BOUNDARY CONDITIONS FOR PALEOLITHIC SOCIAL SYSTEMS: A SIMULATION APPROACH

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ABSTRACT

Pleistocene societies are viewed in this paper as manifestations of band society from which Paleolithic archaeologists can generate hypotheses about this cultural system and against which they can evaluate the validity of general cultural explanations. A general model is posited toward the isolation of Paleolithic societies in the archaeological record. Their numerical size is predicted from Monte Carlo simulations of model populations, and ways are discussed in which distinguishable equilibrium states of such societies can be predicted in time and space. Under the assumption of maximal constraints, simulations are used to predict the size and longevity of social units. The frequency of settlements produced during an equilibrium state of a society is simulated and the utility of survey for activity areas outside the settlements is demonstrated. The models developed in this paper are intended to stimulate deductive research in Paleolithic archaeology.

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I WAS STIMULATED into writing this paper by 3 observations on the state of Paleolithic archaeology in 1973:

(1) Paleolithic archaeologists often commit errors in scale, if not in logic, regardless of whether they move from the general to the specific, or extrapolate from a particularistic aspect to a general model.

(2) Particularistic research has reached its limit in Paleolithic archaeology since, no matter how well an individual aspect is investigated, analyzed, and explicated, we lack a body of hypotheses allowing us to integrate the particular result into a systemic whole.

(3) Paleolithic research cannot proceed to the systemic level without general models which have test implications for the archaeological record.

Paleolithic archaeology will be able to generate its own coherent and logical framework of hypotheses, predictions, and tests only if it can overcome its handicaps. It is my contention that a logical scale for research at the systemic level can be defined, that previous particularistic research results can fruitfully be integrated on such a scale, and that it will be practicable and advantageous to employ the models to be developed here in future Paleolithic research. My paper received its impetus from work with the European Paleolithic sequence, although the methodology employed can be applied elsewhere.

The Problem Within a Cultural Framework

The remains of Paleolithic hunters and gatherers are only a part of the total range of human culture which anthropologists consider as their subject matter. It is the aim of the anthropologist to discover the processes which have structured the anthropological universe, and to formulate the laws which have governed these processes. If culture is viewed as man's extrasomatic means of adaptation (White 1959), then it is the ultimate aim of anthropology to formulate a body of general theory which explains the behavior of this adaptive agent. As in any other field of science, such a body of theory should be sufficiently general to be applicable to all temporal and spatial occurrences of the processes to be explained, and should lend itself to empirical verification within a logical framework of hypotheses, predictions and tests.

In the investigation of cultural systems (for example, band society, ancient civilization), the researcher needs a scale of attack that is both analytically meaningful and operationally practical. For the purpose of this paper, "cultural system" is dealt with in one of its most inclusive manifestations: societies (for instance, Walbiri, Birhor). The systemic processes, mechanisms, and relationships by which particular societies integrate themselves within, and adapt themselves to, their natural and social environment are viewed as instances of the cultural system in which they participate. This approach was pioneered by White (1949, 1959) in a general anthropological frame of reference, while Binford (1962, 1965, 1972) and Wilmsen (1970, 1973) addressed themselves specifically to the archaeological universe.

Paleolithic research derives its relevance within anthropology from the aim of the discipline to formulate general and verifiable explanations for the system of culture. Any cultural theory has to be valid for extinct as well as living cultural systems in order to satisfy the condition of generality. Since the Paleolithic record (at least chronologically) comprises more than 99% of the cultural universe, this segment has to be included in any verification procedure of cultural explanations. In addition, the extinct societies of the Paleolithic form as relevant a basis for generating inferences about general cultural processes as do any other living or extinct societies. The Paleolithic archaeologist should investigate Pleistocene hunters and gatherers in order to generate inferences about general cultural processes and in order to contribute toward the verification of general explanations inferred on the basis of post-Pleistocene and modern cultural systems. However, Paleolithic archaeology can fulfill this role only if it can partition the Pleistocene record into analytical units appropriate to the development of hypotheses, predictions, and tests about cultural processes. Thus, Paleolithic archaeology, in developing anthropological goals, must demonstrate its ability to isolate specific societies as instances of Pleistocene band society. These societies constitute the sample from which general cultural theory can be developed and against which theories of culture can be tested.

The following section will analyze some previous attempts of central and eastern European archaeologists to isolate Pleistocene societies and their cultural behavior. It will document the need to develop new ways in which Paleolithic archaeology can deal with societies as manifestations of a cultural system.

Some Historical Considerations

Paleolithic research has only gradually reoriented itself from an antiquarian preoccupation toward a stronger alliance with the other social sciences. Collection and description exposed the range of variation in Paleolithic form (Hoernes 1903; Obermaier 1912). But the archaeologist was still empty-handed: while sociology, geography and economics were testing and refining a body of social theory, the Paleolithic universe remained a disjointed collection of human artifacts. In order to deal effectively with questions of cultural process, evolution, and ecology posed by its sister disciplines, Paleolithic archaeology had to redefine its subdiscipline within the general framework of logic and science.

This trend had its beginning and has been most effective in the explication and reconstruction of the history of individual settlements. Its groundwork was laid by central and eastern European archaeologists in the period between the 2 world wars. In 1919 and 1920 the Austrian archaeologist Joseph Bayer excavated with meticulous care the first open air settlement structure in central Europe (Langmannersdorf, see Angeli 1952). At the same time, historical materialism stimulated Soviet archaeologists to investigate the evolution of the modes of production, the development of the division of labor, and the formation of class societies. The resulting large-scale excavations of open air settlements in the Ukraine (Černyš 1953, 1961), in Russia (Efimenko 1938, 1953, 1958), and in Siberia (Gerasimov 1931; Okladnikov 1940, 1941), exposed Paleolithic archaeology to classes of archaeological evidence such as living structures, portable art, and ground-working equipment which speleological and francocentric archaeology had neglected. More importantly, it expanded the archaeological universe from artifact classes to human settlements, and provided Paleolithic archaeology with a new level of integration within which the operation of cultural processes could be demonstrated.

In the thirties, Alfred Rust began his well-designed problem-directed excavations of late Paleolithic camps in northern Germany (Rust 1937, 1943, 1958). Besides an exemplary reconstruction of the way of life on these sites, Rust's investigations demonstrated the utility of systematic surveys for Paleolithic settlements within a given period and environmental niche.

Since then, the pioneers have been succeeded by a second generation of archaeologists who have carried further the explication of cultural processes at the level of Paleolithic settlements (for instance, Bosinski 1969; Klíma 1963; Mania and Toepfer 1973; Vértes 1964). This progress has been achieved through refinements in the use of inductive logic, through advances in the auxiliary sciences, and through more inclusive, resourceful and rigid problem-directed research.

Yet, when the investigation of individual Paleolithic settlements is evaluated against the general aims of anthropology, our conclusion has to be more critical. There can be no doubt that the achievement of a higher level of integration for the cultural data has led to the formulation of more realistic hypotheses about cultural processes and about the cultural systems within which they were operating during the Pleistocene. At the same time, however, the concern with explication at the level of individual settlements has prevented the isolation of analytically meaningful units within which such hypotheses could be tested.

Therefore, the analytical universe of Paleolithic archaeologists is still only a disjointed collection of sites. For any society, if such could be isolated, the sample is biased toward sites which are late, close to the surface, and easily accessible to the Paleolithic archaeologist. The sample also overrepresents sites with good preservation and easily preserved materials, that is, those sites which show a high degree of cultural uniqueness.

These individual sites do not properly reflect the cultural system of Pleistocene band society. Instead, they represent only slices of its temporal, formal, and spatial structure. The sites only reflect selected aspects of the operation of the whole system and can only be correctly evaluated once the operation of the system through time and space is understood. The sites were not excavated to solve problems in the systemic behavior of culture, but rather because they were available. "Explanation" was then provided as a by-product of site excavation, valid and verifiable only within the closed system defined by the aspects of form, time, and space of the individual site.

The laws of logic do not prevent the generation of hypotheses about a higher order of integration (society and its cultural behavior, cultural system, culture process) from a biased sample of a lower order of integration (site universe). Such hypotheses, however, will be distorted by the bias in the sample from which they were induced, and will receive additional noise through the expansion in scale of the explanandum. In addition, the logical problem of positing large-scale *open* (cultural) systems on the basis of the sites which archaeologists are accustomed to treat as small-scale *closed* systems has to be overcome. Thus, even though more realistic hypotheses about cultural process can be inferred from a biased sample of Paleolithic settlements than from an unordered collection of Paleolithic artifacts, the a priori validity of such hypotheses is bound to be small. Furthermore, since Paleolithic archaeology concerned with individual sites is not appropriate to the isolation of the cultural systems of which these sites once formed a part, the hypotheses still lack an appropriate analytical unit within which their test implications could be verified.

Archaeologists have been more successful in discrediting some of the overly simplistic traditional stereotypes of Paleolithic society. By formulating alternative systemic hypotheses about cultural processes where simple cause-and-effect explanations had formerly been judged sufficient, they stimulated the development of more complex, more realistic, and more explicit research designs. For example, the central European archaeologists L. Vértes (1955, 1956, 1958) and F. Prošek (1953) brought arguments of regional cultural ecology to bear on the perennial Szeletian question. The malacologist Ložek (1964) also provided many stimulating hypotheses in his discussion of the cultural ecology of the Czechoslovak Paleolithic. Vértes (1964, 1968) later suggested that factors of adaptability, degree of adaptation (compare also Freeman 1964), and the speed of cultural evolution may also be reflected in the formal character of Paleolithic assemblages. Klein (1969a) attempted to integrate the material from the Kostienki sites into a functioning whole, and dealt with the cultural ecology of the Crimean Mousterian (1969b).

The destruction of the stereotypes and the rejection of the simpler cause-and-effect assumptions were necessary steps toward a higher level of integration. But rather than leading Paleolithic archaeology to a new analytical universe within which these assumptions could be tested, the stimulus was absorbed in the explication of behavior on individual sites (Bánesz 1968; Behm-Blancke 1956; Brandtner 1954; V. Gábori 1968; Klíma 1963).

A series of programmatic statements for future research in given regions of the Old World is more explicitly directed toward the explanation of Pleistocene society and to the presentation of testable hypotheses about cultural process. Such schemes have been proposed, for example, for Czechoslovak (Klíma 1967) and Hungarian (M. Gábori 1970) Paleolithic archaeology. They tend to suffer, however, from a logical shortcoming. They usually assume that the formulation of new theory and the achievement of higher levels of integration are dependent on, and subsequent to, the discovery of new and "better" data. There is no doubt that previous data collection and previously tested hypotheses constitute variables within the scientific feedback system of theory building. Yet they are in no way essential to the formulation of any particular hypothesis as long as such a hypothesis can be substantiated within its own logical frame of reference through prediction and test. On the other hand, the discovery of new and better data is directly dependent on, and subsequent to, the formulation of new hypotheses. This can be illustrated by developments in Paleolithic archaeology during the last 20 yr.

