

# Emergent Properties in Small Scale Societies

Dwight W. Read

Department of Anthropology  
UCLA  
Los Angeles, CA 90035  
dread@anthro.ucla.edu

A multiagent simulation is used to explore the relationship between the micro and the macro levels in small-scale societies. The simulation demonstrates the way in which population stability may arise from culturally framed, micro level decision making by women about spacing of births in hunting and gathering societies. According to the simulation, population stability as an emergent property has different implications, depending on resource density. Data on Australian hunting and gathering groups are presented that support the implications of the simulation. Cultural rules on marriage from a hunting and gathering group known as the !Kung san are also shown to have macro level consequences arising from individual level specification. The emergent pattern has significant implications for access to resources.

Extant hunting and gathering societies typify the means of food procurement, if not the precise societal form, used by modern *Homo sapiens* prior to the changes introduced through a shift from a wild to a domesticated food resource base beginning about 10,000 BP. Hunting and gathering societies are thus the context within which the underlying properties of human societies were created and developed. Although extant hunting and gathering societies are not relic populations, understanding the link between the macro/collectivity and the micro/individual level in these societies provides a window opening onto some of the factors affecting the evolutionary development of our species from biologically based social groups into the behaviorally complex and culturally mediated societies that typify modern *Homo sapiens*.

The small population size of hunting and gathering societies – typically around 500 - 1000 persons – makes them an excellent context for multiagent simulations aimed at exploring emergent properties linking the micro and macro levels in human societies. In this paper I consider two such emergent properties – one in detail and the other briefly. The property considered in detail links macro level stabilization of the population size of a hunting and gathering society to micro level, individual decision making by foraging women regarding the spacing of births without consideration of the societal-wide consequences of their decisions. The emergent property of population stabilization, along with its implications for inter- and intra-group competition under different ecological conditions, forms the basis of a multi-trajectory model developed by Read and LeBlanc (In Press) that addresses the complex pattern of different and diverging evolutionary trajectories documented through the archaeological record of past human societies.

The other emergent property is a global marriage pattern of inter-residential group marriages that arises from culturally constrained, individually framed marriage choices among the !Kung san, a hunting and gathering society whose members live in the Kalahari Desert of southern Africa. The importance of the second emergent property, beyond its immediate implications for the pattern of social organization among the !Kung san, lies in the fact that kin relations established through marriages between members of different residential groups are a key means for geographically localized residential groups to have access to the average re-

source productivity of the total region exploited by the members of a hunting and gathering society.

A key aspect of the simulations to be discussed here involves a culturally framed model for a woman's decision regarding birth spacing based on concepts the !Kung san have about the desirability of children, yet simultaneously wanting to ensure the well-being of a family (Marshall 1976). The cultural context, I suggest, is critical since it provides the framework within which decisions to extend spacing between births is rational, hence recurrent. Incorporation of cultural concepts is elaborated further in the simulation when considering the consequences of the way marriage choices are made. Marriage choices by the !Kung san are formulated in accord with their notions of kinship and incest. Both of these are expressed at the individual level. Arising from these marriage choices is a macro level pattern for marriages that, in other societies, would be expressed as a cultural rule directing the construction of kin relations between groups through marriage. For the !Kung san a cultural rule is not needed since the marriage pattern arises as an emergent property.

## **Population Density as a Key Parameter in the Simulation Model**

The simulation focuses on population density due to the fact that, unlike a society based on domesticated foods, little or no positive effect on wild food productivity is achieved through labor investment on the part of most hunters and gatherers. The relatively fixed resource base of hunting and gathering societies thus makes population density a critical parameter since changes in population density and/or extrinsic variation in resource availability could, and did, have significant, negative consequences.

These consequences are typified by extremes ranging from the pre-modern Netsilik Eskimo living along the Hudson Bay in Canada who suffered from periodic starvation when their expected resource base in the form of migrating caribou did not materialize (Balikci 1970), to the !Kung san of the Kalahari desert who only rarely, if ever, faced starvation (Marshall 1976: 107).

