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An Interaction Model for Resource Implement Complexity Based on Risk and Number of Annual Moves

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Abstract

Different hypotheses identifying factors affecting the complexity of implements used to obtain food resources by hunter-gatherer groups are assessed with stepwise regression. A regression model based on interaction between growing season as a proxy measure for risk and number of yearly moves fits data on the complexity and diversity of implements for twenty hunter-gatherer groups. The interaction model leads to a division of hunter-gatherer groups into two subgroups that correspond to collector versus forager strategies for procuring resources. Implications of the interaction model for the evolution of complex implements are discussed.

Diversas hipótesis que identifican los factores que afectan la complejidad de los instrumentos usados para obtener recursos del alimento por los grupos del cazador y recolector se evalúan con la regresión stepwise. Un modelo de la regresión basado en la interacción entre la estación de crecimiento como medida del poder para el riesgo y el número de movimientos anuales cabe datos sobre la complejidad y la diversidad de los instrumentos para veinte grupos del cazador y recolector. El modelo de la interacción conduce a una división de los grupos del cazador y recolector en dos subgrupos que correspondan al colector contra las estrategias del forrajeador para procurar recursos. Las implicaciones del modelo de la interacción para la evolución de instrumentos complejos se discuten.

Key Words: Tasmania, tool complexity, interaction model, tool evolution

1.0 Introduction

The complexity of implements used by hunter-gatherers for the procurement of food resources has an enormous range, going from a simple digging stick with a sharpened end at one end of the spectrum to an elaborate sealing harpoon with 35 parts used by the Angmagsalik Inuit (Oswalt 1976) at the other end. In between we find an extraordinarily wide variety of implements with differing degree of complexity, both in their design and use. In part, this range in the form and use of implements relates to the obvious connection between the task to be accomplished and the design of an implement that can

accomplish the task efficiently. Yet the same task can be accomplished with implements differing in design complexity, hence we need to understand the conditions under which simple implements will be replaced by more complex ones for the same general task of food resource procurement. Much headway has been made on this endeavor (e.g., Binford 1980, 1990, 2001; Torrence 1983, 1989, 2001; Bleed 1986; Shott 1986; Hayden and Gargett 1988; Bousman 1993; Vierra 1995; Osborn 1999; Kuhn and Stiner 2000; Shennan 2000; Henrich 2004, 2006; Collard, Kemery and Banks 2005; Read 2006), following Wendell Oswalt's (1973, 1976) systematic study in which he provided detailed information on implements used to procure food resources in 20 hunter-gatherer societies.

All of these authors have provided arguments that attempt to account for the complexity and diversity of implements used for food procurement. These arguments can, in turn, be used to expand on the information we obtain directly from the archaeological record that relates to the design of implements used for the procurement of resources. Our direct information on the latter is heavily filtered by the differential durability of materials used in the construction of implements. What we obtain from the archaeological record can be augmented by taking advantage of systematic patterning among factors that affect the diversity and complexity of implements from extant (or recently extant) hunter-gatherer groups when those causal factors can be measured for prehistoric groups. A systematic pattern can thus be used to infer the likely range of implement diversity and complexity for an archaeological context and the latter can be integrated with information recovered through excavation, thereby building a more complete representation of a prehistoric group's interaction with its environment through the implements they produced (e.g., Osborn's 1999 study of Folsom fluted points; see also Bonnicksen 1977, among others). As Bousman (1993) comments: "By placing all prehistoric hunter-gatherers in a comprehensive framework, we can begin to understand their specific technological and adaptive strategies" (p. 81).

Though these authors have all added to our understanding of the factors that can relate to the diversity and complexity of tool assemblages used for the procurement of food resources, most of them have presented a single factor argument for phenomena that are not one-dimensional. In addition, though each author presents supporting data for her or his argument, the same groups with the same measurements are not used in all cases, thus making it difficult to determine whether the differences among the arguments set forth are due to lack of an encompassing model that better identifies the conditions and the factors that affect the diversity and complexity of implements used in the procurement of food resources, or to differences in the hunter-gatherer groups considered by different authors.

As I will argue, a more encompassing model can be formulated, based on patterning in Oswalt's (1973, 1976) data on the complexity and diversity of implement assemblages used for the procurement of resources. The model is based on two primary, interacting factors that affect the diversity and complexity of implements. These are the degree of risk in obtaining animal food resources due to the seasonality and patchiness of animal food resources and the frequency of group movement in a group's pursuit of resources. In addition, the hunter-gatherer groups in Oswalt's sample divide unambiguously into two subgroups, one with more complex implements (controlling for kind of habitat and number of annual moves) than occurs with the other subgroup. These two groups

correspond empirically to using a collector strategy versus a foraging strategy as defined by Binford (1980), thus suggesting that a collector strategy, along with more complex implements, involves more intensive exploitation of resources than occurs with a foraging strategy.

2.0 Previous Research

A recent paper by Collard, Kemery, and Banks (2005) attempted to assess the relative importance of the several factors that have been identified as ways to account for variability in the complexity and diversity of implements used for food procurement. They began by grouping these factors into four hypotheses relating to the diversity and complexity of implements. Previous research had shown that the first three of the four hypotheses they identified were each relevant to implement complexity and diversity under some conditions. The fourth hypothesis differed from the other three as it did not refer to the dynamics of individuals interacting with environmental conditions through the implements they have manufactured, but referred instead to possible consequences of demographic factors that may affect the complexity and diversity of implements arising from the dynamics of transferring knowledge and skills from one individual to another.

Next Collard et al. determined a set of measures applicable to all of the hunter-gatherer groups in Oswalt's sample and identified relevant measure(s) for each of the hypotheses. They then tested the relative importance of each hypothesis by using stepwise regression analysis. Stepwise regression allowed them to determine which of the measures would be included in a multivariate linear regression model that could account for the diversity and complexity of food procurement implements.¹ By using stepwise regression and a single data set they were able, in principle, to determine a multivariate model that would relate the diversity and complexity of implements to one or more of the four hypothesized factors as predictor variables. However, as will be shown below, the results of their stepwise regression are problematic due to a technical error in their analysis.

The four hypotheses they identified, along with relevant measures for testing each of them, are as follows.

Hypothesis 1: Properties of food resources are a causal factor for the diversity and complexity of implement assemblages. For example, more mobile resources may require more complex and specialized implements for their procurement than less mobile resources (Osborn 1999, Oswalt 1973, 1976). The method of pursuit, immobilize + ambush versus approach + pursuit + encounter, also correlates with the use of simpler weapons (spears) versus more complex weapons (bow and arrow) (Churchill 1993). Other data supporting Hypothesis 1 include an increasing trend in the total number of technounits (a technounit is a single, distinct part of an implement (Oswalt 1976: 38, 45)) in comparison to the proportion of mobile resources (land and aquatic) in the diet (see Figure 9-3 in Oswalt 1976) or aquatic resource in the diet (see Figure 9 in Bousman 1993). Collard et al. used data on the proportion of land and aquatic (TAA), or just aquatic (AQU) animals in a group's diet from Table 5.01 in Binford (2001) to test Hypothesis 1.

