remains independent of this choice and is subject to the selective constraints confronting individuals in the application of the new (or old) technology. Statistically, conditions of greater risk sensitivity (especially in times of economic crisis) should compel more inventive behavior, and more inventive behavior will increase the probability of an improvement that could get picked up and replicated at an archaeologically visible scale (through processes of innovation).

By problematizing the concept of technological invention, this article challenges common assumptions in anthropological archaeology that technological change can

be understood from a simple stress-induced model of invention following the hopeful phrase, "necessity is the mother of invention." At the same time, the model developed in this article demonstrates that urgency often has a positive influence in the production of technological variants, successful or otherwise. It is also noted that technological innovation under crisis conditions would more often fail than would innovation under times of security. This paradox could help explain why technological change is relatively slow through most of human prehistory. As population density increased relatively late in prehistory, there would have been more people to generate inventions and successful innovations would spread more rapidly due to greater facility of cultural transmission. Both of these conditions would increase the rate of technological change. In the latter case, greater social proximity should result in decreased costs in evaluating new techniques, tools, or strategies, facilitating the diffusion of successful innovations. Additionally, the emergence of social inequality in recent millennia surely changed the dynamics of risk-sensitivity and innovation in unique ways (Fitzhugh 1999). Any evolutionary study of technological change will need to sort out the effects of risk sensitivity from density-dependent effects of population size and the proximity of transmitters.

Showing how decisions made in response to ecological variation can lead to changes in ecological structure, including human technologies and social organization, this article challenges selectionist claims that ecological approaches are inapplicable to studies of human evolutionary change (e.g., Dunnell 1982; Leonard and Jones 1987; Lyman and O'Brian 1998; O'Brian and Holland 1992; O'Brian et al. 1998; for similar defense see Broughton and O'Connell 1999). This article also takes issue with the common claim that invention is random with respect to natural selection and logically prior to it. Within commonly

experienced ecological variation, we can expect humans to make strategic changes in behavior in ways that improve the likelihood of a beneficial outcome (Boone and Smith 1998). Such phenotypic plasticity provides a mechanism for guided variation in the evolution of technology. General trends, such as those observed in the Kodiak archaeological sequence, are predictable given the model developed in this article, while individual inventions and technological sequences could never be predicted, as they are based on accidental discoveries, creative insight, and unanticipated combinations of prior technologies.

The arguments in this article require further examination against multiple archaeological sequences with higher resolution in the ecological parameters discussed here. If successful, this model should help resolve much debate between ecological and evolutionary archaeologists on the nature of human technological change. Additionally, I hope that this treatment, while necessarily incomplete, can contribute to the growth of a more comprehensive anthropological theory of technology.

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## NOTES

<sup>1</sup>The adaptationist critique in biology, and the alternative advocated by Lewontin (1974), underlies much of the core of Dunnell's "evolutionary" ontology (Dunnell 1980, 1982, 1989, 1996; O'Brian 1996). The parallels therefore are hardly surprising.

<sup>2</sup>This recognition that the body or parts of the body can be recognized as tools in the deployment of technology reverses (without contradicting) Dunnell's (1980) observation that manufactured tools can be seen as extensions of the body and are thus in some sense phenotypic.

<sup>3</sup>See Pierre Lemonnier (1992) for a related discussion and definition of technology from a rather different perspective.

<sup>4</sup>I note that the terms invention and innovation have somewhat variable usage in the economic literature on technological change (e.g., Norman 1993:3; Schumpeter 1934; Sundbo 1998:1, 20; Thirle and Ruttan 1987:2).

<sup>5</sup>Production and consumption are treated identically in this discussion. This is justified where products under investigation are consumed by their producers (as we can assume roughly for small scale self-sufficient populations). It is also justified where production can be related to consumption through currency transformation (e.g., conversion of products into money through sale, where money is then used to acquire consumables). The relationship becomes complicated as scales of production increase because the costs of production can be disarticulated from the consumptive benefits (e.g., slave labor).

<sup>6</sup>Decision rules are generally treated by behavioral ecologists as if they were genetically coded, and indeed it would be ridiculous to think that genes are totally uninvolved in the production of psychological proclivities (this is the basis of a large literature in Evolutionary Psychology: e.g., Tooby and Cosmides 1989). For the purposes of this thesis, however, the content of decision rules could be just as easily transmitted culturally (through social learning) as long as a history of selection can be expected to have effected the relative success of rule transmission (see Boyd and Richerson 1985). In the latter case, the definition of fitness becomes more complicated and is beyond the scope of this article.

<sup>7</sup>Costs of switching technologies, or retooling, are external to the productivity of the technology once implemented and are not included in this fitness curve. In modeling when people should decide to switch between technologies, it might be productive to adapt an optimal foraging model, the standard patch choice model (Stephens and Krebs 1986:24-32). In this case, the decision to leave a technology and "travel" to another one (pay the costs of retooling) are structurally analogous to the decision to leave a patch and travel to another.