Lack of starvation among groups such as the !Kung san implies a stabilized population size despite a potential fertility rate of about 10 - 15 children for a woman over her reproductive period (Henry 1961; Jelliffe and Jelliffe 1978: 126;) if there were no behavioral mechanisms negatively affecting her fertility (Wood 1994:77-78). Even when this potential fertility rate is coupled with the high mortality rates experienced by hunting and gathering societies (upwards of 50% mortality before adulthood followed by relatively low mortality rates during the reproductive years), the consequence would still be a rapidly growing population capable of outstripping food resources within a few hundred years. Evidently groups such as the !Kung san are engaging in behaviors that have the effect of limiting population density since empirically it is the case that their population density remains below the point at which stochastic variation in resource availability would otherwise lead to starvation. As Hayden comments "the vast majority of hunter/gatherer populations are and were maintained well below carrying capacity" (Hayden 1972: 205). This raises the question: Are groups such as the !Kung san consciously engaging in population limitation and monitoring current population size against resource availability, or is the limitation a property arising from behaviors whose motivation lies not at the level of population regulation but at the level of self-interested decision making? Ethnographic data on the !Kung san argues against the former (Howell 1976; Marshall 1976: 166). If so, then it is of interest to know what minimal specification of culturally distinguished behaviors will have population limitation as an emergent outcome.

The question can be rephrased in terms of emergent properties as: Is the fact of a stable population size in groups such as the !Kung san an emergent property of micro-level deci-

sion making formulated without taking into direct consideration macro level consequences such as the overall population size of the group? This question contrasts with other approaches where it is the summary characteristics of a group (such as average birth spacing) that are taken as phenomena that need direct explanation, yet the link of these summary characteristics to individually driven decision making is not taken into consideration. For example, ethnographic data indicate that !Kung san women space children approximately 4 years apart (Howell 1976; Lee 1980) with extended nursing suggested as the primary mechanism for birth spacing (Konner and Worthman 1980; Lee 1980). Some researchers have taken the fact of spacing – assumed to be independent of population density – as a datum to be embedded into an appropriate theory about behavior such as selection for behaviors that maximize Darwinian/inclusive fitness via an optimization strategy based on energy expenditure (e.g. Blurton Jones 1986). The selection argument is based on the observation that the marginal increase in parenting effort (measured by transportation cost of carrying children while gathering) when she has another child is minimized with 4 year spacing. But this erroneously assumes birth spacing has been fixed via selection and so is a constant rather than a variable whose value arises from a micro level process of decisions made about birth spacing based on a woman's immediate interests.

## Simulation Model 1: Birth Spacing

A mathematical model for !Kung san population dynamics based upon the assumption that each woman acts in her self interest within the context of cultural specification of what constitutes appropriate behavior (Read 1986) derives the 4 year birth spacing as an epiphenomenon of self-interested decision making. Hence the fact of 4 year birth spacing may be regarded as an emergent behavior arising out of individual decision making and not as a global property requiring a causal explanation such as the adaptive value of 4 year spacing. The model makes two culturally based assumptions:

*Assumption 1:* !Kung san women have a desire for as many children as possible

and

*Assumption 2:* !Kung san women are concerned for, and make decisions to promote, the well-being of their family, where family well-being includes, but is not limited to, ability of a woman to adequately nurse a newborn and to carry infants with her when foraging for resources.

These two assumptions are based on comments elicited from !Kung san women by Lorna Marshall (1976).

The decision making model assumes each woman has some set of activities,  $\{A_1, A_2, \dots, A_n\}$  (such as gathering, preparing food, and so on, where neither the list of activities nor the number of tasks is fixed but can vary from one woman to another) which engage her time and energies. It is assumed that each woman has a limited energy/time budget,  $E$ , which can be partitioned between these activities and the care of offspring. It is further assumed that each woman will allocate some minimal amount of energy/time, call it  $E_I$ , to each infant (see Assumption 2), and some total amount of energy/time, call it  $E_A$ , to the activities that she engages in. The only assumption made about  $E_I$  and  $E_A$  is that  $n_I * E_I + E_A \leq E_{Max}$ , where  $E_{Max}$  is the maximum amount of energy/time she can spend on both child care and activities and  $n_I$  is her current number of infants (defined as offspring who are being nursed, with focus on nursing offspring since the combination of nursing and carrying of nursing offspring places a heavy energy demand on a !Kung san woman). It is assumed in the model that each woman is free to vary both the set of activities,  $\{A_1, A_2, \dots, A_n\}$ , and the amount of energy/time,  $E_j$ , spent on activity  $A_j$ .