Hypothesis 2: Risk is a causal factor for the diversity and complexity of implements either through the probability of success in a given episode of resource procurement (Hiscock 1994; Torrence 1983, 1989, 2001) or the cost of failure when an episode of

resource procurement is unsuccessful (Bamforth 1986; Bamforth and Bleed 1997; Bleed 1986, 1996; Myers 1989; Bousman 1993). (Since both the probability of success and cost of failure must be of concern to hunter-gatherers for the pursuit of food resources -- though with differing relative importance depending on circumstances -- the distinction between the two kinds of risk will not be pursued in the analyses presented below.) These authors argue that risk relates to implement complexity since design considerations aimed at ensuring success in procuring a resource lead to more complex implements whose cost of production (including time, energy, and cost of resources used in production) must be weighed against the probability and cost of failure in each food procurement episode. Read (2006) also argued that tool complexity varied with risk and presented a model that relates an evolutionary change from a simple to a more complex tool to the cost of making and using a simpler versus a more complex tool amortized over the likely time span and rate of usage of an implement. Collard et al. measured risk indirectly via effective temperature (ET) and net aboveground productivity (NAGP), using data from tables 4.01 and 4.07 in Binford (2001) for their test of Hypothesis 2.

Hypothesis 3: Mobility of a hunter-gatherer group is a causal factor due to the costs of carrying implements when moving from one location to another, which should lead to less diversity and more transportable implements (Ebert 1979, Hitchcock 1982, Shott 1986, Torrence 1983, Guenther 1986, Bousman 1993). As noted by Collard et al., Shott's analysis of diversity and measures of mobility for five hunter-gatherer groups had mixed results. Diversity and mobility measured as number of days spent in the winter camp were correlated in Shott's data, but diversity was not correlated with the total distance traveled per year. Collard et al. used data from Table 5.01 in Binford (2001) on the number of moves per year (NMV) and total distance moved per year (DMV) as measures for testing Hypothesis 3.

Hypothesis 4: The fourth causal factor derives from arguing that diversity and/or complexity arises primarily through the internal dynamics of information transfer among individuals mediated by population size, rather than through external constraints arising from the characteristics, costs, or risks involved in resource procurement episodes, as is assumed by the other three hypothesized causal factors. Shennan (2001) has argued, following a population genetics model for the evolution of sexual reproduction (see Peck, Barreau, and Heath 1997), that smaller populations are more likely to lose innovations through transmission drift than larger populations, hence more diversity and greater complexity (both dependent on the number of innovations maintained within a population) should correlate positively with larger populations. Larger populations are also argued to favor greater complexity of implements for reasons relating to transfer of knowledge and skills from competent to naive individuals. Based on a Gumbel distribution for skill levels in a population, Henrich (2004) developed a model showing that the upper bound on the average level of skill for making and using complex artifacts that can be maintained in a population dependent on transfer of knowledge from a few skilled individuals to novices varies directly with the population size and then used the model to account for the loss of bone tools among prehistoric Tasmanians.² Collard et al. used data on population size from Binford (2001 Table 5.01) to test the relationship between population size and tool diversity and complexity.

Collard et al. concluded from their analysis that "risk of resource failure is the primary influence on hunter-gatherer decision-making about the number and complexity

of subsistence tools to manufacture and employ” (p. 12). Though the results obtained by Collard et al. in their stepwise regression analysis are both statistically significant ($p < 0.01$) and robust across several different measures of tool complexity, they nonetheless suggested caution before generalizing from their conclusions since the available hunter-gatherer data set is skewed towards northern latitude hunter-gatherers. In addition, they argued that three other hunter-gatherer groupings – the Yahgan of Tierra del Fuego, the Calusa of Florida and the Beteti, Tshaiti and //Kanihoe San groups – do not seem to fit the risk hypothesis. The Yahgan, they point out, were in a high risk environment yet had a simple collection of implements, whereas the Calusa were in a low-risk environment with a complex and varied set of implements. Also contrary to the risk hypothesis, they argued (based on data from Cashton 1985, 1986, 1987), are San groups who were living in an environment richer in resources than that of the !Kung San but with a more complex set of implements even though they were less exposed to risk of failure when procuring resources.

Even with these cautions, their results still have wide ranging implications. In particular, exclusion of the fourth causal factor brings to the fore the uneasiness many archaeologists find with evolutionary arguments that translate Darwinian evolutionary models directly into an archaeological context without adequately taking into account feedback and evaluative processes that affect behavior (see Read 2007 (in press) and references therein for an extended discussion of this issue). However, as mentioned above, these conclusions are based on a stepwise regression analysis marred by a technical error.

2.1 Problems with the Stepwise Regression Model

The problem with their analysis can be seen in the beta weights (standardized regression coefficients) they obtained using stepwise regression. They list a beta weight for each of the eight predictor variables (see Table 1 for the list of predictor variables) used in their analysis (see Tables 3 and 4 in Collard et al. 2005), but only one of the beta weights (for natural log Effective Temperature) is significant with $\alpha = 0.05$. That seven of the predictor variables do not have significant beta weights makes no sense for a stepwise regression analysis. Stepwise regression yields a linear model based on a *subset* of the predictor variables in which each predictor variable included in the linear model has a statistically significant beta weight. Stepwise regression includes in the regression model those predictor variables that relate significantly to the criterion variable (in this case a measure of the diversity or complexity of implements) and removes those predictor variables that are not significantly related to the criterion variable. Variables whose beta weights are not significant at a 0.05 significance level (the significance level used by Collard et al. for variable inclusion) would not be entered in a forward stepwise regression and variables whose beta weights are not significant at a 0.1 significance level (the significance levels used by them for variable exclusion) would be excluded in a backward stepwise regression. The fact that they report linear models in which only a single predictor variable has a significant beta weight implies all variables were included or excluded as a group, not individually, in their analysis. When all predictor variables are included, the resulting pattern of beta weights is very difficult to interpret, as there may be complex interdependencies among the predictor variables.

2.2 Summary of Results from a Corrected Stepwise Regression

Reanalysis of their data (discussed below) shows that while the risk hypothesis is still supported, the hypothesis about group mobility is also supported (contra Collard et al.'s conclusion), suggesting that the factors affecting diversity and complexity of tool assemblages is more complex than just a response to the single dimension of risk avoidance. Reanalysis also shows that a model based on an interaction effect between risk avoidance and mobility fits very well data on the diversity of complex implements (measured by the number of different complex implements) and includes within its scope the groups identified by Collard et al. as possibly contradicting the risk hypothesis. The interaction model also agrees with Collard et al.'s conclusion that neither the population size hypothesis nor the variety and properties of resources hypotheses are supported by the data. In addition, the interaction effect accounts for the complexity of implements (measured by the average number of technounits per implement) but with a different relationship between the interaction effect and the complexity of implements than between the interaction effect and the diversity of complex implements; that is, the interaction effect is common to both diversity and complexity, but in different ways.

The relationship between the interaction effect and the complexity of implements leads to a division of the hunter-gatherer groups into two subgroups that must differ from each other for structural reasons. The difference between the two groups relates to Binford's (1980) distinction between foragers and collectors and parallels a similar structural difference found by Bousman (1988) between collectors and foragers for the maintenance use-life/extractive use-life ratio for tools. Finally, individual hunter-gatherer groups that are extreme cases in the relationship between the interaction effect and the diversity of complex tools can be accounted for by differences in the animal species available to the groups in question. Hence none of the first three hypotheses can be discounted, though the first hypothesis seems to be hunter-gatherer group specific and does not relate to an overall trend for all of the hunter-gatherer groups.

