DEMOGRAPHY AND DENDROCHRONOLOGY: 
A CRITICAL EXAMINATION OF A 
PROPOSED POPULATION INDEX

By 
SARAH HELEN SCHLANGER

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the requirements for the degree of 

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Chairman
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DEMOGRAPHY AND DENDROCHRONOLOGY:

A CRITICAL EXAMINATION OF A
PROPOSED POPULATION INDEX

ABSTRACT

by Sarah Helen Schlanger, M.A.
Washington State University, 1980

Chairman: William D. Lipe

A proposed index to population growth patterns is
examined and found to be an unsatisfactory method for distin-
guishing between exponential and logistic growth trends thought
to describe population growth in the American Southwest. The
patterns formed by the beam cutting index at the sites studied
by Eighmy are inferred to be a product of post-occupational site
disturbance and sampling difficulties. An alternative approach
derived from the properties of exponential and logistic popula-
tion growth is outlined as a direction for further research.
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1. INTRODUCTION

Population change has been considered as the cause or the consequence of a variety of the developments of both the past and the present, ranging from agricultural innovation to zero population growth (e.g., Binford 1968; Boserup 1965). Some kinds of archaeological data provide good opportunities for studies of changing patterns of human population growth.

The major drawback to the use of archaeological information is that some quantifiable aspect of the record must be chosen as an index or representation of population since the people themselves are no longer available for counting. The growing interest in the study of prehistoric population trends has prompted a search for reliable indices. This paper will present a critical examination of one recently proposed index—dendrochronologically datable beams used in the construction of habitation roofs in Southwestern Pueblo sites.

Interest in this particular index was triggered by Jeffrey Eighmy's conclusions (Eighmy 1979) that a single type of growth trend—the logistic growth pattern—characterized 13 of 14 of the dated beam series that he examined and that this growth pattern was probably characteristic of most of the prehistoric agricultural sites in the Southwest.

A logistic growth pattern is one in which growth is slow at first, rapid during the middle of the growth history, and then
slow again toward the end of the growth sequence. The final stage of the growth pattern is marked by cessation of growth altogether, with population maintaining a constant size determined by some absolute ceiling to growth. Eighmy suggests that in the sites he studied, this cessation of growth was a "result of natural limitations, thereby forcing emigration and/or Malthusian checks to limit further population growth within the community" (Eighmy 1979:217).

It seemed to me that single sites were an inappropriate unit for the analysis of population trends. Group size at a single site may be limited by available building space at that site, by local environmental conditions, or by the social organization of the group. This same group may continue to contribute to the regional population through emigration or some of its members as site-specific limits are reached. Accordingly, I applied the general methodology and assumptions entailed in Eighmy's approach to an analysis of the population dynamics of Pueblo III cliff-dwellers in five regions of the Southwest (Schlanger 1978). I found that the beam cutting trends from these five regions were characterized by a slow initial growth followed by rapid growth during the middle of the growth history. In contrast to Eighmy's site results, however, four of the five areas I studied exhibited an abrupt cessation of tree cutting activity at the point on a logistic curve where growth would have begun to slow. Initially, this suggested to me that either the growth pattern in these areas might be exponential rather than logistic or that a logistic pattern might have been interrupted.
Exponential, or J-shaped, growth patterns differ from logistic ones in that growth increases rapidly "in exponential or compound interest fashion . . . and then stops abruptly as environmental resistance or another limit becomes effective more or less suddenly" (Odum 1971:183).

If population trends on a regional scale could be demonstrated to be exponential, it would imply that the local checks to population growth documented by Eighmy, which may have operated to gradually slow population growth at single sites, were not affecting the growth of population in the larger regions in which the sites were located.

After working with the index, however, I became concerned, along with and partially in the instigation of others, that the pattern of beam cutting dates which Eighmy and I were analyzing was a product of a number of factors in addition to population trends (Schlanger, Lipe, and Kohler 1979) and that it might not be possible to distinguish logistic from exponential growth on the basis of the beam cutting index. I decided that, before making further use of beam cutting dates as population growth indices, I should more fully understand the relationships between population and the beam index at single sites. A consideration of the literature on Pueblo building patterns and the use of structural wood raises a number of specific questions about the reasons for the results obtained by both Eighmy and by myself:

1. Is Eighmy's model linking beams to population adequate?
2. Is the beam index really measuring what it proposes to measure?
3. Is the form of population growth which Eighmy postulates the only possible model, given the beam-cutting data?

4. Is the beam-cutting pattern a function of a single process?

5. Can the beam-cutting index provide information about prehistoric events other than population change?

The following paper is an attempt to answer these questions. By doing so, I hope to evaluate the utility of the proposed beam index for studies of population change and also to suggest research needed to develop and test such archaeological indices. I have organized the paper so that it follows the order of the questions listed above. The first chapters present Eighmy's model, an evaluation of his assumptions linking beams to population, an evaluation of his choice of growth models, and a discussion of his methodology. This is followed by the presentation of a new model which addresses the points raised in the foregoing analyses, by experimentation with the model through simulation, by a reevaluation of the beam data, and finally, by an evaluation of the prospects of the beam index for studying population trends or other prehistoric activities.
2. AN OUTLINE OF EIGHMY'S ARGUMENT

Eighmy recognized that dendrochronologically datable beams have several features which make them useful as an index to prehistoric activity:

1. Dendrochronology provides the potential for the most accurate dating available to archaeologists.

2. Beams are numerous in a number of Southwestern prehistoric sites.

3. Beams are relatively easy to sample.

4. Tree rings can be reliably dated to within one year.

Accordingly, Eighmy employed a beam index to demonstrate his hypothesis of environmentally limited growth in prehistoric Southwestern agricultural communities.

_Eighmy's Model_

In order to use beams as an index to population growth trends, Eighmy had to establish a link between beams and numbers of people, and to demonstrate that evidence of this relationship was recoverable from the archaeological record. His argument rests on three points:

1. There is a constant relationship between the amount of roofed space (and hence numbers of beams) and the size of the population housed.

2. Additions to roofed space were made primarily because of increased population size.

3. The assemblage of tree-ring-dated beams recovered from a site is a representative sample of all the roofing beams which were ever in use at that site.
Eighmy also outlined a number of specific qualifications to the assumptions listed above, as follows:

1. The model is intended to cover only the growth phase of a site.

2. The analysis is limited to beams from habitation structures (other types of structural wood could have been used as well if he had assumed a constant ratio of nonhabitation roofed space to population).

3. The ratio of roofed space to population does not change during the occupation of a site.

4. Wood used for construction of roofs is cut live—wood is not scavenged from other sites and deadfall trees are not used.

5. Beams from abandoned nonhabitation roofs are not used later in habitation roofs. (This is implicit in Eighmy's argument, although he did not address it directly.)

6. Increases in population require increases in roofed habitation space and thus require the cutting of additional beams.

7. When roofs are abandoned at a site, the beams are incorporated into new building, and not destroyed, so that the ratio of beams to population remains the same—ole roofs are replaced by new roofs.

8. The population of roofing beams at the end of the growth phase at a site will have a distribution of cutting dates that tracks the growth rate of the population because beams and population must maintain a constant ratio and because no beams have been discarded.

Although Eighmy's model assumes that no beams have been discarded, he does recognize that beams may be lost to the archeologist during the occupation of the site, after the occupation of the site, or because of an inability to date recoverable beams. He assumes, however, that such loss will occur randomly and that the sample of beams which are dated provide a representative sample of all beams ever used at a site.
Eighmy chose 12 localities for analysis: Betatakin and Kiet Siel in northeastern Arizona; Canyon Creek and Showlow in east-central Arizona; Chetro Ketl in northwestern New Mexico; Pindi Pueblo and Arroyo Hondo near Santa Fe, New Mexico; Cerro Colorado in west-central New Mexico; Wupatki in north-central Arizona; M-3 and Moon House in southeastern Utah; and the Johnson Canyon cliff dwellings in southeastern Colorado.

Eighmy's Methods

Eighmy graphed the beams from each site he studied cumulatively by date—the horizontal axis of such a graph represents time in actual calendar years, and the vertical axis represents cumulated number of beams. The number of beams datable to the second year of occupation is added to number dating to the previous year, the third year's beams to the combined total, and so forth until the latest dated beam or beams have been added to the total. Graphs of this type are known as cumulative frequency distributions or ogives. The number of beams present at year X in a site, on these graphs, is the number of beams which date to that year or earlier (Figure 1). Eighmy chose to use this method of presentation rather than a histogram because "it indicates the number of logs in use each year rather than the number of logs cut each year . . . [and because cumulative distributions] tend to average out yearly variation in log cutting. . . ." (Eighmy 1979:209). Graphing beam cutting in this way simulates the growth of a beam population at a site; and if all Eighmy's assumptions
Figure 1. Cumulative frequency distribution of dated beams from 12 sites on Chapin Mesa, Mesa Verde National Park, southwestern Colorado. Data abstracted from Robinson et al. (1975).
are applicable, it maps the cumulative growth of population at the site.

