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Emergent Properties in Small-Scale Societies

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Abstract A multi-agent simulation is used to explore the relationship between the micro and the macro levels in small-scale societies. The simulation demonstrates, using an African hunter-gatherer group (the !Kung san) as a case study, the way in which population stability may arise from culturally framed, micro-level decision making by women about spacing of births. According to the simulation, population stability as an emergent property has different implications, depending on resource density. Data on Australian hunter-gatherer groups are presented that support the implications of the simulation. !Kung san micro-level cultural rules on incestuous marriages are shown to have macro-level consequences in the form of marriages between residential camps. Between-camp marriages have significant implications for access to resources and thereby for population dynamics of the group as a whole.

Keywords

Simulation, hunter-gatherers, kinship, demography, emergent properties

I Introduction

Extant hunter-gatherer 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. Hunter-gatherer societies are thus the context within which the underlying properties of human societies were created and developed. Although extant hunter-gatherer societies are not relic populations, understanding the link between the macro (collectivity) and the micro (individual) level in these societies provides a window into some of the factors affecting the evolutionary development of our species from primarily biologically based social groups into the culturally mediated and behaviorally complex societies that typify modern *Homo sapiens*.

The small population size of hunter-gatherer societies—typically around 500–1000 persons—makes them an excellent context for using multi-agent simulations to explore possible emergent properties linking the micro and macro levels in human societies. Emergence will be used here “in the sense that global regularities result from the collective behavior of locally interacting objects without those regularities being imposed on the object initially” [7, p. 229]. In this article I consider two such emergent properties—one in detail and the other more briefly. The property considered in detail links macro-level stabilization of the population size of a hunter-gatherer society—the !Kung san of southern Africa—to micro-level, individual decision making by foraging women regarding spacing of births without consideration of the societal-wide consequences of their decisions. Population size stabilization under this decision rule satisfies Fontana and Buss’s definition of emergence, since individual women are not directed by global consequences of their decisions, but are making individual, self-interested decisions.

In contrast, population stabilization under a logistic model for population growth is not an emergent phenomenon, since fertility behavior of individual women in the logistic model is determined by the population size in comparison with carrying capacity.

The other emergent property is a global pattern of marriages between residential groups that arises from culturally constrained, individually framed marriage choices. 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 primary means for geographically localized residential groups to have access to the average resource productivity of the total region exploited by their society and not just to the average productivity of their locality.

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 [16]. The cultural context, I suggest, is critical in that it provides the framework within which decisions to extend spacing between births is rational, hence recurrent. The model for women's decisions about spacing between births, 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 [22] that addresses the complex pattern of different and diverging evolutionary trajectories documented through the archaeological record of past human societies.

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 a pattern of marriages outside one's residential group arises as an emergent property.

2 Population Density as a Key Parameter in the Simulation Model

The simulation focuses on population density because, in contrast with 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 nearly fixed resource base of hunter-gatherer 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 [2], to the !Kung san of the Kalahari desert, who only rarely, if ever, faced starvation [16, p. 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 [9; 11, p. 126] if there were no behavioral mechanisms negatively affecting her fertility [25, pp. 77–78]. Even when this potential fertility rate is coupled with the high mortality rates experienced by hunter-gatherer 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” [8, p. 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 argue against the former [10; 16, p. 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 as: Is the fact of a stable population size in groups such as the !Kung san an emergent property of micro-level decision 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 [10, 15] with extended nursing suggested as the primary mechanism for birth spacing [13, 15]. 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 or inclusive fitness via an optimization strategy based on energy expenditure (e.g., [5]). The selection argument is based on the observation that the marginal increase in parenting effort (measured in large part by the 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.

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 [18], 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 thus need not be considered as a global property requiring a biological causal explanation such as the adaptive value of 4 year spacing.

3 Simulation Model I: Birth Spacing

The mathematical model makes two culturally based assumptions:

ASSUMPTION 1: !Kung san women have a desire for as many children as possible.

ASSUMPTION 2: !Kung san women are concerned for, and make decisions to promote, the well-being of their family, including but 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 [16], but their cultural basis extends beyond the comments of !Kung san women. With regard to the first assumption, while a “desire for children” may

arise from a biological propensity for reproduction, “how we express that want is influenced by our culture” [17, p. 5]. That the number of children a woman will have over her reproductive period is heavily affected by her cultural context can be seen in the demographic transition to reproductive rates below replacement level in several industrialized countries. This transition runs counter to arguments about biological fitness maximization at the individual level and has led some demographers (e.g., [24]) to consider why women in low fertility populations have children at all. This research has not led to a biological “imperative” for having children, but to a “cultural ‘imperative’—such as ‘respectable couples have at least one, but no more than three children,’ ” where it is the systems of value generated by social groups that specify “what features characterize a respectable, or worthy, family” [23, p. 184].