Reanalysis of Oswalt's data with stepwise regression also permits bringing into the argument a previously unnoted strong correlation between the length of the growing season (GS) and effective temperature (ET). Collard et al. used ET (along with net above ground productivity (NAGP)) as an indirect measure of seasonal resource variability (see also Binford 1980; Kelly 1983, 1985, 1995; Shott 1986; Osborn 1999; Henrich 2006; Read 2006). GS, however, is arguably a better measure of annual resource variability than ET (Torrence 1983, 1989). A measure of tool assemblage diversity based on complex implements that relates more to the design aspect of implements than does the total number of implements will also be included in the stepwise regression analysis of Oswalt's data.

3.0 New Measurements

3.1 Measurement of Risk via Length of Growing Season

Torrence (1983, 1986) used latitude as a proxy for risk, whereas most of the other authors have used ET as a proxy for risk. Another measure of risk is the length of the growing season. Each of ET, latitude and length of growing season are measuring, by and large, the same phenomenon. The commonality in these three measures is increasing dependency on the probability of success in obtaining a resource per resource

procurement episode. The dependency arises from what Binford (2001) refers to the attempt by “human actors ... to maximize their vital security in any habitat” (p. 41). With a long growing season/high ET/low latitude environment, resource abundance and diversity does not vary extensively during the year and failure to obtain a resource in one procurement episode does not preclude the possibility of success in obtaining the same (or a substitutable) resource in the same, or a subsequent, procurement episode, hence “vital security” is not closely linked to probability of success in a single procurement episode (Kelly 1985).

Contrariwise, with a short growing season/low ET/high latitude environment, many resources are procurable only during a short time frame and so failure to obtain a resource on one procurement episode may possibly not be made up on a subsequent procurement episode, especially during the seasonal boundaries for the availability of a particular resource (Kelly 1985). Further, a negative trend in species diversity from low to high latitudes (Rohde 1992) implies that with higher latitudes/shorter growing season/low ET value environments, fewer substitutable resources are available when a procurement event does not succeed with one kind of resource. In addition, failure to obtain a kill from one animal species in a tropical environment may be compensated for by obtaining a kill from another, similar animal species, but in an arctic environment, failure by, say, the Netsilik Inuit to obtain a resource such as caribou during their southerly migration in the fall could lead to starvation as there may be no effective alternative food source to the caribou at that time of the year (Balikci 1970).

Data on effective temperature versus length of the growing season show a strong, positive relationship between ET and GS up to $GS = 12$, the maximum value for GS (see Figure 1).

--Figure 1 about here--

Once $GS = 12$, any additional increase in ET will appear only as variability in ET values for regions with a 12 month growing season. If we regress ET on GS for all data points with $GS < 12$ (excluding Tasmania as it is an exception to the trend) and project the regression line forward to $GS = 12$, the projected trend line (dashed line in Figure 1) intersects the lowest ET value for those regions with $GS = 12$. This implies that the range of ET values simply extends, without concomitant change in GS, the range of ET values once the maximum growing season of 12 months is reached at the smallest ET value among those regions having a 12 months growing season. Using ET values as a proxy for risk without taking this threshold into account may produce spurious correlations.³

Tasmania is an exception to the regular relationship between GS and ET. The ET value for Tasmania is less than it should be, given the length of its growing season. Tasmania is in an unusual environmental zone with little annual temperature variation (Binford 2001: 257) despite its low ET value and a longer growing season (9 months) than would be expected for its latitude. The ET value for Tasmania is thus misleading and consequently Read (2006) modified the ET value for Tasmania based on a regression of ET on temperateness.⁴ However, that correction incorrectly assumed a linear relationship between ET and temperateness (Henrich 2006; see Figure 4.05B in Binford 2001).

While the Tasmanian ET value could be corrected using the regression line in Figure 1, the high correlation between ET and GS, the boundary value for ET beyond

which there can be no change in GS, and the fact that GS is a more direct measure of the impact of annual climatic variation on the diversity and abundance of hunter-gatherer food resources imply that we should examine the pattern between implement diversity and complexity using GS rather than ET when testing the hypotheses. Nonetheless, for comparability with Collard et al.'s analysis, the predictor variables, ET and NAGP, used by them will be included in the stepwise regression analysis discussed below.

3.2 Measurement of Complexity: Number of Complex Implement Types

The total number of technounits is an indirect measure of design complexity as the latter involves more than just the number of kinds of parts since design complexity relates both to how the parts are interconnected and the kind of functionality and precision of action provided by an implement constructed from those parts (consider the difference between a sickle and a modern harvester). An implement can have several technounits, yet is neither complex from a design nor a function viewpoint. In addition, the number of technounits gives equal weight to a simple technounit such as a stone weight attached to a digging stick and, say, a technounit that is part of a complex harpoon head used in sealing hunting, even though the two kinds of tools have different design complexity.

We can measure design complexity through the distinction Oswalt made between simple and complex implements. Oswalt defined a simple implement as one for which "the parts do not change their position relative to each other during use" and a complex implement as one for which the parts "change in their physical relationship to each other" during use (1973: 36). We will measure degree of, and diversity in, design complexity of an implement assemblage by the number of complex implement types in the assemblage, including the number of complex facilities (see Table 1).⁵ (Oswalt provides data on both the total number of complex implements (column headed by CSTS in Table 1) and the number of types of complex implements (column headed by NCT in Table 1), where a type is distinguished by the number of technounits in an implement. Both measures will be used in the stepwise regression analysis.) The diversity measure of implement complexity relates to overall knowledge and skills needed to hunt effectively.

---- Table 1 about here----

Increase in the number of complex implements in an assemblage implies a more elaborated articulation between implements (including subsistents, weapons and facilities) and the strategies used for hunting animals and/or for fishing. We will also include the average number of technounits per implement (both for all implements and for just the complex implements) as a measure of the extent to which individual implements become more elaborated. In principle, these two measures – the number of complex tools and the average number of technounits -- can vary independently since individual implements can be made with greater elaboration/complexity without increasing the number of implements and vice-versa.

4.0 Data Set Augmentation: Two Additional Hunter-Gatherer Groups

Also included in Table 1 are data for two of the groups, the Yahgan and the Calusa, that Collard et al. argued do not appear to be consistent with the pattern they found between risk in food procurement and complexity of assemblages. Though data on technounits are not available for the Calusa, they appear to have had a wide variety of complex tools. Based on the work of Marquardt (1984, 1986, 1988) and Widmer (1988),

Collard et al. list around 10 - 13 implement types that have been recovered archaeologically and would likely be considered complex implements in Oswalt's (1973, 1976) typology for implements. So as to allow for the possibility that some complex tool implements have not yet been recovered or identified, I have assumed the Calusa had 13 types of complex implements, the maximum number of types found in any other hunter-gatherer group.