The multiagent simulation, discussed more fully in Read (1998), implements a simpli-

fied version of the above argument by having a female agent act in accordance with a decision rule for birth spacing taking into account both her current parenting costs and her current energy/time allocation for foraging activities. Major events of the simulation, based on a time period of one year for simulation events, are given in Table 1. In addition to the events listed in Table 1, an initial cohort of agents is constructed to begin the simulation but all future agents must be born to a married man and woman. Age-specific mortality rates are implemented using a mortality schedule based on data from hunting and gathering societies. Unmarried males initiate marriages after reaching the age of puberty and males select post-pubescent, unmarried females 3 to 8 years younger than themselves as marriage partners. The reproductive cycle for women can be varied but an age range from 15 to 45 years of age was used in the simulation discussed here. Each simulation year a female may become pregnant and give birth according to (a) her decision to defer pregnancy or not and (b) the probability

Table 1: Birth Spacing Model: Simulation events for each simulation year

Female and Male Agents	Female Agent only	Male Agent only
Age = Age + 1	If Married = True and Age ≤ Menopause and Alive = True, use Decision Rule to set Defer Pregnancy to True or False	If Age ≥ Puberty and Married = False, search for Spouse among Female Agents with Married = False and appropriate age range
Set Alive to True or False based on probability of death computed from age specific mortality rates; if Age = 75 set Alive = False	If Defer Pregnancy = False, set Birth = True or False based on probability of birth computed from a total fertility rate of 15 births over a completed reproductive cycle.	
If Age > Infant Age set Infant = False	If Birth = True, construct a new agent, set Mother = Female Agent, set Father = Spouse of Female Agent, assign Sex = M or Sex = F randomly, set Age = 0, set Alive = True, set Infant = True, set Married = null, set Defer Pregnancy = null.	
If Age = Puberty, set Married = False		
If Spouse found, set Married = True, set Spouse identity for both agents		
If Alive = False for Spouse, set Married = False		

of giving birth as determined by an age-specific fertility rate for women if she does not defer a pregnancy. A uniform, age-specific fertility rate was constructed for the simulation based on a total of 15 births over a completed reproductive cycle.

Marriages in the birth spacing simulation are based on current marital status and age difference alone. In the camp exogamy simulation discussed below, where camp exogamy refers to marriages outside one's camp of residence, cultural rules for contracting marriages are used as well. However, both versions lead to the same general pattern (Read 1998) for the

birth spacing simulation. In addition, for the camp exogamy simulation, incest rules affecting marriage choices are culturally expressed in terms of marriageable kin. Consequently, an agent must be knowledgeable about her/his world of kin. In this part of the simulation a newborn agent inherits knowledge of her/his immediate kin world from her/his parents in accordance with the kinship terminology used by the !Kung san. For the !Kung san the kin term used by an ego for an alter depends on the person for whom a newborn is named by her/his parents due to the fact that naming establishes a special relationship, a name relationship, between the name-giver and the name-receiver. Naming of offspring is rule based – a first born son is named for his father's father, a first born female is generally named for her father's mother, etc. – and restricted: living siblings cannot have the same name. The use of the name relationship as a basis for determining kin relationships makes it impossible to express their incest rules in strictly genetic terms.

The decision rule regarding pregnancy for a married woman is based on the energy expenditure per woman. Her energy expenditure is computed in the simulation via:

$$E = n_I * Wt + P/K, \quad (1)$$

where  $n_I$  is the number of infants,  $Wt$  is a weighting factor that represents the energy expenditure per infant (in arbitrary units),  $P$  is the population size and  $K$  is a weighting factor that converts the population size into the foraging cost per woman. (The expression " $P/K$ " has been used to make this term comparable to the last term in the logistic growth model given by  $dP/dt = rP(1 - P/K)$ . The logistic growth model, however, assumes a continuous, depressing effect on the net growth rate due to population size and does not model the decision process by which a change in fertility rate takes place.) This model captures the notion that the choice to have another child is affected by both (a) the current amount of time/energy spent on obtaining resources (which affects the number of years she will nurse, hence the age for an infant) and (b) her cost of currently having  $n_I$  infants.

