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Population Growth, Carrying Capacity, and Conflict¹

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Abstract

The standard model of population growth and regulation is critiqued. It is argued that any model of population growth and regulation must accommodate ten propositions, and a multitrajectory model that does so is described. This model identifies competition between groups, individual choice in reproductive behavior, the scale for spatial and temporal variation in resource abundance, and the social unit for resource access and ownership as important components of population behavior.

Human population growth and the effect of population stress on human systems have long been topics of concern for anthropologists. Growth and stress have been considered both as prime movers in culture change and as nonexistent and essentially irrelevant. Most arguments about human societal development favor slow to almost nonexistent growth and populations well below carrying capacity for most of human history since at least the middle Paleolithic, and the archaeological record supports this view. However, potential, if not actual, rapid growth at almost all times and places appears to be a more accurate description of human reproductive capability. Resolution of these two seemingly contradictory factors -- high intrinsic growth rate and low net long-term growth rate -- requires a different view of human population dynamics and its relationship to societal organization.

At the risk of creating a straw man, we suggest that there is a standard model (see appendix in the electronic edition of this issue on the journal's web) for the pattern of human population growth and its relationship to carrying capacity (K)², namely, that most of the time human populations have low to nonexistent rates of growth. Implicit in this model is a decoupling of population size from K , with changes in carrying capacity only very rarely affecting the growth rate. It is also assumed that birth rates and death rates are virtually identical, although no mechanism is posited for keeping them so. In its most extreme form the standard model simply assumes a low-to-zero net growth rate without establishing how it arises. Even when feedback mechanisms are introduced, they are often assumed to have fixed effects rather than considered as a process. Also, the standard model does not consider competition between groups a significant factor in the regulation of human population growth

The model is often implicit and may simply assert that, until recently, population sizes until recently have always been well below K , and human population growth rates have been very low

until the last few centuries. In this formulation of the standard model it is the *intrinsic*, not just the net or effective rate of growth that is low. Rates, according to this model, have been low not because of the eventual limitations of K but because humans, through a series mechanisms that are not well understood factors have kept them that way, with the result that the effects of carrying capacity stress were only rarely felt. In other words, unlike all other animals, humans are assumed to have kept their numbers in check far below carrying capacity in a density-independent manner, thus making the value of K irrelevant.

We reject the standard model and offer in its place a multidimensional, multitrajectory model that includes factors that interact with group population dynamics. The factors include resource density, the geographic and temporal scale for resource variability, the production and decision-making units, the form of social organization, and the effect of group competition (intra- and inter-societal). We call it a *multitrajectory model* because the relationships identified in it do not lead to a single, evolutionary trajectory for the form of social organization under all conditions but instead may lead to different trajectories depending on the values for both societal and environmental parameters. Our model has four major components: (1) within-group feedback mechanisms between resource availability and fertility behavior modeled as a cost-decision process based on the self interests of family units; (2) between-group competition, (3) the geographical and temporal scale for variation in resource density, and (4) the social unit for resource access and ownership We argue that the multitrajectory model fits empirical reality far better than simpler models with fixed effects (such as the standard model) and that it can integrate societal changes heretofore viewed as due to different factors and calling for different models.

Key to our multitrajectory model is the empirical observation that human populations, in the absence of culturally mediated behavior that reduces a female's fertility, tend to exhibit rapid growth. Periods of rapid growth may, however, be interspersed with occasional population

crashes that lead to slow or no net population growth over time (Hill and Hurtado 1995: 471).

While periodic population crashes are demographically possible, any population facing a population crash will likely opt, if possible, for a solution other than starvation. Long-term trends, then, are misleading in that they suggest a more benign demographic pattern than may be the case in the short run and it is the short-run effects, not long term averages that, determine behavior. This implies that we must distinguish between the average net growth rate observed over long time scales and the actual growth rate in the short term.

Equally important, we assume that populations did not exist in isolation and we build group interaction (competition) directly into our model. As Anderson (1978) has pointed out, far too often demographic modeling implicitly holds groups to be in isolation without competition, even though such interaction must have been frequent if not universal in the past. We see our model as relevant to foragers, egalitarian farmers, and more complex societies, but we emphasize here those aspects of it that are particularly relevant to hunter-gatherer societies because it is to these societies that the standard model has been most commonly applied and because type of society typifies most of the span of human history.

Our model has a number of implications: (1) The distance between the equilibrium population size, K^* , and the carrying capacity, K , for hunter-gatherer groups varies inversely with resource density. Hunter-gatherer groups living in low-resource density areas are more likely to display long-term demographic stability, and the higher the resource density, the more likely the occurrence either of intergroup conflict or of Malthusian growth constraints such as disease and starvation. (2) Chronic intersocietal conflict arising as populations in a region approach or exceed their equilibrium population sizes is more likely when the scale of geographical and temporal variation in resource density is commensurate with the scale of the catchment area for a group. (3) A shift to a larger-scale social organization is more likely when the scale for significant

change in temporal and geographic resource-density variation is larger than that of the catchment area for a group. (4) Intrasocietal conflict is more likely when the (possibly varying) number of persons in the resource access/ownership unit is independent of the population size of the society of which it is a part. (5) A no-man's land may arise between groups when one group can substantially reduce the resource base of another. (6) A larger-scale social organization integrating groups previously isolated by no-man's lands is likely to have rapid population growth and to be unlikely to revert to smaller-scale groups. (7) The development of agriculture will involve domesticates that are highly elastic with respect to labor intensification.

Assumptions

The model we present is based on the following definition of "competition": *Neighboring groups are in competition whenever the resources used by one group are thereby made unavailable to another group that would otherwise have access to those resources.* Competition in this sense may include but does not presume warfare as its form. It need not involve direct confrontation of one group by another and may simply be the consequence of two groups' exploiting the same resources in the same area (for example, hunting animals whose migration pattern is more extensive than the catchment area of either group). In its most basic form, competition exists whenever the catchment area of one group overlaps with the catchment area of another, whether or not territorial exclusion is practiced.

The model involves the following propositions:

1. *Human populations have an intrinsic growth rate (r_0) that enables them to exceed K in a short period of time*

It is difficult to measure r_0 directly on human populations, since it is defined as the inherent fertility rate, that is, the fertility rate (f) that would occur without behavioral modification of

fertility. Even for so-called natural-fertility populations, the current value of f need not represent r_0 accurately, as is evident from both variation in f over such populations (ranging from a low of 4.3 for the Gainj of Papua New Guinea to a high of 6.3 for the Amish [see Wood 1994:49, fig. 2.2]), and the difference between the actual value of f and its estimated potential value of ten births for breast-feeding women over a 30-year reproductive period (Jelliffe and Jelliffe 1978:126).

An intrinsic growth rate of 8 live births over a woman's reproductive span (a rate well below the estimated potential) coupled with a 50% mortality rate of offspring from birth to adulthood, leads to about 4 surviving adults per reproductive female, assuming that all women of reproductive age are equally fertile. Assuming a 25-year reproductive period with half of the population pre-adult and half of the population male, the net growth rate would be about 0.02 adults per person per year. For exponential growth, the population doubling time is given by $\ln 2/r = 0.69/r$, or $0.69/0.02 = 34.5$ years. A population doubling every 34.5 years would have more than eight millionfold increase in population size in 800 years, and at this rate a single hunter-gatherer group of 1,000 reproductive persons would grow to a population size exceeding the world's current population in about 800 years. Obviously a doubling time of 34.5 years could not long be sustained.

The fertility rates of 4.0 - 4.7 births per reproductive female reported for !Kung groups (Kelly 1995) would produce a growth rate of about 0.0023 adults per person per year, yielding a tenfold increase in adult population size over 1,000 years. This amount of increase would likely either have required a shift in resource base or led to conflict over territory or other resources.

These rough estimates highlight the fact that, even when mortality rates are high, a stabilized population size can occur only if there is substantial depression of the potential fertility rate. Of course, under extreme conditions such as those experienced by the Netsilik Eskimos,

who were at periodic risk with respect to resources upon which they depended for survival (Balicki 1970), mortality rates increased drastically via starvation when an unexpected change in availability of resources led to the population's suddenly being above K because of a temporary reduction in the value of K . While these fluctuations in the net growth rate may average out, in the long run, to a value close to zero, the population dynamics experienced by such a group and the implications for its response to swings in its actual growth rate are obscured by focusing on the long-term average.

2. In populations with a stabilized population density, fertility and/or mortality rates are coupled negatively (positively) with density

If $r < 0$ independent of population density, the population will eventually become extinct. If $r = 0$ independent of density, the population will be unable to recover from demographic accidents (famine, natural disaster, etc.), and repeated demographic accidents will eventually reduce density to zero. If $r > 0$ independent of density, then density will increase indefinitely. Only when r varies negatively with population density and ranges from positive to negative will density become stable over time.

3. Reduction of human female fertility occurs primarily through behavioral means or behaviorally mediated biological mechanisms rather than through uniquely biological mechanisms.

Hypothesized biological mechanisms that might link fertility negatively to population density independent of behavioral choices or practice, such as the hypothesized reduction of fertility through interaction of physical activity with reduced body fat (Frisch 1975, 1978), seem to operate only under exceptional conditions such as extreme weight loss or unusually high levels of sustained physical activity. The more common pattern is reduction of fertility through behavioral means or behaviorally mediated mechanisms.

When correction is made for the three primary proximate factors known to limit fertility (age of marriage, deliberate fertility control, and breast-feeding-induced lactational infecundability), an estimate of about 15 births over a female's reproductive period is found whether the population is from a developing country, a developed country, or a historical European country (see Wood 1994:77-78, Table 3.5, modified from Bongaarts and Potter 1983). It is evident that all populations have behavioral practices (whether intentional or not) -- or, in the case of breast-feeding, interaction of behavioral practice with a biological mechanism -- that keep fertility well below its potential value. As Wood (1994:31) has noted, "no natural-fertility population reproduces at its maximum biological potential. In other words, behavioral factors operate in every population to limit the fertility achieved by its members."

4. Lactation can be an effective mechanism for reducing fecundity.

Survey data on world populations suggest that the most common contraceptive mechanism is lactational amenorrhea due to prolonged and intensive breast-feeding (Ellison 1994: 267; see also reviews by Gage et al. 1989, Vitzthum 1994) that leads to increased spacing of births: "Differences in interbirth intervals account for most the variation in TFRs (Total Fertility Rate) . . . while differences in lactational infecundability account for almost all the variation in interbirth intervals" (Wood 1994:519). Data from India suggest that lactational amenorrhea "compares quite favorably with that provided by barrier methods, such as condoms and diaphragms, and is only slightly less effective than oral contraceptives and intrauterine devices in the United States" (p. 339 and references therein). There appears to be no biological limitation on the length of the period of lactational amenorrhea (p. 353). Instead, fertility returns in response to a decrease in the amount of breast-feeding as the child ages or, to put it another way, the length of the period of lactational amenorrhea is potentially under the control of a woman via the pattern of breast-feeding that she employs, since the frequency and pattern of suckling is the triggering

mechanism for continual lactational amenorrhea.

The contraceptive effect of breast-feeding is common knowledge (Jelliffe and Jelliffe 1978:117; van Ginneken 1974 and references therein) and therefore part of the cultural repertoire of individuals (see Mayer 1966 for an example from rural Tanzania). Breast-feeding may be combined with sexual abstinence as a way of extending spacing between births (see Singaringbun and Manning 1976 for an example from Java). Thus the pattern of breast-feeding may be culturally mediated (Maher 1992, Stuart-Macadam and Dettwyler 1995), but even so it does not lead to homogeneity on the part of women in terms of the pattern of breast-feeding that they employ. When attempts have been made to model birth spacing using breast-feeding as a causal factor, models that posit heterogeneity in breast-feeding patterns within a population obtain significantly better results than those that assume homogeneity (Wood 1994:361). Therefore the question of interest becomes why "so much variation in suckling behavior actually exists" (p. 370).

5. Decisions are both embedded in a cultural context and responsive to material conditions

Modeling of decision making tends to emphasize either the cultural/ideational or the external condition/material circumstances affecting how decisions are constructed. Our position is that neither the ideational nor the material framework alone adequately accounts for human decision making. Instead we argue that the cultural context provides the framework within which external/material conditions are "interpreted" and evaluated with regard to individual goals. As Bourdieu points out, "the principle of practices has to be sought . . . in the relationship between external constraints which leave a very variable margin for choice, and dispositions" (1990:50). Goals may either be individual in origin or assimilated by individuals from their cultural milieu. The inclusion of individual goals adds to the complexity of modeling decision making in that it

introduces the historical/particular into the decision-making process.³ The distinction we make looks to the cultural context for information on how decisions are framed and to the material/external for an evaluation of alternative decisions within that cultural context. While reduction of fertility for behavioral reasons requires a decision by a female with regard to her behavior (whether to act in a manner consistent with culturally framed behavioral schemas or in terms of an individually constructed choice), her evaluation depends first upon the way in which external conditions are given meaning – or ignored – through a culturally mediated process of evaluation.