<sup>8</sup>I do not mean to discredit the risk-buffering approach. Indeed, we might expect the two approaches to each reflect different aspects of technological evolution. Following the logic developed in this article, the risk-as-variance model should prove useful to help explain variation in technological innovativeness, while the risk-buffering (or better the hazard-buffering) approach might reasonably explain which innovations persist in particular environments. Hazards are one (the negative) side of variation. They can be both the source of selective constraint that makes people more risk-prone in their decision making and the target of technological invention (the desire to reduce exposure to hazards). Ironically then, we can say that people become risk-seeking in an effort to reduce exposure to risk (conflating the two definitions).

<sup>9</sup>Drawing from psychological models of risk, Van der Leeuw (1989) discusses a superficially similar model of technology using a sigmoid risk perception curve. While fundamental to the process of human decision making, the psychological models of risk perception have tended to be asynchronous with the behavioral ecological models (Bateson and Kacelnik 1998) and a synthesis of these approaches is beyond the scope of this treatment.

<sup>10</sup>A model of the *process* of innovation, including the testing of solutions and points at which the invention could be determined to be unworthy of further application, could be developed using Bayesian models (Savage 1955; see Cross 1983). One aspect of such a model, beyond the scope of this discussion, would consider the role of mental modeling at an early stage of innovation development.

<sup>11</sup>I note that this theory is strictly limited by the simplifying assumption that selection will favor technological efficiency over other goals. Rate maximization vs hazard ("risk") minimization is a topic of lively debate in evolutionary ecology (see discussion in Stephens and Krebs 1986). In fact, it can be demonstrated that increasing technological efficiency will reduce exposure to environmental hazard (negative variance, or "risk" in insurance terms). This is because increased efficiency will effectively lower the dashed line in Fig. 4a relative to the experience of environmental variability. Although the theory has unexplored implications for the evolution of hazard-buffering ("risk-buffering") technologies like storage, other models have handled this problem successfully (e.g., Goland 1991; Halstead and O'Shea 1989) and I expect that the "risk-buffering" approach can ultimately be shown to be consistent with this theory. I note, however, that risk-buffering models developed in archaeology often share the limitation of the traditional "mother-of-invention" approach in failing to provide a mechanism for the selective reproduction of hazard-reducing strategies, especially where the interval of hazard recurrence is greater than an individual adult life span.

<sup>12</sup>Formally, individuals at the low end of the scale without the reserves to innovate fall off the curve altogether (the tail of the accelerating curve shown in Fig. 4b is anchored some distance from origin on the production axis), or they are included by means of an extended concave-downward curve anchored at the origin (0 productivity). For conceptual clarity, this case is not illustrated in the graphs presented.

<sup>13</sup>A complication that will not be addressed in this article concerns the fact that different individuals in any given population will commonly have different preferences for risk depending on their unique environmental context and beliefs. As soon as individuals in a population can have dramatically different and contradictory goals, strategic models will be needed and predictions relating to aggregate archaeological data will need greater specificity. This is one of the rationales for focusing on technological change in small-scale, hunter-gatherer societies in the remainder of this article.

<sup>14</sup>I thank Peter Bleed for sharing the point that anatomy provides an additional dimension of technological constraint that I had not previously considered.

<sup>15</sup>If we accept a close link between economic and social organization (recognizing some variability), non-hierarchical societies tend to be those in which the utility of production is relatively uniform to all participants (at or above the household level, at least). This case can be relatively easily modeled using the simple sigmoid function. Among hierarchical societies, by contrast, socioeconomic strata are at least partially defined by the member's abilities to convert "work" into utility. The multiple-cycle sigmoid model may be the best way to represent this situation in simple terms (see Boone 1992).

<sup>16</sup>This prediction becomes complicated in the common case of division of labor in subsistence production. Increased realism would be generated with the expectation that higher utility resources would receive technological focus first within the optimal set of resources targeted by each class of producers (e.g., hunters vs gatherers).

<sup>17</sup>Calibrated intercept of radiocarbon age (Standard <sup>14</sup>C, charcoal), using INT93CAL: N. Hemisphere (Stuiver et al. 1993).

<sup>18</sup>Calibrated intercept of radiocarbon age (Standard AMS, charcoal), using INTCAL98 (Stuiver et al. 1998)

<sup>19</sup>The large error factor of the older date is somewhat problematic, leading to a two sigma range of roughly 900 years. This sample was taken from the bottom occupation layer of a test excavation trench, and the date range overlaps a more precise date taken from about five occupation lenses higher in the stratigraphic column (6380 ± 50 BP; Beta 71714, Standard AMS on charcoal). This implies that the bottom occupation should be older than 5300 B.C. (the calibrated intercept of Beta 71714). Observations from the 1999 field season indicate that at least two distinct occupation regimes are included in this record, potentially separating a dense upper component

(dated in the range of 4500 to 5000 B.C.) from a series of older and thinner occupations (Fitzhugh, field notes).