Eighmy found that the cumulative frequencies produced S-shaped curves which he attributed to logistic growth trends in the human population at a site. Logistic growth is characterized by a fairly slow start, a rapid increase in population over the middle portion of the growth history, and a slowing to an upper growth limit at the end of the growth history as a result of density-conditioned growth (Figure 2).

The next step in Eighmy's analysis involved verification of his hypothesis that growth in Southwestern agricultural communities was logistic. To do this, he calculated a correlation coefficient ($R^2$--Pearson's product-moment coefficient) for the best fit of logistic curves versus exponential curves, the alternate growth pattern which he considered. The values of the squared correlation coefficient were quite high, averaging 0.95 for the fit between his data and a logistic growth curve. Finally, Eighmy concluded that the density-dependent growth pattern and the limits to growth were a result of similar subsistence strategies in all of the communities studied, which placed a limit on local population sizes. This aspect of his study will not be dealt with in this thesis.
Figure 2. Logistic growth pattern.
3. ANALYSIS OF THE MODEL AND THE METHODOLOGY

In this chapter I will review both Eighmy's model and the methods he employed to test it. The analyses will be conducted through a review of the literature on beam use in prehistoric Southwestern sites, mathematical models of growth, and the properties of cumulative curves.

Links between Beams and Population

In order to use the beam cutting record as an index to population trends, Eighmy made a number of assumptions, outlined earlier, aimed at satisfying two conditions:

1. The cutting dates of roof beams from any site or group of sites are a representative sample of all roof beams cut for use at that site or group of sites; and

2. Roof beams were cut in response to a need for increased roofed space, resulting from an increase in population.

Through a search of the relevant literature, I identified means by which actions of the aboriginal inhabitants of a site or area might affect sample representativeness. For example,

1. Beams may be removed from a site for use in other nearby sites. The original provenience of such beams cannot be determined so that the effect cannot be corrected for a reassigning beams to their original proveniences (Bannister and Smiley 1955:190; Bannister 1962:509; Haury 1935:104; Dean 1969:77-78; Dean 1978a:241; Dean 1978b:149). This process could occur either during the occupation of a site or following its abandonment so
long as nearby sites were still being used. In cliff dwellings, well protected beams may be preserved almost indefinitely and serve as a source of construction materials well after the site has been abandoned.

2. Beams may be burned as firewood, as noted by A. E. Douglass.

Many a prehistoric jewel has been given to the flames unwittingly because no one knew the importance of tree rings in recording the passage of years. Where fuel was scarce, fragments of precious timbers at many an ancient ruin in the American Southwest may have been used as firewood by sheep-herder, prospector, and even archaeologist . . . (1935:738-739).

Although Douglass' remarks are directed toward post-occupational beam destruction, the aboriginal inhabitants of sites probably burned timbers from unused roofs as well. Dean (1969:144) also notes this possibility.

An equally common use for these old timbers [from abandoned rooms] apparently was firewood. This may account for the fewer number of early dates than might otherwise be expected . . .

Roofs may also have burned during the occupation of a site, resulting in the removal of at least some of their beams from the archaeological record, as Haury recorded at Showlow (Haury and Hargrave 1931).

3. The occurrence of "repairs," or beams which yield dates later than the probably construction date of roofs (Dean 1969:63-74, 112-138) makes it clear that beams sometimes had to be replaced during the occupation of a site. The subsequent provenience of the beams which were replaced cannot be determined. Since they had become unsuitable in their original context, it
seems likely that at least some of these would simply have been discarded.

The effects of processes such as these on the assemblage of beams present at the end of the site's growth phase is difficult to predict or assess, since they result in removal of beams from the assemblage. It would seem, however, that such losses would differentially affect beams emplaced early in the site's growth phase. That is, the longer a beam has been in use, the greater its chances for loss through deterioration, replacement, discard, or fire. Consequently, such processes should bias the early part of the beam cutting record in favor of the later part.

Post-occupational and noncultural processes would probably also have a great effect on the beam record and also seem likely to have operated in a nonrandom fashion. The best example of post-occupational, nonrandom destruction of beams comes from Tsegi Phase cliff dwellings, where Dean (1969:73-74) suggests that the latest beams at these sites were often removed by erosion. According to Dean's analysis, the more protected portions of these sites--behind the dripline of the sheltering overhang--were built up first. When the protected space was completely occupied, people were forced to build in areas outside the dripline (Dean 1969:73-74, 138). Thus structures located beyond the dripline were probably the latest built at a site. These same poorly protected and easily accessible structures would also be the most likely to be affected by erosion, vandalism, and other damage.

This same argument can be extended to surface sites as well. The most obvious case would be a multistory site where the
lower levels and interior rooms would tend to be better preserved than those on the outside of the structural block. If the site had grown by accretion, it seems likely that the upper levels and some exterior rooms would tend to be younger than those below and on the inside—natural erosional processes and human agents would affect these rooms and their constituent beams differentially. Therefore, post-occupational destruction or loss is most likely to remove the youngest beams from sites with exposed building and thereby bias the archaeological record toward older dates.

Not all the beams sampled will yield usable dates. Some beams may have come from species difficult to date or from trees which grew on complacent sites. In the Tsegi area Dean (1969:80, 146-147) documents a shift through time from aspen, a nondatable species, to datable coniferous species such as juniper, white fir, and Douglas fir. Presumably, the supply of aspen near the sites was exhausted by removal of trees for land-clearing or construction. Robinson (1967) has documented similar shifts through time among juniper, pines, and fir, each of which has a different dating potential. In addition to these difficulties, datable species may yield either a "cutting" date—the last year of growth before the tree was cut down or died, or a "noncutting" date, where the distinguishing characteristics which mark cutting dates are absent. Some species are more likely to yield cutting dates than others (Dean 1978b:139, 148).

Finally, sampling at a site may be limited by the accessibility of beams, their apparent age, or other criteria. Sampling at Chetro Ketl, for example, was limited to those beams exposed
during excavation; therefore, not all stories at the five-story site are equally represented (Hawley 1934).

In contradiction to Eighmy's second condition, beams may have been cut and used for reasons other than a need for increased roof space:

1. Beams may have been lost and/or replaced due to the effects of some of the processes outlined above.

2. Beams may be added to structures as additional support after the initial roof construction, usually to shore up cracking timbers (Bannister 1962:509; 1965:124; Ahlstrom et al. 1978:20). Roofs may be partially or entirely rebuilt during remodelling efforts as well (Dean 1969:139-142). If some of the replaced beams were destroyed and their replacements were freshly cut, a false apparent "growth" could result.

3. Beams may be cut and stockpiled for future use. This process has been documented by Bannister at Chaco Canyon (1965:151) and Dean in Tsegi Canyon (1969:77, 144). Stockpiled timbers are cut and accumulated in response to an anticipated construction need rather than in response to a current need. Unless this practice is detected and corrected for, analysis will indicate an apparent population growth in advance of the actual growth event. Stockpiled beams at Betatakín were kept for three to seven years before use in construction. At Kiet Siel, beams were kept for two to five years (Dean 1969:77, 144). The rate at which these stockpiled beams are taken up in construction will affect the shape of the projected population curve.
4. Finally, nonhabitation roof beams may be reused in habitation roofs and habitation roof beams may end up in nonhabitation roofs. Nonhabitation roofs, covering kivas, storage, and other types of structures may act as large reservoirs of wood. If the wood requirements of these two groups of structures maintain a constant ratio and the beams are kept separate through the occupation of a site, Eighmy's model is not violated. It seems likely, however, that beams from abandoned kivas and from storage structures would become incorporated in habitation structures and vice versa. Furthermore, room functions may change, most commonly in the conversation of habitation rooms to storage. If ratios among ceremonial, storage, and habitation space remain constant, a model of beam cutting might easily be expanded to cover these sorts of structures as well. On the other hand, there is also evidence that the relative proportions of these structures types changes through time in Anasazi sites. In particular, the period Eighmy addresses saw a growth in the relative amount of space devoted to storage (Lipe 1978). If beams are being exchanged between habitation and nonhabitation structures and the relative size of the nonhabitation "reservoir" is changing, effects could be created which would violate the conditions of Eighmy's model.

Properties of Cumulative Frequencies and Logistic Curves

As mentioned earlier, Eighmy used cumulative frequency distributions in his analysis rather than frequency histograms used by earlier workers analyzing chronological and behavioral aspects of prehistoric beam usage (Dean 1969; Harrill and Breternitz 1976).
This choice had two important effects:

1. Use of cumulative curves led Eighmy to infer that the observed pattern of beam cutting was a function of population growth, and because of the shape of the curves, of a particular type of growth.