6. Individual choicess are triggered by individual experience and made in terms of individual self-interest

For example, though !Kung women are embedded in a cultural context that expresses the need to breastfeed until a child is about three or four years of age, the actual age at which breast-feeding stops has declined under more sedentary conditions when less time/energy has to be expended on obtaining resources. While altruistic acts do occur, they arise under exceptional conditions. For this reason we argue that women will not maintain a replacement level of fertility in the interest of the group -- which has been called "the second tragedy of the commons" (Cohen 1995 and references therein) -- as is assumed by the standard model. Rather, a replacement level of fertility must be a consequence of the dynamics, both cultural and individual, that affect individual female (and family) decision making about becoming pregnant and, if pregnant, whether the fetus will be carried to full term and, if the fetus is carried to full term, whether the newborn offspring will be allowed to survive, and if so, the quality of parenting it receives.

7. The demographic dynamics of one group may impact the population dynamics of adjoining groups

Groups do not exist in total isolation but interact with one another through competition,

territorial conquest, trade, and the like, all of which introduce interdependencies among adjacent groups. Even the absence of interaction due to a “buffer zone” impacts the population dynamics of a group by removing resources in the buffer zone from their catchment area.

8. Both the geographic scale at which resource density is patchy in space and resource variability in time (yearly cycle, long-term trends) affect human population dynamics.

The degree of resource patchiness depends upon the geographic scale being utilized. What might be a more or less random distribution of resources with small units may become patchy at a larger scale (Pielou 1969:100). The baseline scale of interest to us is the catchment area for a group; therefore we are concerned with resources that are more or less randomly distributed over the catchment area in comparison to resources that have a patchy distribution. A second source of variation is seasonal variation in the aggregate resource density during the yearly cycle over the catchment area for a group. A third source of variation is longer-term trends that affect the yearly time-dependent mean yield of resources over the catchment area.

9. The composition of the unit of resource access/ownership is a relevant parameter for human population dynamics.

The unit of resource access/ownership is the set of persons who have coequal rights to exploit resources within the catchment area associated with that group. When the unit is larger than individual (extended) family, it may sometimes be referred to as a corporate group. For a hunter-gatherer group such as the *!Kung san*, the members of a camp make up a corporate group with respect to the *n!ore* (catchment area) of that camp. In contrast, families were the unit of access/ownership of acorn trees for the Cahuilla of southern California (Bean 1972). Although some resources may be individually owned, we are concerned here with the ownership of the bulk of resources from which nutritional and caloric needs are being met.

10. The modeling of population dynamics across different societies requires a

multitrajectory, multidimensional model.

The Model

No single model adequately accounts for demographic processes in human societies. While a logistic growth model may adequately *describe* long-term growth patterns, since for any human population there is eventually a limitation on possible growth, what we want is not descriptive models but theory models (see Read 1990) and, moreover, models derived from theory about the processes that structure the phenomena in question. Although identifying the basic parameters for demographic processes (e.g., birth rates, mortality rates, fertility rates, average age of first conception, average reproductive period, and so on) is not problematic, their values and how those values relate to other conditions and processes are less obvious. An adequate theory model for human population dynamics must involve at least four components, each with its own sub-model.

First of all, fertility rates are ultimately dependent upon decisions made by females with regard to (1) exposure to risk of pregnancy (which relates to decisions made regarding contraception, length of intensive lactation, and sexual abstinence, among other factors), (2) whether to allow the pregnancy to develop to full term, and (3) whether an offspring produced will be kept and, if kept, the quality of parenting it receives. These decisions are made not in isolation but within a cultural context that affects the range of decisions that are considered legitimate and one in which others with whom a female interacts may have an impact on her decision. In addition, her specific conditions (current demands on her time, cost of parenting, desired life style for her family, and so on) affect the parameter values in whatever model is used to relate the above three components to fertility rates. Thus, while the three parts of the decision process listed above are universal, the way in which they play out in any particular situation has

both an ideational and a material component. The first model takes up this aspect of the multitrajectory model in the context of simple hunter-gatherer societies by relating the decision process regarding additional offspring to its consequences for the overall growth rate of the society.

This model lays the groundwork for the second by predicting not a single consequence for all hunter-gatherer societies but variable consequences depending on the resource density in each society's catchment area. It demonstrates that a low-resource/high-resource gradient is also a gradient in terms of the risk of exceeding carrying capacity, and the latter introduces intergroup competition into the multitrajectory model. The competition model examines the various outcomes that are likely under competition between groups, depending upon their respective demographic parameter values.

The competition model introduces a third component, namely, the scale of temporal and spatial variability in resource density in comparison with the geographic scale for catchment areas. The third model addresses this component. It illustrates that the extent to which a successful and expanding competing group (expanding through replacement of other groups or coalescence of groups) will have long-term stability depends upon the difference between the average resource density (taking into account both spatial and temporal variability) for the group prior to expansion and the density after expansion. It is only when the expanded group accrues a substantial increase in its average resource base that it can be expected to be stable. This introduces the fourth component to the multitrajectory model, namely, the composition of the resource access/ownership unit.

The fourth model considers the effect of fission of corporate/political units under population growth, thereby shielding decision making by individuals within the corporate group from the society-wide consequences of population growth. Fission may simply be triggered by

the death of a living relative around whom the basic food-procuring unit was defined, or it may involve a political dimension such as might occur with lineages subdividing in accordance with political alliances. In either case, the consequences of a growing population are shifted from individual decision making to relations between units within the society, thereby leading to intrasocietal conflict. The latter, we suggest, becomes an impetus for centralization as a means to ameliorate it. Even if centralization succeeds in reducing or eliminating intragroup conflict, it does not "solve" the problem of population growth (see n. 3 above).

In brief, our multitrajectory model distinguishes a decision process and three dimensions that affect the way in which demographic processes are likely to play out (Fig. 1). No single trajectory through this three-dimensional space shows how societies change from small-scale to large-scale societies.⁴ Instead, there are multiple trajectories with their own dynamics and potential for stabilization in accordance with particular sets of intra- and intergroup relationships. Stabilization can also include permanent aggression. The next several sections develop the four models that make up the multitrajectory model.

Model 1: Fertility Rates, Equilibrium Population Size, and Resource Availability

Our first model delineates the consequences of decision making, primarily by women as the bearers of offspring, that affect the number of children a female will produce and its impact on the population size of the female's group. The "default condition" of generally high intrinsic rates of population growth even with the mortality rates that apply to traditional hunter-gatherer societies but long-term low average rates of population growth imply that we need to understand the conditions under which there can be stabilization of population size and what happens when population size is not stabilized. For this task we consider a model developed by Read (1986) that links fertility rates and equilibrium population size in comparison with K and resource

availability through two factors: (1) decision making by a woman with regard to the well-being⁵ of her family based on current demands for her time and her desire for as many children as possible - - each of which is culturally mediated -- and (2) the effect of resource density on these time demands.

Decision making. The model is based on two simple relationships and a decision process that links them to interbirth spacing.⁶ The first relationship is the positive effect of population size (keeping the catchment area fixed so that population size is a proxy for population density) on foraging cost per unit of resource per female (see CA+ fig. A), assuming that each female forages for the same number of persons (e.g., her family) regardless of population size. The relationship is positive because as more females forage over the same resource base the foraging cost per female per unit of resource must increase. The second relationship is the negative effect of interbirth spacing on total parenting costs (see CA+ fig. B). As the interbirth interval decreases, each female with offspring will have more dependent offspring; hence the total parenting cost will increase. The negative relationship between interbirth spacing and total parenting costs has been demonstrated for the !Kung san (e.g., Blurton Jones and Sibly 1978; see also extensive discussion and references in Surovell 2000).

We now make three assumptions about decision making that affects the spacing of offspring:

1. Women are willing to control birth spacing. Effective non-Western methods for so doing include sexual abstinence, lactational amenorrhea induced by extended breast-feeding, induced abortion, and infanticide.

2. On the average, a woman will make decisions aimed at ensuring the well-being of her family.

3. Women desire to have many offspring.

We do not claim that these three assumptions are or can be expected to be universally true. Instead, we propose to demonstrate the consequences when these assumptions hold. The degree of applicability of these assumptions relates to the kinds of behaviors that are culturally sanctioned, and therefore the model is culture-specific. One group for which we have evidence for their applicability is the !Kung san: "They want children, all the children they can possibly have," though this is tempered by their view that "children must have strong legs, and it is mother's milk that makes them strong . . . a child needs milk till he is three or four years old at least," and when infanticide occurred "they spoke of the nourishment of the children as the primary reason" (Marshall 1976:166). An infanticide rate of about 1% is reported by Howell (1976:147).

The decision process arises from the fact that women (and men) will usually have multiple tasks that require time and/or energy. When the sum of the time/energy needed for all of these tasks exceeds the amount of time/energy one has or is willing to allocate to them, a decision must be made about which tasks will not be accomplished (see appendix in the electronic edition of this issue). If a woman places a high priority on the well-being of her family (where the meaning of "well-being" is specific to a cultural context), then the activities that are minimized will not be directly related to the well-being of her family and will be activities for which she controls the allocation of time/energy and therefore the decisions aimed at ensuring that she has sufficient time/energy for her family's well-being. A task such as foraging has a time/energy requirement per unit of resource recovered that increases with the number/density of foraging women, keeping fixed both the number of persons for whom each woman forages and the catchment area. Therefore foraging is an activity that is directly related to the well-being of a woman's family and one for which she has little control over the average time/energy cost required per unit of resource obtained. In contrast to foraging, parenting is a time demand over which she does have control, with the number and closeness in age of offspring often serving as major determinant of

the cost per unit of time of parenting.⁷ The cost of parenting is directly related to interbirth spacing of offspring. Consequently, the model posits that interbirth spacing of offspring will be modified when her total available time/energy is insufficient to accommodate both the costs of foraging and the total amount of parenting needed for the well being of her family.

With increasing population density, foraging costs per woman will increase. If they rise sufficiently, then it will become necessary to increase interbirth spacing in order to reduce the total parenting costs if family well-being is to be kept constant (see Fig. 2). With increasing population size and constant total catchment area (that is, assuming that adjoining areas are already being exploited by other groups), we would expect an increase in the spacing of offspring when assumptions 1 and 2 of the decision model are satisfied. As the spacing of offspring increases, a woman's net fertility rate decreases. If the reduction in her fertility is great enough, the net growth rate may become negative and the population will shrink.⁸ Conversely, when the population size declines she will spend less time on foraging, and if the decrease is sufficient then she will have enough time/energy to enable her to reduce the interbirth spacing of offspring. According to assumption 3, she will now have offspring closer together while maintaining the well-being of her family in order to satisfy her desire for as many children as possible, and population size will increase.

The net effect is to couple fertility with population density (or, equivalently, with population size for a fixed catchment area). The population now meets the requirements for density-dependent population growth, namely, that the net growth rate must decrease with increase in population density (including the possibility of a negative growth rate) and increase as density decreases. (see CA+ fig. C; see Read 1998 for a computer simulation). Or, put more simply, the decision process of each woman making choices solely in the interest of the well-being of her family will lead to stabilization of population size when the increased cost of foraging as

population size/density increases sufficiently and when she places a sufficiently high value on the well-being of her family.