The upper age boundary for an infant,  $I_A$ , is determined by a female agent's current foraging costs:

$$I_A = 4 * (P/K). \quad (2)$$

Eq. 2 relates a woman's current willingness to have an offspring to the time/energy she must expend on obtaining resources. The value of 4 represents what appears to be the maximum number of years that a child will be nursed under any circumstances. (The weighting factor,  $K$ , thereby scales with carrying capacity since a spacing of about 4 years between births is close to the birth spacing needed to arrive at a net, zero growth rate.) Limited ethnographic observations on the !Kung san indicate that the age of weaning is variable and decreases among more sedentary groups who have access to foods that do not require foraging, such as milk products obtained from neighboring Herero pastoralists, as predicted by the model. For the more sedentary women, a woman's cost for obtaining food for her family, controlling for population density, is less among sedentary groups than for more mobile groups due to the difference in travel time to obtain foods. For the more sedentary groups less energy is expended on carrying infants while obtaining food for her family than in more mobile groups. The linear relationship between the age boundary of an infant and the current foraging costs is not based on data but assumed for simplicity in the simulation.

The value of  $E$  is computed each simulation year for each woman and if  $E < T$ ,  $T$  a threshold value, then she makes a decision to become pregnant in accordance with Assumption 1. Whether or not she becomes pregnant when exposed to pregnancy depends probabilistically on the inherent fertility rate  $f_0 = 15$  offspring over a reproductive cycle converted to an age-specific fertility rate. If, however,  $E \geq T$  then  $f = 0$  for the simulation year in accordance with Assumption 2.

In the simulation run reported on here,  $Wt = T = 16$ , and  $K = 300$ . Setting  $Wt = T$  has the effect of changing the fertility rate to 0 if a female agent has 1 infant, yet allows for the

age boundary of an infant to change with the current population size. This also has the effect of spacing offspring according to the current value of  $I_A$  and its translation into a cost via the first term in the right hand side of Eq. (1) in conjunction with a female agent's current cost of foraging as given by the second term on the right hand side of Eq. (1).

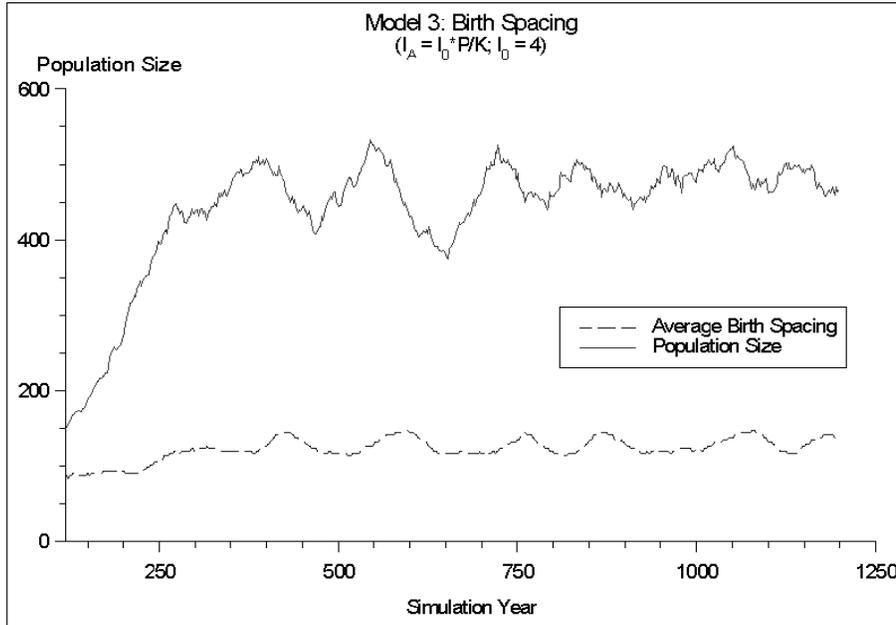


Figure 1: Multiagent simulation of population growth versus average birth spacing for a hunting and gathering society. (No scale for birth spacing.)