2. By using cumulative frequencies, Eighmy generated artificially high correlation values between his data and a logistic growth curve.

Eighmy's argument and needs to be discussed because the possibility for confusing growth-related and growth-unrelated phenomena is critical to the use of any index of population change.

It should be noted immediately that cumulative frequency curves have a tendency to be S-shaped, regardless of the underlying process of formation (Hays 1973:106-107), because of the tendency for values in many distributions to be clustered toward the center of the distribution. The size and shape of the "tails" of the curve (Figure 2) are dependent on the particular distribution (Hays 1973:107). As might be expected, the closer the distribution is to a normal distribution, the closer the resemblance between its cumulative frequency distribution and that of a cumulated normal distribution, which is itself very close in form to that produced by a logistic equation (Bliss 1970:167).

I do not mean to suggest that the frequencies of dates of beams cut at the sites which Eighmy examined are the product of normal distributions in the ordinary sense--this could only result from prehistoric selection of beams from a population of beams normally distributed with respect to age at cutting--something which is not in the realm of possibility. What I mean to suggest is that the present S-shaped distribution of cutting dates may
well be an artifact of something other than logistic growth. For example, an originally uniform distribution of cutting dates might be transformed to one resembling a normal distribution by post-occupational destruction combined with occupational beam destruction and loss through the processes outlined in the previous section. As noted, beams incorporated earliest have greatest probability of loss during occupation, while those emplaced latest probably have the greatest probability of loss after occupation. Hence, the middle part of the distribution might have a better chance of survival than the earliest and latest parts. I will expand on this point in the next chapter. For now, I want to introduce the possibility that the observed distributions may not be entirely due to underlying human population growth patterns.

*Logistic Growth and Other Mathematical Models of Growth*

Because the preceding discussion has cast doubt on the use of cumulative beam-cutting distributions as an accurate or reliable record of population growth, it is necessary to examine the nature of human population growth and mathematical models that describe it. The logistic growth pattern was first introduced by a Belgian mathematician, P. F. Verhulst (1847, in Hiorns 1972), but did not gain wide recognition until its rediscovery by Raymond Pearl and Lowell J. Reed (1920), who developed it as a method of estimating population for those years which were not covered by official census counts. To this end, they endeavored to develop a mathematical model and curve-fitting procedure which would not only account for the observed population growth pattern (they were
studying the growth of the U.S. population as seen in the census records from 1790 to 1910) but also state a general law of population growth (Pearl and Reed 1920:280). They state their general law in terms of the rate of increase to be expected in human populations:

... [The] rate of population increase in a limited area at any instant of time is proportional (a) to the magnitude of the population existing at that instant (amount of increase already attained) and (b) to the still unutilized potentialities of population support existing the limited area (Pearl and Reed 1920:281).

This logistic growth pattern, where the rate of growth is governed by both the size of the population and an upper limit to the size of the population which can be achieved that becomes increasingly effective as population builds, slowing growth, is often contrasted with a growth pattern in which there is density- (or size-) conditioned growth, but population growth is halted abruptly when it reaches the upper limit. In other words, the logistic form results from an increasingly greater effect of some factor detrimental to the population in contrast to a form where the effects of the limiting factor are delayed until a critical threshold is reached. E. P. Odum (1971:186-187) described these two types of growth as S-shaped and J-shaped and notes that "the J-shaped form may be considered an incomplete sigmoid curve since a sudden limiting effect is brought to bear before the self-limiting effects within the population become important."

All plant and animal population growth patterns described to date have corresponded to one of these two general growth patterns. Is one of these patterns more likely to occur in human populations? Ideally, the regulation of populations such that
they conform to an upper population limit is achieved by changes in birth and death rates. In cases of logistic growth, as population density increases, birth rates tend to decline and death rates tend to increase. When birth rates equal death rates, an equilibrium is reached and population growth ceases. Some density-dependent control mechanisms which have been observed in empirical studies of nonhuman animals include competition for feeding space and food among the young, which increases death rates relative to birth rates; competition for food among the adults, resulting in reduced fecundity, or a relative decrease in birth rates compared to death rates; and emigration of individuals (Wilson and Bossert 1971:93-110). Emigration has the same effect as increasing death rates in a local population because it results in the removal of population members. Density-dependent controls which have been suggested for human groups include disease, emigration, warfare, infanticide, abortion, contraception, senilicide, and other mechanisms which operate in response to a wide variety of hypothesized emic ideals concerning family size and community size, age at marriage, and spacing of children (Cowgill 1975). Some combination of such factors appears to operate in many human groups, at the least, to keep population size well below that which would appear possible given available resources.

Arguments can be developed for J-shaped human population growth trends, however. The human tendency to form social alliances may affect the ability of a population or group to regulate its size most efficiently. Growth in human groups may be more likely to be affected by immigration and emigration of groups of
people, probably bound by kin ties, than is the growth of nonhuman populations, where growth is more likely to be a function of individual births and deaths. Both nonhuman and human responses, such as territorial spacing and limitation of breeding opportunities, affect fecundity more or less directly. This difference in response in growth potential means that human groups have the ability to grow or decline faster than would be possible if increase was limited to group birth/death interactions. The rapid build-up potential of human populations may result in "overshooting" the upper limit to population size. The necessary reduction in group size may be achieved through emigration of socially connected units, which should result in faster compensation than limitation of births or increased deaths. Where the possibility for emigration exists, this J-shaped growth and rapid drop may be the most characteristic human growth pattern. Ethnographically documented groups such as the Yanomamo of South America are a good example of this type of growth, where groups fission abruptly when population rises to a point where social friction becomes intolerable (Chagnon 1972:257). Where emigration is not a viable response—where the area occupied by a population is truly limited, as in the original formulation of the Pearl and Reed logistic equation, human populations are more likely to behave in accordance with the predictions of the logistic equation. As noted by Deevey (1958:84-86), human populations, with their complex life history, exhibit a lag between the birth of individuals and the realization of the individuals' reproductive potential. This makes human populations likely to "overshoot" their upper
population limit even though growth may be slowed in response to the approaching limit. Humans cannot respond as rapidly to environmental changes as can animals with shorter birth intervals and shorter lifespans. The oscillations which ensue when the population shoots past the upper limit may decrease with time and allow the population to settle at the level of the local carrying capacity (the upper limit to growth). The size of the oscillations will be due in part, however, to the response which the group makes to the "overshoot." If social or economic ties between individuals do affect the way in which human groups respond to stress, as I suspect they must, humans may not always be in a position to dampen oscillations. The result may be a repetitive pattern of exponential or slightly logistic buildup followed by a rapid drop well below carrying capacity (Figure 3).

Although, as the previous discussion points out, both J-shaped and S-shaped growth could be expected in human populations, one factor gives J-shaped growth a slightly greater probability in the situation discussed here. All of the sites which Eighmy studied were abandoned completely sometime after the time-span covered by the beam cutting dates. As noted by Odum (1971: 189), violent oscillations are characteristic of J-shaped growth patterns and dampened oscillations are characteristic of S-shaped growth. Abandonment can be considered as a special case of violent oscillations are typical of agricultural ecosystems such as the Pueblo one which presumably was dependent on a small number of resources.
Figure 3. S-shaped and J-shaped growth and types of oscillations. (a) S-shaped growth to limit; (b) S-shaped growth with dampened oscillations around limit; (c) J-shaped growth to limit; (d) J-shaped growth and oscillations around limit.
Do Eighmy's Best-Fit Curves Really Fit?

The detection of a logistic pattern is dependent on the upper limit to growth remaining either constant or lowering gradually during the period of observation. If the limiting conditions change such that the limit is raised, the logistic pattern would be disrupted and the distinctive tail would not be produced. In the same way, if conditions changed so that the upper limit to growth was lowered rapidly, logistic growth may be interrupted before a tail is produced. External limiting factors may interrupt a logistic pattern at any point along the curve, of course, but it may not always be possible to determine what the population trend was before interruption.

One can test whether or not an asymptotic limit has been reached and so demonstrate a logistic growth pattern conclusively by comparing the asymptote of the best-fitting curve with the observed upper limit of the curve produced by a cumulative frequency distribution of the data points. Half of the cases which Eighmy studied had best-fit curves in which the asymptote was greater than the last data point and half had asymptotes that were lower than the last data point (Eighmy 1979:Table 8.1). Since logistic curves are defined by an asymptotic limit to growth, this suggests that either these data represent some other phenomena altogether or that the pattern produced by these data follows, but does not contain, an entire logistic curve.