Similarly, what constitutes “well-being” of a family in the second assumption arises out of a cultural context affecting decisions about the degree of care for, and extent of family resources directed toward, family members. Foundling homes in pre-twentieth-century Europe had high rates of infant and child mortality that served as a means to limit family size through a cultural overlay that legitimized leaving unwanted children at these homes even though it was known that the child was not likely to survive [12]. Children may also be unwanted with respect to a single sex for culturally induced reasons. In societies such as India or Bangladesh, for example, where marriages may involve large dowries, marrying off daughters is costly and daughters may be considered as potentially ruinous to family resources, thereby leading to “their abuse and neglect” ([1, p. 305]; see also [6]). Or, where religious injunctions may dictate large families regardless of family resources, “well-being” must accommodate a religious injunction that does not take into account the time and energy expended in parenting. Under these circumstances a woman with limited financial resources may end up with a large family that overly taxes her energies and her family’s resources.

These assumptions have been implemented into a multi-agent demographic simulation, discussed more fully in Read [20], by having a female agent use a decision rule for birth spacing that takes into account both her current parenting costs and her current energy and 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 once the simulation has begun, all future agents must be born to a married man and woman. Unmarried males initiate marriages after reaching the age of puberty, and males select post-pubescent, unmarried females 3 to 8 years younger than themselves for marriage partners. In the residence-camp exogamy simulation discussed below, where exogamy refers to marriages outside one’s camp, a cultural rule for contracting marriages is used as well. However, both versions lead to the same general pattern for the birth spacing simulation [20], and so marriage rules will be ignored in this simulation with its focus on birth spacing.

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 of giving birth, as determined by an age-specific fertility rate for women, if she does not defer a pregnancy. Although her decision to become pregnant is absolute in the decision model, whether or not she becomes pregnant is a stochastic event in the simulation and is based on a uniform, age-specific fertility rate that assumes a total of eight live births over a completed reproductive cycle. An unbiased stochastic, rather than absolute, decision model would not change the qualitative results of the simulation and would increase slightly the variance of the simulated population size around its time-dependent expected value.

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 \leq Menopause and Alive = True, use decision rule to set Defer Pregnancy to True or False	If Age \geq 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 based on hunter-gatherer societies; 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		

The decision rule regarding pregnancy for a married woman begins with the assumption that each woman has some set of activities, $\{A_1, A_2, \dots, A_n\}$ (gathering, preparing food, child care, and so on, where the list of activities and the number of tasks are not 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 among these activities, including 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 non-child-care 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 all activities and n_i is her current number of nursing infants (with focus on nursing infants because 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 for the decision rule that each woman is free to vary both the set of activities, $\{A_1, A_2, \dots, A_n\}$, and the amount of energy or time, E_j , spent on any activity, A_j .

Pregnancy decisions in the simulation derive from the energy expenditure per woman. Her energy expenditure is computed via

$$E = n_1 \times Wt + P/K' \quad (1)$$

where n_1 is the number of nursing infants, Wt is a weighting factor that represents the energy expenditure per nursing 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 notationally 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.] The decision rule captures the notion that the choice to have another child is affected by both (a) the current amount of time or energy spent on obtaining resources (which affects the number of years she will nurse, and hence the maximum age for a nursing infant) and (b) her cost of currently having n_1 nursing infants.

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

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

The linear relationship between the age boundary of a nursing infant and the current foraging costs is not based on data but assumed for simplicity in the simulation.

Equation 2 relates a woman's current willingness to have an offspring to the time/energy she must expend on obtaining resources, P/K' . The factor of 4 represents what appears to be the maximum number of years that a child will be nursed under any circumstances. Limited ethnographic observations on the !Kung san indicate that the age of weaning is variable and is smaller among more sedentary groups who have access to foods that do not require foraging, such as milk products obtained from Herero pastoralists living next to more sedentary !Kung san camps. For the more sedentary women, a woman's cost for obtaining food for her family, controlling for population density, is less than for more mobile groups, due, in part, to the decreased travel time for obtaining food. Consequently, less energy is expended on carrying nursing infants while obtaining food for her family than in more mobile groups.