## Results: Birth Spacing

A typical run for the birth spacing model is shown in Fig. 1. The population size initially grows rapidly (upper curve) and then is stabilized via the decision model for birth spacing. Stochastic variation in the stabilized population size is reduced in comparison to what occurs with stochastic, density dependent population growth based on a logistic model (see Fig. 2, Read 1998) due to asynchronous decision making by women with regard to when decisions are made to space births. That is, for the same population size, decisions about birth spacing relate to a woman's current family structure (number and ages of offspring) as well as

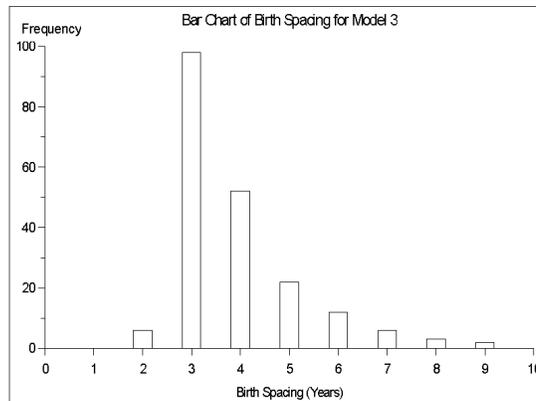


Figure 2: Bar chart of simulated birth spacing years

her current cost of foraging. Since the parenting cost varies across married women in the same simulation year due to variation in family structure, stochastic variation introduced via

the probabilistic implementation of a fertility rate at the individual level tends to be averaged out.

As can be seen in Fig. 1, birth spacing (lower curve) is tracking the population size (upper curve) as predicted. For this simulation run the *mean birth spacing* = 3.90,  $s = 1.31$  and  $n = 201$  females. The mean birth spacing is close to the 3.68 year average spacing ( $n = 55$ ,  $s$  not available) observed for the more nomadic !Kung san women (Lee 1980: 336). However, the closeness of the two values mainly reflects the fact that the !Kung san have a population size that appears to be in equilibrium, hence the agreement between the simulation and the observed data only reflects the fact that the average birth spacing is a proxy measure for whether or not the population is growing, stable, or shrinking. All stable populations will have approximately the same average spacing between births (keeping age-dependent mortality rates the same), though spacing patterns within the same society may be highly variable from one woman to the next. Consequently it is more useful to compare the frequency distribution for birth spacing in the simulation to the observed pattern for the !Kung san. As shown in Fig. 2 (previous page), birth spacing is almost always 3 years or longer in the simulation, which compares well with the observation that common values for birth spacing among the !Kung san are 3 and 4 years and birth spacing is seldom less than 3 years (Howell 1976: 145).

One of the unexpected implications of the simulation relates to the difference between the stabilized population size,  $K^*$ , and the carrying capacity,  $K$ , with  $K$  based on assuming a fixed resource procurement strategy. The cost of foraging increases more rapidly than a decrease in resource density alone would suggest due to the non-linear increase in search time when comparing a low-resource density to a high-resource density region (Read and LeBlanc In Press, n. 12), the value of  $K^*$  will initially decrease more rapidly than the value of  $K$  when comparing higher versus lower resource density regions. Eventually the value of  $K^*$  must

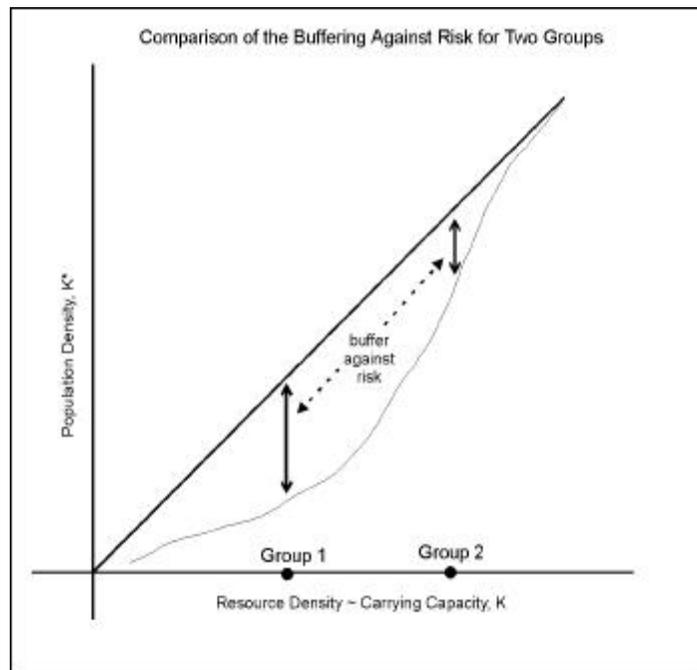


Figure 3: Comparison of  $K$  (straight line) with  $K^*$  (curved line) for two different groups in environments with different resource density. Group 1 has a larger buffer against resource shortage than does Group 2.

converge to  $K$  as the resource density continues to decrease since in the limit,  $K = K^* = 0$  (see Fig. 3). The expected pattern is matched by data on hunting and gathering groups from Australia (see Fig. 4, next page).