The Bordian system of classification and summary description of whole Paleolithic assemblages (Bordes 1953, 1961; de Sonneville-Bordes and Perrot 1953-56) resulted in the discovery and collection of new and better data in central and eastern European Paleolithic archaeology. Thus, all artifacts including debitage had to be collected and analyzed where formerly a few type fossils had been considered sufficient. Even so, Paleolithic archaeologists would still be content with cumulative graphs if a series of new hypotheses had not been formulated for the existing data. These hypotheses led to the discovery of several new classes of "data", such as *spatial distributions* and *multivariate correlations*. New insights are not generated by new data, but by the logic of archaeologists.

It appears from the preceding discussion that isolation of Paleolithic societies is not a by-product of other research endeavors, such as the explication of individual settlements, or the formulation of hypotheses about cultural processes, or the mere acquisition of better data. Rather, it constitutes a research problem by itself and forms a precondition to many other avenues of investigation. This problem can be approached within a framework of deductive logic by positing a general model of a Paleolithic society, by generating predictions from such a model for the archaeological universe, and by testing the implications of the model against appropriate sets of data within the Paleolithic cultural record.

In the following sections, I will outline the first 2 stages in such a research design as a first step toward the isolation of Paleolithic social systems.

BASIC ASSUMPTIONS

A model appropriate to the isolation of Pleistocene societies should satisfy the following constraints: (1) it should be general enough to accommodate the expected range of variation; (2) it should be sufficiently simple so as to reduce the complexity of the archaeological and cultural reality to intelligible dimensions; (3) it should have practicable test implications for future research.

Initially, the 3 constraints appear to be too restrictive for this task. How are we to know which range of variation to accommodate and what degree of complexity to expect without knowledge of these variables in the data?

Actually, the 3 conditions facilitate our task. The imposition of generality requires the model to be as culturally nonspecific as possible in order to accommodate a wide range of culture-specific data. The condition of simplicity forces us to include only culture processes which are absolutely essential to our model so that the less essential processes do not obscure the operation of the more pertinent variables. The need for test implications, finally, reminds us to keep our model focused on the problem and to exclude all those aspects which have no bearing on the isolation of Pleistocene societies within the archaeological record. All 3 constraints work in the direction of a minimal model which is built upon the least number of assumptions and which incorporates only variables of relevance to the problem.

Beyond the assumptions about cultural systems and culture outlined above, my model requires the following basic assumptions:

(1) The maximum band is the social correlate of the cultural system of hunters and gatherers. It thus constitutes the natural analytical unit in the investigation of Pleistocene cultural processes.

(2) Paleolithic social groups are territorial. "Territorial" implies that the members of a given social group moved within an area which was more or less delineated by social factors, by the proximity of other such groups, by considerations of distance, by familiarity with the environment, and by natural obstacles.

(3) A network of regular hexagons forms the best geometric approximation of the social and geographic space organization within and between Paleolithic social systems.

(4) Given the generally low Pleistocene population densities, and the relatively small number of people required for Paleolithic cultural units, the size of the maximum band was maintained at an equilibrium level due to a balance between the procurement strategies, the mating system, and the population sex ratio, mortality, and fertility rates. The spatial extent of a given society can then be estimated from the equilibrium size of the maximum band and the carrying capacity of the regional environment.

(5) Societies articulate the components of their cultural system in response to stimuli from their natural and social environment. A major change in stimuli will require a different articulation of the systemic components. Thus, we can estimate the temporal extent of specific constellations of systemic components in particular Pleistocene societies from the duration of specific steady states in the set of stimuli to which they formed a response. This does not imply a change in the cultural system, nor a knowledge of the magnitude or direction of the rearticulation.

Each of these assumptions will be justified and discussed in more detail below.

Assumptions about Pleistocene Social Organization

Steward (1969) has introduced 2 terms useful to a discussion of the social organization of Pleistocene hunters and gatherers: the *minimum* and the *maximum social aggregate* or *band*.

Leaving the nuclear family aside, the former is defined as the most permanent and strongly integrated social unit in a hunting and gathering society. Its size is large enough so that it will survive prolonged periods of isolation through the cultural practices of cooperation among its members, division of labor according to age and sex, and mutual food-sharing. On the other hand, it is sufficiently small to not place an undue strain on the local food resources.

Such minimum bands tend to consist of several families of consanguine and/or affinal relatives who, at least during part of the year, share a common settlement and participate in a given range of cultural activities. The size of these units allows the unimpaired transmission of the cultural system from generation to generation. The collective experience accumulated during the lifetime of its members provides the individual with a sufficient range of choices to cope with day-to-day crisis situations. The exact composition, size, and stability of the minimum band will, of course, vary with the social and natural environment of Paleolithic societies.

While at least potentially self-sufficient, a given minimum band tends to participate in a larger social network in order to enhance its chance of biological and cultural survival. Steward (1969:290) defines this larger social network (*the maximum band*) as "frequently . . . little more than a group with which its members somewhat vaguely identify." It essentially constitutes a marriage network which guarantees the biological survival of its members, since the members of a minimum band have to rely on a larger number of persons than their own membership in order to provide a member with a mate upon reaching maturity.

Mate recruitment is made possible by, and itself stimulates, integrative processes between the different minimum bands of the social network. The integrative processes, in turn, enhance the chance of survival of the minimum bands and their members. Thus, food sharing and visiting between adjacent bands create an atmosphere conducive to the exchange of mates. At the same time, and at least as importantly, they help to counteract variations in food supply at the local level and dynamically adjust the local population size to a level which can be supported by the resources at a given time. Barter meetings and work parties between members of different bands broadcast the availability of mates within the communication network of the maximum band. At the same time, the former process provides a given band with exotic raw materials, while the latter increases the exploitative efficiency of local groups.

The maximum band is, thus, a loosely interlocking network of minimum bands maintained through ritual communication and exchange. The communication density within this network tends to level the social and stylistic idiosyncracies of the participating minimum bands and their members, and integrate them into a more or less coherent social unit. This unit, loose as it is, constitutes the highest level of social integration among hunters and gatherers. For this reason, it usually serves as the descriptive universe of ethnographers (compare Murdock 1968). It thus forms the natural analytical unit for the investigation of Pleistocene cultural processes.

The Territoriality of Pleistocene Hunters and Gatherers

"It cannot be mere chance which accounts for close similarities in the equipment of sites as far separated as Le Placard (Charente) and Mammoutova (Cracow) (160 km), and one should not rule out the probability of great treks, over very long distances" (Breuil and Lantier 1965:84).

This traditional view of Paleolithic man as the eternal nomad of prehistory cannot be maintained for a variety of demographic and cultural reasons. The absence of skis, sleds, the wheel, boats, draft animals, and beasts of burden in the Paleolithic cultural equipment implies that Paleolithic man had to walk and carry his necessities on his back whenever he wanted to move. The purposeful acquisition of surplus for some future necessity appears to be foreign to those hunter-gatherers who have been studied by ethnographers (Lee and DeVore 1968:12). These factors place a restriction on the distance to be covered and on the ease and speed of movement.

Band society is characterized by low labor input and a highly flexible set of procurement strategies (see Lee 1972; Sahlins 1972; Woodburn 1971). Nevertheless, if a local group leaves the niches it is accustomed to exploit, its chances of success in hunting and gathering decline while its chances of failure due to unpredictable events increase. Thus, long-distance moves would tend to lower the population density and introduce an element of instability into an interregional social network.

The movement of entire maximum bands, or their components, beyond the area which their cultural systems permitted them to exploit, and with which they were familiar is also effectively blocked by social boundaries. A given society was not located in a vacuum but in a social environment, that is, in a network of neighboring maximum bands. Although a few individuals certainly move from 1 maximum band to another, this process cannot have been large-scale or directional in the sense that a band migration from Le Placard to Mammoutova would imply, but would have occurred in a random fashion between the immediately adjacent sections (minimum bands) of 2 societies.

Even those instances when an empty niche "suddenly" became available, such as the New World or Australia, would not lead to large-scale or long-distance migrations. Rather, colonization would take place gradually and randomly by small breakaway groups along the fringes of the settled area.

For the sake of argument, let us assume that the New World constituted some 41.5 million km^2 of empty niche. The mean equilibrium density in the Old World prior to the time when the New World became accessible might have been .008 persons/km^2. Pleistocene hunters and gatherers were probably able to survive at lower population densities, such as .004, in areas to which they were not specifically adapted. Initially, the New World would then have supported 160,000 people. While Birdsell's (1968:230) observation that human colonizing populations can triple in size every generation in a previously unoccupied niche appears highly unrealistic under the demographic conditions prevailing during the Pleistocene, there is no doubt that an empty land mass such as the American continent would have facilitated rapid population growth among the colonizing population. Assuming, for simplicity's sake, a uniform environment and an initial colonizing group of 25 people (an unrealistically low number to assure survival), after 100 generations a mean population density of .004 would have been reached over the entire continent with an intrinsic rate of population growth of only 1.091. The resulting 3000 yr would still appear as a mass migration in the archaeological record. In reality the "migration" derives only from population increase along the margins of the colonizing population and its gradual expansion into previously unoccupied territory. At the maximum, the "migration speed" would be only 5 km/yr and could hardly be conceptualized as a conscious process of migration and mass movement.

The territoriality of hunters and gatherers is determined at the organizational level of the minimum band. The "territory" of these groups is usually not maintained through an exclusive claim but through habitual use. It is delineated by the proximity of other minimum bands, by distance, by familiarity with the environment, and by natural obstacles.

The Hexagonal Abstraction of Pleistocene Spatial Units

The regular hexagon appears to be the best geometric abstraction for much human spatial organization. Among the regular polygons, only the hexagon combines optimum packing efficiency with minimal movement and boundary costs (Haggett 1966:49). While circles provide better accessibility from the center and have the shortest periphery in relation to their area, they cannot be tightly packed without leaving unaccounted voids between neighbors. Triangles and squares can be packed tightly but have poorer accessibility characteristics and longer boundaries per given area. Because of these optimal features, networks of regular hexagons play a prominent role in theoretical works on locational analysis (Lösch 1954; Christaller 1933) and recently have been successfully applied to the archaeological record (see, for instance, Wilmsen 1973; Johnson 1971).