The last qualifier points to the fact that the model does not imply an equilibrium population size, K^* , arising from the decision model under all conditions. Rather, it implies that an equilibrium population size will be a consequence only if a forager translates the increased cost of foraging into a sufficient reduction of interbirth spacing so that, on the average, she now has a negative net fertility rate. We can view this implication in two ways. First, K^* is a function of the value a woman places on the well-being of her family, that is, on the amount of parenting she deems needed per offspring. The decision component is triggered by her total parenting cost, which is the cost, C , per offspring times the number, n , of offspring, nC . If C increases, the value of n needed to trigger a change in interbirth spacing decreases, hence, all other things being equal, the value of K^* is inversely related to the parenting cost per offspring that she deems needed for the well-being of her family. A shift in the cultural specification of what constitutes well-being in the direction of requiring an increase in time/energy per offspring will lead to a decrease in the equilibrium population size, even for the same resource base. Consequently, the difference in magnitude between K^* and K is, in part, determined by the cultural specification of what constitutes the well-being of a family. When substantial resources are required to attain what is considered necessary for the well-being of a family, the net growth rate may remain negative despite the presence of sufficient resources for more offspring, even where the mortality rate has been substantially reduced through medical resources, increased food production, and the like.⁹

Second, the decision model may not lead to an equilibrium population size if the translation of increased foraging costs into a change in interbirth spacing does not reduce the net fertility rate sufficiently to lead to a negative growth rate prior to the intervention of Malthusian parameters increasing the mortality rate. This may occur in situations in which, for cultural

reasons (such as religious belief), decrease in average parenting per offspring does not translate into change in interbirth spacing. Another instance in which net fertility may remain high is the special case of migrants moving into a previously unoccupied zone (i.e., one with no competition); Surovell (2000) has argued that under these circumstances the value of r may be high for foragers even though the cost of parenting, measured as the cost of carrying children, is a limiting factor. Yet another instance in which an equilibrium population size may not be the outcome even though the assumptions of the decision model are satisfied occurs when resource density is high.

Resource density: A critical parameter for the relationship between equilibrium population size and carrying capacity when foraging is a primary means for resource procurement is the density of resources. Under conditions of low resource density and where resources are cropped on the basis of their natural abundance with few or no effective means to increase it) foraging results in high mobility because of the relatively quick exhaustion of resources in any one locality (Binford 1980, 2001; Surovell 2000). Classic foraging hunter-gatherers such as the !Kung San, Central Desert Australian Aborigines, and interior Eskimo groups, represent this kind of foraging in regions with low density of resources.

Although hunter-gatherer groups in low-resource-density environments can be perceived as being at risk of exceeding the environment's carrying capacity because of the low density of resources, we argue the opposite. We can measure the buffering of a group against insufficient resources by the expression $K - K^*$. On an individual basis, we can measure the buffering against insufficient resources per person via the expression $(K - K^*)/K^*$.¹⁰ A more rapid increase in foraging costs than is implied by the decrease in resource density implies that both $K - K^*$ and $(K - K^*)/K^*$ will initially *increase* as resource density *decreases*, starting in a high-resource-density region; thus a hunter-gatherer society in a region with lower density of resources has more

buffering against stochastic variation in resource density than one in a region with higher density of resources. As the resource density decreases, K and K^* must eventually converge and therefore $K - K^*$ will eventually start to decrease. On a per person basis, however, the change in foraging costs with resource density decrease implies that $(K - K^*)/K^*$ should continue to increase until K^* is constrained by the decrease in K , indicating that individuals are at less risk with respect to stochastic changes in the value of K as resource density decreases.¹¹ Data on Australian hunter-gatherer groups confirm these predictions (see appendix in the electronic edition of this issue). In addition, foraging regions for these groups vary in size by more than two orders of magnitude between high- and low-resource-density regions. Environmental stochastic effects are likely to be less pronounced when averaged over a larger region in comparison with a smaller region.

We justify the claim about $K - K^*$ and $(K - K^*)/K^*$ by noting that the travel and search time required for resource procurement increases more rapidly per forager than the decline in resource density even if population density decreases in the same proportion as the reduction in resource density.¹² Under relatively low-resource-density conditions then, the model implies that women will decide to increase the spacing of offspring sooner (in terms of population density) than would be predicted from the change in resource density alone. Consequently, stabilization of population size will occur at a population density smaller than would be predicted from the change in resource density alone (see Figure 3), contra Wood's claim that equilibrium will always occur "at the margins of misery" (1998:110). Instead, groups in high-resource-density regions will have K^* close to K or even reaching the Malthusian constraint when the population size reaches the value of K . For these groups a small change in K can lead to K 's being temporarily less than K^* , hence to starvation if the group has access only to the resources in its catchment area.

If neighboring groups are in a low-resource-density region, a roughly steady-state configuration can endure, since each group will stabilize well below its K and is at little risk with

respect to stochastic variation in resource availability. Over the long run we might expect an overall increase in population size in response to technological and other changes that could increase the efficiency of resource procurement, but population size is still coupled with the value of K . Increases in K simply result in increases in the equilibrium value, K^* . The rate of overall population increase under these conditions will be linked to the rate of increase in resource procurement efficiency and not to the potential or net growth rate of the population.

In a region with high resource density, a population will grow until it comes close to or reaches K . When resource density becomes high enough, travel time to resources may become short enough (e.g., catchment areas will be no more than about 10 km in diameter for a local group) that it is unnecessary to carry infants while foraging, especially if not all women need to forage at the same time. For example, Goodale (1971: 45) reports that among the Tiwi, a hunter-gatherer group living in a high-resource-density region, women would leave infants with cowives while foraging or hunting. Neighboring hunter-gatherer groups in high-resource-density regions are not likely to maintain a stable arrangement. A group for which K^* may be temporarily greater than K may respond by expanding its catchment area and thus entering into conflict with neighboring groups.

Model 2: Intergroup Competition

Populations do not exist in isolation but interact in ways that affect the population dynamics of each group. For hunter-gatherer groups the interaction may occur mainly through partial overlap in catchment areas. For other types of societies it may take the form of defended boundaries (see Dyson-Hudson and Smith 1978). Competition, as we have defined it, is a situation in which the use of resources by one group has the effect of removing those resources from use by the other group. It need not involve aggression or warfare, nor does it require defense of boundaries by one

group in exclusion of other groups. Further, though replacement of one group by another may occur, it is not a necessary consequence of competition. Our primary interest in this section is to outline the conditions under which competition leads to coexistence versus the conditions under which it leads to replacement of one group by another.

The model we use was introduced by Lotka (1925) for competition between species and has been discussed extensively by Pielou (1969:53-75). We extend it to the case of competition between two groups each of which has a cultural identity as a distinct society (for the mathematical basis for the model, see appendix in the electronic edition of this issue).

We begin with a single population that reaches its equilibrium population size via internal mechanisms such as those discussed in the previous section and then consider how this baseline condition is affected by the addition of a second, competing population. Competition can be modeled by introducing parameters expressing the effect of one group on the other's growth rate. We will use a modified form of the standard logistic model that replaces K with an initially unspecified value of K^* . We do so because for the baseline condition we are assuming that the group has an equilibrium population size, K^* , where possibly $K^* < K$, whereas the standard logistic model assumes that the equilibrium population size is given by K . For a single population in isolation the modified logistic model of a population growing until it reaches an equilibrium population size uses two parameters: a , the intrinsic net growth rate (i.e., the growth rate that would occur if there were no restriction on the growth of the population, including reduction in fertility through behavioral practices) and K^* . For this model the net growth rate, r , at time t is given by $r = a(1 - P(t)/K^*)$. This expression indicates that the intrinsic growth rate, a , has been reduced in magnitude by the multiplicative factor, $(1 - P(t)/K^*)$, at time t . When $P(t) = K^*$, the multiplicative factor has value 0, the net growth rate is 0, and the population has reached its equilibrium population size and ceases to grow. If we let $b = a/K^*$ or, equivalently, $a/b = K^*$,

then $a(1-P(t)/K^*) = a - bP(t)$. The parameter b has the useful interpretation of measuring the impact of each additional individual on the current net growth rate of the population. For larger values of b , the impact of each additional person on the net growth rate is greater, and therefore K^* becomes smaller because $K^* = a/b$.

When we introduce a second, competing population, we need to identify parameters for the second population in parallel with the parameters for the first population -- that is, we need a parameter for the intrinsic growth rate of the second population and a parameter that measures the extent to which each added individual in the second population reduces its net growth rate. For convenience we use subscripts to indicate whether a parameter refers to the first population or to the second population. Thus, the population dynamics of the first population are characterized by the parameters a_1 (the intrinsic growth rate) and b_1 (the impact on the intrinsic growth rate of each individual person in the population) and the population dynamics of the second population are characterized by the parameters a_2 and b_2 . We will begin by assuming that we have two populations with $a_1 = a_2$ and $b_1 = b_2$.

To introduce competition, we need to identify parameters that measure the impact of additional persons in one population on the net growth rate of the other population, that is, for each population we need a parameter that measures the impact on the net growth rate of one population due to the addition of persons to the other population. Let b_{12} measure the impact on the net growth rate of population 1 due to increase in the number of persons in population 2 and, conversely, let b_{21} measure the impact on the net growth rate of population 2 due to increase in the number of persons in population 1. In order to keep the subscript notation consistent, we rewrite b_1 as b_{11} and b_2 as b_{22} . Thus b_{ij} measures the impact on the net growth rate of population i by the current number of persons in population j , for $i = 1, 2$ and $j = 1, 2$. If the two populations are identical in their characteristics and symmetric in their effects on each other, then $b_{12} = b_{21}$ and

$b_{11} = b_{22}$. We assume that the two populations are isolated from one another with respect to reproduction. For culturally distinct groups the assumption of isolation is not exact, but marriage rules, especially prescriptive rules, ensure that rates of introduction of new individuals from culturally different groups are generally low. The effect of a low rate of movement of individuals between populations for reproductive purposes can be treated as noise and will not change the qualitative relationships in the growth trajectories of the populations in competition.

Four patterns of competition arise from this characterization: (1) population 1 wins out against population 2, (2) population 2 wins out against population 1, (3) populations 1 and 2 converge to a stable equilibrium, and (4) there is an unstable equilibrium between populations 1 and 2.

For hunter-gatherer societies we can measure the parameters b_{ij} , $i \neq j$, by the degree of overlap in the catchment areas of populations 1 and 2. While a stable equilibrium between population 1 and population 2 is theoretically possible with catchment area overlap, it assumes that neither population alters its parameter values. A more likely scenario allows one of the two populations to reduce its coupling with other through change in its competition parameter. If we allow for change in parameter value, then stable equilibrium occurs only when there is little or no overlap in catchment areas (see appendix in the electronic edition of this issue for a more detailed discussion of competition between two groups). We will assume, then, a baseline competition model consisting of two populations with the same parameters and a stable configuration in which there is little or no overlap in catchment areas.

Stable equilibrium and group extinction. When two groups in competition are at stable equilibrium and each has an adequate buffer between its equilibrium population size and the carrying capacity of the region from which the groups obtain resources (see Fig. 3), we will expect long-term stability between them. This configuration allows each group to obtain

sufficient resources even in the face of resource variation without increasing its competition with the other. When the buffer is not large enough to protect against resource fluctuation, a group that is short of resources must either obtain resources at the expense of a neighboring group or face reduction of its population size through higher mortality rates. The former response, say, by population 1, implies that b_{21} increases if population 1 increases the mortality rate of population 2 through aggression or, alternatively, takes over a portion of population 2's catchment area. The effect is to shift what was a stable equilibrium in the direction of a configuration in which population 1 wins out in competition with population 2, and if the parameter change is large enough population 2 will face extinction unless it withdraws from competition or counters the actions of population 1. Withdrawal from competition is likely to be only a temporary solution, because increase in population size and expansion of its catchment area by population 1 will bring it back into competition again with population 2. In either case, population 2 is eventually eliminated unless it can counter the actions of (i.e., engage in aggression against) population 1 (see appendix in the electronic edition of this issue).

Cyclical pattern of expansion and fission. While population 1 expands both its size and its catchment area so as to include the catchment area of population 2 under the above scenario, the expanded catchment area and increased population size may be only temporary. As a hypothetical example, suppose that one of several competing neighboring groups is able to expand its territory through displacement of others and thereby translate its potential for population growth into territorial expansion. If it expands into neighboring territories without increase in population density, then the local cost of resource procurement is decoupled from the overall change in population size and the local population dynamics (e.g., relationship of birth spacing to cost of resource procurement) will be largely unchanged.¹³ Consequently, after territorial expansion without increase in population density, the equilibrium population size of a subgroup for the

original catchment area has not changed, and therefore we can assume that the pre-expansion person/resource dynamics are essentially unchanged. In effect, from a population dynamics viewpoint the territorial expansion is similar to what would have occurred had the original, neighboring groups simply coalesced into a single group without change in the location of groups or in their catchment areas.

The lack of change in the parameters expressing the person/resource dynamics for catchment areas implies that fission of the larger group will give rise to new groups that can survive, potentially, on a smaller territory but with the same population density than the group prior to fission. The relationship of a subgroup to local resources will be essentially the same as the relationship it had before territorial expansion, since there is no need to postulate any change in person/resource dynamics as part of the population expansion. There is, however, a cost to maintaining a larger population as a single unit. More subgroups must be integrated into a cohesive whole, and links between subgroups must be maintained over longer distances. Further, the number of links of a subgroup to other subgroups must be greater than before if isolation of subgroups or small sets of subgroups is to be avoided.