Although the asymptotes in Eighmy's curves do not coincide with the last data points, he did not recognize the possibility that he may have been dealing with incomplete logistic patterns
These incomplete patterns may have been produced by a drop in the upper limit to growth with sites abandoned fairly rapidly as a result or by a temporary raising of the upper limit before sites were abandoned.

As previously noted, the form of the cumulated beam cutting dates is unlikely to be due entirely to population growth. The question that must be addressed now is if the form of the data is not entirely due to an underlying human population growth tendency, or if there is some doubt, why are the correlations between the actual data and a best-fitting logistic curve so high? The logistic "fit" which Eighmy calculated using a squared coefficient, $R^2$ (the square of Pearson's product-moment correlation), was consistently better than the exponential "fit": The value calculated for the fit to a logistic curve averages 0.95 for the 12 sites or groups of sites; the fit to exponential curves ranged from 0.16 to 0.93 with an average of 0.65.

There are several factors which might account for this:

1. As noted previously, cumulative frequency distributions have a tendency to be S-shaped, which would automatically give better fits to logistic curves than to exponential or other non-S-shaped types of curves.

2. Cumulative frequency distributions tend to smooth out the variance from one data point to the next because the curve can only grow in one direction—up. Dampening the variance should raise correlation values.

3. The curve-fitting procedure for fitting logistic curves, first introduced by Pearl and Reed (1920) and later
elaborated by Hiorns (1965) from earlier work by Stevens (1951) uses three points from the data curve in fitting the logistic curve. As Pearl and Reed (1920:283) remark,

It must not be forgotten, however, that the error is reduced in the present case by virtue of the fact that in three out of the thirteen ordinates [or whatever number of observations there are in a particular case] theory and observation are made by the procrustean method of fitting, to coincide exactly.

4. The use of a correlation coefficient such as Pearson's \( r \) on cumulated data violates one of the assumptions of the statistic. According to Guilford and Fruchter (1973:95), the derivation of the formula for the Pearson \( r \) assumes that "... the scores have been obtained in independent pairs...." The values of the points along a cumulative curve are not unrelated; in fact, they are serially correlated. A more appropriate test for this situation is the Kolmogorov-Smirnov One-Sample Test. This test is specifically designed to compare the fit between the cumulative relative frequency distribution of sample data with the cumulative relative frequency distribution of a theoretical model (Gibbons 1976:56-64). The reduction of error introduced by the method of curve-fitting will affect the results of this test as well, however. The Chi-square test can also be applied to these data. The Chi-square test requires no assumptions about the form of the data and can be used to determine where the data depart from the ideal model as well as testing the overall goodness of fit.
4. A MODEL OF BEAM USAGE AND THE FORMATION OF
THE ARCHAEOLOGICAL RECORD OF CUTTING DATES

The previous chapter has shown that the interpretation of beam
cutting can be complicated by processes operating on beams and
beam usage in occupied sites, processes of beam preservation or
deterioration in unoccupied sites, and even the effects inherent
in the analytical method. These complications do not necessarily
negate the usefulness of the beam index in tracking population
trends, but it is important to evaluate the possible effects of
these complications when interpreting the beam-cutting record.
One way to do this is to construct a model of beam usage and pres-
servation which incorporates the various processes and to experi-
ment with the effects of the various processes by manipulating
the model. Such an exercise should allow one to specify the con-
ditions which produce various patterns in beam-cutting records and
to distinguish between the effects of population change, beam-
usage processes, beam preservation effects, and methodological
effects. At best, manipulation of such a model will be able to
specify the actions of these effects; at the least, it should
point out conditions under which interpretation of the beam-
cutting record is liable to be difficult. The model developed
here is an attempt to sort out these effects by delineating the
processes which form the pattern of cutting dates observed
archaeologically.
The model diagrammed in Figure 4 consists of two parts:

1. The processes responsible for the beam complement formed during the occupation of a site, which comprise the **occupational beam-use system**, and produce the **occupational beam set**.

2. The post-occupational processes, which result in the **post-occupational beam set**.

This second beam complement is composed of two subsets. The first subset is in place at a site and can be sampled by an archaeologist. The second subset consists of beams which yield dates which can then be subjected to various sorts of analyses. The second subset is called the **dated-beam set**; it is this subset that carries the dates, which are the object of interest.

**The Occupational Beam-Use System**

The occupational beam-use system is modelled as being composed of three major elements: the **beams** themselves, which have been cut for use in construction at a site; the **roofs**, which beams are cut to build, and which must be maintained as serviceable structures while they are occupied; and **people**, who cut the beams, construct the roofs, and live under them. These three elements are linked by the action of cutting beams and by the incorporation of these beams into structures. The beams themselves are markers of prehistoric activity. It is the causes of that activity that eventually provide the link that enables one to discuss population change or other cultural processes reflected in the beam-cutting record. Population change or other processes associated with beam-cutting activity cannot, of course, be observed directly but must be inferred.
Figure 4. Organization of the occupational beam-use system and the post-occupational system.
The impetus for beam-cutting activity can derive from one or more of the processes that can act upon the major elements (beams, roofs, people). Each of the elements has processes which are specific to it; these processes act as avenues along which beams can enter or leave the occupational beam-use system and the post-occupational beam set.

The processes which affect beams increasingly take effect through time. Construction materials may be altered through decay, inset infestation, drying and cracking, fire, or increased load stress on the timbers. These alterations may render beams unsuitable for continued use in structures; if so, they will be replaced and the altered beams will be discarded or diverted to some non-construction purpose. Such beams, because they are no longer in roofs, will be missing from the post-occupational beam set available for study by archaeologists and will pass out of the beam-use system.

Processes which affect roofs are primarily governed by change in the room function. Room functions may vary through time. If these alterations are sufficient to cause rebuilding of the roof, the original beams may need to be replaced or augmented. Examples of this process would include roof remodelling or replacement as changes in room function resulted in a need to alter roof size or to increase the load-bearing capacity of the roof. Dean (1969:65, 124) gives two examples of roof alteration in response to stress from an increased load on the roof. In one case, beams were added to halt "attrition of the roof caused by the cross-roof traffic" that took place after the construction of neighboring
rooms (1969:56). In the other case, the original roof was removed and a new, stronger one built to support the addition of a second story (1969:124). Single beams or groups of beams might be replaced in the roof to effect changes of this type. The beams which were replaced, although no longer useful for their original purpose, may still enter into the occupational beam set through incorporation into another structure. Although their original context has been lost, these beams remain part of the occupational beam set.

Changing space requirements of a population determine the processes by which population changes result in beams entering or leaving the system. These space requirements may result from a change in group size or organization and may be satisfied through:

1. A rearrangement of existing space, which would result in the processes outlined above for changing roof function.

2. Additions to existing space to accommodate a growing population.

3. Decreases in the total amount of space utilized to conform to population decrease.

4. Changes in the per capita allocation of living, storage, or ceremonial space.

Each of these events may result in the shift of beams from place to place within a site, the additions of beams to the existing beam set, or an increase in the availability of beams through the abandonment of space and hence of the beams which formed the roof of that space.

In developing the model outlined here, I assumed that the actual introduction of beams into the occupational beam set is dependent on:
1. The amount of unused or modifiable roofed space available in relation to the space requirements of the occupying group. A shortage of space may result in new construction or remodelling.

2. The continued suitability of roofed structures, which will determine the lifespans of these structures (both in their original and modified forms).

3. The need for new timbers to maintain or modify existing structures.

4. The availability of used timbers at the site.

5. The nature of the available wood itself. The suitability of different types of wood for construction and their resistance to stress and decay will determine both which woods are selected for construction and how long the wood will last.

All of the factors listed above may vary through time to different extents. It is clear that, in general, the longer a site is occupied, the greater the effect these factors are likely to have on the occupational beam set. Conversely, if the occupation of a site is short, there is greater likelihood that beams will remain in their original construction contexts. Because these factors may vary in their rates, however, the movement of beams through the occupational beam set may occur at varying rates.

The Post-Occupational Beam Set

Those beams, and their cutting dates, that are available for study are a set comprised of those that survived as members of the occupational beam set at the time of site abandonment and that also survived post-occupational attrition. Loss from the post-occupational beam set can take place in the ways which were outlined earlier. The survival of beams is modelled as a function of three factors:
1. The nature of the wood, which determines its suitability for dendrochronological dating.

2. Beam location within a site, which determines exposure to nonhuman erosive forces.

3. Human scavenging of beams which are no longer in use.

Again, the effect of these factors may vary greatly. Their cumulative effect will be partly a function of the amount of time which has passed since abandonment of the site.
5. EXPERIMENTATION

Once the major components and associated processes of a system have been described and their various relationships and interactions established, the magnitude of the effects imposed by the processes inherent in the system can be estimated by experimenting with the rates assigned to the processes. This simulation study is a first step in a process of experimentation. The rates used in the simulation were chosen to correspond as closely as possible to rates which could be derived from well documented Southwestern Pueblo sites. The simulations themselves were confined to the occupational beam-use system, and the effects of further changing the rates were extrapolated from the results. Post-occupational processes did not lend themselves to a simulation approach, primarily because I could not devise a reliable method for assigning rates to the processes. Consequently, the effects of post-occupational processes are educated guesses.