The degree of regularity which this abstraction imposes on modern spatial distributions and human spatial networks is often not warranted due to the forces of agglomeration and regional specialization inherent in the modern market economy (Isard 1956). The hexagonal model, however, is less likely to introduce gross distortions of reality if applied to hunting and gathering societies. This is due to the egalitarian nature of Paleolithic societies, the lack of intraband specialization except by sex and age, and the ecological restraints on population agglomerations of hunters and gatherers.

The relevance of hexagons to the spatial organization of hunters and gatherers can be documented from the ethnographic literature. We can express the degree to which human spatial units conform to the hexagonal standard by means of the following parameter: the mean number of boundaries with neighboring territories (per territory) excluding only natural obstacles and the periphery of a spatial network (Haggett 1966:51). This parameter has a value of 5.67 (median 6) for a group of 31 minimum band territories among the eastern subarctic hunters (determined from a map in Rogers 1969:23). Birdsell (1958) obtained values of 5.5 for the Australian tribes, and Wilmsen (1973) calculated a mean of 5.6 (N = 155) for the North American tribes based on Kroeber (1939).

The shape of the actual territories utilized by hunters and gatherers may not at all look like equilateral hexagons when plotted on a map. But the fact that minimum or maximum bands of hunter-gatherers on the average find themselves surrounded with close to 6 neighboring bands recommends this spatial patterning as an ideal approximation of Pleistocene conditions.

The Spatial Extent of Pleistocene Societies

Paleolithic social units should display a range of size variation at least as large as that observed among modern hunters and gatherers. This variability is not random, but forms a predictable response to stimuli in the natural and social environment, and to the integrative and centrifugal forces of band society (see Woodburn 1971). We are, at present, unable to determine the size and range of Pleistocene societies because the stimuli are of such infinite variety, because the archaeological record is too biased, and because hypotheses with test implications have not yet been advanced. However, we can approximate the spatial dimension by means of the maximum band as the social correlate of the cultural system of band society.

This approximation is guided by 2 considerations. The *minimal equilibrium size* of any society may be defined as the number of people which will consistently guarantee the presence of a suitable mate for a group member upon reaching maturity. The *maximal equilibrium size* of the society may then be defined as the maximal number of people which can be consistently integrated by the cultural mechanisms of a given cultural system and which is consistently required for the successful operation of such a cultural system.

These definitions approximate the size of Pleistocene social groups rather open-endedly. For, while the lower size limit of the social group might represent a constant, depending on the mating system, on population mortality and fertility rates, and on the sex ratio at birth, the upper limit seems to leave much room for variation. It is doubtful, however, whether the maximal equilibrium size has any bearing on the cultural system of Pleistocene hunters and gatherers.

Let us assume, for the sake of simplicity, that the units of a Pleistocene society (the minimum bands) are evenly spaced over a territory, that a definite intensity of communication is required to maintain the maximum band as a social unit, and that the social units can spend only a finite amount of their time in communication as opposed to other tasks. As population density decreases, a point will be reached at which it becomes impossible to maintain the necessary intensity of communication without impairing the probability of survival or without the social group breaking apart for lack of communication.

In analogy to modern band societies, Pleistocene hunter-gatherers can be expected to have such low population densities that the minimal equilibrium size will hover only slightly above this point, or will fluctuate around it in a random fashion, thus not permitting any larger culturally maintained groups than those consisting of a few minimum bands.

This is also evident from the comparatively small size of hunting and gathering work parties or exploitative task groups (Lee and DeVore 1968:12; Steward 1969:265). These tend to stay conveniently below the biologically required minimum size, only exceptionally involving members from more than 1 minimum band. One expects that this is not only due to the vagaries of food supply, but also to distance, communication, and population density, that is, to the same factors which might keep the Pleistocene social group at the minimal equilibrium level.

Once the minimal equilibrium size of Pleistocene maximum bands is determined, we can predict the spatial extent of Pleistocene cultural systems by matching the *caloric requirements* of such a group with the *carrying capacity* of specific environments (see Birdsell 1953). The isolation of the minimal equilibrium size of Pleistocene social groups is thus a necessary prerequisite for the isolation of social systems.

While this sounds unrealistic given the present state of Paleolithic research, population density predictions and hypotheses about the spatial extent of Paleolithic societies have test implications for archaeological fieldwork. A cursory investigation of the anthropological literature on band society, however, suggests some important methodological caveats. Carrying capacity is a function of stochastic variables. Each of these variables has its own probabilistic distribution function and its own chance to generate a limiting condition within the lifetime of a population. If a society of hunters and gatherers is in essential equilibrium, it will be adapted to the worst possible conditions occurring within a generation or within reasonable memory of its members. Thus, it is useless to employ mean values of environmental variables to determine the carrying capacity of various environments, as for example has been recently attempted by Casteel (1972). Secondly, band society puts a premium on minimizing work effort and tuning demands down to the level of relatively easily obtainable supplies (Sahlins 1972). Thus, work effort has to figure importantly in any prediction of band society carrying capacity, and diminishing return functions will depress the population density that could conceivably be supported by a region's resources. As population increases toward a given carrying capacity, the tighter packing will increase social labor, the increased population density will increase productive work effort, and the increased person to person contact, coupled with increased population clustering, will increase population morbidity and mortality (requiring an increase in female fertility to maintain the population size). All factors combined significantly depress the potential carrying capacity of an area for band society.

The Time Depth of Pleistocene Cultural Systems

Archaeologists frequently generate a model of a given society on the basis of a specific constellation of the system's components at a fixed point in time. This approach has certain shortcomings, particularly if applied to the Paleolithic record, as I will illustrate by means of a model.

Let us suppose that it would be possible to isolate the year 30,000 B.C. in the archaeological record. Let us further assume that at this time the equilibrium population size of a particular maximum band was 500 people and that the population density was fixed at .02 persons/km^2. Finally, let us assume that only habitation sites would yield sufficient cultural material to be recognizable and datable, that each person produced 10 m^2 of habitation debris (Cook and Heizer 1965), and that only 50% of this area has escaped erosion.

Our task then consists in finding the 2500 m^2 of remaining habitation space within the 2.5 billion m^2 originally exploited by the given maximum band. The chance of hitting any of the originally occupied square meters in a single try is depressingly low (1:10 million), while any sampling scheme designed to obtain a representative sample would require so much excavation as to discourage this approach.

It is, of course, impossible to establish convincingly the contemporaneity of any 2 Paleolithic sites. When applied to the dating of Pleistocene cultural materials, chronometric and paleoenvironmental methods cannot differentiate more than gross chronological differences with any degree of reliability. Thus, archaeologists have to be content with chronological sections large enough (several hundred years for the Upper Paleolithic, several thousand years for the Middle Paleolithic and several tens of thousands of years for the Lower Paleolithic) to be differentiated with the available methods.

While important to the archaeologist interested in exact historical reconstruction, a specific constellation of systemic components is of small consequence to the operation of a cultural system. Immediately before or after the particular year in our model, the same system will still be operating but its components will be articulated slightly differently. Lacking time depth, the archaeologist interested in the preceding and succeeding year would generate a different model of the cultural system even though these year-by-year or generation-by-generation changes are only manifestations of the same self-regulating equilibrium system (see Maruyama 1963).

To avoid such errors in scale, one should isolate equilibria of sufficient duration so that the processes which structure the interaction between the members of a society, and between the society and its natural and social environment, become intelligible. In the Pleistocene context, the changes in fauna and flora associated with glacial events in the northern hemisphere may be the least arbitrary boundary markers by which a societal continuum can be partitioned into analytically distinct temporal units. Such changes will affect regional carrying capacity, and population density and distribution, in a lasting way so that, in turn, the predominance and distribution of tool kits will differ, the procurement strategies will change in their seasonal round and spatial focus, and different cycles of seasonal dispersal and aggregation will result. While the archaeologist is faced with the same society before and after such a change, as well as with 2 instances of the same cultural system, the articulation of the systemic components will be sufficiently distinct to make it analytically easier to talk about the before and after separately.

The analytically distinct equilibrium states of Paleolithic societies should closely follow the duration of equilibrium states in Pleistocene regional environments. This conclusion has 3 beneficial consequences for archaeological analysis: (1) it allows us to deal with analytical units which can be isolated archaeologically, chronometrically and paleoenvironmentally; (2) it allows us to deal with the processes which operate cultural systems rather than with time-specific fossils of systemic structure; and (3), as will be shown below, it allows us to verify hypotheses about cultural processes during the Paleolithic by testing them against representative samples.

THE MINIMUM EQUILIBRIUM SIZE OF PLEISTOCENE POPULATIONS

Choice of Approach and Predictions

The basic assumptions of the foregoing discussion suggest a logical approach to the isolation of Pleistocene societies. The size of social groups can be approximated in terms of the *minimal equilibrium size* (MES) of Paleolithic populations. Under the assumption of territoriality, the spatial extent of Pleistocene societies becomes a function of the carrying capacity of regional ecological systems, and of the size of the maximum bands. The time depth of specific cultural systems can then be predicted from the duration of equilibrium systems in the natural ecology of regions. Our major aim should thus be the determination of the MES of Pleistocene maximum bands.

My approach is based on the assumption of maximal constraints. Therefore, the results reported in the following chapter do not establish constants to be found in all hunting and gathering societies, rather, they establish the lower limits of a range. However, the models are sufficiently simple so that they can be modified for the habitat of specific societies, and thus can be adapted to the requirements of the individual archaeologist.

As defined previously, the MES describes the number of people which can consistently provide group members with suitable mates upon reaching maturity. It is operationalized here as the mean and median number of persons that live in the intervening distance between 2 marriage partners. These partners are nearest neighbors among the available mates in the mating pool. This mean or median value should adequately reflect the required size of the MES. It is frequently used in historic demography and population genetics (Harrison and Boyce 1972; Spuhler 1961) and has recently been applied to hunter-gatherers by Yellen and Harpending (1972). The MES cannot be a cross-cultural constant due to the large variety of factors which may be expected to influence it. At the same time, the value of the MES should be predictable within narrow limits from the constellation of the variables that exert an influence on it.

Thus, all other factors being equal, we would expect a negative correlation between life expectancy at age 15 and the MES. As life expectancy increases, more persons per given population size would be in the pool of potential mates. Juvenile mortality and MES should be positively correlated with each other. When it increases, fewer persons per given population size would reach reproductive age. This would imply increased distances between potential mates, and thus cause an increase in MES. Strong deviations from a sex ratio of 100% should reduce the MES, if the closest neighbors within the pool of mates are removed first, since, per member of the less frequent sex, there would be more potential mating partners per given population size.

The MES should also be strongly correlated with the cultural rules reflected in a mating system. Here we can predict that the more restrictive the rules on mate selection, the larger the required MES will be since fewer mates will be available per given population size. Therefore exogamy, age restrictions, and prevention of remarriage after widowhood would all tend to decrease the number of eligible mates and increase the MES.