The value of E is computed each simulation year for each woman, and if $E < T$, T a threshold value, then, in accordance with Assumption 1, she makes a decision to become pregnant. Whether or not she becomes pregnant depends probabilistically on the assumed intrinsic fertility rate $f_0 = 8$ offspring over a reproductive cycle, converted to an age-specific fertility rate. For $E \geq T$, we have $f = 0$ for the simulation year in accordance with Assumption 2.

4 Results: Birth Spacing

In the first simulation run reported on here, $Wt = T = 16$, and $K' = 400$. Setting $Wt = T$ has the effect of changing the fertility rate to 0 if a female agent has one infant, yet allows for the age boundary of a nursing 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 Equation 1

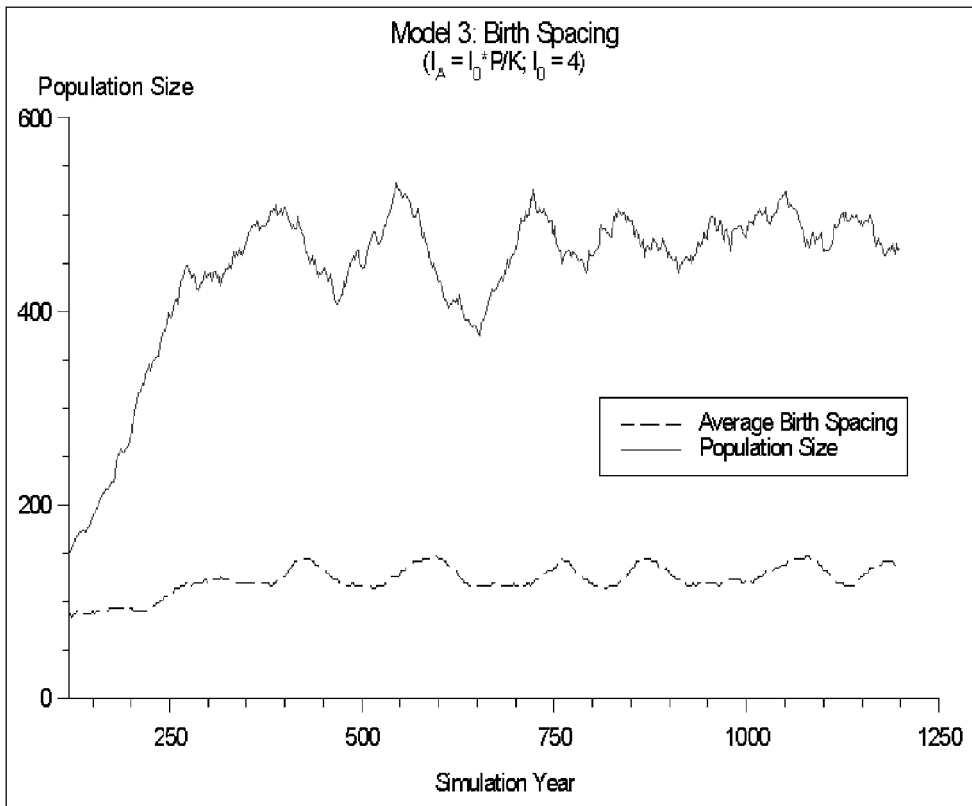


Figure 1. Multi-agent simulation of population growth versus average birth spacing for a hunting and gathering society. No vertical scale is shown for average birth spacing measured in years. (Reprinted from [20, Figure 7] with permission of publisher.)

without taking into account the cost of foraging. The effect of changing the value of Wt is shown below.

A typical run with $Wt = T = 16$ is shown in Figure 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 with what occurs with stochastic, density dependent population growth based on a logistic model (see [20, Figure 2]) due to asynchronous decision making by women with regard to when decisions are made to space births. In the logistic model, all reproductive women form a single cohort with a population-density-dependent fertility rate; hence stochastic variation in fertility rates is summed over all reproductive females. In contrast, decisions about birth spacing in the multiagent simulation relate to a woman's current family structure (number and ages of offspring) as well as her current cost of foraging. Thus the set of reproductive women is composed of women in different (and changing) cohorts, depending on a woman's current family structure. For some cohorts, the decision for the current cost of foraging is to defer a pregnancy. This implies that stochastic effects are introduced only for cohorts with currently reproducing women; hence variation is based on cohorts smaller in size than the total number of reproductive women, and so the stochastic variance in the population size is smaller than for the logistic model.