We suggest that fission is a likely outcome under these circumstances, since the relationship of a subgroup to resources will be largely unchanged but subgroups will have higher costs if the expanded population is to maintain itself as a cohesive whole. In effect, fission costs little or nothing in terms of resource availability per person and reduces the cost of maintaining linkages with distant subgroups required to keep the larger group intact. Fission will simply return the territorially expanded group to smaller subgroups spatially configured similarly to the situation prior to expansion.

Stability through shift to a higher population density. In contrast, increase in population size through increase in population density as well as territorial expansion introduces a cost in

terms of mortality rates if a subgroup breaks off from the expanded group. If the larger group were to split into subgroups, each with a territory comparable to its catchment area prior to territorial expansion but now with an increased population density, a new subgroup would have a population density that could not be sustained by the catchment area available to it. Prior to the population increase it had a population density determined by its equilibrium population size, K^* , in accordance with its catchment area; after the increase it had an equilibrium population size $K^{*'}$, with $K^{*'} > K^*$. The extra population was maintained only because each local subgroup was able to get resources not only from its immediate catchment area but also from the entire territory of the expanded group of which it was a part. In contrast, a new subgroup would have access only to the resources of its own catchment area, and therefore its population would be bounded by its previous equilibrium population size, K^* . But if the population size for that catchment area grew to $K^{*'}$ when territorial expansion took place and $K^{*'} > K^*$, then the mortality rate for the subgroup would have to increase until the population size was once again given by K^* .¹⁴ The increase in mortality rate that must be experienced by a subgroup if it breaks off from the expanded group with its higher population density becomes a substantial deterrent fission.

Long-term outcomes. Though both patterns of population expansion involve territorial expansion and, presumably, some kind of new social organization, the long-term outcomes for the two scenarios differ substantially. Territorial expansion without increase in population density can result in a cycle of territorial expansion by one of the competing groups followed by a return to smaller territorial units. From the viewpoint of a local group, the system will appear unstable, since each local group is at risk of losing out in competition with a neighboring group.¹⁵ But the pattern of expansion followed by fission is a cycle that could repeat itself without any long-term change in the structural configuration of a large territory partitioned among local groups. There would be a kind of stability through the cyclical repetition of territorial expansion by one

subgroup followed by the splitting of that group into smaller groups.

The pattern of endemic warfare found in parts of New Guinea appears to be an example of this cyclical pattern. For example, Strathern (1971) reports that local groups around Mount Hagen may expand their territorial base through warfare, but in time fission takes place and new local groups are formed. A similar pattern prevailed for the Kuma (Reay 1959).

Model 3: Spatial and Temporal Variability of Resources

We have suggested that a group in competition with neighboring groups may increase in size through territorial expansion with or without increase in population density. As noted above, these two types of expansion will have different, long-term consequences. We need now to characterize the conditions under which we expect each of these types of expansion to occur. The key factor is the scale at which there is spatial and temporal variation in resource distribution in comparison with the scale for catchment areas and the temporal scale for resource variability.

By the *scale of spatial variation* in the abundance of a resource we mean the average size of a patch for that resource, where a patch is a region within which the resource has an approximately uniform and relatively high-density distribution in comparison with areas outside it. By the *scale of the catchment area* we mean the average area of the catchment area for a group in the context of competing groups. We assume that prior to any territorial expansion all catchment areas are comparable in size. By the *scale of temporal variation* in resource abundance we mean the time period for cyclical reduction and increase in the abundance of a resource. Generally the time scale is likely to be on a yearly basis, but it could be longer, as for example with cyclical changes in rainfall patterns.

We assume that the cultural rules (such as corporate or individual ownership of resources, and rules for sharing of resources) by which minimal social units (such as a nuclear or extended

family) have access to resources ensure that the average abundance of resources is available to groups throughout the catchment area at any point in time. We do not assume any particular means by which this occurs, and access might be gained in a number of ways, such as movement of social units and redistribution of resources. Nor do we require that any single social unit potentially have access to all the resources in the catchment area. Rather, we are assuming only that no social unit faces a shortage of necessary resources for which other social units have a local surplus.

One group with seasonal variation in resource abundance. We first consider a single group and its response to temporal variation in resource abundance. Under the above assumptions we may assume that a relevant parameter for population dynamics for a group is the average resource abundance over the catchment area at a point in time. The average resource abundance may also vary over time, and in general we expect more such variation in more seasonal environments (Fig. 4). According to Liebig's Law of the Minimum, the equilibrium population size, in the absence of storage, responds to resource minimums in the cycle of varying resource abundance.¹⁶ Therefore, even though the total resource abundance may be about the same, the group facing greater temporal variability in resource abundance will have a lower equilibrium population size.

Competing groups with seasonal variation in resource abundance. We now consider three competing groups. Suppose that the scale of spatial variation in resource abundance is substantially smaller than the scale of catchment areas (see Fig. 5). Regardless of the location of a catchment area, the average resource availability is about the same and therefore so is the temporal graph for resource variation. If groups 1 and 2 were to coalesce, the resource availability per individual for the newly formed, larger group would be essentially the same as it was initially for the two groups of which it was composed. We expect no change in population density for the combined group in comparison with the density for each of the two groups prior to coalescence.

In terms of competitive advantage, the increase in the catchment area for the coalesced group, group 1+2, implies that the parameter b_{13} is now reduced to a new value, $b_{1+23} < b_{13}$. This is because the portion of the catchment area represented by overlap in the two catchment areas measures the competitive impact of one group on the other due to the use of resources otherwise available to that group. For group 3 the portion of the catchment area represented by overlap has not changed, but for group 1+2 the approximate doubling of the catchment area reduces the impact of the overlap portion by approximately half. The effect on equilibrium population size, assuming that parameter values do not change further, is mainly a slight increase in the size of group 1 (Fig. 6, bottom). There has been minimal impact on the competitive relationship between group 3 and the coalesced groups 1 and 2 in comparison with the situation before they coalesced (Fig. 6, top).

Thus the larger group formed by coalescence of groups 1 and 2 has achieved neither a gain in resource availability in comparison with the two groups of which it is composed nor a competitive advantage. It now has the cost, however, of maintaining itself as a larger group. Returning to two constituent subgroups has no cost in terms of mortality rates, and therefore we assume that the larger group will split into subgroups comparable in size with the groups from which it was formed.

A different scenario occurs when (1) the scale of resource variability is large in comparison with the scale of catchment areas, (2) there is seasonal variation in resource abundance, and (3) seasonal resource abundance in one resource patch is out of sync with variation in other resource patches (Fig. 7). Groups 1 and 2 have the lowest equilibrium population sizes because of the low abundance of resources for group 1 in the first season and for group 2 in the second season (Fig. 8). If they now coalesce into a larger group with a new, larger catchment area, this new group will have greater resource abundance because the seasonality in

resource abundance for catchment areas 1 and 2 is out of sync and one area has a higher abundance of resources when the other area has a lower abundance of resources. The net effect is greater equilibrium population size for group 1 + 2 than for group 3.

The population of the consolidated group will increase in size and therefore in density until it reaches its new equilibrium population size, K^*_{1+2} . Since $K^*_{1+2} > K^*_3$, the new group will have a competitive advantage over group 3, since $b_{33} = b_{22} = b_{11} > b_{11}^*$, where $a/b_{11}^* = K^*_{1+2}$ (Fig. 9). Resource variability on a scale larger than the scale for catchment areas introduces a qualitative change in the competitive relationship among groups that initially had similar parameters. Coalescence of groups that are out of sync in terms of seasonal resource variability can shift a competitive relationship to one in which the newly formed group may win out in competition with other groups. Since the population density has also increased, fission is not as likely.

While the new group may win out in competition with smaller groups, territorial expansion is ultimately limited by two factors. First, smaller groups have the option of coalescing in the face of competition from a larger group that then restructures the competition as competition between groups with comparable parameters. Second, as the size of the territory expands, the scale of the total catchment area of the expanding group will increase and eventually exceed the scale of spatial variation in resource abundance. At this point the relationship of the group to resources matches the configuration in the model discussed above, in which increase in the territory of a group does not lead to increase in population density. Fission now becomes a more likely outcome of further territorial expansion.

Model 4: The Resource Access/Ownership Unit

The logistic model for population growth assumes that the addition of a person to a group has equal effects on resource availability for all persons in the group. Similarly, the competition

model assumes that the addition of a person in one group has equal effects on resource availability for all persons in the other group. These models fail to take into account that the culture frames the way in which individuals have access to resources. Ownership of resources ranges from corporate to individual, and the kind of ownership may depend upon the particular resource. When food resources are obtained through agriculture or horticulture, rights to land and access to land become major determinants of the ability of individuals or social units to produce food resources. Coupled with rights of ownership or access are rules of inheritance that affect the distribution of land rights and access to land in the next generation. These rights are highly variable from one society to another.

The assumption that impacts on food resources arising through change in the population structure are distributed across all individuals in a group is valid only to the extent that cultural rules for ownership and sharing of resources ensure the availability of resources to all with little inequity. So long as local surpluses and shortages are eventually redistributed over time scales relevant for decision making, the assumptions of the models are satisfied, and we can ignore (for modeling purposes) the details of how individuals or social units have access to resources. When a large animal is killed, a local surplus is created, and in most if not all hunter-gatherer societies there are cultural rules requiring sharing or redistribution of the meat. Here the time scale for procurement and redistribution is measured in days and is comparable to or shorter than the time scale for making decisions about spacing of offspring. Contrariwise, when there is storage of foods, local food surpluses may be stored and owned by the food-producing unit with only limited redistribution. Any redistribution may be linked to rituals or other events that occur only annually or even less often.

Another complexity not taken into account by these models relates to the potential growth in population size of the resource access/ownership unit.¹⁷ In some cases the corporate group for

resource access/ownership may be an extended family, and the size of extended families, for a given fertility rate, is independent of overall population size. Extended families are typically based on common affinity to a living ancestor, and they are likely to split along sibling lines when the focal ancestor dies. In other cases, such as lineage systems, the corporate group may grow if there is a net positive growth rate, but it may also split for internal, structural reasons as the number of members increases. The lineage may subdivide when the members of a subgroup within it no longer see it as in their interest to remain part of it. Internal conflict that may arise as population size increases can be resolved through splitting into smaller, daughter-lineage groups.

In both of these examples the size of the corporate group for access to and ownership of resources is largely independent of population growth. Even if the current spacing of offspring leads to a net positive growth rate, fission of the corporate unit may uncouple the long-term population size of the corporate group from a net positive growth rate for the population as a whole. In this situation population growth will translate into an increase in the number of corporate groups and not in the size of each corporate group.

According to the decision model on birth spacing, it is when a woman's costs (parenting costs plus food procurement/preparation costs) are high that she makes a decision to defer the next pregnancy. Where the size of corporate units is uncoupled from the long-term population growth of the group as a whole and the corporate group is also the unit for resource access/ownership, then her food procurement/preparation costs will be unaffected (in the short run) by any increase in the population size of the group as a whole. Therefore she will space offspring on the basis of her assessment of her costs, and her decision will not be affected by its consequences for net population growth. If her assessment leads to birth spacing that translates into a net positive growth rate, then the size of the group as a whole will increase through increase in the number of corporate groups (cf. Cowgill 1975). If her assessment leads to birth

spacing that translates into a net negative growth rate, then the population size of the group as a whole will decrease. In both cases the model implies that her decisions about birth spacing will not be affected by the changes in the overall population size of the group.¹⁸ What will be changing is the number of corporate units attempting to utilize the same catchment area.

With an increase in the number of corporate units and a catchment area bounded by the presence of other groups, the outcome of an increase in the number of corporate units must be conflict between corporate units for access to resources (Carneiro 1970). In contrast to competition that may lead to aggression between groups in different societies, the conflict under the conditions discussed here is conflict *within* a society. While individual corporate units may be wiped out, within-group conflict does not lead to an increase in the overall catchment area, and therefore we will expect endemic conflict under the conditions posited here. Population size is stabilized only through elimination of excess corporate units (e.g., directly through aggression or possibly through migration if that is feasible), but the positive net growth rate of corporate units not engaged in conflict is unaffected and consequently an excess number of new corporate groups is continually produced (cf. Evans-Pritchard 1940, Irons 1975, Sahlins 1961, Strathern 1971, Brown 1964).¹⁹

Summary

We have distinguished three independent dimensions each of which has an effect on how the basic decision-making model will play out (see Fig. 1).