The effect of polygyny on the MES will depend on the sex ratio at birth. If the sex ratio of the members of the pool of potential mates is close to 100%, polygyny should not change the size of the MES appreciably as compared to a monogamous society. If, however, the sex ratio of the same mating pool strongly and repeatedly deviates from 100%, the MES should increase perceptibly. For, while in the monogamous society, one sex of mates can pick out of the excess of the other-sex mates those that are closest and leave the remainder unmated, in a polygynous society those excess mates (which on the average would be further away from their potential partners) would be mated too, and thus increase the mean distance figures.

Let us suppose that a group of Pleistocene hunter-gatherers suffers from a recurrent shortage in marriage partners. Under these conditions, 3 nonviolent alternatives are open to the group: (1) it could relax the culturally restrictive mating rules and thus make more mates available per given population size; (2) it could include neighboring minimum bands in the mating network to achieve the same effect; or (3) it could simply let the queue of unmatched mates accumulate in the mating pool until other potential mates reach reproductive age. Alternatives 1 and 2 are normal and expected responses of band society and have frequently been reported in ethnographic literature. Strategy 3 can be expected to endanger the survival of the group. If a sizeable fraction of the group membership is kept unmated, the chances for group survival should decrease. Conversely, if the population were kept stable under these conditions, a strong increase in female fertility rates would be required to make up for the lost reproductive potential of the unmated group members.

Only alternatives 1 and 2 appear to be strategies that are adaptive in the long run in the context of band society.

The value of the MES in Pleistocene societies cannot be induced from presently available archaeological data. It would also be dangerous to derive it from modern hunting and gathering populations due to distortions introduced by their modern cultural environment such as imported epidemic diseases, means of transportation absent in the Paleolithic archaeological record, and negative migration balances. Only the simulation of a hypothetical Pleistocene population offers an economical means to arrive at a numerical approximation of the MES during the Paleolithic.

In its most abstract form, simulation reduces a complex reality to a set of general mathematical equations which then can be manipulated for particular research aims. I am aware of only 1 attempt in which this approach has been applied to Pleistocene societies (Thomas 1967). Deduction from this model for the purposes of my research design is made difficult by the logical framework of higher mathematics in which it was conceived and by its research focus on primitive economics rather than primitive cultural systems.

I chose to simulate hypothetical Pleistocene populations by means of *Monte Carlo techniques* which permit a mathematically less demanding and culturally more rewarding model. Monte Carlo techniques imply "that a society of 'robots' is created in which 'life' goes on according to certain probability rules given from the start" (Hägerstrand 1968:372). A particular Monte Carlo simulation can best be conceptualized as an educational game consisting of a gaming table (area), pieces (people), rules (biological or cultural rules of behavior), and a series of different outcomes depending on the specifications of the components. Its educational purpose is either the isolation of the specifications under which a given outcome was produced, or the approximation of the outcome given a set of complex instructions. The latter purpose is ideally suited to the determination of the minimum equilibrium size of Pleistocene populations.

The Simulation Model

A complex simulation cannot be carried out without the use of the computer. I wrote the simulation program originally in FORTRAN-IV for use on the IBM 360 computer system of the University of Michigan. Subsequently, I revised the program, included several additional options, and adjusted it for 3600 FORTRAN to be used on the CDC 3800 system of the Research Computing Center at the University of Massachusetts. A technical description, flow chart, listing, and sample output of the program are contained in Wobst (1974). This section will deal with the assumptions and rules of the simulation model in a nontechnical way.

In my model, the gaming table is considered to be a geographic region of hexagonal shape. Its size is immaterial except that it should be large enough to place an upper limit on the amount of intraregional communication. The regional environment is uniform over space, constant through time, and lacks geographical barriers to communication. The entire area is taken up by a tightly packed network of smaller-sized regular hexagons. Each of these subterritories is exploited by a minimum band. The region as a whole is occupied by a regional population without any assumptions about intraregional social and stylistic differentiation beyond that given by the minimum bands. The size of this population has to be large enough (1200-2000 people) to include all expected sizes of the Pleistocene MES. The number of minimum bands is dependent on their size. In the simulation runs on which this paper is based, the minimum bands (61 in number) had a mean of 25 members. Thus, the region can be visualized as a network of hexagonal minimum band territories, 4 tiers in radius (see Fig. 1).

Each individual in this population is identified by name, age, sex, place of residence and marital status, and by the names of mate(s), parents, grandparents, and great-grandparents. Individuals are born, grow up, mate, produce offspring, and die. Individuals, nuclear families, or minimum bands

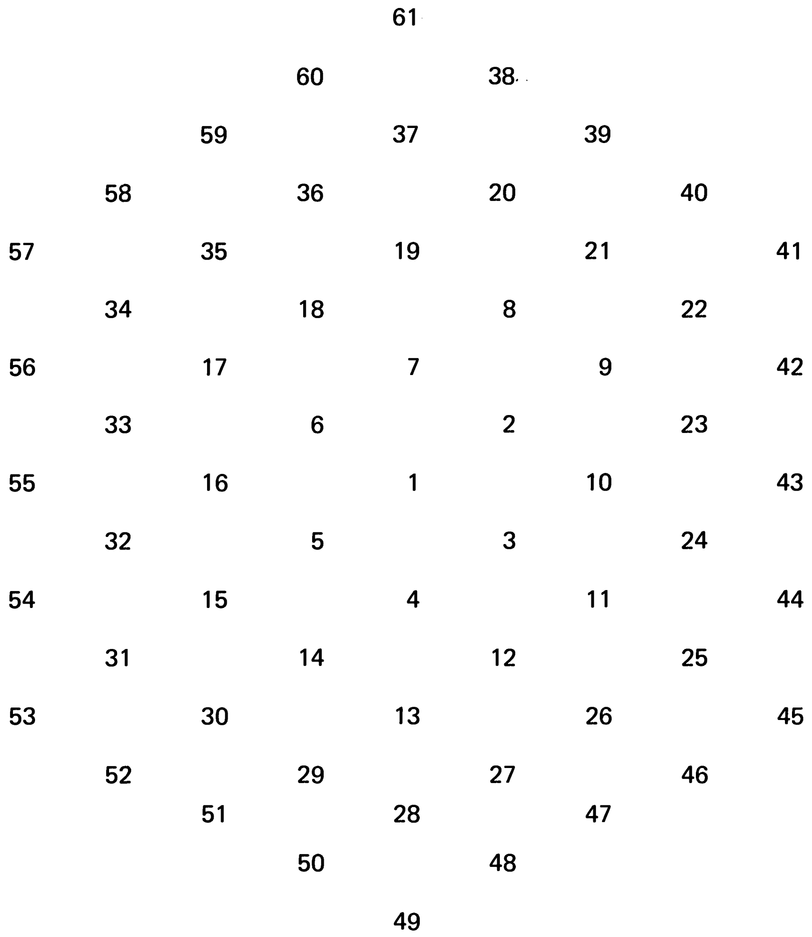

Fig. 1. Arrangement of minimum bands in the simulation runs. The bands are numbered in terms of their closeness to Band 1 within the hexagonal matrix.

can move from subterritory to subterritory or outside the region if cultural rules prescribe it. Time proceeds year-by-year.

The basic stochastic variables controlling the operation of the system are the age-specific mortality rates (the chance of an individual dying within a given year of life), age-specific fertility rates (the chance of a mated female giving birth to live offspring in a given year), and the sex ratio (the chance of a live birth being male or female).

It would have been difficult to generate these variables from known Paleolithic populations as the largest preserved series contain less than 50 members (Krapina, Předmostí, Ofnet Höhle). Sampling error would have distorted any life tables generated for these populations to such a degree that this approach had to be discarded. Instead, model life tables for preindustrial populations were utilized (Weiss 1973) which can be closely matched against the demographic characteristics of living hunters and gatherers. Most of the simulation runs were carried out with Weiss's *MT:25-40* (1973:144) which approximates the demography of several Eskimo and Alaskan Indian groups. For comparison, a few simulations were run with *MT:27.5-45* (1973:154), best fit by other Eskimo groups. The relevant parameters of these models are given in Table 1. For lack of data, I was not able to use sex-specific mortality rates. Since the age composition and mortality

Table 1. Model life tables utilized in the simulations.

1) *MT:25-40 (Weiss 1973:144)*

Age	Mortality Rates	Fertility Rates (annual)	Age Composition
0-1	.3330		4.4%
1-5	.2130		13.0%
5-10	.1350		13.9%
10-15	.1191		12.1%
15-20	.1476		10.5%
20-25	.1516	.070	8.9%
25-30	.1556	.191	7.5%
30-35	.1598	.191	6.4%
35-40	.1640	.155	5.3%
40-45	.1684	.108	4.4%
45-50	.1728	.045	3.7%
50-55	.1774	.009	3.0%
55-60	.2134		2.5%
60-65	.2823		1.9%
65-70	.3619		1.3%
70-75	.4704		0.8%
75-80	.6125		0.4%
81	1.0		0.2%

2) *MT:27.5-45 (Weiss 1973:154)*

Age	Mortality Rates	Fertility Rates (annual)	Age Composition
0-1	.3000		3.9%
1-5	.1850		11.9%
5-10	.1220		12.9%
10-15	.1016		11.5%
15-20	.1305		10.2%
20-25	.1336	.059	8.8%
25-30	.1367	.161	7.6%
30-35	.1400	.161	6.6%
35-40	.1432	.131	5.6%
40-45	.1466	.091	4.8%
45-50	.1500	.038	4.1%
50-55	.1536	.008	3.5%
55-60	.1879		2.9%
60-65	.2513		2.3%
65-70	.3270		1.6%
70-75	.4315		1.0%
75-80	.5698		0.5%
81	1.0		0.2%

rates in the model tables are listed by age group, the program calculates values specific to the year of age from this input. Fertility is already in the form of annual rates in Weiss so it only has to be multiplied by 2 to reflect births of both sexes.

Weiss's model life tables assume a stationary population. This implies that the simulated population would rapidly die out if no adjustment were possible in the population mortality or fertility rates. Since the stationary population model assumes an infinite population, any significant deviation from infinity will work to decrease the size of the population steadily until it dies out (produced by randomly fluctuating births, deaths, and sex ratios). The age-specific fertility rates were self-adjusting to prevent this. Since "the relative amount of fertility at each age in the child-bearing period follows generally similar patterns in most human populations" (Weiss 1973:31), the age-specific fertility rates were multiplied by a constant whenever the population had increased or decreased to a specified level. The sex ratio in most runs was set at 100%, while a few simulations were run with differing sex ratios for comparison. The program allows for the simulation of a large number of different cultural assumptions. Thus, the simulated society (among others) can be monogamous or polygynous, endogamous or exogamous, incestual or with various different incest taboos, and patrilocal or matrilocal.