### Comparison of $K$ and $K^*$ Values for Australian Hunter/Gatherers

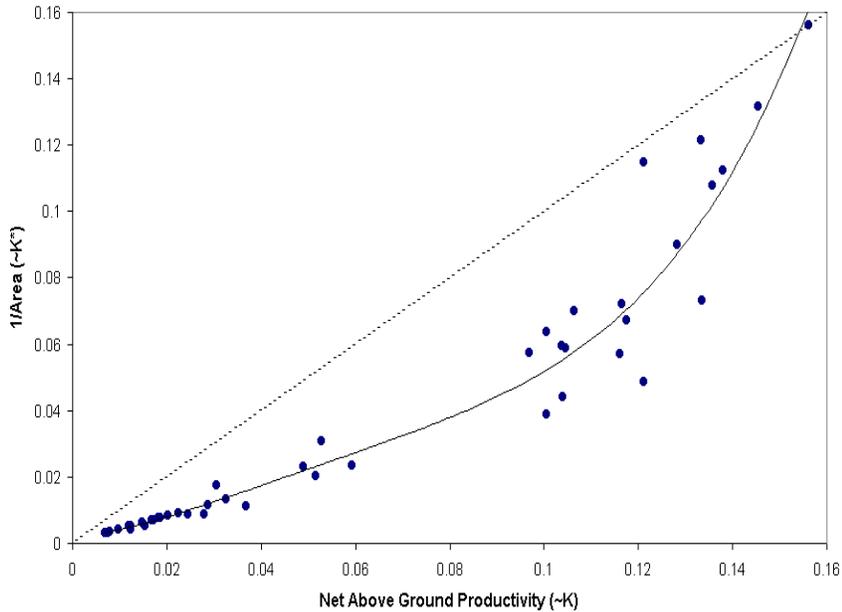


Figure 4: Comparison of  $K$  and  $K^*$  for Australian hunting and gathering groups. Carrying capacity  $K$  is assumed to be proportional to the net above ground biomass productivity (NAGP) (Binford 2001:175). The area value is computed from the equation  $y = 7112.8x - 1.58$  derived by Birdsell (1953) for Australian hunting and gathering groups, where  $y$  is the area of a hunting and gathering group and  $x$  is the mean annual rainfall in inches.  $K^*$  is assumed to be proportional to  $1/\text{area}$  based on a fixed, modal value of the population size of Australian hunting and gathering groups. The curve is a 4th degree polynomial fit to the data points computed solely to show the general trend under the assumption that the left group of data points (NAGP < 0.06) connects smoothly with the right group of data points (NAGP > 0.1). The coefficients in the polynomial have no particular interpretation and so their values are not shown. Axis scales are relative and not absolute. Data on rainfall, NAGP and population size are from Binford (2001), Tables 4.01, 4.07, and 5.01, respectively. Seven data points with population size listed by Binford as questionable have been excluded and one data point (Mineng) has been excluded as an outlier. The data have been scaled so that the most extreme point (upper right) has the same  $K$  and  $K^*$  value under the assumption that a group in the environment with the highest resource density will be close to carrying capacity. The pattern of increasing and then decreasing values for  $K - K^*$ , however, does not depend upon the scaling choice.

## Simulation Model 2: Camp Exogamy

When asked, the !Kung san say that it is permissible to marry someone from one's own residential camp. In fact, marriages within the same camp (camp endogamy) are very rare. While it has been suggested that the pattern of *de facto* camp exogamy is due to !Kung san concepts of incestuous marriage relations (Marshall 1976: 252), this has been a hypothesis lacking adequate empirical verification.