Simulation of the Occupational Beam-Use System

The processes incorporated into the simulation included roof repair (beam replacement), beam cutting, reuse of available beams, roof construction, roof reuse, and roof abandonment. These processes are set in motion by population change. Three different types of population growth were examined: a logistic, or density-dependent type with an upper limit which restricts growth; an exponential, or density-dependent type with an abruptly acting
upper limit to growth; and a linear, or density-independent type. Two versions of the linear growth pattern were run. In one, growth was constant; and in the other, a rapid population growth was followed by an equally rapid decline. Two versions of the simulation were run for each type of population pattern. In the first version it was assumed that beam cutting was always a direct response to population growth and that beams were not removed from the occupational beam set (Eighmy's model). In the second version beam cutting was not always triggered directly by population growth; beams entered and left the occupational beam set in response to repairs, roof abandonments, and the availability of reusable beams.

Rates for the various processes were chosen as follows: The number of beams per roof in use was set at eight. This figure could be adjusted for particular applications where the actual number of beams per roof was known. Since the number of beams per roof was treated as a constant in the following simulation runs, the actual number of beams chosen to make up a roof was not critical.

Beams in a roof were replaced at a rate of one beam per 10 years of room occupancy. The beams were considered to have been destroyed as they were replaced. Therefore, they were removed from the occupational beam set and hence from the resulting post-occupational beam sets. (It might have been desirable to treat some fraction of these beams as suitable for continued use in construction in other roofs, reflecting removal for remodelling. This was not done, however.) The beam replacement rate used in the
simulations was based on an examination of the ratio of new to reused beams at Betatakin and Kiet Siel, northeastern Arizona (Dean 1969), and Moon House, southeastern Utah (Lipe, personal communication). Both Betatakin and Mouse House contained approximately 70% reused beams, and Kiet Siel contained approximately 50% used beams. Beams in a structure were inferred to be reused if their dates were earlier than the date ascribed to the building of the structure by the investigators. In the simulation described here, the rate of replacement would give the simulated site approximately 50% replacement of beams by the end of its 40-year lifespan. It should be noted that the simulated discard of replaced beams violates one of the assumptions of Eighmy's model and should result in diminished survival of beams from the earlier portions of the site's history.

Each roofed habitation was assumed to have been occupied by a single family containing five individuals, following Turner and Lofgren (1966), who calculated an average of five persons per Pueblo residence. In the simulation, individuals were assigned to specific rooms. When the modelled population was growing, a new room was added whenever the number of unhoused individuals reached five or more. As population declined, however, a room was abandoned only with the loss of all five of its occupants. Changes in the number of roofs were thus conservative during both growth and decline. The beams in the roof of an abandoned dwelling were made available for use in building new roofs or for the replacement of beams in older roofs. Older rooms were the first to be abandoned in these simulations; in other words, people were subtracted from
the oldest rooms until it was abandoned, then the next-oldest room began to lose its inhabitants, etc. A 40-year period was simulated in each of the computer runs.

In the simulated situations, as opposed to those observed archaeologically, reusable beams were rarely available. This was a result of an oversimplified model of the prehistoric beam-use system that showed less population movement, remodelling, repair, and rebuilding than is known from actual sites.

Because beams that were replaced for roof repairs were considered to be destroyed, used beams did not become available for repairs or new building until population declined and a room was abandoned. When used timbers were available for construction, however, they were chosen first for construction or repair needs. When the supply of used timbers was exhausted, new beams were cut as they were needed. Although the model allowed rooms to be abandoned at any time during a site's history, only one room was abandoned in any of the simulation runs, except for the growth-decline runs with linear growth patterns. As a consequence, the simulations employ primarily new beams for repair and construction.

The simulated annual population growth rate averages about 2% per year. This rate was chosen to achieve a population of about 130 people in 40 years and thereby make the simulations comparable to the sites of Betatakın and Kiet Siel. The actual growth rate realized in any given year of the simulations varied from this average for two reasons. First, the underlying model of population growth (logistic, exponential, or linear) differed from run to run. Secondly, the actual population change in any year
was chosen from values distributed normally around the growth curve of the particular growth model driving the particular run.

The output from each run of the simulation was a yearly summary of the events which acted to change the number of roofs and beams in the system. This output was then translated to a graph which displayed the population size per year and the cumulative frequencies of beam-cutting dates. Although the population curve shows the actual number of people present in the simulated site each year, the beam curve is calculated from the number of beams cut per year which remain at the end of the 40 years. Consequently, in simulation runs in which beams are replaced, with concomitant destruction of old beams, and the removal of their dates from the record, the beam curve does not represent the total number of beams used at the site. In generating the population curves, a fluctuation around the growth pattern was introduced to make the simulations more realistic and in an only partially successful effort to allow roofs to be abandoned during site occupancy under any of the growth patterns.

The simulations were programmed in SIMSCRIPT II.5, a general purpose simulation language chosen because it is an event-oriented language in which the simulation advances from one discrete event to another; changes in the state of the system are brought about through changes wrought by these discrete events. This type of language was thought to better fit the beam-use model than a continuous-system simulation language in which the state of the system is continuously updated through the solution of a set of related equations. The simulation program, which was written
by Dr. Timothy A. Kohler of Washington State University, is presented in the Appendix.

Simulation Results

At first glance, the simulation results (Figures 5, 6, 7, and 8) confirm Eighmy's suggestion that the cumulative frequency curves of beam-cutting dates are an accurate reflection of population trends. The dashed-line curves, recording the results of a model in which beam replacement and discard are not allowed to affect the beam-cutting trend, can be recognized as approximating the underlying growth trends. The beam-cutting trends plotted in solid lines are derived from simulating a beam-use system in which beam replacements and discards do occur as a function of beam age; these also follow the population growth patterns quite well. In the logistic growth simulations, however, the logistic "look" of the "no discard and replacement" curve is derived from the artificial levelling off at the end of the curve produced when population stabilizes and no more beams are cut. When this period of zero growth is graphed in a cumulative curve, it results in a flat line, the logistic "tail." Because archaeologically we would have no way of dating the continued use of this artificial site, the use record given by the available dates presents a pattern of growth--best described as linear--much different than expected from knowledge of the population growth pattern.

The same abrupt end to the tree-cutting activity and the resulting record of tree-ring dates described for the logistic simulations would also occur in linear and exponential population
Figure 5. Frequencies of beams and population under the logistic growth model.
Figure 6. Frequencies of beams and population under the linear growth model.
Figure 7. Frequencies of beams and population under the exponential growth model.
Figure 8. Frequencies of beams and population under the growth-decline model.
growth situations if population growth ended after 40 years and if beams were never replaced by newly cut wood. If Eighmy's conclusions about the beam-cutting records that he observed were correct (i.e., that they reflected logistic growth), then his predicted population curves should have recorded population stabilization immediately following the last recorded dated beam. Eighmy's best-fit curves, however, ended above and below the last recorded dates (Schlanger 1978, Eighmy 1979).

Extrapolation from the simulation results can give us the form of the curves expected if population growth in the simulations had stabilized, but site occupation continued along with site maintenance. If this had happened, the final portions of each of the beam-cutting records would have registered identical "tails" produced by the addition of beams in response to identical rates of repair and beam reuse. In other words, when Eighmy's model is violated to the extent that some new beams can be added even in the absence of population growth, the cumulative beam date distribution continues after population stabilizes and the form of the beam-cutting records after such a period of stabilization will be similar even with different patterns of population growth prior to stabilization. Under these circumstances, the form of the beam-cutting curves will be S-shaped. The overall form of the curve results from:

1. The rate of new building. The model simulated calls for new room building only when population outgrows existing rooms, but it would probably have been more realistic to allow some new building to take place in response to the "wearing out" of existing structures.
2. The rate at which beams need to be replaced or at which
remodelling is done.

3. The availability of used beams for repair, remodelling,
or new building.

4. The rate at which new beams are cut (affected by the
availability of used beams, the rates of repairs and
remodelling, etc.).

5. The length of time that a site is occupied.

The simulation results suggest that, with the rate of one
beam per roof needing replacement every 10 years, a site occupation
of only 40 years is sufficient for this process to begin to affect
the beam-cutting record. It should be possible to detect the
point at which building maintenance, indicating population stabi-
lization, replaces new building, indicating continued population
growth. This change should entail a change in the rate of beam
use at a site. Before the population stabilizes, beams may have
to be cut to house a growing population; after stabilization,
beams should only have to be cut for maintenance or remodelling.
A high rate of beam replacement may, however, make the detection
of such a shift difficult.