As can be seen in Figure 1, birth spacing (lower curve) is tracking the population

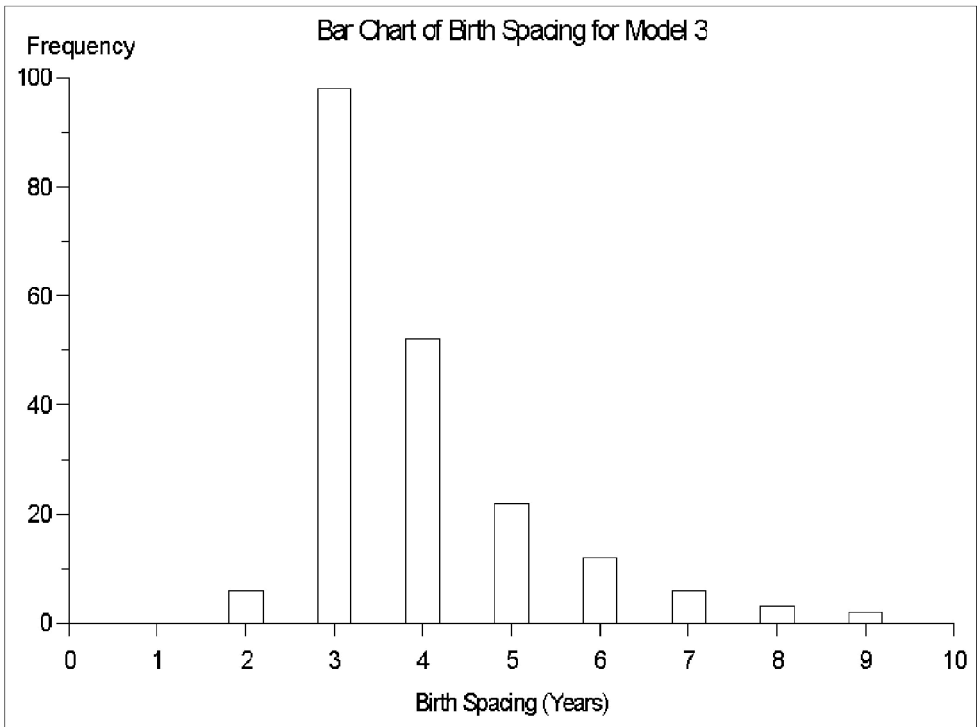


Figure 2. Bar chart of simulated birth spacing years. (Reprinted from [20, Figure 10] with permission of publisher.)

size (upper curve) as predicted. For this simulation run the mean birth spacing is 3.90 years, $s = 1.31$, and there are $n = 201$ reproducing females in the simulated population at the end of the simulation. The mean birth spacing is close to the 3.68 year average spacing ($n = 55$ females with completed reproduction, s not available) observed for more nomadic !Kung san women [15, p. 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 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 with the observed pattern for the !Kung san. As shown in Figure 2, 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 [10, p. 145]. In contrast, the logistic model has a different pattern with birth spacing of 2 years occurring frequently (see [20, Figure 9]).

Three runs with approximately the same stabilized population size but different parameter values for Wt are shown in Figure 3. The run with $Wt = 16$ and $K' = 400$ has the same parameter values as, and is similar to, Figure 1. The next run has $Wt = 8$ and $K' = 120$. For this run the parenting cost and the foraging cost are weighted equally. There is a slight increase in the variance of the stabilized population size in comparison with the first of these three runs, suggesting that stabilization of population size through