Incestuous marriages among the !Kung san are expressed in terms of marriages among certain categories of kin. Like our own cultural rules regarding incest, marriage within the nuclear family or with parent's siblings would be unthinkable. Beyond these close relations are other kin with whom marriage is also considered by the !Kung san to be incestuous. A simple specification of these kin is difficult as it is expressed in terms of kin relationships that have no exact translation into English due to the way the naming relationship affects kin relationships, along with a joking/avoidance relationship that is associated with each kin term.

From a woman's perspective, a woman should not marry a man with whom she has an avoidance relationship, that is, males for whom she uses the kin term *tsu* (this includes males in an odd generation ( $\pm 1, \pm 3$  generations from ego) with respect to her name giver). Marriage is permissible with some, but not all, males with whom she has a joking relationship (i.e., males in an even generation ( $0, \pm 2$  generations from ego) with respect to her name giver); that is, males for whom she uses the kin term *!gun!a*. The prohibited males appear to be close relations (Marshall 1976: 253-262). These relations are defined in the simulation as the relations that are part of her parent's nuclear families or are part of the nuclear family into which she is born, including individuals named for persons in this group of close kin. Call this the *!gun!a* incest rule.

## Results: Camp Exogamy

The *!gun!a* incest rule, in conjunction with rules about camp membership after marriage (a newly married couple initially lives in the bride's camp as the groom has obligations to hunt for his parent-in-laws), led in the simulation to the emergent property of agents almost always marrying outside of the camp for which one is a resident (see Table 1) even though the simulation was biased towards selecting a mate from one's camp if possible.

Table 2: Proportion of marriages within a camp for different incest rules

Incest Type	Marriages in Camp/Total Marriages	Total Population
<i>!gun!a</i> Incest	2/91 = 0.02	270
Cousin Incest	16/67 = 0.24	243
Parental Incest	22/74 = 0.30	281

The failure to marry within one's camp is related directly to the specification of the incest rule as a version of the incest rule (cousin incest) given by Marshall but based on 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> cousins – kin categories unknown to the *!Kung* san – allowed for up to 25% of the marriages to be within the same camp. An even less restrictive rule that only makes marriage with members of the nuclear family and parental siblings incestuous allowed for about 30% of the marriages to take place within a camp.

The simulation result obtained with the *!gun!a* incest rule is in accord with the observed, *de facto*, practice of camp exogamy. Although not a topic for this paper, the fact that camp exogamy emerges as a macro level property from micro level, kin based incest rules may account for why the *!Kung* san do not have any cultural restriction on marrying within one's living group despite the fact that a cultural rule of camp exogamy with respect to one's living group often occurs in small scale societies (see Read 1998 for a more extended discussion of camp exogamy arising as an emergent property.)

## Discussion

The simulation model implies that hunting and gathering groups in low resource density regions will tend to have more buffering against stochastic variation in the value of *K* than hunting and gathering groups in high resource density regions. Consequently, hunting and gathering groups in low-density regions will be less likely to experience resource shortage and possible starvation than groups in high resource density regions.

In effect, hunting and gathering groups in low resource density regions not only individually have a stabilized population size as an emergent property, but collectively are likely to be in a stable configuration as no group faces resource shortages. In contrast, hunting and

gathering groups in high resource density regions are less likely to individually have stable populations emerging from the decision model (since foraging costs may be sufficiently low so as not to trigger stabilization of the population size via self-interested decision making with regard to birth spacing) and are more susceptible to stochastic variation in the value of  $K$ . The two effects together imply that hunting and gathering groups in high resource density regions should be more likely to have aggressive intergroup interaction than is true for hunting and gathering groups in low resource density regions. Aggression against neighboring groups is a phenomenon well documented in the archaeological record of past societies (LeBlanc 1999). Unfortunately data are lacking on differences in aggression rates in hunting and gathering groups according to resource density. Nonetheless, the pattern of the relationship between  $K$  and  $K^*$  is supported by data from Australia as noted above, hence it is not unlikely that aggressive encounters more often occurred in hunting and gathering groups in high resource density regions. If so, it appears likely that evolutionary change in societal structure and modes of resource procurement would have arisen in hunting and gathering groups facing inherent instabilities due to population sizes that are not stabilized by internal decision making processes at the individual level (Read 2002; Read and LeBlanc In Press). These changes may also be reflected in cultural practices such as the marriage rules among the !Kung san that, in turn, become the basis for other, emergent phenomena.

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