The operation of the stochastic variables is governed by the use of uniformly distributed random numbers. Thus, given an individual's age and the chance of death at this age, a random number between 0 and 1 is drawn. If this number is smaller than the probability of death, the person will die in the given year; if it is larger, the individual survives the year in question.

Each simulation run consists of the following sequence of events. As a first step, the initial population is generated on the basis of the given age and sex distribution. The annual cycle of events then begins. First, all individuals are aged by 1 yr and their status is adjusted as required. Next, those individuals new to the marriage pool, due to widowhood or due to having reached maturity, enter the mating loop. The males-to-be-married check through the pool of females-to-be-married until a compatible partner is found. This is for the sake of programming efficacy only and does not imply any cultural assumption. If there should be more than 1 potential partner per male, the one closest to the male's place of residence is preferred. The status of the marriage partners is adjusted and moves required by marriage residence rules are carried out.

Following the mating loop, all females of reproductive age enter the procreation loop. Here, a random number decide whether they should give birth to live offspring, and whether the sex of this offspring should be male or female. The simulation proceeds to the mortality loop where all members of the regional population can be evaluated against their age-specific chance of death.

Next, a series of fusion and fission moves can be carried out. Thus, a minimum band of smaller-than-specified size can be made to join the closest larger-sized band. Conversely, subterritory populations which have increased beyond a specified point can be split into 2 sections. The smaller one can be placed into the nearest empty subterritory or join another group.

At the end of the annual cycle, the basic stochastic variables are checked for the necessity of adjustments and the annual census data are accumulated.

In order to reduce chance noise in the system, a single run should simulate at least 400 yr of actual time. Out of this total, census data should be accumulated only during the last 200 yr since it takes several generations before all traces of disturbance due to the initial population generation have subsided. With most of the cultural assumptions, 400 yr of simulated time will require less than 4 min of execution time on the CDC 3800 computer.

The Outcome of the Simulation

Given the assumption that under Pleistocene conditions a person would tend to "marry" the closest available suitable mate in order to minimize movement, the MES of Paleolithic social groups can be derived from our model in 3 ways: (1) as the mean or median radius (in terms of

Table 2. Summary of 40 simulation runs.

Run	Life table	MES-Mean	-Median	P(olygyny) M(onogamy)	Fertility Level
1	25-40	175.4	100	M	119.1
2	25-40	198.0	100	M	122.8
3	25-40	166.7	100	M	127.4
4	25-40	183.3	100	M	124.7
5	25-40	198.5	100	M	126.4
6	25-40	220.6	125	M	127.2
7	25-40	213.3	125	M	117.2
8	25-40	221.5	125	M	120.5
9	25-40	233.5	150	M	133.5
10	25-40	210.8	125	M	123.3
11	25-40	243.3	150	M	121.0
12	25-40	240.9	150	M	127.2
13	25-40	319.0	175	M	121.1
14	25-40	332.7	200	M	122.3
15	25-40	331.3	200	M	127.7
16	25-40	273.5	150	M	139.4
17	25-40	275.6	150	M	132.8
18	25-40	236.7	150	M	128.0
19	27.5-45	315.8	175	M	118.0
20	27.5-45	79.3	75	M	148.6
21	27.5-45	218.2	125	M	122.1
22	27.5-45	74.7	75	M	144.9
23	27.5-45	201.8	125	M	124.7
24	27.5-45	201.1	125	M	129.0
25	27.5-45	194.3	125	M	124.4
26	25-40	242.8	125	P	115.3
27	25-40	246.1	125	P	121.6
28	25-40	248.2	125	P	124.7
29	25-40	248.6	125	P	126.7
30	25-40	254.3	150	P	121.1
31	25-40	271.9	150	P	123.8
32	25-40	283.5	150	P	121.4
33	25-40	266.3	150	P	103.5
34	25-40	294.3	175	P	157.2
35	25-40	265.6	150	P	157.1
36	25-40	254.8	150	P	102.2
37	25-40	240.0	150	P	102.5
38	27.5-45	301.9	175	P	158.3
39	27.5-45	279.1	150	P	120.3
40	27.5-45	258.7	150	P	101.7

tiers of minimum band territories) within which marriages are contracted; (2) as the mean or median number of minimum bands living inside the radius within which marriages are contracted; and (3) as the mean or median number of persons living inside the radius within which marriages are contracted.

However, given an equal number of persons within the mating distance, the hexagonal radius will vary with the location of the marriage partners relative to the periphery of the region and with the mean size of the minimum bands. The number of minimum bands again will be affected by their mean size. Thus, we will focus our discussion on the *mean* and *median* number of persons living within the mating distance. These 2 values are of differential utility. The mean is very sensitive to extreme values and thus will better reflect the variance and the range of the MES, while the median better reflects the average experience of the population.

Under the given assumptions these 2 values are obtained as follows: whenever a mating is contracted, the population sizes of all minimum bands living within the mating distance are added up clock-wise, beginning from the territory of the male, until the territory of the female is reached. Addition is terminated here (rather than counting out the full hexagonal tier) in order to avoid minimum bands in the summation which might have provided an equidistant mate. At the end of the simulation the simple arithmetic mean and the median are calculated.

Forty simulation runs are summarized in Table 2. These runs represent a total of 16,000 yr of simulated time and 8000 yr of censused population simulation. At first glance, the large spread of the MES under different conditions and assumptions appears to be rather discouraging (range of mean 79-332, range of median 75-200 people). If the results are translated into a spatial network of minimum bands with a mean size of 25 members, a maximum band will consist of a single tier or 2 tiers of hexagonal territories and thus will have between 175 and 475 members. However, once the individual runs are separated according to the assumptions under which they were run, the MES behaves according to our predictions and the effect of different strategies on the MES becomes apparent.

Two factors do not have any effect on the MES: the total size of the regional population, and the mean size of the minimum bands. Simulations 6 and 8 were run under identical assumptions. As is apparent from the values of the mean and mode, their MES is practically identical while their mean population size differs by 45 members (which amounts to 9000 members over the censused 200 yr duration of the run). If all the simulations are combined, the range in mean population size is less than 5% of the maximum population size, while the range in MES approaches 400% for the mean and 300% for the median, indicating that the size of the population has no influence on the MES. The same applies to the mean size of the minimum bands: its range (24.8 to 26.9 members) is only 8% of the minimal value and no directional effect of this variable on the MES can be observed. Since changes in population or minimal band size do not change the composition of the population, this is to be expected.

The results of changes in adult life expectancy and juvenile mortality on the MES are shown in Table 3. In 5 simulations, the 2 different model tables were run under identical cultural assumptions. While the 2 tables are relatively close to each other, given the range of human mortality and fertility experience modeled by Weiss, the decreased juvenile mortality (expressed in an increase in survivorship to age 15 from 40% to 45%) and the increased life expectancy at age 15 (from 25 to 27.5 years) decrease the MES. This bears out our prediction that the MES should be positively correlated with juvenile mortality and negatively correlated with adult life expectancy.

If mortality rates and cultural rules are held stable, changes in the age-specific fertility rates do not have a lasting effect on the MES. Table 4 shows 5 paired simulations which were run with identical assumptions and input fertility rates. As in all runs, fertility rates were self-adjusting to maintain a stable population size. The amount of adjustment required is indicated in the mean fertility level which gives the mean value of the age-specific fertility rates relative to those in the input life table. There does not seem to be any correlation between crude birth rate or mean fertility level and the mean or median MES. However, the MES will temporarily increase or

Table 3. Paired life tables run with identical assumptions.

	Life Table	Run	Median MES	Mean MES
	25-40	18	150	236.7
	27.5-45	25	125	194.3
	25-40	9	150	233.5
	27.5-45	21	125	218.2
	25-40	19a	125	213.4
	27.5-45	23	125	201.8
	25-40	31	150	271.9
	27.5-45	39	150	279.1
	25-40	15	200	331.3
	27.5-45	19	175	315.8
mean MES decrease			15	15.1

decrease in response to sudden changes in fertility rates, so that it should be positively correlated with the standard deviation of the annual crude birth rates. This was illustrated with some simulation results in Wobst (1971). Thus, a population might find it advantageous to maintain annual crude birth rates within relatively narrow limits to stabilize and minimize the size of its mating network.

Fertility will have a strong indirect effect on the MES. Since it can cause large changes in the absolute sizes of populations, it acts as a stimulus to cultural feedback mechanisms which keep the

Table 4. The effect of age-specific fertility rates on the MES. Pairs of runs simulated with identical assumptions.

Run	Mean Fertility Level (Percentage of Life Table Value)	Crude Birthrate	Median MES	Mean MES
1	119.1	69.4	100	175.4
2	122.8	69.4	100	198.0
3	127.4	71.1	100	166.7
4	124.7	70.6	100	188.3
5	126.4	71.6	100	198.5
7	117.2	67.8	125	213.3
6	127.2	70.6	125	220.6
8	120.5	68.8	125	221.3
9	122.0	69.8	150	233.5
10	123.3	69.7	125	210.8

population size in check. These cultural mechanisms in turn affect the MES. This will become more apparent after the effect of cultural rules on the MES has been discussed.

The following cultural assumptions govern all runs: (1) the regional population is 100% endogamous; (2) the nuclear families are monogamous or polygynous as specified for the run; (3) male and female reproductive life span lasts from age 16 to 50; (4) within this period remarriage after widowhood is encouraged; (5) a mate searches for the closest available suitable partner; (6) optimally, all persons of reproductive age are married; (7) the sex ratio is 100% unless otherwise specified; (8) fertility is determined solely by the age-specific fertility rates as defined above; (9) there are no cultural causes for mortality and no ecological disasters except as might be contained in the age-specific mortality rates; (10) members of a minimum band move only (a) if they become married; (b) if 2 or fewer productives (between ages 16 and 50) remain in the minimum band (fusion); (c) if a minimum band increases beyond a specified size (fission). If the first occurs, depending on the locality rules, one mate joins the subterritory of its partner. If the second occurs, the remaining members of the minimum band join the nearest band which will not overflow by this influx of population. If the third occurs, a given number of couples and their offspring moves to the nearest unoccupied territory or, if none is available, joins the nearest group that is of sufficiently small size that it does not have to fission when the new members are added; (11) in the simulations of polygyny, unmarried males choose their mates before males with 1 or 2 partners in order to facilitate programming for the small memory of the CDC-3800. While this may not adequately reflect reality, it should not bias the size of the MES significantly.