5.0 Results

5.1 Stepwise Regression Results

The predictor variables for the step-wise regressions are the eight predictor variables used by Collard et al. plus GS. In all cases both forward and backward stepwise regressions were used with $p = 0.1$ for removal of a predictor variable and 0.05 for inclusion of a predictor variable in order to keep the stepwise regression comparable to the methods used by Collard et al. For diversity of implements the criterion variables are: CSTS, NCT, and STS. For complexity of implements the criterion variables are TTS/STS, CTTS/CSTS and MXT. The data used in the analyses are given in Table 1.⁶

The model results of the stepwise regression analyses for each of the criterion variables are shown in Table 2. The CTTS/CSTS stepwise regression does poorly, and so ---- Table 2 about here---

the criterion variable CTTS will not be considered further. With the exception of STS and TTS/STS, the forward and backward regressions lead to the same regression model for each criterion variable. The linear model consistent with the results of the stepwise regression based on all of the criterion variables (except CTTS) is: Complexity Measure = $\alpha + \beta_1GS + \beta_2NMV + \epsilon$, where ϵ measures the error terms for each data point and Complexity Measure is any one of the criterion variables (except CTTS/CSTS). With the exception of LDMV, none of the predictor variables other than GS or NMV has a significant relationship with the number of complex tools for any of the stepwise regression analyses.

The results obtained here are consistent with those of Collard et al. with regard to the risk variable (measured here by GS and measured by them with ET and NAGP) as the primary factor affecting complexity of implements, but differs from their results by including NMV in the regression model. The difference is due to the fact that the regression model reported by them includes all eight of their predictor variables and interaction effects among the predictor variables obscure the significant relationship of NMV with the measures for tool complexity and diversity.

Including the NMV variable in a linear regression model clarifies the relationship between tool complexity and percent aquatic animals in the diet noted by Oswalt (1973), Torrence (1983), Bousman (1993) and considered by Bamforth and Bleed (1997) as evidence against the risk hypothesis. Bamforth and Bleed note that aquatic resources may require more complex tools, hence the relationship between risk and tool complexity could be a consequence of that relationship in conjunction with the fact that Oswalt's data set is skewed towards northern latitude hunter-gatherer groups who are also more dependent on aquatic resources. Though there is a moderate correlation between NCT or TTS/STS and AQU ($r = 0.62$, $r = 0.51$, respectively), the beta coefficients for the criterion variables AQU, GS and NMV when using just these three variables in a multiple linear

regression ($NCT = -0.68 \text{ NMV} - 0.34 \text{ GS} + 0.11 \text{ AQU}$ and $TTS/STS = -0.74 \text{ GS} - 0.33 \text{ NMV} - 0.05 \text{ AQU}$, respectively) show that the correlation between AQU and NCT or TTS/STS is substantially attenuated when controlling for the effects of NMV and GS, implying that the connection between AQU and NCT or TTS/STS is indirect. Hence Bamforth and Bleed's conclusion that "latitude is essentially irrelevant ... once diet is taken into account" (1997: 121), is not supported once we include the NMV variable in the regression analysis.

Next we fit the linear model, $\text{Complexity Measure} = \alpha + \beta_1 \text{GS} + \beta_2 \text{NMV} + \varepsilon$, for each of the criterion variables. The parameter estimates and beta coefficients for each of the criterion variables are given in Table 3. The beta coefficients are consistent in magnitude across the regression models and imply that the growing season has more of an effect on the complexity and diversity of implements than the number of annual moves. Further, among the diversity measures, CSTS

---Table 3 about here---

and NCT have the highest coefficient of determination. Since CSTS and NCT have almost the same coefficient of determination and NCT allows us to include the Calusa and the Yahgan data in the analysis, we will use NCT as the measure for diversity of complex implements.

5.2 One Dimensional Models: Additive and Interaction Effects

We can translate the two-dimensional linear model into a one-dimensional cause and effect model in two ways. First, we can posit an additive model for GS and NMV, $\text{Complexity Measure} = \alpha(\omega \text{GS} + \text{NMV}) + \varepsilon$, where ω is a weighting factor for the relative effect of GROWC in comparison to NMV and ε is an error term assumed to have a normal, homoscedastic distribution if the model fits the data. The additive model presumes GS and NMV are independent causal factors, which is supported by a correlation of $r = 0.007$ between these two variables. The estimates for the parameters α and ω may be determined from the two-dimensional linear regression model. For $\text{Complexity Measure} = \text{NCT}$, the estimated value for ω is $w = 2.37$ and the estimated value for α is $a = -0.27$. We can graph $2.37 \cdot \text{GS} + \text{NMV}$ versus NCT (see Figure 2).

With the exception of the Calusa data point, the model generally satisfies the goodness-of-fit criteria regarding the frequency distribution of the residuals.

--Figure 2 about here--

Second, we can posit an interaction effect between GS and NMV based on the idea that either a low value for NMV or GS would lead to many complex tools being produced and a high value for one variable but not the other would imply that few complex tools would be produced. The interaction model has the following interpretation. The length of the growing season directly measures the risk involved in procuring resources. With greater risk, more elaborate and more "nuanced" tools and facilities are constructed to reduce risk. The number of residential moves is an index for when there has been a shift from one kind of resource to another during the yearly round of food resource procurement by a hunter-gatherer group, hence is an alternative to complexity of implements as a way to decrease risk: move to new areas as the risk of failure increases through exploitation of locally available animal resources (Butzer 1988; Rowley-Conwy and Zvelebil 1989).

We can introduce an interaction effect by constructing the variable, $GS * NMV$. For some of the complexity measures, the relationship between $GS * NMV$ and Complexity Measure is nonlinear, in which case it can be modeled as a power function via $CM = \beta_1 \beta_2^{GS * NMV} + \epsilon$, where ϵ is an error term assumed to have a normal, homoscedastic distribution if the model fits the data. Nonlinear regression must be used to estimate β_1 and β_2 since the data set cannot be linearized using a natural log transform on CM as $CM = 0$ for some of the hunter-gatherer groups. The results of regressing CM on $GS * NMV$ are shown in Table 4.

The graphs corresponding to the CM measures, NCT and TTS/SST, are shown in Figures 3 and 4, respectively. Figure 3 clearly has a nonlinear trend, hence the reason for using the nonlinear model $NCT = \beta_1 \beta_2^{GS * NMV} + \epsilon$ for the relationship between NCT and $GS * NMV$. Figure 4 has a linear trend for TTS/STS versus $GS * NMV$ and has two outliers (Aranda and Andamese) (see top of Figure 4). After a linear regression model is fit to these data (excluding the two outliers), it is evident that the hunter-gatherer groups can be subdivided into two subpopulations based on whether the group is above or below the regression line (see top graph in Figure 4). Linear regression lines for each of the two subgroups defined in this manner are shown in the bottom graph in Figure 4. Each of the two subgroups shows a strong correlation between $GS * NMV$ and TTS/STS.

----- Figure 3 and Figure 4 about here-----

5.0 Discussion

5.1 Comparison of the Additive and the Interaction Models

The additive model has the drawback that it assumes the effect of the number of moves a group has on the complexity of its implements is independent of the growing season. However, compare the Iglulik with the Angmagsalik and Tareumiut Inuit groups. All three have complex tools and short growing seasons, but the Iglulik move frequently and therefore should have less complex tools under the additive model (see Table 2). (The Copper Inuit, though, fit the additive model since they have a short growing season, move often and have few complex tools.) Similarly, the Nharo have a long growing season (hence should have few complex tools) and seldom move (hence should have many complex tools). The additive model would sum these two effects, which would lead to a moderate number of complex tools, but in fact the Nharo have few complex tools. For the Calusa, the additive model underestimates the number of complex tools as the long growing season and lack of yearly moves have opposite effects under the additive model.