<sup>20</sup>Macroblades are defined in this assemblage as a class of blade that is roughly 5 or more cm long when intact. Blades are defined as having roughly parallel lateral edges and being at least twice as long (measured from platform to termination) as they are wide.

<sup>21</sup>These two points share a common form with squared stems, one flat surface and one ridged surface. One is minimally retouched to form the point, and the blade morphology is apparent on unmodified surfaces. The second item is more heavily retouched, and the morphology of the parent flake is not as apparent. Nevertheless, the similarity in form between the two, in contrast to all points found higher in the site, suggests a common technological origin.

<sup>22</sup>One complication to this scenario involves the possibility of submerged sites of greater antiquity than 5500 B.C. Current models of eustatic sea level history suggest that post-Pleistocene sea level rise evened out at approximately this time and older coastal sites would be drowned and largely destroyed by coastal erosion (Carver, personal communication 1999). Two factors mitigate against a lost pre-Ocean Bay occupation of the archipelago, despite this regional pattern of sea level rise. The first is a history of tectonic tilting on the Kodiak Archipelago that has persistently elevated sites on the southeast side where the author conducted an intensive survey between 1993 and 1995. The second factor involves the common use of elevated landforms for camping (Fitzhugh and Gilpin n.d.). A combination of occasional site placement above sea level, tectonic emergence, and intensive survey should have resulted in discovery of one or more such sites. Additionally, an as-yet-unpublished analysis of raw material change through the Tanginak Spring site sequence illustrates a shift from emphasis on off-island basalt toward more local stone sources through time, as expected for a colonizing population in the process of "settling in" to a new environment. These arguments notwithstanding, time and continued research will add clarity to this picture and may uncover evidence of yet earlier occupation.

<sup>23</sup>The sample of blades from the site is differentiated by examination of modality in length and width measurements taken from complete specimens. The sample contains at least two modally distinct populations ("macroblades" and smaller blades). Blades smaller than 50 mm in maximal length may be further subdivided into "microblades" (smaller than 30 mm in length) and "mesoblades" (between 30 and 50 mm); however, modality in this subset is less distinct. Microblades tend to be more standardized in shape, while mesoblades tend to be less so. This may correspond to a noticeable difference in core technology, where microblade cores tend to be well prepared, while mesoblade cores from the assemblage tend to be more expedient.

<sup>24</sup>Ground slate rods are known from several Ocean Bay I sites, including the early OBI Tanginak Spring site. These stone tools appear to be derived from naturally cylindrical beach pebbles roughly 5 to 10 mm in diameter and several centimeters long. They are finished by scraping and/or grinding in the direction of the long axis. Their function is unknown, although some appear awl-like, and one example from Tanginak has a drilled and red ochre-filled cavity on its side. In addition, a single fragment of worked slate was found at the Tanginak Spring site that has clear evidence of sawing and snapping. These curious pieces show that Ocean Bay I people understood the principle of slate grinding but had not put it into the production of sharp piercing and cutting tools during this phase. As yet, no edged tools of ground slate have been found in good context in early Ocean Bay I assemblages.

<sup>25</sup>The advantages of slate grinding for maritime sea mammal hunters are compounded by the greater ease of resharpening these tools while at sea in a tippy kayak.

<sup>26</sup>There is some disagreement currently about the status of a few large and dense Ocean Bay sites, such as Rice Ridge, Broad Point, and the Tanginak Spring site (cf. Steffian et al. 1998). Resolution of this debate will require detailed excavation of these sites to determine whether their size and density reflect contemporaneous occupation by large populations or the reuse of popular camp sites over centuries or millennia. Nevertheless, there is a qualitative difference between Ocean Bay sites and Kachemak sites in floor thickness and the volume of accumulated debris that is reasonably seen as a significant change in settlement intensity and duration.

<sup>27</sup>We can predict that increased human hunting of sea mammals would have pushed sea mammal rookeries and haul-outs farther from protected waters and away from areas easily accessible to human hunters. Hildebrandt and Jones (1992) have argued for a similar change in the distribution of prehistoric California and Oregon pinniped colonies as a result of human predation.

<sup>28</sup>If side room area is removed from comparisons between Kachemak and Koniag house areas, the difference is somewhat reduced but no less significant (Kachemak = 15 m<sup>2</sup>; late Koniag = 29 m<sup>2</sup>). See Fitzhugh (1996) for a more complete analysis of house variation.

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