Six sets of mating rules were simulated with monogamous and polygynous societies. These specifications should provide a range from least to most restrictive.

Set 1: Minimum bands are endogamous, if possible, and patrilocal. Any age combination is possible for the marriage partners. There is no incest taboo.

Set 2: Incest taboo specifies that Fa, Mo, FaFa, FaMo, MoFa, and MoMo of the mates have to be different. If only one of these names is shared at whatever level, marriage is excluded. Otherwise, like *Set 1.*

Set 3: Incest taboo now applies to all names in the potential partners' genealogy, including the great-grandparents. If only 1 is shared, marriage is excluded. Otherwise like *Set 1.*

Set 4: Minimum bands are exogamous and patrilocal. Any age combination is possible among the marriage partners. There is no incest taboo.

Set 5: Incest taboo as in *Set 2*; otherwise like *Set 4.*

Set 6: Incest taboo as in *Set 3*; otherwise like *Set 4.*

Fig. 2 depicts the outcome of 18 runs with life table *MT:25-40*; of these, 2 each simulate *Set 1-6* assumptions for monogamous societies, while polygynous societies are represented with a single run for each of the assumptions. Inspection of this figure confirms our prediction that cultural restrictions will tend to increase the size of the MES, and that polygyny will affect this variable in the same direction. While there is a certain amount of random noise inherent in the MES because of the stochastic variation in the number of males and females of a given age and status, the MES increases steadily from endogamy and incest to exogamy with a strong incest taboo. At the same time, for the same set of assumptions, polygyny results in a higher MES than monogamy. The same is reflected in Table 5, where the percentages of closest matings (within the minimum band and its closest neighboring band) are also given.

It is surprising that the removal of the incest taboo under *Set 1* and *Set 4* assumptions has little or no effect on the size of the MES. Particularly in the monogamous simulations, *Set 1* vs. *2*, and *Set 4* vs. *5* (incest vs. incest taboo) produce almost identical results. The runs in which the incest taboo was not enforced appear to be mere variants of the runs with *Set 2* and *Set 5* incest taboos. This cannot be accounted for by the low frequency of incest. For, if all types of incest are

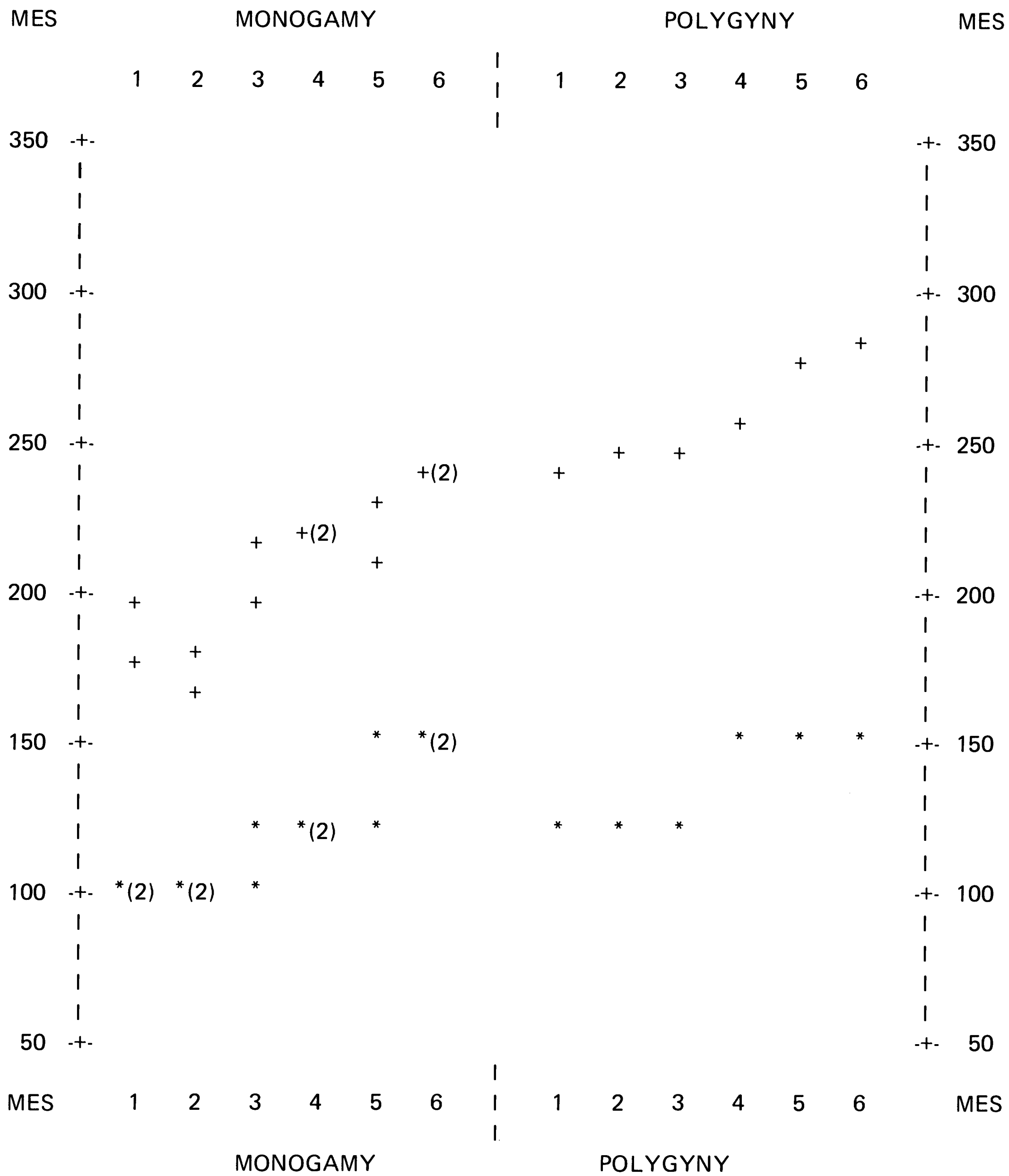

Fig. 2. Result of simulation runs to determine the effect of cultural restrictions on the size of the mating network. Top and bottom: sets of assumptions introduced in the text; left- and right-hand side: value of the MES in numbers of people residing in the mating distance; * indicates a median, + a mean value.

permitted, about one-fifth of all matings will be incestuous with the given vital statistics. If only exogamous incest is permitted, still about 5% of all matings will be incestuous.

The effect of incest is limited for 2 reasons: incest increases the number of potential mates only slightly and it does not increase the size of the mating pool. At the same time, while incest decreases the mean mating distance for some marriages considerably, it also can be expected to increase mating distances for the remaining matings once all incestual matings are removed from

Table 5. The effect of cultural restrictions on the size of the mating network.

Run	Assumptions	Life Table	MES:Mean	Median	Percentage of Matings Between Two Closest Minimum Bands
1	1 Monog.	25-40	175.4	100	–
2	1 Monog.	25-40	198.0	100	42.75
3	2 Monog.	25-40	166.7	100	44.47
4	2 Monog.	25-40	183.3	100	41.53
5	3 Monog.	25-40	198.5	100	38.40
7	3 Monog.	25-40	213.3	125	36.97
6	4 Monog.	25-40	220.6	125	24.73
8	4 Monog.	25-40	221.5	125	25.77
9	5 Monog.	25-40	233.5	150	22.47
10	5 Monog.	25-40	210.8	125	27.05
11	6 Monog.	25-40	243.3	150	21.51
12	6 Monog.	25-40	240.9	150	22.19
26	1 Polyg.	25-40	242.8	125	35.26
27	2 Polyg.	25-40	246.1	125	33.47
28	3 Polyg.	25 40	248.2	125	30.42
30	4 Polyg.	25-40	254.3	150	21.08
31	5 Polyg.	25-40	271.9	150	20.40
32	6 Polyg.	25-40	283.5	150	18.91

the mating pool. Therefore, while incest has little impact on the *mean* mating distance, it affects the *variance* of the mating distance. This is illustrated in Wobst (1971).

The increase in variance caused by incest thus introduces instability and unpredictability into a mating system. If the mating network in which individuals, families, and minimum bands participate is to function in a stable, predictable, and dependable way, incest would be counter-productive. It increases the social work effort (a larger communication and exchange network has to be maintained to counterbalance the decreased predictability in mate choice), and it increases differential access to goods between the members of the same minimum band (some members find mates very close, others have to go much further). Both of these factors would counteract important cultural processes of the band society cultural system.

If age restrictions are placed on mate choice, the MES increases drastically. This is shown by the runs below:

Run	Assumption	Median MES	Mean MES	Life Table
13	*Set 1*	175	319.0	*MT:25:40*
14	*Set 4*	200	332.7	*MT:25:40*
15	*Set 5*	200	331.3	*MT:25:40*

In these runs, only 1 assumption was changed compared to the previous series: males have to find younger marriage partners. In terms of Pleistocene minimum bands with a mean population size of 25 members each, this is equivalent to an increase in the size of the required spatial network from 1 tier (7 minimum bands with 175 members) to one with 2 tiers (19 minimum bands with 475 members). The effect of this rule can be mitigated somewhat, if the time span during which a male can marry is increased. This was done in Run 17: here the males were required to look for mates 5 or more years younger and the time span in which they were allowed to marry was increased to age 55. Compared to Run 14, which was simulated under otherwise identical assumptions, the mean MES decreased to 275.6 people, and the median MES decreased to 150 people.

Changes in the rules of postmarital residence do not have any effect on the size of the MES. In the following 4 runs, all simulated with Model Life Table 27.5-40 under *Set 5* assumptions, Run 21 assumes patrilocality, Run 23 matrilocality, Run 24 the partner from the larger minimum band joins the other band, while in Run 25 the reverse is assumed:

Run No.	Median MES	Mean MES	Number of Moves
21	125	218.2	130
23	125	201.8	146
24	125	201.1	0
25	125	194.3	677

It is interesting to observe the effect of the opportunistic postmarital residence rules in Run 24 and 25. In Run 24, where the smaller minimal band receives the mates (as might be the case where hunting or gathering are negatively affected by increased band size), the frequency of minimum band fusion and fission moves drops to 0, while in Run 25, with the larger bands receiving the mates, the frequency of fusion and fission moves increases to the maximum of the 40 runs, and fission of minimum bands involves a large proportion of band membership in addition to those that have to move due to postmarital residence rules. Thus, the pattern of Run 25 conceivably may be found in areas where a particularly strong stress is placed on food sharing and exchange between minimal bands (for instance, areas that have a high temporal and spatial variance in the productivity of the resources exploited by hunter-gatherers).