Another factor which may affect interpretation of the
beam-cutting record is the rate of site abandonment. The linear
growth and decline simulation was designed to study the effects of
this process. Although the beam-cutting record from a site cannot
show when a site was abandoned, since it is impossible to tell
from the dates alone how long a site was occupied after the last
beam was cut there, the simulation suggests a way in which the
problem of the rate of site abandonment can be approached. One
would expect that the rate at which a site was abandoned will
affect the pattern of dated beams because of the increasing availability of reusable beams from abandoned roofs. If a site is abandoned slowly, there is a greater probability that beams from abandoned rooms will be incorporated into later construction and repair activities. The range of dates in a single roof or set of roofs from a site should be a rough measure of the rate of site abandonment, or possibly, population fluctuation during site occupancy. There should be a greater range of dates in individual roofs in sites which were abandoned slowly than in roofs from sites which were abandoned rapidly.

Post-Occupational Effects

Up to this point, discussion has been limited to the record of beam cutting as it appears at the time that occupation of the site ended. The post-occupational disturbance processes discussed previously were not included in the simulation study, but the effect of these processes can be predicted by drawing on the background provided by the simulation results.

The most serious post-occupational disturbances would result in destruction of beams differentially with respect to their cutting dates. This type of disturbance was explicitly discounted by Eighmy, who assumed that all beams would be affected equally by post-occupational processes. If, however, the more protected portions of a site were built up first as Dean (1969:73-74, 138) demonstrated in Tsegi Canyon, then protected portions of a site would probably be among the youngest; consequently, weathering and erosion might disproportionately affect the younger beams. Even
if these outer structures were protected from the weather, they would have been easier prey for prehistoric and historic beam robbers. In either case, the relatively greater loss of young beams would produce an apparent slowing in the rate of beam cutting at the end of the site's occupation. The resulting "tail" at the end of the cumulative curve of beam frequencies would mimic a logistic curve and a logistic growth pattern. If the process of deterioration continued long enough, many of the later structures at a site might be entirely destroyed, making a determination of what sort of growth characterized the community extremely difficult, if not impossible. Sites which have been affected in this way should not be considered as good candidates for growth trend analysis.

The other post-occupational effect which must be considered involves the dating potential of different species of wood. Changing preferences for species with different dating potential during a site's occupation will affect the pattern of beam dates.
6. AN EVALUATION OF THE BEAM-CUTTING EVIDENCE

The conclusions from the previous chapters will now be used to interpret beam-cutting data from Southwestern sites. The cumulated dates from 11 of the 12 sites that were examined by Eighmy followed a logistic-looking pattern. The simulations also suggested that even under more "realistic" assumptions there were patterned relationships between the terminal occupational set of beam-cutting dates and population growth trends. Consideration of certain implications of the revised beam-use model, however, as well as the differential effects of post-occupational processes, suggested that the beam-cutting index must be used with caution. Use of the beam-cutting record as a proxy for population will be hindered under certain conditions that may occur:

1. When beams have been differentially destroyed with respect to age through erosion or vandalism.

2. When preferences for differentially datable species as construction material varied during occupation and construction of a site.

3. When a site exhibits a history of extensive reuse of beams, resulting in loss of the original provenience of the beams.

4. When the sample of beams recovered for dendrochronological analysis is not representative of all beams ever used.

If the earlier and/or later portions of the beam-cutting record are seriously biased, incomplete, or missing, it will not be possible to determine the actual shape of the underlying growth trend. If the data are not available, growth trends that are
density-dependent, density-independent, or restricted by an upper limit cannot be distinguished on the basis of the beam-cutting record alone. In light of this possibility, the sites which Eighmy used in his analysis were reexamined. A brief description of the sites, with emphasis on preservation and sampling of construction wood, is presented below along with an evaluation of each site as a candidate for population trend analysis.

Betatakin

Betatakin is located in a canyon tributary to Tsegi Canyon, northeastern Arizona. The site consists of an arc of 100 to 200 masonry and jacal rooms, the central portion of which was lost during the collapse of part of the cave roof and back wall. The site was apparently occupied for 30 to 50 years—the earliest and latest cutting dates from construction beams at the site were AD 1246 and AD 1286. Although Dean (1969) attempted to obtain samples from all accessible construction wood at the site, the beam-cutting record cannot serve as an accurate reflection of population growth trends because:

1. What appear to be the youngest rooms at the site are located outside the cave dripline and datable wood was not preserved in these rooms (Dean 1969:73-74).

2. The oldest rooms at the site were evidently dismantled midway through the occupation of the site, and some of the beams reused (Dean 1969:74). It is impossible to know the number of beams lost during this operation or the cutting dates of those beams.

3. Rooffall destroyed part of the ruin after abandonment.

Taken together, these features suggest that the logistic character of the surviving cumulative beam curve may result from differential destruction of both early and late beams.
Kiet Siel

Kiet Siel is located in Tsegi Canyon, northeastern Arizona, in a large cave with two levels—an upper one of bedrock and a lower one of alluvial fill. The site contains about 150 masonry and jacal structures. Those on the alluvium have been damaged considerably by recent erosion. As at Betatakinn, all structural wood was collected for dating purposes. Although the site appears to be a good candidate for population trend analysis, there are several problems:

1. No tree-ring dates are available for the structures located on the lower level. If Dean is correct in assuming that construction of rooms would have proceeded by filling up the best (most sheltered and level) spaces first, then these lower cave structures may have been among the most recent at the site.

2. There are no structures remaining from the early phases of occupation AD 950 to the early 1200s. All the timbers dating to this period come from structures which were built later, using the old beams. It is likely that the site was abandoned or underwent population decline between the earlier occupations and the later one, which produced most of the remaining structures. Use of the earlier dates has the effect of making the increase in building during the last occupation appear more gradual than it actually was.

3. The early construction at this site included a good deal of aspen, a wood which was not datable, whereas coniferous wood, which does date, was used later. This change in building
material means the earlier beams have less chance of entering the
dated-beam set than do the later ones.

As at Betatakin, the record from Kiet Siel is likely to be the
product of differential preservation rather than of a logistic
population trend.

*Canyon Creek*

The Canyon Creek site is located in a shallow overhang on a
side canyon to Canyon Creek, on the Fort Apache Indian Reservation,
east-central Arizona. The ruin contains 58 rooms, arranged in two
stories. Cutting dates place the occupation of the site between
AD 1326 and AD 1348. The excavator, Emil Haury, sampled all parts
of the site in an attempt to determine the building sequence. The
outside rooms of the site have been adversely affected by erosion,
however. Haury's careful dating of the rooms at this site estab-
lished that growth expanded outwards from a core of rooms against
the back wall in the central part of the shelter; the construction
dates of the outer rooms were consistently later than the inner
ones, and presumably, the outermost rooms, containing no databe
wood, would have yielded the most recent dates of all (Haury and
Hargrave 1931:23-58). Loss of the latest dates makes it impos-
sible to evaluate the final form of the growth curve at this site.

*Chetro Ketl*

Chetro Ketl, an open pueblo of over 500 rooms, thought to
have once contained five stories (Hawley 1934:7-8), is located on
the north side of Chaco Wash, in Chaco Canyon National Monument,
northwestern New Mexico. Based on the earliest and latest cutting
dates of AD 945 and AD 1116, occupation of the site spanned about 200 years. Tree-ring samples have been collected by numerous workers, starting with Neil Judd in 1922 and 1925. Judd was followed by Florence Hawley and Roy Lasseter in 1930 and 1931, and by Paul Reiter at about the same time. Gila Pueblc collections were made in 1940; collections were also made by the School of American Research and turned over to Gila Pueblo. Finally, Gordon Vivian collected datable samples during repair work following a flash flood in 1947 (Bannister 1965:139-146). A total of 380 dates has been derived from Chetro Ketl specimens, from which a chronology of building involving several phases has been developed. Hawley's analysis (1934), the original and perhaps most thorough of the dendrochronologically based studies of Chetro Ketl, brings out a number of ways in which Chetro Ketl falls short as a subject for population-trend analysis.

1. There was apparently an early occupation dating from AD 945 to AD 1030 which is represented only by reused beams in later structures (Hawley 1934:22); the original extent of the occupation and the number of beams involved cannot be determined. Another period of rebuilding took place between AD 1088 and AD 1090, with similar implications for sample adequacy for this period (Hawley 1934:73).