The first dimension is resource density. The effect of higher resource density is to decrease the spacing of births more rapidly than the increase in density. As a consequence, the model predicts an equilibrium population size for hunter-gatherer groups in regions with low resource density and a nonequilibrium population size in regions with higher resource density.

The second dimension is the patchiness (taking into account simultaneously both geography and seasonality) of resources. With low patchiness relative to the size of a catchment area, we expect endemic intergroup competition, as all groups have comparable time and geographic scales for access to and quantity of resources. High patchiness at a scale below the size of a catchment area leads to stable coalescence of groups (or takeover of territory), as the population density will increase after coalescence because the larger group has access to a larger average resource base throughout the year.

The third dimension is the degree of decoupling from population growth of the corporate group through which individual families have access to resources. When the corporate group is decoupled from overall population growth by virtue of fission, then we predict intragroup conflict, since growth in the number of corporate groups will lead to a population size that exceeds the carrying capacity of the group's total territory.

In Figure 1 we have indicated the eight possible configurations of High (H) and Low (L) for each of the three dimensions, Resource Density, Patchiness of Resources and Decoupling of Corporate Group. Each configuration, with the exception of (L, L, L) and (L, H, L), has a different pattern for its outcome ranging from stability for the (L, L, L) combination to centralization for the (H, H, H) combination.

Conclusions

The multitrajectory model that we have developed underscores the complexity of the relationship between population growth and societal change. Rather than population growth's being a universal "prime mover" for societal change, as some have argued, or the exceptional condition, as others have argued or assumed, the matter is more complex, especially since both parameter values and structural relationships that affect the long-term demographic outcome are culturally

dependent. The cultural dimension makes it difficult to consider the demographic consequences of the potential for rapid population growth for a group as being explicable within an ecological context alone. Moreover, groups do not exist in isolation; only by including the existence of other groups and their potential for competition can we hope to have realistic models of these factors. We have also argued that specifiable types of social organizations and subsistence strategies will have the capacity for changing the organizational and structural relationships of their societies. There is nothing inherent in hunter-gatherer or other social structures that results in zero population growth. It is not growth itself that is automatic or a given but the potential for rapid growth that always exists among humans. Potential growth is always under some degree of control, with the control ultimately linked to carrying capacity, but control does not necessarily mean absence of growth. It is probably fair to say that in most times and places in the recent past, population growth and consequent competition were the norm. It is this reality that we must take into account in our models.

The outcome of the self-centered decision model for reproductive decisions may be a population in equilibrium or one that fails to achieve equilibrium, depending on the valuation placed on the well-being of one's family and how that translates into birth spacing. The latter depends not only on one's evaluation of having another child under one's current circumstances but on the way in which that evaluation is made within the context of cultural meanings that may transcend individual calculations. Culturally imposed limitations (including religious ideology) on contraceptive methods and/or abortion may lead to direct conflict between individual calculations about the desirability of having another child under one's current circumstances and actions that are socially acceptable.

Throughout our discussion we have kept the self-centered decision model constant while varying parameter values to make it more evident that seemingly radically different consequences

"on the ground" may simply reflect the differential effects of the same decision model in different contexts. At the same time, restructuring of the interplay among individual decision making, societywide demographic implications, and intergroup relations does occur, making any single structural model of this interplay inadequate. Rather than a single model we have posited a multitrajectory model that can assume different structural states depending on both the cultural and the ecological context. The multitrajectory model shifts the emphasis to understanding the conditions under which transitions from one state to another may occur and determining when those transitions are likely to represent a long-term restructuring of relationships rather than a "temporary" readjustment to a perturbation.

Since larger-scale systems have additional costs associated with them (for example, the costs involved in maintaining an organizational structure that links social, economic, and other units) there is a tendency for larger-scale organizations to dissipate. Ultimately individuals and groups must bear those costs and therefore must make either individual or collective decisions about the benefits obtained versus the possibility of "opting out" as more or less self-sufficient units. We have argued that a key factor for evaluating the consequences of this kind of calculation is the demographic consequences of restructuring. When restructuring produces an increase in population density, there is a cost for opting out, namely, the introduction of Malthusian constraints because the increased population density cannot be maintained under the prior, lower level of organization. As individuals or groups opt out, it becomes increasingly difficult to meet daily metabolic requirements in comparison with one's earlier condition, and this makes it more likely that some kind of evaluation will be made of the organizational cost of opting out versus its increasingly apparent Malthusian consequences.

We suggest that it is this kind of dynamic that helps us to understand the different trajectories that different societies and cultures have followed, ranging from hunter-gatherers that

have maintained small-scale societies virtually to the present to Western societies for which change in both organizational form and population size/density has been more or less constant throughout their history. For some trajectories the long-term population consequence is stability in the classic sense of a stable equilibrium point, such as our model for a hunter-gatherer society in a low-resource-density region. For other trajectories the stability takes the form of an attractor – the locality within the phase space for population trajectories in which the populations are most likely to occur -- but has no single equilibrium point. Our model for populations in high-resource-density areas in which the scale of spatial variation in resource abundance is small in comparison with the scale of catchment areas is a case in which an attractor characterizes the long-term outcome. Yet other trajectories may lead to quasi-stability arising from the decoupling of groups otherwise linked through resource competition via a no-man's land in which neither group can maintain a long-term presence because of competition from the other. The latter introduces yet another possible trajectory, namely, a more highly centralized system that can control between-group competition and thereby gain access to the no-man's land, thus gaining an immediate increase in the carrying capacity of the region containing the no-man's land and creating the conditions for its own maintenance as population density increases in response to the acquisition of the no-man's land's resources -- but that is another story.

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Fig. 1. *The three dimensions identified as affecting the outcomes of the decision-making model and the outcomes predicted for the eight configurations defined by extreme values on each dimension. H, high; L, low.*

Fig. 2. *Interbirth spacing and total parenting costs (schematic).*

Fig. 3. *Relationship between K (straight line) and K^* (curved line) illustrated by two groups with different resource density. Group 1 has a larger buffer against resource shortage than Group 2.*

Fig. 4. *Hypothetical yearly cycles with little and substantial seasonal variation in resources. Resource abundance at a point in time is averaged over the relevant catchment area. Carrying capacity is determined by the minimal resource abundance during the year. Dashed line, K for pronounced seasonal variation in resource abundance; solid line, K for minimal seasonal variation in resource abundance. Both graphs have approximately the same total quantity of resources summed over the year (areas under the curves are approximately equal).*

Fig. 5. *Scales for resource variation (small squares) and catchment areas (circles). Darker shading, higher average resource abundance. The groups with catchment areas 1 and 2 have consolidated into a single group with a large catchment area. This area has the same average resource density as the smaller catchment areas, and therefore there will be no increase in population density. The consolidated group (1 + 2) will have no competitive advantage over group 3.*

Fig. 6. *Competitive relationships between group 1 and group 3 before group 1 and group 2 coalesce (top) and between subgroup 1 of group 1 + 2 and group 3 after group 1 and group 2 coalesce (bottom). The impact of group 3 on subgroup 1 has been reduced, but the carrying capacity of subgroup 1 has not changed. The stable equilibrium point shifts slightly to the right in favor of subgroup 1. No qualitative change in the relationship between (sub)group 1 and group 3 has taken place.*

Fig. 7. Scales for resource variation (squares) and catchment areas (circles) in two seasons. The groups with catchment areas 1 and 2 have consolidated into a single group with a large catchment area. This area has greater average resource abundance than the smaller areas for both seasons, and therefore there will be an increase in population size and population density. The consolidated group (1 + 2) will have a competitive advantage over group 3.

Fig. 8. Average resource abundance for each of the three catchment areas in Figure 7 (top) and for catchment areas after groups 1 and 2 have coalesced (bottom). Solid or dashed line, abundance by season. Carrying capacity for a catchment area is constant and based on the minimal resource abundance during the year. The combined group now has a larger carrying capacity, K_{1+2} , than either group 1 or group 2 before coalescence.

Fig. 9. Competitive relationship between group 1 and group 3 before (top) and after (bottom) group 1 and group 2 coalesce (see figs. 7 and 8). After coalescence, the impact of group 3 on group 1 has been reduced and the carrying capacity of group 1 has increased; the stable equilibrium point changes qualitatively to a configuration in which group 1 + 2 wins out in competition with group 3.