Now consider the interaction model. The residuals for the curve fitting from the interaction model for the Complexity Measure, NCT, are shown in Figure 5. Both the pattern for the magnitude of the residuals and their distribution around the regression curve show that the interaction model reasonably satisfies the goodness-of-fit criteria. In addition, the three hunter-gatherer groups that have previously been identified as purportedly being outside the pattern for other hunter-gatherer groups – the Tasmanians for allegedly having an unusually simple set of implements (Henrich 2004) and the Calusa and the Yahgans for having implements that are either too complex or too simple for their respective exposure to risk (Collard et al. 2005) – are all within the bounds of

variation for the interaction model (see Figure 5) and there is no reason to consider any of these three groups as exceptional in comparison to other hunter-gatherer groups.

---Figure 5 about here--

Collard et al. also considered the Beteti, Tshaiti and //Kanihoen san groups living along Botletli River as another possible exception to the risk hypothesis since they each lived in a rich riverine environment that had lower risk yet each had a more complex toolkit than the desert-living san people. However, with similar growing seasons for the two regions, if the former three groups made fewer moves per year than the desert san people then their more complex tool kit would be consistent with the less complex tool kit for the desert san people. Overall, the interaction model provides a better fit to the data than does the additive model.

Since the interaction model applies to both the diversity measure for complex implements and the complexity measure for individual implements, we might expect that both diversity and complexity are changing equally with the interaction measure. If so, diversity and complexity of individual implements would be measuring the same property. However, the curvilinear pattern for the relationship between diversity and the interaction term versus the linear pattern for the relationship between individual implement complexity and the interaction term (as well as the two outliers for the latter that do not appear as outliers for the former) imply that diversity and complexity of individual implements vary in a common, but slightly different, manner with the interaction measurement. Both change positively with increase in the interaction measurement, but not in the same manner. The commonality can be measured by the correlation between diversity and complexity of individual tools. For these two measures $r = 0.89$ ($n = 20$, $p = 0.00$) and NCT varies linearly with TTS/STS (graph not shown). The nonlinearity versus linearity in Figures 3 versus Figure 4 arises from the fact that each of NCT and TTS/STS responds differently to the interaction measure, $GS * NMV$. Consequently we need to consider the implications of the interaction model for each of NCT and TTS/STS.

5.2 Implications of the Interaction Model For the Diversity Measure, NCT

For any model, we want to know both what it does and does not account for. The interaction model implies that the value for $GS \times NMV$ is dominated by the growing season when the growing season is short; hence variation in NMV should not affect the value for NCT when there is a short growing season and so the model does not account for variation in NMV when GS is small. At the other extreme, when $GS = 12$, the value of $GS \times NMV$ will be determined by NMV, hence we should find a strong relationship between NCT and NMV when $GS = 12$. Thus we can consider variation in NMV with NCT across the hunter-gatherer groups for the two extremes of $GS = 0$ and $GS = 12$ as another aspect of how NCT values relate to NMV.

In addition, the statistical results indicate that the interaction model accounts for about 70% of the variation in the number of complex subsistants among hunter-gatherer groups, which also means that it does not account for about 30% of that variation. The latter is measured by the residuals. In order for the interaction model to satisfy the goodness-of-fit criteria, the residuals for the statistical model should not be patterned with respect to the criterion variable. Though there is no systematic patterning among the residuals (see Figure 3) that would warrant a modified model, some of the residuals are

sufficiently large so as to signal that these cases should be considered in more detail to determine if there are particular aspects of a hunter-gatherer group that would account for why it has a large residual.

5.2.1 Relationship Between NMV and NCT when GS = 0 or GS = 12

For the three Inuit groups with GS = 0, the NMV values vary from 2 to 12 while NCT values vary only from 10 to 12, which is consistent with the interaction model. The one exception is the Copper Inuit with GSD = 1 and NMV = 14, yet NCT = 4 (to be discussed below).

At the other extreme with GS = 12, the value of GS x NMV is dominated by NMV and NCT should vary negatively with NMV according to Hypothesis 3. In fact, for the 7 groups with GS = 12, NMV varies from 0 to 14 and NCT varies from 13 to 0, with a correlation of $r = -0.68$ ($n = 18$, $p = 0.09$) between the two measures. The correlation is negative as expected, though it is not significant. The non-significant value for r is due to the fact that one of these hunter-gatherer groups, the Nharo, is not consistent with the trend implied by the correlation coefficient as they had few complex tools, yet NMV = 2. The NMV = 2 listed by Binford (2001) for the Nharo, however, is almost surely in error as it is neither consistent with other, comparable, groups in the Kalahari, each of which have much higher rates of mobility (5.5 for the !Kung san, 11.5 for the G/wi, 9 for the Kua, 12 for the !Ko (Binford 2001, Table 5.01)) nor is it consistent with ethnographic accounts for the Nharo. Bleek (1928) comments that: "Their movements are regulated by the supplies of food and water. When they have eaten up all the fruit and roots in one place, they go to another" (p. 4), a nomadic style also reported by Guenther (1986), even under the acculturated conditions of present day (1980's) Nharo: "They move a great deal" (p. 112).⁷ Neither of these ethnographers provide quantitative data on the nomadism of the Nharo, so we will use the mean value, 9.5, for the other Kalahari hunter-gatherer groups in place of NMV = 2. With this corrected value, $r = -0.80$ ($n = 6$, $p = 0.03$).⁸ The negative relationship between NCT and NMV and the lower limit of NCT = 0 implies there will be a boundary value for NMV beyond which it will have diminishing impact on NCT.

The relationship between NMV and NCT is thus not a simple one for the extreme values of GS. For long growing seasons, NMV may act as an alternative to tool complexity as a way to reduce risk by shifting residence location when local resources are harder to come by and so each resource procurement episode has greater risk of failure. This would place NMV, in the context of a long growing season, as a strategy for risk reduction, along with other strategies such as prevention-of-loss, resource pooling, storage, and transfer-of-loss discussed by Wiessner (1977, 1982). In contrast, for short growing seasons where the complexity of implements appears to be the primary means for coping with risk, NMV, seem to vary as a consequence of the method of hunting, especially aquatic animals.

The two Inuit groups with high NMV values, the Iglulik and Copper, contrast with the low NMV values for the Angmagsalik and the Tareumiut Inuit groups. The difference appears to relate, in part, to the fact that the former two groups hunted seal through the seal's breathing holes in the arctic coastal ice in the winter and needed to change the location of hunting camps as the marginal rate of return on seal hunting dropped (Damas 1969, Park 1997). The Tareumiut of Alaska were beluga whale hunters

(Spencer 1959) and did not have the same need to change residences in their pursuit of whales. The Angmaksalik on the eastern coast of Greenland were also seal hunters, but with a low NMV value. This suggests that winter sealing on the east coast of Greenland did not require extensive relocation, as was the case for winter seal hunting along the Canadian Arctic coast.⁹ Regardless, in all four cases the NMV value varies, in the context of a short growing season, with the procurement strategy and not as a risk reduction strategy. Hence the effect of NMV on complexity of tools acts in interaction with the growing season, which supports the interaction model over the additive model.