2. Although the site originally contained as many as five stories, there are no dates from the fifth floor, only one date from the fourth floor, and only 15 dates from the first floor. The remainder of the dates for which the floor is known—97 out of 112 remaining dates—are split fairly evenly between the second
and third floors (54 on the second and 42 on the third). The lack of datable wood from the upper floors is almost certainly due to erosion from exposure to the elements. The lack of dates from the first floor, however, is probably due to a lower rate of sampling, because the first floor beams were not exposed and had to be recovered through excavation. In concert, these factors would be sufficient to cause an S-shaped bend in the tree-cutting curve regardless of the underlying population trend, which cannot be determined from the datable data.

Pindi

Pindi Pueblo is another open, masonry and adobe, multi-storied pueblo located five miles south down the Santa Fe River from Santa Fe, New Mexico, on the north bank of the river. Tree-ring samples were collected during excavation of some 200 ground-floor rooms during 1932 and 1933. Unfortunately, the excavators were forced to rely on charcoal fragments taken from fire pits, room fill, and floor deposits for their dendrochronological specimens. Only one room out of all the rooms they excavated had burned and thus allowed the preservation of structural timbers in situ. As the site's reporters, Stanley Stubbs and W. S. Stallings note,

Pindi was never burned in the course of its varied history, and physical conditions were not conducive to preservation of wood in its original state. We found traces of beams in a few rooms, for the most part reduced to powder and none were sufficiently preserved to be dated, but even these traces were scarce. It is presumed that beams of the earlier buildings were salvaged for use in succeeding structures, and it is likely that during its final decay the pueblo was stripped of beams for use in the Agua Fria Schoolhouse site . . . (Stubbs and Stallings 1953:22).
There are three major problems with the tree-ring data from Pindi:

1. Although some of the fragments which they collected undoubtedly came from structural members, these cannot be separated from the rest, making it very difficult to evaluate beam-cutting trends derived from this data base.

2. There are no collections from the upper story rooms, or at least, none are so designated.

3. A "sizable" portion of the site had been removed by stream cutting prior to excavation (Stubbs and Stallings 1953:1). Pindi represents probably the most drastic case of loss of beams from the beam-cutting record of any of the sites which Eighmy analyzed.

Showlow

Showlow, an open-masonry pueblo of some 200 rooms, standing one-story high for the most part, is located about 55 miles south of Holbrook, in east-central Arizona. The tree-ring collections made in 1929 by Emil Haury yielded over 500 dates, from nearly 30 proveniences (Bannister et al. 1966:39, 47). Haury suggests that building at Showlow was earliest at the center of the roomblock and latest at the extreme ends of the E-shaped pueblo, with additions at the north being earlier than those at the south, "the only direction in which the pueblo could be easily enlarged" (Haury and Hargrave 1931:15). The final portion of the beam cutting at this site is well preserved, due to a fire which apparently swept through the roomblock from north to south, preserving the structural timbers through carbonization. The site was not reoccupied following this disaster, and the beams and fragments thus preserved were apparently undisturbed until recent historic-period construction destroyed much of the center of the roomblock. Although the most recent dates are probably well
preserved at this site, the early and middle parts of the record are largely lost, making it impossible to fit a curve to the earlier growth tendencies here.

Johnson Canyon

The Johnson Canyon designation refers to a set of nine cliff dwellings in tributaries of Johnson Canyon, southwestern Colorado, where tree-ring samples were collected during 1974. The collecting strategy followed the example set by Jeffrey Dean in his Tsegi Canyon studies: Samples were collected from all accessible structural wood, both in situ and loose (Harrill and Breternitz 1976:396). The 145 cutting dates suggest an initial occupation of the sites beginning in the 1140s. This was followed by an abandonment and then a reoccupation of the same sites in the early 1200s which lasted for 30 to 40 years (Harrill and Breternitz 1976:375). Eighmy noted that the Johnson Canyon dates form two logistic curves, corresponding to the two periods of occupation. The investigation by Harrill and Breternitz suggests that the "tail" of the earlier curve and the slow start of the later curve are functions of the reuse of beams and the renovation of structures remaining in the sites after 20 to 30 years of abandonment. Further, the generally poor state of preservation in the sites suggests that the apparent slowing in the second curve may be a function of loss of beams through erosion and decomposition (Harrill and Breternitz 1976:378-386).
Arroyo Hondo

The site of Arroyo Hondo is located five miles south of Santa Fe, New Mexico, on the edge of the Arroyo Hondo. This site is a large, rambling, primarily adobe pueblo, exhibiting two temporally distinct building periods. The earlier of the two periods produced a complex of 20 to 24 roomblocks, containing a total of about 1,000 rooms. The second roomblock was smaller, with only 10 to 13 roomblocks and about 230 rooms (Schwartz and Lang 1973:3). Tree-ring specimens were collected during excavations directed by Douglas Schwartz of the School of American Research. No description of the sampling technique was provided in either of the brief preliminary field reports of the two seasons of excavation (Schwartz 1971; Schwartz and Lang 1973) so that I cannot evaluate the adequacy of the sampling procedures. The excavations yielded 147 dates from 25 proveniences in the site. Of these 147 dates, only 21 are from the earlier, larger component. There are two major problems with the tree-ring data from this site:

1. Poor preservation of the earlier structures, which evidently did not burn, but which, evidently, were razed by builders during the construction of the later component at the site. A good deal of early component wood was salvaged during this razing and appears in rooms of the second component as reused beams (Schwartz and Lang 1973:26).

2. The specimens with cutting dates which were recovered from the second component come primarily from a single provenience: 60 of the 95 dates come from Roomblock 16. Roomblock 15 yielded 13 dates; and the remaining 22 dates are distributed among
five other roomblocks and one kiva (Schwartz and Lang 1973:28-29). This bias in recovery or preservation becomes especially critical in light of the reconstructed sequence of roomblock building order (Schwartz and Lang 1973:27)--none of the latest roomblocks yielded cutting dates, leaving the pattern of cutting toward the end of the occupation unknown.

*Cerro Colorado*

This site is a multi-component, primarily Basketmaker III, pithouse village site, eight miles north of the town of Quemado in west-central New Mexico. The site is believed to have contained up to 50 simultaneously occupied pithouses (Bullard 1962:7); 17 pithouses, 14 of which dated to the Basketmaker III occupation and one to the Pueblo I occupation, were excavated in all (Bullard 1962:12). Objections to the use of the dates recovered from this site for population-trend studies stem from two sources:

1. Sampling at the site was not done in a systematic fashion, so that the excavated pithouses and their dates cannot be used as a representative sample of the site as a whole.

2. There is reason to believe that pithouses at this site were not all occupied simultaneously. Instead, it appears that old pithouses were abandoned and burned, with new pithouses erected to replace them when the residences had reached the age of about 30 (Bannister et al. 1970:21). The evidence at this site contradicts several of Eighmy's assumptions: houses were not all occupied continuously or simultaneously, and new housing may not have been built in response to population growth. The Cerro
Colorado data may reflect an increase in the termite population but not necessarily in the human one.

_M-3 and Moon House_

Both of these sites are located in McLoyd's Canyon, in the upper part of a deeply incised drainage on Cedar Mesa, south-eastern Utah. The sites are small masonry and jacal cliff dwellings located within 300 meters of each other and appear to have largely overlapping occupations. M-3 contains nine rooms, one of which is a kiva and three of which can be identified as habitation rooms. The remaining rooms have been identified as storerooms or granaries. Moon House is slightly larger, containing a total of 17 rooms: one kiva, five habitation rooms, and eleven storerooms or granaries. All of the accessible structural wood was cored for dendrochronological analysis; preservation in the sites was excellent and only the kivas suffered greatly from erosion. It would appear that these sites are excellent candidates for population growth trend analysis, except for one striking feature of the sites: within the individual rooms, there is tremendous variation in the cutting dates of the structural wood. At Moon House, in one wall containing 11 dated elements which represent a single building event, cutting dates ranged from AD 1226 to AD 1264, with four dates from the 1250s, two from the 1220s, and four dates from the 1260s. (The remaining date is a noncutting date.) Another wall at the same site contains six dated elements, all part of the same construction event, with a range of dates from AD 1243 to AD 1261. A third wall contains five dated beams incorporated
during the same construction event. The range here is from AD 1251 to AD 1262, with the other four dates falling in the late 1250s. The remaining two walls at the site from which more than a single cutting date was recovered also exhibited a span of dates. The only walls of the seven samples at the site which did not include a mixture of dates were those from which only one date was recovered. The same situation occurs in roofing beams. The one room with more than one dated beam yielded three dates: AD 1245, AD 1239, and AD 1264 (Laboratory of Tree-Ring Research Archaeological Date Report for Moon House, on file at Washington State University).

The dating of the structures at M-3 follows the same pattern. Where more than one beam or element from a structure was dated, the dates recovered form a range—one spanning over 50 years in some cases (Laboratory of Tree-Ring Research Archaeological Date Report for M-3, on file at Washington State University).