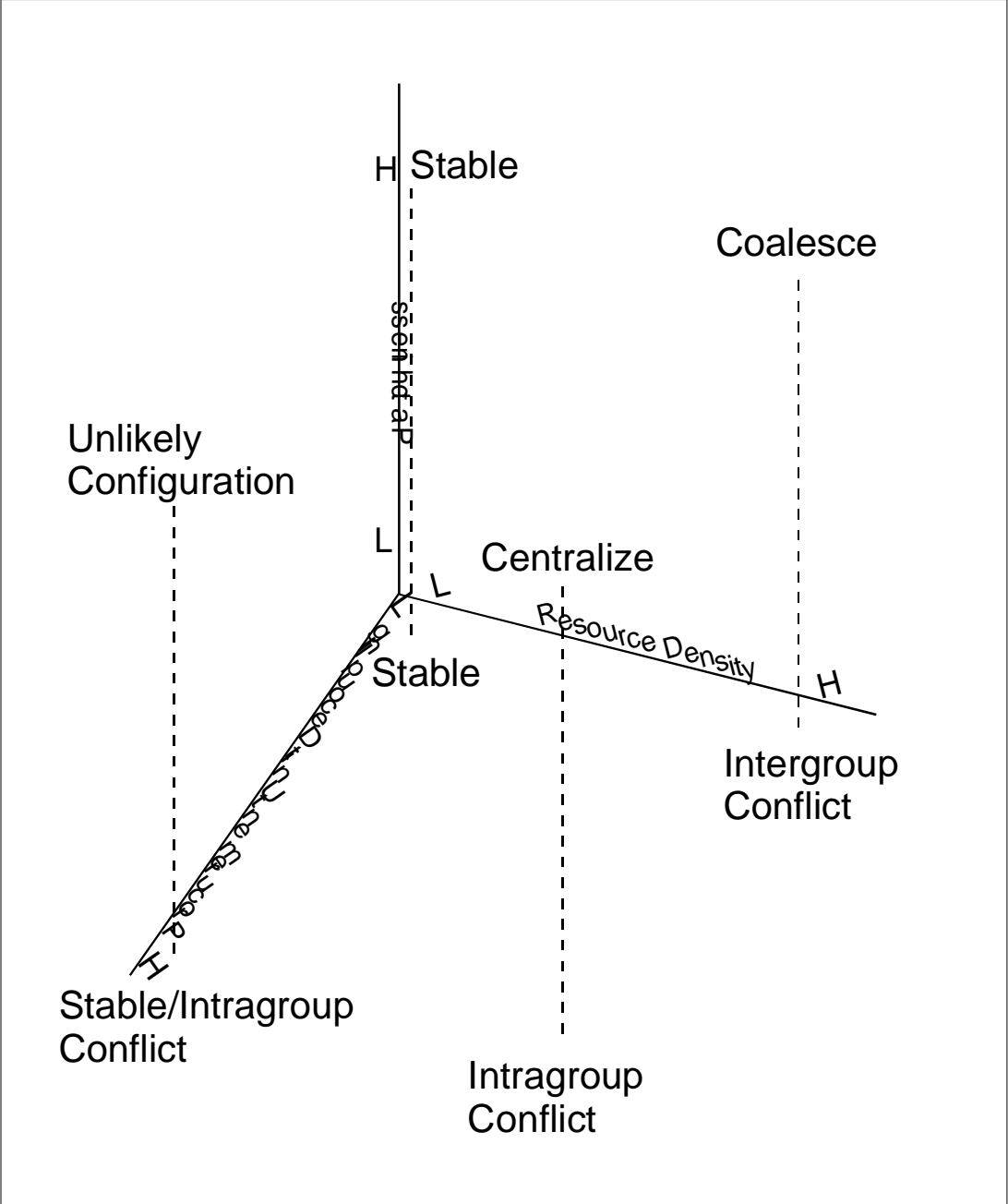


Figure 1 - Read/LeBlanc

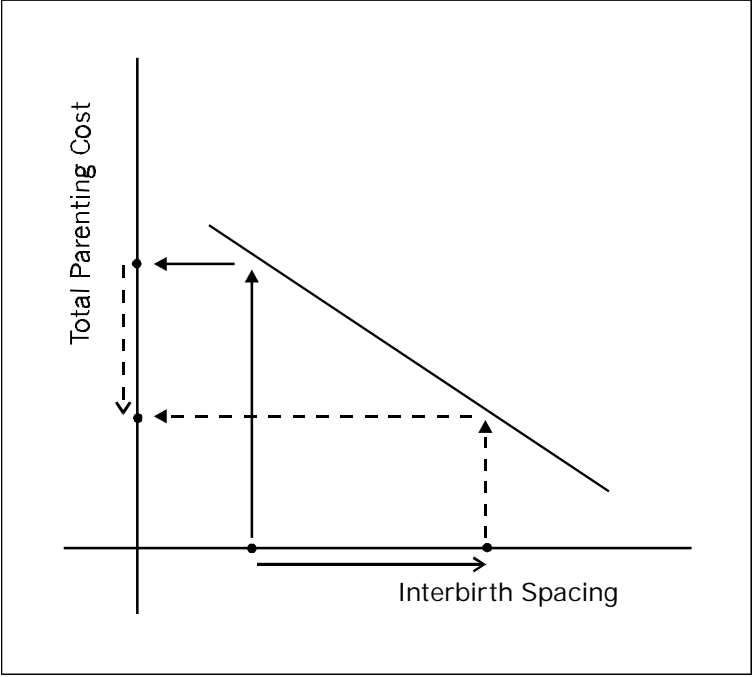


Figure 2

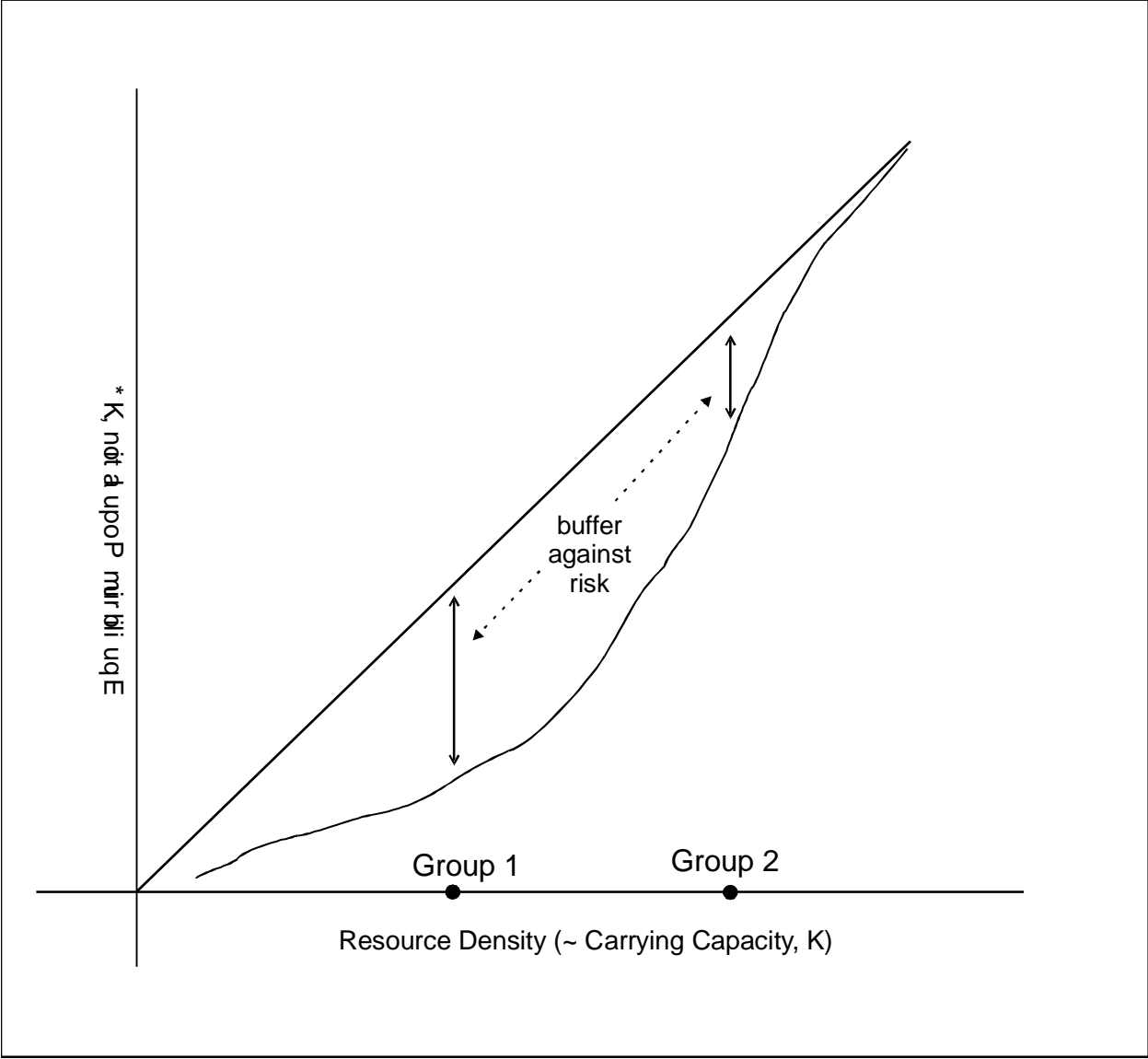


Figure 3 -- Read/LeBlanc

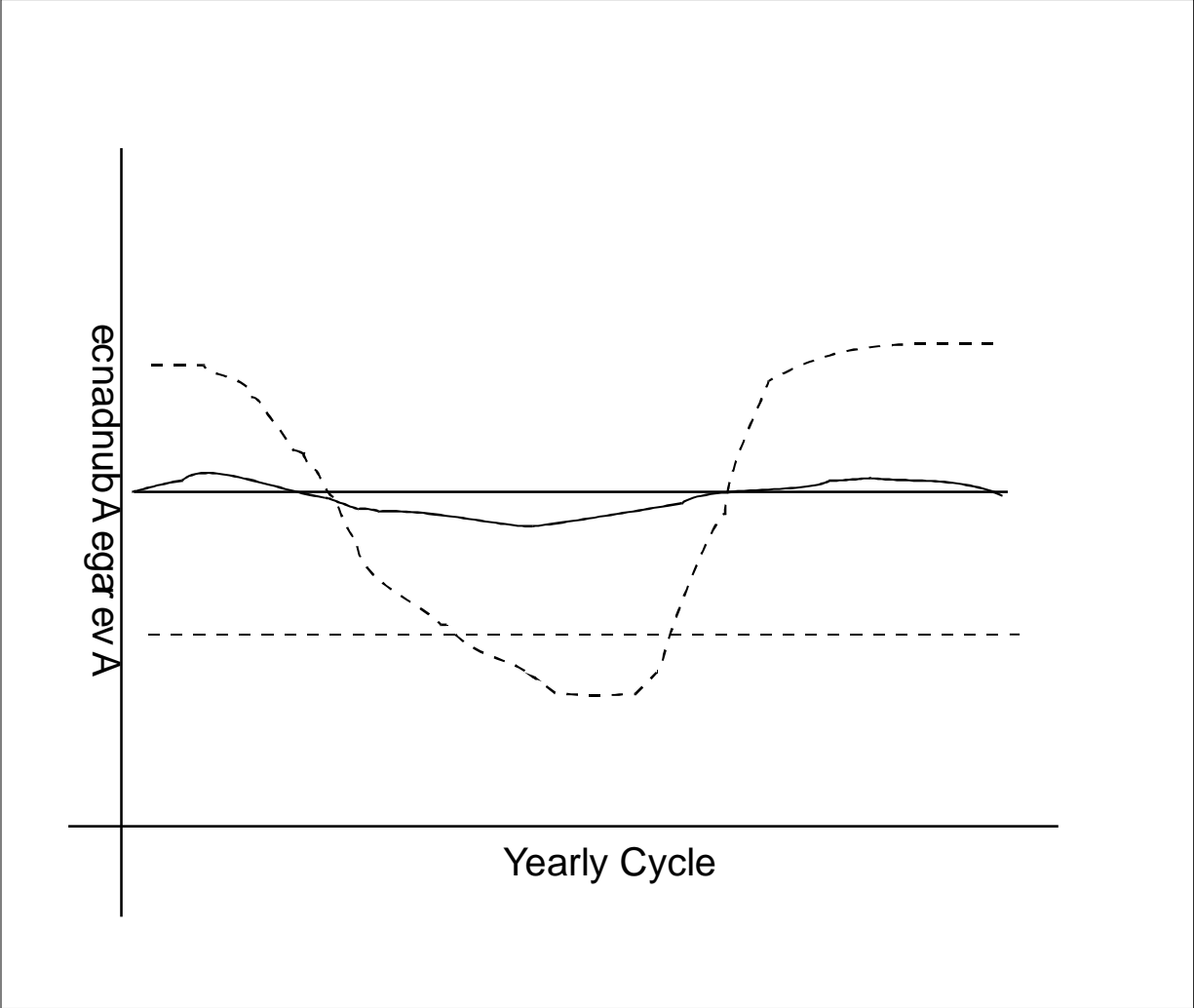


Figure 4-- Read/LeBlanc

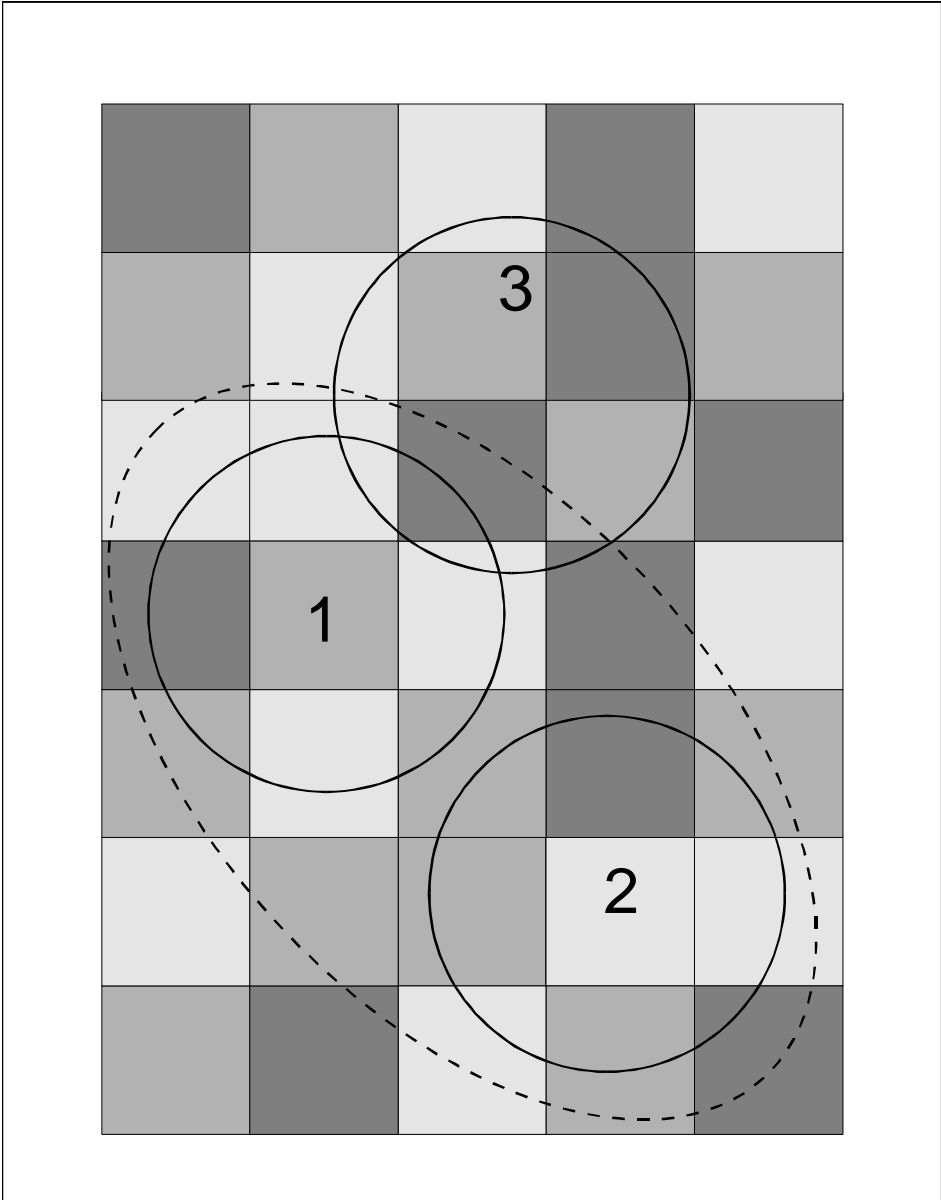
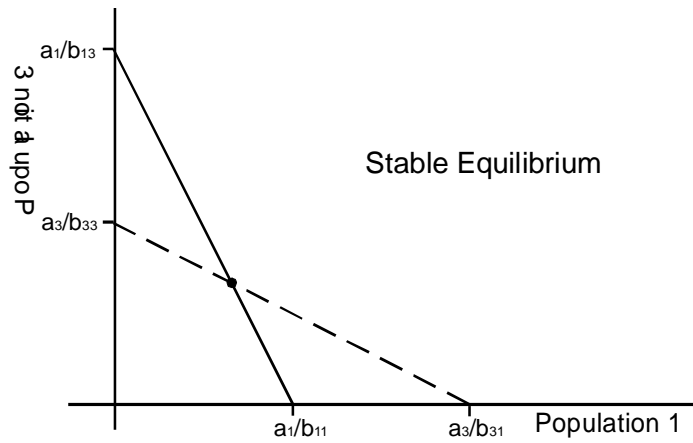