5.2.2 Large Residuals (Negative or Positive)

The Copper Inuit have the most negative residual due to their lack of complex implements despite a short growing season. The lack of complex implements is striking, particularly in comparison to the Iglulik who had a yearly subsistence pattern similar to that of the Copper Inuit (salmon fishing, caribou hunting and seal hunting through seal breathing holes in the winter). A comparison of the complex weapons reported by Oswalt (1976) for the Iglulik to those of the Copper Inuit suggests that the difference in NCT values relates to resource differences in the two areas. For the Iglulik, 3 of their 9 complex weapons were for hunting birds on a regular basis. In contrast, the Copper Inuit used opportunistic hunting of birds such as ptarmigan (e.g., in late July and early August the Copper Inuit “knocked down ptarmigan and longspurs with stones” (Jenness 1922: 124)) since birds are “not in such numbers as to influence the economic situation to any marked extent” and “the supply is too uncertain for them to go out of their way to look for them” (Jenness 1922: 15, 105). In addition, one of the complex harpoons used by the Iglulik was for hunting walruses, but walruses were not present in the region occupied by the Copper Eskimo. A second complex harpoon was used by the Iglulik for hunting narwhals from kayaks, but whales were not available to the Copper Inuit. Finally, the Iglulik used a combination harpoon + bladder to kill caribou from kayaks after the caribou were driven into lakes, whereas Jenness reports that the Copper Inuit, though using the same method of driving the caribou into lakes and killing them from kayaks, killed the caribou with “a short knife lashed to the end of a pole” by stabbing them “in the nape of the neck, nooses are thrown over their horns and their carcass dragged to the shore” (1922: 149). Oswalt (1976) neither lists the combination of a knife lashed to a pole and the use of a rope noose as a weapon combination for the Copper Inuit nor does he include any weapon for the killing of caribou from kayaks, though Jenness describes a lance with a copper blade used for killing caribou (1946:135, Figure 175).

In accordance with the risk hypothesis (Hypothesis 2), the difference in the implements used for killing caribou from kayaks may relate to the fact that caribou were at least as important a resource for the Iglulik as aquatic mammals, whereas seals dominated the diet of the Copper Inuit (Oswalt 1976: 180). If we correct for these differences between the Iglulik and the Copper Inuit resource base and include the lance plus noose as a complex weapon for killing of caribou from kayaks, we would have comparable NCT values of $NCT = 5$ for the Copper Inuit and $NCT = 7$ for the Iglulik. Hence the low NCT for the Copper Inuit in comparison to the other Inuit groups appears to be due to differences in animal resources available to the Inuit groups, along with a missing weapon for the Copper Inuit in Oswalt’s list of their weapons.

In the opposite direction from a large negative residual, the Tanaina have the most extreme positive residual (see Figure 4) for the interaction model and are as extreme in a positive direction as the Copper Inuit are in a negative direction. The NCT value of 13 for the Tanaina plausibly relates to their unusually rich and diverse hunting and fishing environment: “The Tanaina have one of the most justly famed hunting grounds in the world” that included “twenty-odd land animals of importance” along with “thirteen species [of fish] ... [that] were present seasonally” (Osgood 1933: 695, 697). Whereas Inuit groups have high NCT values due to specialized complex implements for the three kinds of resources (fish, caribou, and sea mammals) they exploited extensively, the Tanaina have specialized complex implements for a wide variety of animal and fish species that includes the following: salmon harpoon, sea otter harpoon, beluga harpoon, bear snare, grouse deadfall, bear deadfall, marmot deadfall and fox torque trap (Oswalt 1976: 286-287). The combination of a relatively short growing season ($GS = 4$), few annual moves ($NMV = 2$), highly varied topography (steep mountains rising from the sea), extreme seasonal variation in climatic conditions, and exploitation of a wide variety of aquatic and land animal resources plausibly accounts for an ensemble of implements more complex than would be expected from the interaction model on the basis of the growing season and number of moves alone (see also Section 5.3.1).

Lastly, lack of mobility in conjunction with a long growing season would account for the complex tools among the Calusa. The Calusa, a complex hunter-gatherer group with no mobility, best exemplifies, among the groups considered here, the distinction Binford (1980) has made between foragers and collectors. As collectors they should exploit resources in bulk using reliable (Bousman 1993), hence more complex (Hayden and Gargett 1988), tools.

5.3 Implications of the Interaction Model For the Complexity Measure, TTS/STS

The validity of the division of the hunter-gatherer groups into two subgroups as shown in Figure 4 is corroborated by systematic differences between these two groups. If the division were artificial, other measures for these two subgroups should have similar if not statistically indistinguishable values. However, the following measures are statistically different at the 5% significance level for the two groups: TTS ($t = 2.20$, $p = 0.049$, unequal variances), CTTS ($t = 2.23$, $p = 0.01$, unequal variances), NCT ($t = 2.34$, $p = 0.03$, $df = 18$, equal variances), and CSTS ($t = 2.47$, $p = 0.03$, unequal variances). In brief, the upper subgroup is characterized by greater diversity of complex implements and more complex implements than is the case for the lower subgroup. The near-perfect linear trend for the upper subgroup suggests that they form the boundary for intensity of exploitation as measured by TTS/STS; that is, more intense exploitation of resources by one of the hunter-gatherer groups in the upper subpopulation would likely result in both a decrease in residential mobility and an increase in the diversity of complex implements as well as the complexity of individual implements.

The fact that the two subgroups have linear relationships between $GS * NMV$ and TTS/STS with essentially the same slope (see linear regression lines, bottom of Figure 4) for groups ranging from desert to arctic implies that the difference between the two subgroups should be due to a structural difference in the organization of the hunter-gatherer groups making up the two subgroups. The most obvious candidate for a

structural difference is Binford's (1980) distinction between foragers (residence group moves more-or-less as a unit while foraging) and collectors (logistic foraging from a more-or-less fixed settlement). Of the 9 groups in the upper subgroup, 6 of them are collectors and in the lower subgroup 6 of the 9 groups are foragers (see Table 1). Now consider the exceptions in each of the two subgroups.

5.3.1 Forager Groups In the Upper Subgroup of Collectors

One of the forager groups in the upper subgroup, the Iglulik, hunted seals through breathing holes in the ice and so winter settlements moved as a whole when a sealing area became exhausted. Hence by definition they are classified as foragers even though their CSTS, CTYPE and TTS values all imply a diversity of complex implements and a complexity of individual implements comparable to the other arctic groups in the upper subpopulation.

The other two groups in the upper subgroup with foraging, rather than collector, patterns of resource exploitation are the Tiwi (point to the right of Tasmania) and the Ingura of Groote Eyland (point to the left of the Tiwi along the regression line), both in tropical environments. Binford (1980, 2001) and Kelly (1985, 1995) have argued that foraging strategies should characterize tropical environments, regardless of the intensity with which resources are exploited and the data support their arguments (see Table 8.05, Binford 2001). Hence the fact that the Tiwi and the Ingura are classified as foragers is not inconsistent with their position in the upper subgroup. Instead of collector versus forager being the criterion for inclusion of these two groups in the upper group, we need a measure of the extent to which each of these two groups are intensively exploiting resources.