Three sets of runs simulated the effect of infanticide on the MES. In order to program this assumption in a way that did not overtax the capacity of the CDC 3800 computer, infanticide was simulated by modifying the sex ratio at birth. This is not an ideal reflection of reality, but the bias it introduces should be minimal. The result of these runs is shown below, paired with identical runs using a 100% sex ratio.

	Run	L.T.	Sex Ratio	Assumptions	Mean Fertility Level	Median MES	Mean MES
(1)	20	27.5-45	66	Set 5 (monog.)	148.6	75	79.3
	22	27.5-45	66	Set 5 (monog.)	144.9	75	74.7
	21	27.5-45	100	Set 5 (monog.)	122.1	125	218.2
(2)	32	25-40	100	Set 6 (polyg.)	121.4	150	283.5
	33	25-40	66	Set 6 (polyg.)	103.5	150	266.3
(3)	39	27.5-45	100	Set 5 (polyg.)	120.3	150	279.1
	40	27.5-45	66	Set 5 (polyg.)	101.7	150	258.7

Male infanticide is modeled above, not for cultural reasons, but because of the way the simulation program is written. The direction, if not the magnitude, of its influence on the MES should be similar to that of female infanticide. In a monogamous society, infanticide drastically increases the demands on female fertility to keep the population stable. This is due to the fact that a large number of females remains unmated (male infanticide), or that there are fewer fertile females per population size. Thus, the mated females have to increase their fertility to make up for this reproductive loss. At the same time, however, the MES shows the smallest value of all simulation runs. Ninety-nine percent of the matings take place within the population occupying a single tier of hexagons. In a polygynous society, on the other hand, infanticide (of males) greatly reduces the fertility requirements on females, while the MES does not seem to be affected at all.

Sex-specific infanticide introduces an imbalance in the adult sex ratio. In a monogamous society, this increases the number of mate choices for one sex and, concomitantly, decreases the size of the MES relative to a society without infanticide. In a society which permits polygyny, sex-specific infanticide cannot have the same effect. Since all members of the mating pool, with or without infanticide, will find a mate anyway, there is no change in the number of potential mates (per person looking for a mate) and the MES should stay at the same level. These results give some additional support to the prevalence of infanticide among living hunters and gatherers.

Infanticide certainly is one of the mechanisms by which hunters and gatherers maintain their population density at a level that can be supported by local resources and far below the point where diminishing returns for productive effort set in.

However, sex-specific infanticide allows for a stable and minimal size mating network in a society that is largely monogamous. It makes mate choice a more predictable event and it decreases the distance to which one has to extend one's communication network to facilitate mate exchange. At the same time, it increases the fertility requirement for females. This makes it difficult to accept *sex-specific* infanticide in areas where females carry a large burden of the productive effort.

Several conclusions can be drawn from my simulations of the minimum equilibrium size of Pleistocene societies. The most important of these concerns the range of this parameter. Given a large variety of cultural and biological assumptions, the minimal equilibrium size remains within a range equivalent to a maximum band consisting of 7 to 19 minimum bands of 25 people each. In terms of spatial distribution, this is equivalent to spatial networks consisting of either 1 or 2 tiers of hexagonal subterritories. Within this narrow range, Pleistocene populations were able to select from among a large number of alternative strategies those which suited their particular cultural, biological and spatial adaptive requirements.

The size of the minimal equilibrium group is determined by population fertility rates, mortality rates, and sex ratio, as well as by cultural rules imposed on the mating system. Juvenile mortality is positively related to the size of the MES, while adult life expectancy is negatively related to this value. The suspected high infant mortality of Paleolithic hunters and gatherers would tend to move the MES toward the upper part of the observed range. Fertility influences the MES through its variance, the variance of the fertility and the MES being positively correlated. It would be advantageous for Paleolithic populations to maintain an almost constant birth rate in order to keep the MES down. Child spacing, infanticide, and family planning in general, as reported in the ethnographic literature for hunters and gatherers, would tend to work toward this aim.

The imposition of cultural rules on the mating system significantly influences the value of the MES. The more restrictive these rules, the larger the size of the MES will be. We might expect the imposition of such rules under certain circumstances: in areas which require large cooperative work parties; in areas with a very uneven raw material distribution requiring constant and stable reciprocity between large numbers of minimum bands; and in areas of high population densities, in which competition and friction might be lessened through stable and large mating systems and their cultural corollaries. Under low population densities a minimal number of restrictive rules would be expected. Rules that will increase the size of the MES include age restrictions on matings, exogamy, polygyny, and regulations against mating with certain classes of relatives.

Incest is not advantageous to hunting and gathering populations because it introduces an element of instability and imbalance into the social system. If incest is permitted, mate selection becomes a less predictable process. Incest increases the variance of the distances between the social units from which the mates derive. At the same time, it has little effect on the mean mating distance and on the size of the MES. The incest taboo is thus of adaptive advantage to hunting and gathering populations. The same was shown for sex-specific infanticide. In societies that allow only a minimum of polygyny, sex-specific infanticide will stabilize the mating network, decrease its size, and make mate choice more predictable.

In conclusion, the MES is not a constant, but a variable with a relatively narrow range. This range is controlled by mortality, fertility, sex ratio, and cultural rules on the mating system. Placed into a regional, ecological, and cultural frame of reference, the MES can be used to predict the spatial extent of Pleistocene societies.

THE MINIMUM BAND

Since "25" has been so frequently used in this paper as the mean size of minimum bands among Pleistocene hunters and gatherers, I will discuss the relevance of this or comparable values to Paleolithic societies. So many ethnographers have recorded minimum band sizes around 25 people among modern hunters and gatherers that this figure has recently been labelled "magical" (Lee and DeVore 1968). The list below is only a selection from those groups mentioned by the participants in the symposium *Band Societies* (Damas 1969).

Band Society	Minimum Band Size	Source in Damas (ed.) 1969
!Kung Bushmen	25 mean	Marshall p. 281
Hadzapi	20-60 range	Bicchieri p. 209
Birhor	25 mean	Williams p. 146
Semang	20-30 range	Gardner p. 211
Andaman Islanders	30-50 range	Gardner p. 211
Athapaskans (in general)	20-75 range	McKennan p. 104
eastern subarctic hunters	25-50 range	Rogers p. 52
Iglulingmiut	35 mean	Damas p. 210
Copper Eskimos	15 mean	Damas p. 210

If we add Australian aborigines, for whom Birdsell (1957) reports a mode of 25, a range of 20-70 people per minimum band appears to be characteristic for modern hunters and gatherers on 4 continents, in the northern and southern hemispheres, in the tropics and in the Arctic, and at population densities from .002 to .8 persons/km^2. Thus, the "magical range" appears to be of general adaptive significance to hunting and gathering societies.

The existence of powerful feedback mechanisms, which keep the size of minimum bands within this relatively narrow range, can be best demonstrated in a negative fashion. For this purpose, the simulation model was slightly altered so as to prohibit any moves except those required by patrilocality. This removed all negative feedback controlling the size of minimum bands. At the beginning of the simulation, a regional population of 169 "minimum bands" was created containing 8 members each. (This simulation was carried out with a life table derived from the Illinois Archaic, see Wobst 1971.) The birth rate was allowed to fluctuate in order to keep the regional population balanced against the population mortality. The results of this run by ten-year intervals are shown below.

Ten-Year Period	Mean Number of Occupied Territories	Mean Number of Occupants
1	168.8	8.67
2	164.0	8.88
3	157.8	9.68
4	149.8	10.44
5	139.0	10.75
6	125.0	11.15
7	120.3	11.84
8	115.0	12.44
9	107.8	13.17
10	102.3	13.96

In the absence of counterforces, the number of occupied territories will steadily decrease, while the mean size of the minimum bands will steadily increase. If this program were allowed to run for several centuries, the number of occupied territories would decrease to 1, while the size of the minimum band would increase to that of the regional population. This is not an artifact of the particular simulation, but a response predictable from small sample statistics.

All minimum bands are subject to small, annual size fluctuations from the cumulative effects of the probabilistic variables of mortality, fertility, and sex ratio. These population parameters are binomial in character, that is, they are summary statements of individuals' chances to die or survive, and to be barren or to bear offspring (the mortality chances of a given individual are expressed in the binomial equation: [the chance of survival of individual of given age in given year] + [chance of death] = 1). This has 2 implications: as the minimum band increases in size, the fluctuations due to mortality become proportionally smaller; and, the larger the band, the smaller its chance to die out due to such fluctuations.

The binomial series given below illustrates the different effect of mortality on groups of different sizes. The mean chance of an individual to die is derived from the crude death rate of Weiss's *25-40* life table.

Group Size	Chance of "Band" to Die Out in Given Year
1	.0566
2	.0030
3	.0001
4	.00001
5	.0000005

A similar series characterizes population fertility so that the larger the number of women in the local group, the smaller the proportional fluctuations in the number and the sex of births and the smaller the probability of 0 births in a given year. Thus, in the absence of natural and cultural mechanisms controlling the size of local populations, local groups of small size are strongly selected against and a strong trend operates toward the agglomeration of the minimum bands of a society into a single local group.

A local population aggregate of the size of the MES, however, is not adaptive to most hunting and gathering societies. Most natural environments do not permit consistent long-term aggregates as large as the MES. Given nonrandomly distributed, seasonally and annually varying food resources, the larger the size of the co-resident group, the higher will be the cost of transport in relation to the amount of production. A point is reached at which it becomes more profitable to split the local group in order to maximize the amount of production and to minimize transport costs and trampling space. Given Pleistocene population densities, and Paleolithic exploitative technologies and means of transport, this point must have been far below the size of the MES.

At the same time, cultural feedback mechanisms prevent the aggregation of large, consistent local groups. Band societies are characterized by a lack of formal political institutions such as courts, councils and chieftainships. Conflicts are usually resolved through fission of the band (Lee and DeVore 1968:12). This process effectively keeps the band size at low and stable levels since the larger the size of the minimum band, the more numerous are the causes of potential conflicts. The higher the number of such conflicts, the greater will be the chance for band fission, thus maintaining the minimum band at a low equilibrium size.

The previously mentioned processes of interband food sharing and visiting work in the same direction. If, through the random variations in mortality, fertility, and sex ratio, the size of a given minimum band increases to a level far above that of other bands within a given society, it is more profitable for the surplus to move to smaller bands (with smaller density of producers and thus higher chances of hunting and gathering success) than to maintain the larger social aggregate. These moves are made more easily since the amount of personal property is kept at a minimum level, and since there is no immovable personal possession such as individual claims to land or fishing rights.