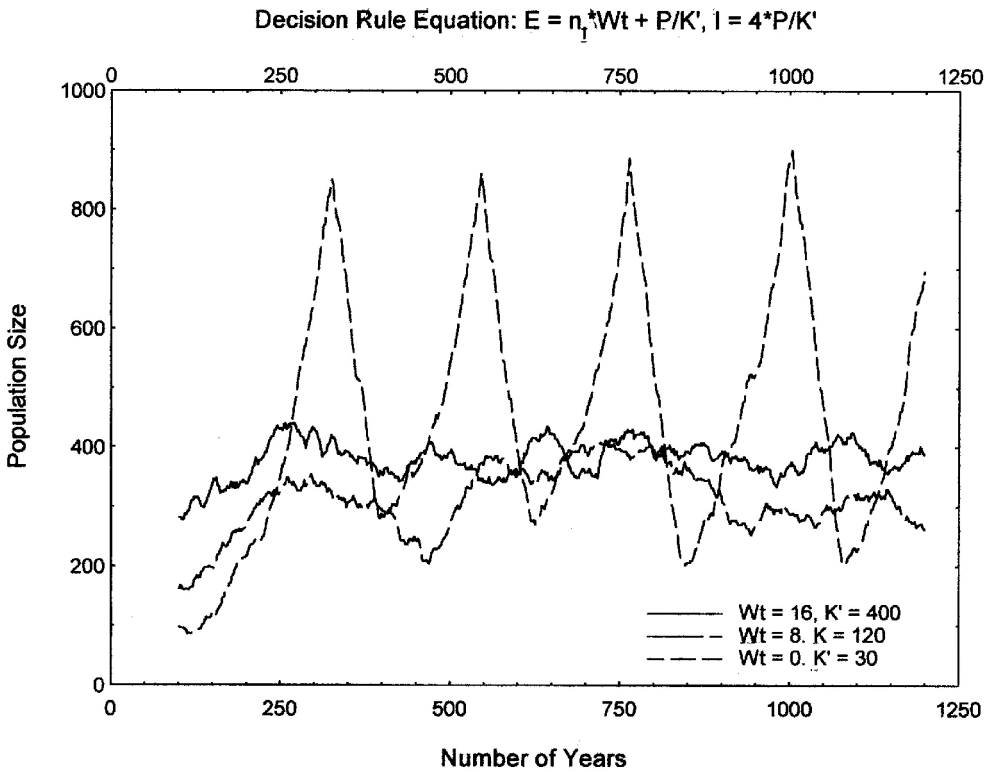


Figure 3. Three runs with different weights Wt for parenting costs.

parenting cost is a relatively robust solution. The pattern is not robust for all parameter values, though. The third run has $Wt = 0$ and corresponds to females responding only to foraging costs. In this run, fertility rates are unchanged until foraging costs are too high, and then all women shift to $f = 0$. The pattern has changed qualitatively to oscillatory behavior, because (1) all women are now acting synchronously and (2) there are time delays between a shift to a fertility rate of 0 due to high foraging costs and a return to $f \neq 0$ when foraging costs drop due to decrease in the population size. As is well known, for systems with feedback, time delays introduce oscillatory behavior.

For all three runs the environmental conditions are the same. The only change is in the value of Wt , that is, the weighting placed on family well-being. The shift in pattern for the population size of the group represents, then, the effect of changing the cultural valuation placed on parenting.

One of the unexpected implications of the simulation relates to the difference in magnitude between the stabilized population size K^* and the carrying capacity K , defined as the maximum number of individuals that can survive when there is full utilization of a fixed set of resources. The cost of foraging increases more rapidly than a decrease in resource density alone would suggest, due to the nonlinear increase in search time on going from a low-resource-density to a high-resource-density region [22, note 12]. Consequently K^* will initially decrease more rapidly than does K on going from higher- to lower-resource-density regions. Eventually, though, K^* must converge to K as the resource density continues to decrease, since in the limit, $K = K^* = 0$ (see Figure 4). The expected pattern is matched by data on hunter-gatherer groups from Australia (see Figure 5).