We can obtain such a measure from the argument provided by Read and Leblanc (2004) regarding factors affecting fertility rates in hunter-gatherer populations. They presented a model for the equilibrium carrying capacity (K^*) in comparison to the potential carrying capacity (K) for hunter-gatherer groups, based on the extent to which an increasing population size for a hunter-gatherer group translates into foraging costs by women that, in turn, affects their fertility rates assuming women balance the cost of foraging against the cost of parenting. Data on Australian hunter-gatherer groups verifies the relationship between K^* and K predicted from the model developed by Read and LeBlanc (see figures in Read and LeBlanc 2004). For Read and LeBlanc's model, buffering (B) against the stochastic risk of exceeding carrying capacity, K , can be measured by $B = (K - K^*)/K^* \times 100$. For the Tiwi, $B = 26\%$. In comparison, $B = 130\%$ for Tasmania, a group with a comparable toolkit but located in the lower subgroup in Figure 4. Thus with equally simple toolkits, the Tiwi were at much greater risk of exceeding K than the Tasmanians, hence the Tiwi (but not the Tasmanians) were pushing the limit of their resource exploitation even with a tool kit composed of simple implements. Hence the location of the Tiwi in the upper subgroup and the Tasmanians on the lower subgroup is consistent with their respective risk of exceeding K . The Ingura, however, have an in-between value: $B = 104\%$, and it is not evident that they are in risk of exceeding carrying capacity, K .

Altogether then, with the possible exception of the Ingura, all of the hunter-gatherer groups in the upper subgroup either have a collector strategy and/or a level of resource exploitation consistent with the upper subgroup being characterized as composed of

hunter-gatherer groups pushing the limit of resource exploitation given the magnitude of the interaction term for a hunter-gatherer group, thus the reason for the complexity of the group's implements. For example, the Tanaina were identified in Section 5.2.2 as having an unusually complex assemblage of implements that may relate to the variety of animal species they were exploiting. They are also in the upper subgroup, hence the complexity of their implements would also relate to their intensity of resource exploitation. The combination of the two effects would account for the complexity of their implements.

5.3.2 Collector Groups In the Lower Subgroup of Foragers

Now consider the lower subgroup. Of the three groups in the lower subgroup classified as collectors, one of them, the Chenchu of India are “demonstrably in the process of adopting agriculture” (Binford 1980: 16) and so may have a collector strategy for reasons unrelated to being a hunter-gatherer group. The second group, the Tlingit, were collectors due to their specialization in aquatic resources (see Table 1) that made possible permanent settlements. Though they had a large population, their density was substantially lower (11.42 persons per 100 sq. km) than the Twana (32.4 persons per 100 sq. km.), a hunter-gatherer group in the upper subgroup and also located in a temperate ecological zone. The Tlingit also had a lower population density than all but one of twelve other hunter-gatherer groups in the coastal area from British Columbia to Alaska ($n = 12$, mean density = 33.6, $s = 27.3$) (data from Binford 2001, Table 5.01). These densities imply that the Tlingit are consistent with their location in the lower subgroup. A third group, the Owens Valley Paiute “owned and defended economically important subsistence territories, including seed lands, irrigated plots, and pinyon groves (Steward 1933:305, 1938:50-52)” (Bettinger 1978: 40), hence their sedentism is related to emphasis on plant resources (see also Eerkens 2004). Whether the Owens Valley Paiute were “pushing the margin” in their exploitation of vegetal resources is not clear. As with the upper group, then, all (except possibly the Owens Valley Paiute) are consistent with either having a forager strategy or a collector strategy without pushing the margin through their resource exploitation.

5.3.3 Outliers: Aranda and Andamese Hunter-Gatherer Groups

Both the Aranda and the Andamese have more complex implements than would be expected based on their respective values for $GS * NMV$. As discussed above, just as there is a boundary value for the relationship between ET and GS, there is also a boundary for the relationship between increasing values of $GS * NMV$ and decreasing complexity of implements. The Tasmanians and the Tiwi with $GS * NMV$ values of 85.5 and 120, respectively, do not have any complex implements and have low values for TTS/STS, hence we can posit that a boundary for the negative relationship between $GS * NMV$ and TTS/STS occurs around $GS * NMV = 100$. With $GS * NMV$ set to 100 for the Aranda, they would be comparable to the Ingura and would be part of the upper subgroup. For the Aranda, $B = 135\%$. However, this value is misleading since the Aranda are in the central part of Australia under extremely dry conditions that absolutely limit the size/density of foragers. For the Aranda, $K - K^*$ is about an order of magnitude smaller than for the Tasmanians, hence in absolute, rather than relative, numbers the Aranda were close to K . Consequently it is consistent for the Aranda to be located in the upper subgroup.

The Andamese are more problematic. Even with $GS * NMX = 100$ they are still an outlier. The Andamese had an unusual arrow for killing pigs characterized by Oswalt as the “most developed form of arrow” and the “most complicated arrow in the sample” (1976: 88, 103) in his comparison of arrows from different hunter-gatherer groups. If that arrow with 13 technounits is not included, then TTS/STS decreases from 4.6 to 3.8, but the Andamese are still an outlier. Apparently the Andamese were making more complex subsistants: “the Andamese made more complicated forms than did any of the other tropical foragers sampled” (Oswalt 1976: 165). The Andamese are also an outlier in what otherwise is a regular relationship between male contribution to diet and ET ($r = 0.74$, $n = 65$, $p = 0.00$, based on Table 7-1 in Kelly 1995 but excluding 5 outliers; see also Figure 7-1 in Kelly 1995), which may relate to their high ET of 23.3 in comparison to ET values around 20 for the other tropical hunter-gatherer groups (see Table 1). High ET values correspond to high primary biomass and high primary biomass “is inversely correlated with the accessibility of plant resources” (Kelly 1975: 285). The Andamese may thus have been in tropical conditions not matched by any other hunter-gatherer in Oswalt’s sample of hunter-gatherer groups and for whom resource procurement was made difficult by the high primary biomass and that led to greater reliance on meat and fish obtained with complex implements suitable for animal hunting and fishing. For example, the pig arrow did not just have more technounits; it also served to trap a pig: “The head of this arrow detached from the shaft ... the shaft dragged along by the cord [and] ... caught on undergrowth to hold the pig fast until the hunter arrived to kill it” (Oswalt 1976: 88).

6.0 Conclusions

When drawing inferences from data collected under different conditions by a variety of ethnographers we need to keep in mind that the data are not precise. In addition, we still lack well-defined measures for concepts such as risk and complexity of implements. Despite these cautions, the overall pattern appears to be one in which the length of the growing season and the mobility of hunter-gatherer groups are primary factors affecting complexity of implements. That about 70% of the variation in the data can be accounted for by just these two factors is more than might be expected given all of the uncertainties in the data. These data show make it evident, then, that variation in the complexity of implement assemblages is evolutionarily driven by the response of a hunter-gatherer group to ecological constraints through its mode of resource procurement, taking into account both the implements that are employed and the way a group maps itself onto resource locations and obtains information about the status of the environment that is being exploited (Binford 2001).