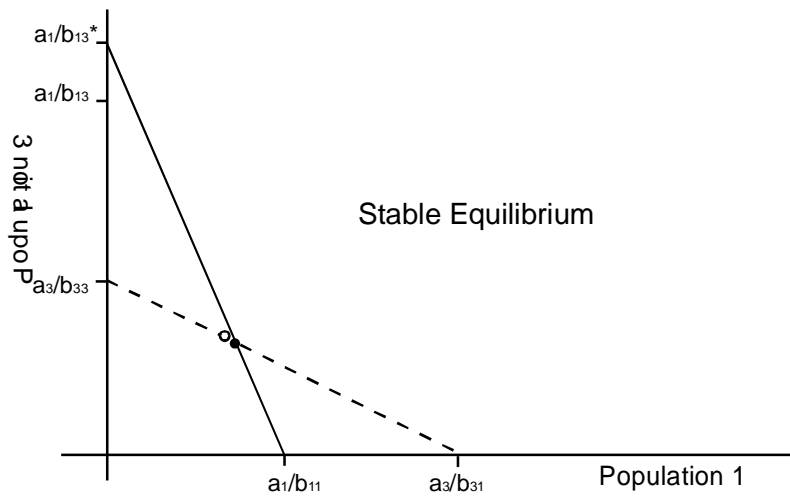
Figure 5--Read/LeBlanc

Partial overlap: $b_{13} = b_{31} < b_{11} = b_{33}$



Single equilibrium point

Partial overlap: $b_{13}^* < b_{13} = b_{31} < b_{11} = b_{33}$



Single equilibrium point

Figure 6--Read/LeBlanc

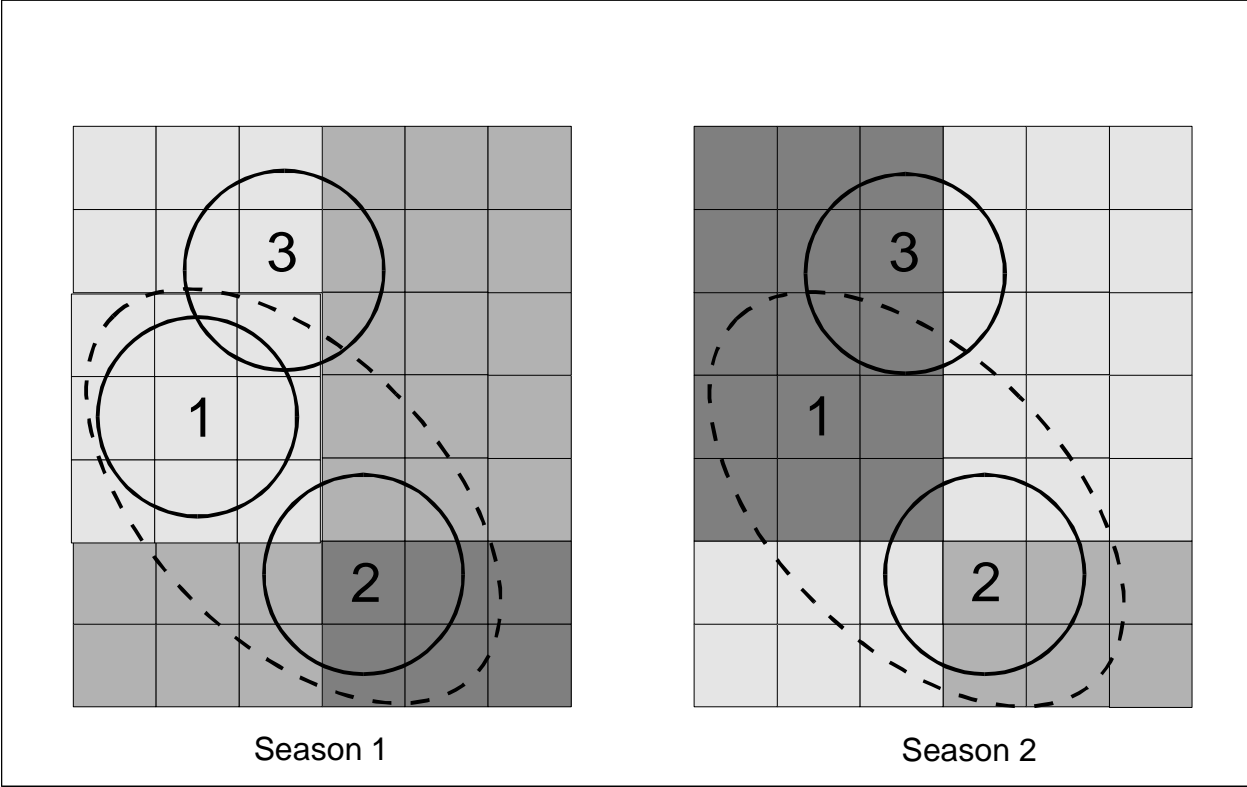


Figure 7--Read/LeBlanc

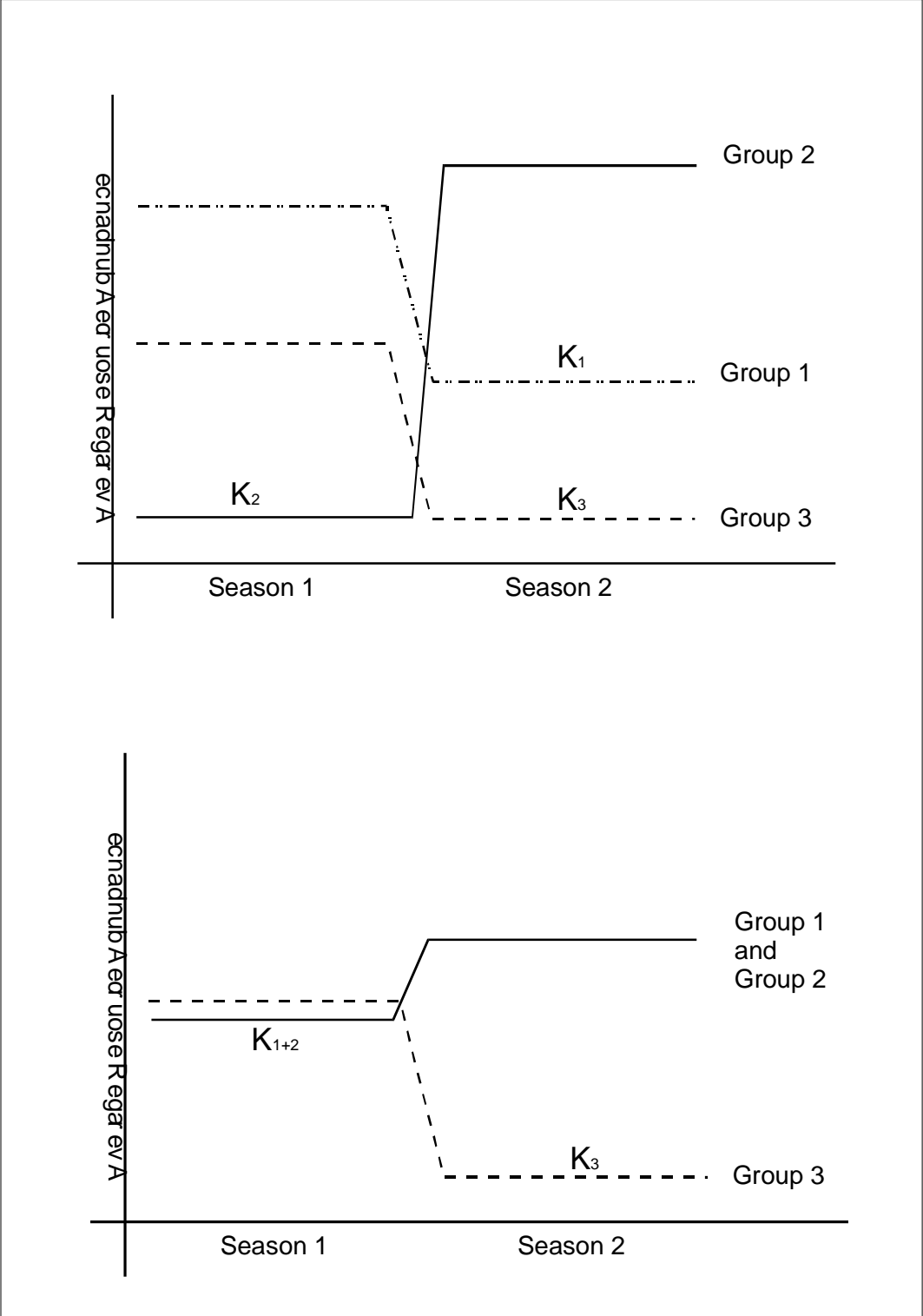
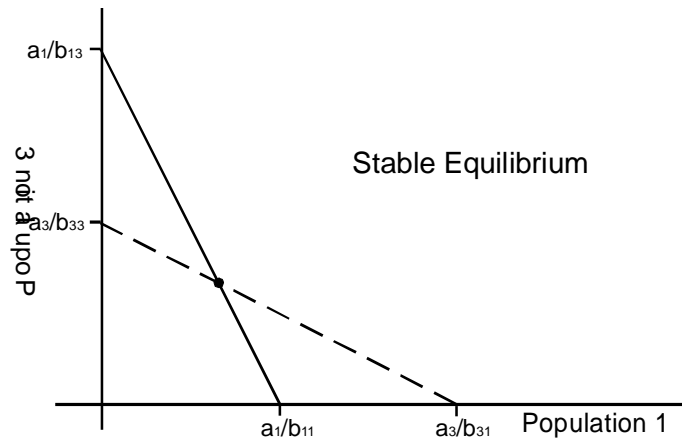