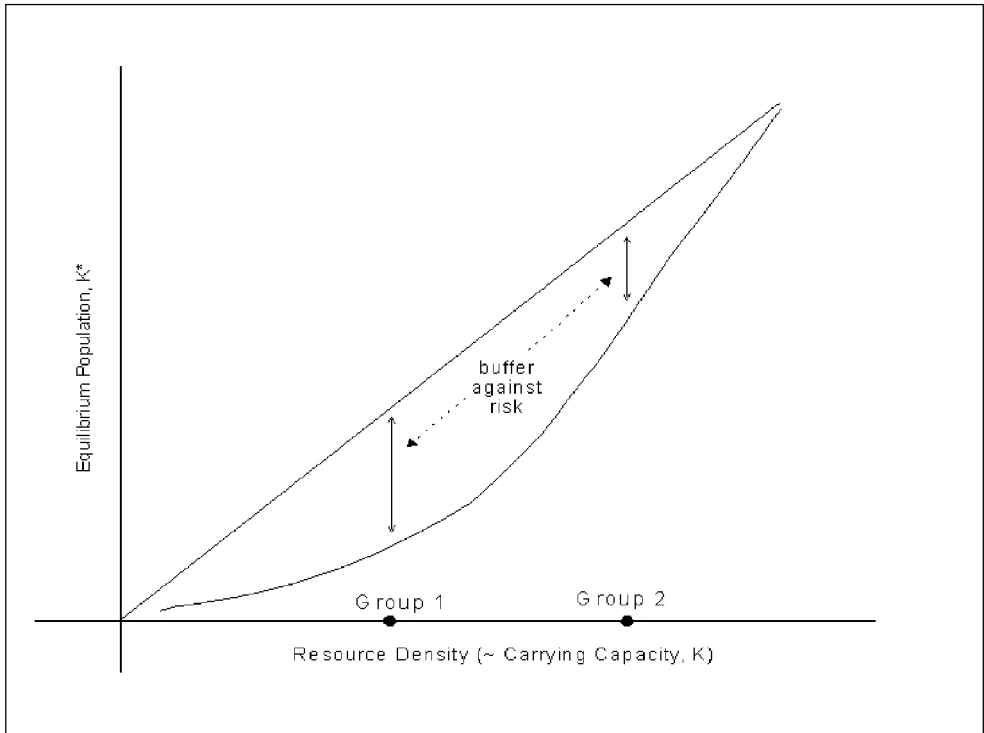


Figure 4. Deviation of the stabilized population K^* (curved line) from the theoretical maximum K (straight line). For two different groups in environments with different resource density, one group (group 1) may have a larger buffer against resource shortage than the other group (group 2). The curve is schematic and not exact.

5 Simulation Model 2: Camp Marriage Exogamy¹

When asked, the !Kung san say that it is permissible to marry someone from one's own residential camp. In fact, however, marriages within the same camp (camp endogamy) are very rare. While it has been suggested that the pattern of *de facto* camp exogamy (marrying someone not residing in one's residential camp) is due to !Kung san concepts of incestuous marriage relations [16, p. 252], this has been a hypothesis lacking adequate empirical verification. We now use the simulation to show that camp exogamy is an emergent property arising when marriages do not violate what are considered to be incestuous marriages by the !Kung san.

Incestuous marriages for the !Kung san involve categories of kin. As in our own culture, marriage within the nuclear family or with a parent's siblings would be unthinkable. Beyond these close relations are other kin with whom marriage is considered to

¹ From a cultural anthropology viewpoint, exogamy refers to forming kinship links between social groups, not inbreeding avoidance. Forming kin ties between subgroups within a society has been viewed as crucial for societal integrity. Without these kin ties there would be much greater opportunity for fission were the society divided into subgroups with few interlinking kin. For this reason, the absence of a rule of exogamy among the !Kung is unusual; hence the desire to know if exogamy arises as an emergent phenomenon. With *de facto* exogamy, kin ties among residence camps arising from marriages suffice to keep the residence camps socially integrated despite physical separation. In addition, the form of their incest rule suggests a bias towards a marriage partner who is not from the natal camp of either of one's parents—though this pattern is made weaker by the way the naming of a child affects kin relations. From a genetic viewpoint, someone who might be incestuous from a strict genealogical viewpoint may become marriageable, depending on who is named for whom. Hence the naming pattern for children may sometimes make otherwise incestuous marriage partners into non-incestuous ones. Unfortunately there is little ethnographic information on the choice of names other than the naming rules for first-born children (see text, below).