The stepwise regression analysis establishes patterns, but does not identify the underlying causal processes. The statistically derived separation of hunter-gatherer groups into two subgroups suggests it is useful to distinguish between foraging versus collecting strategies as a causal factor in the complexity of resource procurement implements that crosscuts broad environmental groupings such as desert, temperate, tropical, and arctic since the hunter-gatherer groups in each of the two subgroups are from the same range of environments. Collector strategies have been linked to patchily distributed resources or restrictions on mobility (Binford 1980, 1983, 2001; see also Bettinger and Baumhoff 1982, Bettinger 1991 for an alternative view). Under the

assumption that increased complexity of implements relates to risk, the pattern determined here of more complex implements (including more complex simple implements) occurring with a collector strategy also suggests that that strategy entails greater risk through increased intensification. We can thus hypothesize that under conditions where population growth leads to increased density (rather than increased dispersion), foraging strategies will tend to shift to collector strategies in conjunction with increased complexity of implements in order to exploit resources with greater intensity. More broadly, evolutionary change in implement complexity appears to be driven by a variety of factors that relate to the goal of “human actors ... to maximize their vital security in any habitat” (Binford 2001: 41).

The means to achieve “vital security” varies along a number of dimensions, of which risk and mobility appear to be particularly salient with regard to the complexity of implements and the diversity of complex implements. Risk, though, is not a fixed property of a particular set of environmental conditions, but is also affected by the intensity with which resources are exploited. The latter relates, as modeled by Read (2006), to the diversity of complex implements and the complexity of implements through consideration of the cost (learning costs, manufacture costs, repair costs, performance costs, etc.) of obtaining resources with more complex implements amortized over anticipated time demand for those resources and the complexity of the tasks at hand (e.g., whale hunting versus shellfish gathering); i.e., one invests in more complex implements when it is also perceived that associated costs are justified by the returns that will be obtained with the more complex implements.¹⁰

In Read’s model, evolution (including devolution) is driven by change in the need for, and means of access to, resources. The later takes into account factors such as the space and time distributions for the abundance and diversity of resources, the means by which one can access those resources (direct contact, with an implement used as an extension of one’s limbs, at a distance through a propulsion system, without being present through the use of traps and other facilities, and so on), the labor requirements for accessing a resource, the social organization requisite for forming a work group of the required size as discussed, for example, by Read (2005) with regard to the Netsilik Inuit, and so on.

The skills and knowledge necessary both for innovating and maintaining complex implements as part of the procurement system used by a hunter-gatherer group for obtaining resources does not appear to require large populations as population size drops out of the stepwise regression. Ethnographic observations on the complexity of Inuit implements also leads to the same conclusion since the Inuit groups had some of the most complex implements yet lived in small, relatively isolated groups with low population density. Nor does transmittal of skills in small-scale societies require little more than children learning from adults in a domestic context (Goody 1989; Crown 2002, 2007). Though there is a period of time between invention and innovation, that is between when a few individuals have made a new implement and when knowledge of that invention has spread throughout a hunter-gatherer group (hence a period of time when models of information transfer through imitation and the like are relevant), that period of time can be relatively short for functionally more efficient implements (e.g., the shift from making bone points to using points made of wire by San groups in the Kalahari only took a few years after fence wire became available to them). Thus the evolution of implements from

simpler to more complex (or the loss of more complex implements) is not, in general, constrained by interaction between population size and information/knowledge/skill transmittal, but by trade-offs between the costs of investment in procurement systems based on more complex implements versus the benefits achieved from that investment. The pattern revealed through the stepwise regression analysis strongly supports this conclusion through identifying risk, group movement and organizational strategy (collector versus forager) as the primary determinants of both the diversity of complex implements and the complexity of implements used by hunter-gatherer groups.

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Table 1: Hunter-gatherer Groups

	F/C ₂	NCT ₁	CSTS ¹	STS ¹	MXT ₁	TTS ¹	GS ²	ET ²	LET ⁷	NMV ²	LDMV ₂	TAA ₂	AQU ²	LNAGP ²	POP ²	GSx NM V
Angmaksalik	2	10	13	33	43	202	0	9.02	2.20	2	2.57	100	90	5.23	567	0
Tareumiut	2	11	16	35	47	205	0	8.85	2.18	3	4.09	100	75	3.79	550	0
Iglulik	1	12	16	42	44	225	0	9.52	2.25	12	5.95	100	85	3.68	1193	0
Tanaina	2	13	20	40	52	224	4	10.71	2.37	2	3.58	97	46	6.08	4500	8
Ingalik	2	8	16	55	61	296	3	10.75	2.37	4	4.16	98	55	6.03	1500	12
Copper	1	4	5	27	39	122	1	9.78	2.28	14	6.10	100	75	3.75	2000	14
O.V. Paiute	2	5	10	28	52	107	7	13.79	2.62	2	2.83	35	5	4.24	2100	14
Tlingit	2	9	10	28	33	121	5	11.25	2.42	3	3.40	99	84	6.63	12000	15
Nharo	1	3	4	12	24	40	12	16.06	2.78	2	3.43	33	0	6.06	7500	24
Twana	2	9	13	48	47	237	7	12.75	2.55	4	4.17	90	70	6.55	965	28
Klamath	1	4	6	43	40	151	5	11.93	2.48	6	4.43	70	50	5.66	1200	30
Caribou	1	7	8	34	22	118	2	10.11	2.31	16	6.09	100	45	4.50	700	32
Nabesna	2	7	9	25	42	105	3	10.73	2.37	14	5.77	9	57	5.32	162	42
Chenchu	2	3	6	20	29	55	12	20.45	3.02	4	2.64	15	5	7.55	426	48
S.V. Paiute	1	5	7	97	29	97	6	12.68	2.54	9	5.35	50	20	5.61	367	54
Tasmania	1	0	0	11	7	15	9	12.62	2.54	9.5 ⁵	4.75	80	50	6.82	575	85.5
Ingura	2	4	5	13	13	32	12	20.06	3.00	8	4.09	70	60	7.57	595	96
Tiwi	1	0	0	11	6	14	12	20.24	3.01	10	4.32	60	35	7.73	2662	120
Andamese	1	2	3	11	31	51	12	23.29	3.15	12	4.33	40	5	8.00	464	144
Aranda	1	2	2	16	20	42	12	16.03	2.77	14	5.65	45	0	5.52	2045	168
Yahgan	1	5 ⁴			23 ⁴	69 ⁴	3	9.60	2.26	7	4.50	95	70	6.18	2500	21
Calusa	2	13 ³	nd	nd	nd	nd	12	17.83	2.88	0 ⁶	--	75	65	7.99	5500	0
F/C: forager/collector -- 1 = "move the entire group"; 2 = "move into and out of a central location" (Binford 2001: 117) NCT: number of complex subsistant types CSTS: total number of complex subsistants STS: total number of subsistants TTS: total number of technounits MXT: sum of maximum technounits per subsistant group (Henrich 2006) GS: length of growing season in months										ET: effective temperature LET ⁷ : natural log effective temperature LNAGP ⁷ : natural log net above ground productivity NMV: number of yearly residential moves LDMV ⁷ : natural log total annual migration TAA: percentage land and aquatic animals in diet AQU: proportion of aquatic animals in diet LPOP ⁷ : natural log population size						
¹ Data from Oswalt (1976, Appendix)										⁵ Average of values for east and west Tasmania						
² Data from Binford (2001, Tables 4.01, 4.07, 5.01)										⁶ differs from Binford (2001); Binford uses 0.1 for 0 moves and 0 for missing data						
³ Estimate										⁷ Collard et al. used a natural log transformation on variables with a right skew distribution						
⁴ Data from Oswalt (1973)																