Finally, the exploitative technology of hunters and gatherers does not require year-round maintenance of large cooperative groups in a given place. A minimal band group provides a sufficient manpower reservoir for most task-specific groups in a hunting and gathering society. In the model life table population used in most of our simulations (*MT:25-40*), there are 11 to 12 adults in a minimum band of 25 people. This is sufficient for manning a range of different task groups for the day-to-day exploitation of the environment. The few occasions during the seasonal activity cycle which require larger groups, such as game drives, the maintenance of game fences, or rituals, can be handled at a lower year-round cost by means of temporary alliances between neighboring minimum bands, rather than through the year-round maintenance of larger local groups.

The lower size threshold of minimum bands is determined by a series of cultural and statistical considerations. Thus, a minimum band has to be large enough to offer a reasonable chance for the unimpaired transmission of cultural knowledge to the next generation. The collective lifetime experience of the members should provide the individual with a sufficient range of choices to cope with daily crisis situations and with sufficient input from daily observations to insure hunting and gathering success. There have to be enough members to effectively carry out the daily activities required for the group's survival, to decrease the impact of individual failure through mutual food sharing and cooperation, and to exploit the environment more efficiently through a division of labor by age and sex.

The *half-life*, borrowed from nuclear physics, can be used to describe the longevity and relative stability of social units (in the absence of cultural factors counteracting the stochastic variables of fertility, mortality, and sex ratio). Since populations under equilibrium conditions and on a regional scale never completely die out, there can be no finite value for their longevity. Rather, extinction is an exponential decay process which theoretically has an infinite tail. The *half-life* is then simply the number of years required until one-half of the originally existing social units have ceased to exist.

For minimum bands, this value was calculated by tabulating all runs with life table *MT:25-40*, and adding the number of minimal bands that had become extinct for each run. These sums were then totalled. The resulting value was divided by the total length of the runs in order to determine the mean number of bands dying out per year. This figure was in turn divided by the mean number of bands per year, the result being the chance of an individual band to die out in a given year. Based on 21 simulations, which ran for a total of 4200 yr, I obtained a value of .00389 (as the chance of a band to die out due to mortality, fertility, and sex ratio fluctuations in a given year). The half-life can then be calculated using the following equation: .5 = (chance of minimum band to survive a single year [.996])$^{(\text{number of years } [x])}$. Solving this equation logarithmically, we obtain a value of 177 yr for the half-life of minimum bands. Due to the simple assumptions governing the simulations, this value can only be considered as a rough estimate. Nevertheless, its magnitude suggests that local groups in the range of 25 members are adaptive to hunting and gathering societies. This size is sufficient to guarantee the survival of minimum bands over many generations.

This is not to imply that minimum bands are actually this long-lived, or that they are of the stable composition implied by the model. It only serves to show that minimum bands are of sufficient size to survive most stochastic fluctuations of mortality, fertility, and sex ratio: in addition to their cultural adaptiveness, they are statistically and demographically long-lived. Compared to this, the nuclear family is a statistically short-lived event. As was shown in Wobst (1971), the half-life of a nuclear family household ranges between 21 and 29 yr depending on the life table utilized. Statistically, only 50% of the nuclear families will survive a single generation.

Before these "magical numbers" can be applied to specific Paleolithic societies, they have to be adjusted to take into account the specific environmental conditions to which a given social group is adapted. As in the case of the MES, the value of "25" establishes only the lower limit of the range of mean sizes of minimum bands under equilibrium conditions due to our assumption of maximal environmental constraints.

Since the survival chance and the diachronic stability of nuclear families are both so low, households could not function as independent cultural or biological units. The cultural units which are significant to the survival of the cultural system are the minimum band with its half-life of approximately 180 yr and the maximum band as the breeding population.

SOME ARCHAEOLOGICAL IMPLICATIONS

In the preceding sections we have posited 3 cultural units of predictable and consistent membership within Paleolithic cultural systems: the *maximum band*, the *minimum band*, and the *nuclear family*. The maximum band, as a distinct manifestation of the cultural system of band society, is expected to range in size from 175 to 475 people under Paleolithic conditions. The minimum band, as the maximal local aggregate, is expected to contain around 25 people. A Paleolithic society, then, must have consisted of between 7 and 19 minimum bands. If their territories were hexagonally packed, the spatial network of a Pleistocene society must have consisted of 1 or 2 tiers of hexagonal minimum band territories. The nuclear family identifies a household group. This unit is the minimal structural pose of which the membership is predictable and recurrent.

Based on modern hunters and gatherers, we would expect to find a large number of additional cultural units within Pleistocene societies, such as hunting groups, parties organized to obtain raw materials, and aggregates for rituals. While their presence can be inferred crossculturally, their membership, size and composition are society-specific. They become predictable only once the social and natural environment of a given society is understood. It is expected that game theory and Monte Carlo simulations will advance our understanding of these task-specific groups at the level of the individual society.

The longevity of the minimum band and household were determined in terms of the *half-life*: if only demographic and statistical variables are allowed to enter into the calculations, a minimum band under the stated assumptions will have a half-life of around 180 yr while that of the nuclear family household amounts to around 25 yr. Thus, 0.38% of the minimum bands and about 3.1% of the nuclear family households will be discontinued every year. Under the assumption of a stationary population, the same figures express the rate at which new households are formed. Given life table *MT:25-40* and a maximum band with 19 local groups of 25 members each, around 5 nuclear family households will be discontinued in an average year; for minimum bands the same value should lie around 0.07.

The last 2 figures have strong implications for the archaeological record if the following model is considered. We can make the (doubtlessly unrealistic) assumptions that a settlement will be revisited as long as the cultural unit occupying it remains functional; that the settlement will fall into disuse if the cultural unit is discontinued; that newly founded cultural units will occupy new settlement locations; and that (for illustrative purposes only!) the seasonal cycle of a certain Paleolithic society involves only household winter camps and minimum band summer camps. Under the given assumptions, the annual rates of minimum band and household discontinuation and founding can then be used to calculate the number of nuclear family and minimum band camps in the area occupied by the assumed Paleolithic society.

If the model population remains in essential equilibrium over 1000 yr, it will produce around 5000 family camps, and around 70 minimum band camps. For hunters and gatherers, these estimates are clearly too low by several orders of magnitude. The assumed degree of settlement stability is not confirmed ethnographically (Campbell 1968). Nuclear families and minimum bands function as camping units for a variety of purposes in the course of a year. The number of camps utilized during the lifespan of a given cultural unit is heavily influenced by the character, distribution, and density of resources, the strategy of resource exploitation, the regional vegetation and geomorphology, the proportion of inhabitable space within the environment, and the ease of overland travel, as well as by hygienic and epidemiological factors. Depending on the specific habitat, the number of camps of the given types should be considerably larger.

Likewise, the ratio between minimum band camps and household camps (1 to 71) is distorted if it is evaluated against ethnographic data. The home bases of minimum bands receive more structural input than those of households. More ritual is associated with home bases than with household camps. Locations suitable for the base camps of a minimum band are rare; a far larger proportion of the territory can be utilized for nuclear family camps. Finally, a minimum band is less mobile than a nuclear family. Thus, one would expect more family camps per minimum band camp than is evident from our calculations. Nevertheless, it indicates that the Paleolithic archaeologist need not despair about the lack of potential subject matter.

In this context, I would like to introduce a class of archaeological data which is usually neglected, overlooked, or misinterpreted. Let us consider the annual activity cycle of a hypothetical Paleolithic society. Year after year, sections of the environment will be exploited by gathering and hunting without leaving traces which archaeologists usually consider worthy of investigation, at least if butchering and kill sites are excluded. The hunting and gathering adaptation demands that a large proportion of the daily work effort be spent outside of settlements proper. These activities require tools and produce archaeological remains of potential interest for the understanding of different procurement strategies. If a Pleistocene society remained in an equilibrium state for a sufficiently long period, we can recover these remains and incorporate the activities which they reflect into reconstructions of the way of life of Paleolithic societies.

Let us consider that a minimum band exploits a territory of 1250 km^2 (at .02 population density). If 10% of this territory is visited regularly and an average of 5 artifacts per person per day is deposited during these visits, after a period of 1000 yr there will be an average of .36 artifacts/m^2 within the 125 km^2 visited frequently. Under a *Poisson* distribution (random dispersal of the artifacts over the area), 125,000 of the meter squares (.2%) would contain 5 or more artifacts.

My own experiments suggest that we can expect far greater concentrations in certain areas if models of random walk are fitted to regional habitats and communication routes. Let us consider the following simulation model. A gathering camp is visited year after year during a given season. The material to be gathered is spaced randomly over the surrounding area in patches 10 to 100 m apart from each other. A collecting trip of 10 km length will provide a sufficient return to the gatherer. In the actual simulation, the gathering camp is the origin of a coordinate system. The gathering trip was segmented into increments of random length between 10 and 100 m. For each of these increments, a random direction between 0° and 360° (in relation to the x-axis) was generated. Under these assumptions, there is less than 1% chance that the gatherer will touch areas more than 1 km away from the camp. Even if we rule that a gatherer has to avoid all patches previously visited on a given collecting trip, and that a group of gatherers goes on a collecting trip together, the chances for reaching areas further away from the camp increase only slightly. The more restricted the field of movement, the greater the resulting density of artifacts will be, and the more the activity area has been exposed to subsequent erosion, the greater will be the postdepositional concentration of artifacts. It would be well to reanalyze some of the archaeological evidence in this light. Thus, some of the Lower Paleolithic "sites" strung out along the terraces of the Thames, the Somme, and the Seine may present only chance accumulations of artifacts deposited outside of occupation areas by repeatedly performed tasks. The dense concentrations of Upper Paleolithic remains along the rivers which enter the Pannonian Basin may be interpreted in the same way. By careful investigation of the habitat of Paleolithic societies, we should be able to define these activity-specific areas. Their remains do not constitute clusters of artifacts and features clearly delimited in time and space, but continuous distributions of task-specific artifacts and tool kits.

The preceding considerations suggest that it is possible to apply systematic survey procedures to Paleolithic societies. The large number of settlements occupied in the course of a given equilibrium state of a society, as well as the large number of artifacts which will accumulate in specific areas outside the settlements, should enable us to develop sampling models for the areas of given Paleolithic societies. Such research can proceed only in areas where the Pleistocene stratigraphy is fairly complete, such as in the loess areas of France, eastern Austria, and southern Moravia. Based on detailed paleoenvironmental investigations, the area inhabited by a given Paleolithic society has to be classified in terms of those factors which are significant to the spatial articulation of the given cultural network. Stratified random sampling methodology can then be applied to obtain unbiased and representative information concerning aspects of the system's operation. Given this approach, the predictions derived from my models for conditions of maximal environmental constraints can be put to a test in appropriate habitats. By means of game theory and Monte Carlo simulations, more specific models can be developed to generate predictions for specific societies and their habitats, so that the models presented here can be revised and improved in terms of the archaeological evidence.

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