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

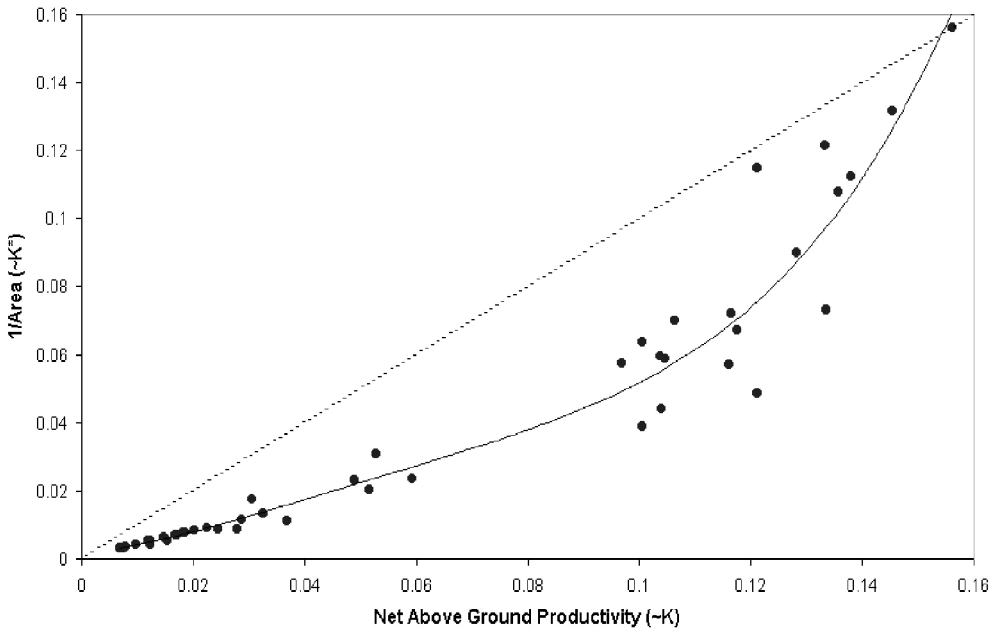


Figure 5. Comparison of K and K^* for Australian hunting and gathering groups. The carrying capacity K is assumed to be proportional to the net above-ground biomass productivity (NAGP) [3, p. 175]. The area value is computed from the equation $y = 7112.8x^{-1.58}$ derived by Birdsell [4] for Australian hunting and gathering groups, where y is the area of the 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 fourth 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 (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 [3, Tables 4.01, 4.07, 5.01], respectively. Seven data points with population size listed by Binford [3] 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.

be incestuous. Simple specification of these kin is difficult, though, as !Kung san kin relationships do not translate directly into English.

For the !Kung san, and outside of the nuclear family, the kin term used by an ego for an alter depends on the person for whom a newborn is named by her/his parents, because the !Kung san consider naming to establish a special 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 daughter is generally named for her father's mother, and so on—and restrictive: living siblings cannot have the same name. To see the effect of the naming on the use of kin terms, we need to briefly discuss the joking-avoidance contrast that is part of !Kung san kinship.

For all relatives, a person (ego) has either a *joking* or an *avoidance* relationship with a given relative (alter). This relationship affects the behavior of ego towards alter. When ego has a joking relationship with alter, then ego may be casual and informal in his/her dealings with alter and is permitted to make what otherwise might be offensive jokes, such as jokes about alter's lack of sexual prowess. In contrast, an avoidance

relationship requires formal, circumspect behavior on the part of ego toward alter, and joking of the kind permitted in a joking relationship would be considered highly offensive.

Of the four kin terms applicable to persons outside the nuclear family, the term used by ego for an alter outside of the nuclear family depends on the joking or avoidance relationship ego has with alter in conjunction with the sex of the alter: (1) *!gun/a* (joking relation, male), (2) *tsu* (avoidance relation, male), (3) *t_n* (joking relation, female), and (4) *//ga* (avoidance relation, female). For analytic purposes (but not in terms of their conceptualizations [16, p. 208]) these four terms can be approximated by linking a joking relation with an even number of generations between ego and alter (i.e., *!gun/a* and *t_n* are, to a first approximation, the terms use for male and female alters, respectively, who are 0 or ± 2 generations removed from ego) and an avoidance relation for an odd number of generations (i.e., *tsu* and *//ga* are the terms used when alter is male or female, respectively, and ± 1 generations removed from ego). Within an extended family ego normally will have an avoidance relation with his/her parents and his/her children, but a joking relation with his/her grandparents and his/her grandchildren. Also, one may joke with a same-sex sibling but not with an opposite-sex sibling. However, complicating the genealogical characterization is the fact that the joking or avoidance relation is not determined from the relation between ego and alter, but from that between ego's namesake and alter. Thus if ego receives her/his name, *A*, from person *x* whose name is *A*, and *x* is in a joking relation with person *y*, then ego is in a joking relation with person *y* regardless of *x*'s actual genealogical relation with *y*.

From a woman's perspective, the basic incest rule is that 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*. Marriage is permissible with some, but not all, males with whom she has a joking relationship; that is, males for whom she uses the kin term *!gun/a*. The prohibited males appear to be close relations [16, pp. 253–262]. These close 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. As a first approximation, a female may marry males who are an even number of generations away from her and who are not her close relatives (see Table 2a); as a second approximation, a female ego may marry males who are in an even generation with respect to her name giver and who are not close relatives (see Table 2b). More accurately, she may marry males for whom she uses the term *!gun/a* and who are not close relatives (see Table 2c). Call this restriction on marriage the *!gun/a* incest rule.