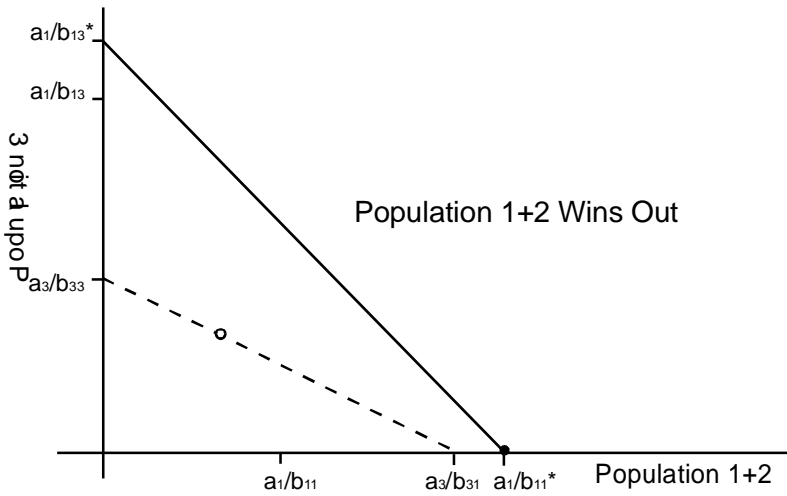
Figure 8--Read/LeBlanc

Partial overlap: $b_{13} = b_{31} < b_{11} = b_{33}$



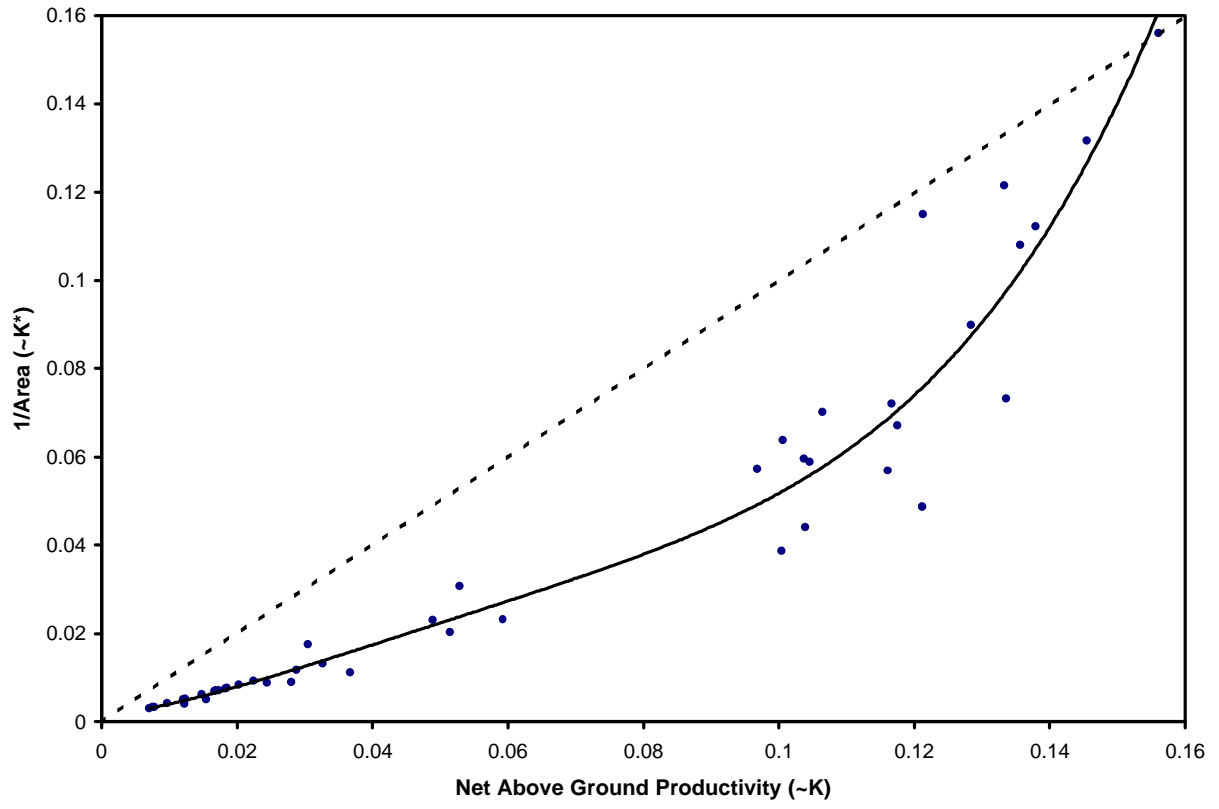
Single equilibrium point

Partial overlap: $b_{13}^* < b_{13} = b_{31} < b_{11} = b_{33} > b_{11}^*$



No joint equilibrium point

Figure 9--Read/LeBlanc



Endnotes

¹ We thank the anonymous referees for their helpful comments on the manuscript. One referee in particular made unusually detailed and thoughtful comments that led us to make a number of changes that we hope have clarified the argument and removed the ambiguities of an earlier draft. [Supplemental materials appear in the electronic edition of this issue on the journal's web page (<http://www.journals.uchicago.edu/CA/home.html>).]

² We do not deal with the concept of carrying capacity in detail. We realize that carrying capacity is dependent on human behavior. What one is willing to eat, how much the resource has been cropped in the past (Winterhalder et al. 1988), the technology available to gather or produce it, and capital improvements that have been made (e.g., terraces) are some of the factors that affect carrying capacity. Nevertheless, in the time spans and societies of interest to us carrying capacity, whatever it may be, is relatively constant in most cases. Most increases in carrying capacity over which humans have any control will involve increased costs, and these costs will be part of a decision matrix including the benefits of incurring them. Dewar (1984) has reviewed the concept of carrying capacity (see also Chapman 1988), especially in relationship to humans, and there is no need here to reconsider this literature in detail. We do want to stress the distinction between the equilibrium population size, K^* , as determined through population dynamics, and an intrinsic limit – carrying capacity, K – determined by measuring the total available resources. The latter represents the population level beyond which resources are inadequate for normal biological functioning, while the former represents the population level, if any, at which population size stabilizes even though there may be adequate resources for a larger population size. We will make use of both concepts.

³ The population dynamics of Tikopia (Firth 1936, 1959, 1961; Borrie, Firth, and Spillius 1957) illustrate the way in which decisions affecting population growth and control are historically contingent. Traditionally the Tikopia had a number of communally encouraged mechanisms to control population, including celibacy, coitus interruptus, a cultural norm of two children, abortion, and infanticide. The decision-making and productive unit was the family or the individual woman. Even though chiefs exerted some overall control over resources and reproduction, there is no evidence that they could enforce reproductive behavior. When, under pressure from missionaries and outsiders, infanticide and abortion were outlawed, the range of decisions available to women suddenly changed. As a consequence, the population grew from around 1,280 in 1929 to 1,750 in 1952 (37% growth with $r = 1.4\%$ per year). In the absence of abortion and infanticide as options, women were no longer able to achieve their previous spacing of births and the consequence was population growth. When drought hit in the early 1950s, the

population was saved from starvation only by food shipments from outside and out-migration became a major means of controlling population size. A less well-documented but quite similar case is found on Ontong Java and nearby islands (Bayliss-Smith 1974). A similar situation also occurred in Europe, where, in spite of a great number of social mechanisms to control population growth, populations increased rapidly from 1750 to 1850 and famine and out-migration played increasingly important roles (Langer 1972, 1974).

⁴ Though models of unilineal evolution of societies have long been discredited, figure 1 provides a more precise way of delineating the problem with the unilineal claim. Were the unilineal claim valid, there would be but a single trajectory through the space displayed in figure 1 rather than the potential for multiple trajectories some of which may arrive at stable configurations.

⁵ Wood (1998) has also used the idea of well-being as a central component in his demographic model. He defines it slightly differently, though, considering it to refer to "any aspect of health or physical condition that is either positively associated with the probability of childbirth or negatively associated with the risk of death" (p. 104). Whereas Read (1986) used the idea of well-being with regard to decisions that women may make about spacing of offspring, Wood relates it more directly to parameter values in his demographic model: "A person's well-being can be thought of as determining (within a particular social context) a set of probabilities of surviving and reproducing at each age" (p. 105). In effect, Read deals with decision making that anticipates the deterioration in either a woman's or her children's health or physical condition should the demands on her time exceed what she can reasonably accomplish. In contrast, Wood focuses on the consequences that may arise should there be deterioration in her health or physical condition.

⁶ Surovell (2000) has developed a model for interbirth spacing among hunter-gatherers that is based on the two relationships we discuss but assumes an automatic effect between fertility rates and the carrying costs of young children: "*If carrying costs are high, fertility will be low; if carrying costs are low, fertility can be high*" (p. 495).

⁷ We are not excluding the possibility of shifting the cost of parenting to other persons (for example, co-wives) or sharing the cost when there are scheduling conflicts. However, to the extent to which these involve reciprocity, the total cost of parenting is not reduced.

⁸ We do not exclude the possibility that mortality rates may also be increasing with increased population density, but without reduction of the expected 10-15 births over a woman's reproductive period that would occur in the absence of behavioral modification of her fertility rate, mortality rates would have to increase drastically to achieve a net negative growth rate. We think it more plausible, other than for exceptional circumstances such as populations dependent upon high-risk resources, to focus on behavioral factors leading to an increase in birth interval of sufficient magnitude that an increased birth interval, in conjunction with whatever is the current mortality rate (which may have increased as the population density

has increased), yields a zero or negative net growth rate.

⁹ One implication is that the negative net growth rate in some Western countries (or among some ethnic groups) today may be due to the perception of resources that need to be allocated to offspring in order to achieve the desired well-being of one's family (see Kaplan 1996).

¹⁰ These two measures need not be positively associated. The value of $K - K^*$ may decrease while $(K - K^*)/K^*$ increases, depending on the rate at which K^* changes in comparison with change in the value of K .

¹¹ Lorna Marshall (1976:69, 107) notes that although the !Kung San have a season, *!kuma*, which can be translated as "starvation," actual starvation was unknown to her informants.

¹² Suppose that under the current resource density n foragers fully utilize a catchment area of size A during the yearly round to obtain food resources for a population of size N , and therefore each forager must travel to and search over A/n units of area. If the resource density is now, say, $1/2$ as great, then $N/2$ persons, with $n/2$ foragers (keeping fixed the ratio between number of foragers and total population size), will still need a catchment area of size A to have access to the same quantity of resources per person, and now each forager must travel to and search over $A/(n/2) = 2A/n$ units of area, spending up to twice as much time procuring resources.

¹³ We are assuming that the population growth occurs primarily on the boundaries, with interior subgroups being more or less isolated from the changes. While migration from the interior to the boundary would allow for temporary increase in the fertility rate for an interior subgroup through reduction of population density, the population of interior groups would still be limited by the local value of K and would simply grow until the net growth rate was again zero.

¹⁴ Alternatively, it might be able to get access either to new resources (e.g., introduction of horticulture or agriculture) or to an increased quantity of resources (e.g., introduction of irrigation) from its catchment area due to modes of resource procurement made possible by the larger population. Introduction of a new resource may allow for a higher density in the same catchment area and subdivision into smaller groups. The extent to which this can occur will depend on whether variability of the new resource is of the same or an expanded scale.

¹⁵ An important component of our formulation is that intergroup conflict had a significant impact on group extinction. Massacres, although infrequent, did occur and entire communities would be wiped out. Those who did survive would flee to other groups, and the social unit would disappear. Such group extinctions were surprisingly common where data are available, with perhaps more than 10% of all basic social groups becoming extinct per century (Soltis, Boyd and Richerson 1995). Where archaeological information is good, the intensity of warfare can be seen to change over time. For some time periods group extinction rates can be very high (exceeding 50% per century) (LeBlanc 1999).

¹⁶ It might be argued that a group with temporal variation in resource abundance should use storage to even out the highs and lows of resource abundance, but this argument is based on the premise that the group has the goal of larger population size. For a population stabilized well below carrying capacity as discussed in model 1, there is no resource shortage for any family, and so there is no gain at the level of a family unit to be achieved by storage. Storage, however, may have a social cost. For example, the *Cahuilla* required that storage of acorns be done publicly so that everyone would be aware of the amount of food being stored by a family (Bean 1972). It seems likely, then, that storage would only be introduced under circumstances in which it could be demonstrated that it produced gains that outweighed its costs.

¹⁷ There need not be a single resource ownership unit for all food sources. Some resources may be corporately owned and others individually owned. For the !Kung San most resources are corporately owned, though some resources such as honey may be individually owned. Again, the unit may vary depending on the season and the kind of resource. Among the Netsilik the resource ownership unit in the winter may have consisted of 10 - 20 families when they were hunting seals on the pack ice but a single extended family when they were salmon-fishing (Balikci 1970:115). We will be concerned here with the largest resource ownership unit for a resource that contributes the majority of the food upon which the group depends over at least a time period of a few weeks or months.

¹⁸ This need not be strictly true for a net negative growth rate. If the woman's assessment of costs is related to the current population size of the group and the net growth rate is negative, the size of the group may decrease (e.g., the constant value for the overall size of an extended family depends on birth spacing), and her decision may now be to decrease spacing between births. The decreased spacing between births may lead to growth of the group (within the overall limits on its size), which would again trigger an increase in the spacing of births. The overall result would be cyclical increase and decrease in birth spacing. It is interesting to note that if the resource ownership unit is the nuclear family, then her cost assessment includes only a fixed cost of procurement of resources, and the variable cost is the parenting cost. If the fixed cost of procuring resources is high enough, she may space offspring sufficiently far apart that the net growth rate is negative. But when the nuclear family is the group the negative growth rate will have no effect on her total costs, and so the model predicts that females will continue to have a birth spacing that leads to a negative net growth rate. Kaplan (1996) has made essentially the same argument to account for the below-replacement birth rates in a number of Western countries.

¹⁹ Aggression may increase the mortality rate in groups engaged in it, but not all groups will be engaged in aggression at any one point in time. Groups not engaged in aggression will continue with the same birth spacing, thereby leading to the production of new groups through fission as a group grows.