In the simulation a newborn agent inherits knowledge of her/his immediate kin world from the kin world of her/his parents. Marriage choices are made in accordance with the *!gun/a* incest rule. In addition, a newly married couple is assigned membership in a camp in accordance with !Kung san rules about camp membership. A newly married couple initially lives in the bride's camp, because the groom has obligations (bride service) to hunt for his parents-in-law. They continue to live in her parent's camp for 12 years, or until around the time the couple has a child who is reaching marriageable age. At this time the couple may decide to stay as members of the wife's camp, or they may return to the husband's parents' camp. In the simulation the choice to stay in her camp or to return to his parent's camp is determined by the camp with a smaller number of persons, on the grounds that that camp currently has higher resource abundance per camp member. In order to test whether or not camp exogamy emerges from !Kung san incest rules, marriage choices are biased in the simulation toward selecting a marriage partner, consistent with the incest rule, from one's own camp if possible.

Table 2. Marriage rule.

(a) First approximation		
Generation (ego to alter)	Distance	Marriageable
Even (0, ±2)	Near	No
	Far	Yes
Odd (±1)		No
(b) Second approximation		
Generation (namesake to alter)	Distance	Marriageable
Even (0, ±2)	Near	No
	Far	Yes
Odd (±1)		No
(c) !Kung san conceptualization		
Kin term (namesake to alter)	Distance	Marriageable
!gun!a (joking)	Near	No
	Far	Yes
tsu (avoidance)		No

Table 3. Proportion of marriages within a camp for different incest rules.

Incest type	(Marriages in camp)/(total marriages)	Total Population Size
!guna!a incest	2/91 = 0.02	270
Cousin incest	16/67 = 0.24	243
Parental incest	22/74 = 0.30	281

6 Results: Camp Exogamy

The !gun!a incest rule, in conjunction with rules about camp membership after marriage, led in the simulation to the emergent property of an agent’s almost always marrying outside the camp for which he/she is a resident (see !gun!a incest, Table 3), even though the simulation was biased toward selecting a mate from one’s camp if possible.

The failure to marry within one’s camp is related directly to the specification of the incest rule. A version of the incest rule given by Marshall but based on first, second, and third 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.

7 Discussion

The simulation result obtained with the *!gun!a* incest rule is in accord with the observed de facto practice of camp exogamy. The fact that camp exogamy emerges as a macro-level property from micro-level, kin-based incest rules may explain a fact not discussed here: that the *!Kung* san do not have any cultural restriction on marrying within one's living group despite the fact that a cultural rule of exogamy with respect to one's social group often occurs in small-scale societies (see [20] for a more extended discussion of camp exogamy arising as an emergent property). Marriages between families in different camps are important for a group such as the *!Kung* san, as these marriages provide a way for individual families to have access to resources in localities other than their own through kin relations created through marriages with families in other localities. Gaining access by individual families to the average resource abundance throughout the region exploited by the entire society and not just to the average resource abundance in one's own locality was central to the shift from a primate form of resource exploitation by competitive troops to cooperative exploitation of resources among subgroups (such as residential camps) making up a hunter-gatherer society (see [19] for a model of this transition based on the Lotka-Volterra equations for between-group competition). The resource base upon which families can draw directly affects the population size and density for a hunter-gatherer group and provides the basis for treating the population dynamics of a group such as the *!Kung* san as a group and not a subgroup phenomenon. The foraging cost experienced by the women in a residential camp is not just a consequence of the number of persons in the residential camp, but also of the total population size of the *!Kung* san, due to resources being accessible not only locally but throughout the region via kin ties created by patterns of marriages between members of different residential camps. Another important dimension is the density of resources in the region exploited by the hunter-gatherer group.

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

In effect, hunter-gatherer 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 in that region faces resource shortages. In contrast, hunter-gatherer groups in high-resource-density regions are less likely to 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 hunter-gatherer groups in high-resource-density regions are more likely to reach Malthusian constraints on population size, due either to stochastic variation in resource availability or to continually growing populations, than are groups in low-resource-density regions. Since a plausible alternative to starvation is aggression against neighboring groups in order to gain access to their resources, we postulate [22] that between-group aggressive encounters for hunter-gatherer groups should occur more frequently in high-resource-density regions than in low-density regions.

Although aggression against neighboring groups is a phenomenon well documented in the archaeological record of past societies [14], unfortunately data are lacking on differences in aggression rates in hunter-gatherer 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 hunter-gatherer groups in high-resource-density regions. If so, it is plausible that evolutionary change in societal structure and modes of resource procurement would have arisen in hunter-gatherer groups facing instabilities due to population sizes that are not stabilized by internal decision making processes at the individual level [21, 22]. 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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