The range of dates recovered from some of these rooms suggests to me that these sites were subject to a great deal of rebuilding and of reuse of older building materials. No structures remain from the earliest periods of occupation (at least, none containing datable wood). It cannot be determined how many of the structural wood elements from the earlier occupations remain. I would suggest, however, that the availability of old wood lessened the need to cut new wood for structures, producing a "slow-down" in beam cutting early in the construction of the remaining
structures similar to one which would have been produced under a logistic-type population growth pattern.

Another problem with interpreting the beam-cutting records from the McLoyd's Canyon sites is that some rooms use masonry construction and some jacal. Roof size also varies in part due to the degree to which rooms used the low roof of the shelter instead of a constructed roof. Consequently, jacal-walled rooms contribute much more to the cumulative beam-cutting curve than do masonry-walled rooms.

**Wupatki**

Wupatki is a multi-storied pueblo located 28 miles northeast of Flagstaff, Arizona, in Wupatki National Monument. Collections of tree-ring materials were made by three separate parties: A. E. Douglass, for the Laboratory of Tree-Ring Research in 1926 and 1927; L. L. Hargrave, for the Museum of Northern Arizona in 1933; and Roland Richert, in the early 1950s, for the National Park Service, which was doing stabilization work at the site (Robinson et al. 1975:92). These collections resulted in a total of 50 cutting dates from 20 separate proveniences within the site, usually separate rooms or roofs within rooms. The span of dates documents an occupation of over 100 years, from AD 1106 to AD 1212. There are presently standing walls of three stories at the site. Colton suggests that the walls were once, however, a good deal higher (1933:62). This raises the possibility that some of the latest beams have been lost as the site eroded. Wupatki occupies a fairly short, narrow sandstone ridge, and building, once it had
expanded to the limits of the top of the ridge, would have had to extend upwards rather than outwards—no structures were found off the ridge (Colton 1946:56). Sampling of the dendrochronological specimens is not described in the Laboratory of Tree-Ring Research report on the site available to me (Robinson et al. 1975:92-96), nor is it given in Colton's (1946) description of the site so that I cannot evaluate the representativeness of the beam sample.
7. CONCLUSIONS

Post-occupational erosional damage and lack of unbiased samples of dated beams preclude distinctions between logistic and exponential growth patterns at the sites which I have reexamined. The variety of site types affected suggests that this may be the case for most prehistoric sites in the Southwest. Because the beam-cutting records from all the sites were affected by similar patterns of post-occupational disturbance and sampling difficulties, I have inferred that the S-shaped trend of cutting dates Eighmy interpreted as a product of a specific population growth pattern is more likely to be a product of differential erosion and sampling of structural wood. Conclusive demonstration of this inference would require independent field studies of another sample of sites which exhibited similar post-occupational histories or simulation work that treats post-occupational disturbance and preservation in addition to the occupational factors used in the simulations reported here.

Changing the unit of study from single sites to regions does not eliminate the problems of post-occupational disturbance and sampling raised at the site level of analysis. A regional approach that incorporates longer timespans and a number of sites raises its own problems. First, although a region may be a more appropriate unit of study for human populations than a site, beam cutting at the regional level may not reflect population growth as
much as population movement. The use of the cumulative graphing technique assumes additive population growth. This assumption will be violated if there is sequential occupation of a number of sites in a region by the same group of people. Second, the contribution which a site makes to the regional pattern depends on the sampling strategy and preservation at each site. The effects of sampling and preservation must be standardized before sites can be compared or combined into regional groupings. If the beam-cutting records from sites in a region lack the data necessary to distinguish between different growth patterns, simply combining these records to produce a regional record will result in compounding the errors present in the sites.

It appears that the best way to study the pattern of population growth at the regional level will continue to be based on estimating the population of a regional sample of sites and dating the occupations of these sites as precisely as possible. A better understanding of the way datable elements are incorporated into the archaeological record can help increase the precision of such regional population reconstructions.

Eighmy's hypothesis of logistic growth in individual sites and my own hypothesis of regional exponential growth in the Southwest cannot be supported using beam-cutting patterns. Because the beam-cutting index is influenced by beam use and beam preservation, it should be used with caution. The beam index may still be an important source of information about prehistoric behavior. For example, it can be used to study the construction of a site, the frequency of reorganization or remodelling in a site,
and possibly as an indicator of the rate of site abandonment. In some circumstances, the beam index may provide a means of comparing the rates of population growth at different sites. The simulation experiments reported here barely scratch the surface of what could be done to better understand how artifacts—roofing beams in this case—become a part of the archaeological record.

Resolution of the question of what type of growth pattern—logistic, exponential, or some combination of the two—was present at a site or in a region will depend on the development of a different method of analysis. What follows is a brief outline of how such research might be approached. The method which I am proposing here lacks the quantitative basis of Bighmy's index, but I think it addresses the problem more directly.

Because the pattern of growth derived from any single index will still be a product of both post-occupational erosion and prehistoric population trends, the analysis of population trends should be based on as many indices as possible. A number of indices for growth trends can be developed directly from the properties of exponential and logistic population growth. In exponentially growing populations, the rate of population increase is equal to the maximum possible rate of increase. A population with this type of growth pattern behaves as though its environment were unlimited. In populations exhibiting logistic growth, the rate of growth is conditioned by the population density and an upper limit to growth. These populations are encountering resistance to growth from their natural or social environments. Such populations may react to this environmental resistance either by
limiting population in proportion to the resistance encountered so as to remain at or below the limit to growth, or by altering the relationship between their population density and the upper limit to growth such that the upper limit is raised.

Population-limiting strategies might be reflected in the archaeological record as:

1. An increase in the rate of infant mortality and a decrease in the proportion of younger people in the population in general as birth rates and infant survival decline in response to deteriorating environmental conditions.

2. A decrease in the amount of living space per household and possibly a standardization in the amount of living space per household as household size becomes more closely regulated.

3. A decrease in the number of new households formed as population growth rate decreased. A population limiting strategy which involved delaying the formation of independent households or the age at which women begin producing offspring would have a similar effect on the number of households established and would also slow the rate at which population grew.

Strategies directed at raising the upper limit to growth might be reflected in the archaeological record as:

1. Intensification of food procurement strategy through additions to or changes in the utilized resource base.

2. Intensification of food yield through the development of new production or processing techniques.

The degree to which these strategies are developed in a site or in a region will serve as an indication of the amount of resistance to population growth and hence to the type of population growth present. Populations which are growing exponentially should be interpreted as encountering no environmental resistance as population grows and there should be no development of the
strategies outlined here. Where these strategies are present, limits to growth may be inferred.

This brief discussion is not intended to be an exhaustive treatment of the test implications that could be derived using the approach I suggest. Other test implications, some probably already developed in conjunction with research in other areas, will surely suggest themselves to those interested in pursuing this type of study.

As the archaeological study of population growth and population growth trends has become more sophisticated, the demand for growth indices has increased. Continued experimentation with population indices should yield more sophisticated means of measuring population trends in the past, and we can expect that the development of such indices will in turn stimulate increasingly sophisticated research in the field of demographic archaeology.
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APPENDIX
SIMSCRIPT II.5 PROGRAM LISTING

PREAMBLE
NORMALLY, MODE IS INTEGER, DIMENSION IS 0
DEFINE POPULATION AND REMAINDER AS VARIABLES
DEFINE CM.ID.ROOM AND CM.ID.BEAM AS VARIABLES
DEFINE RM AND BM AS 1-DIMENSIONAL ARRAYS

EVENT NOTICES INCLUDE TO AND POP.CHANGE
EVERY BUILD.ROOM HAS A H.M.NEW
EVERY ABANDON.ROCM HAS A HOW.MANY.GONE
EVERY REUSE.ROOM HAS A H.M.AGAIN
EVERY REPLACE.BEAM HAS AN IN.WHICH.ROOM
EVERY DESTROY.ROCM HAS A WHAT.ROOM

NORMALLY, MODE IS REAL, DIMENSION IS 0
TEMPORARY ENTITIES
GENERATE LIST ROUTINES
EVERY ROOM HAS A TM.CREATED, A TM.DESTROYED, AN AGE, AND A RID, OWNS A
RM.BM.SET, AND BELONGS TO THE RM.SET, AND THE UNUSED.RM.SET
DEFINE TM.CREATED, TM.DESTROYED, AND AGE AS VARIABLES
DEFINE RID AS AN INTEGER VARIABLE
EVERY BEAM HAS A TM.CUT, A TM.LOST, AND A BM.AGE,
AND MAY BELONG TO A RM.BM.SET, AND A BM.PILE.SET
DEFINE TM.CUT, TM.LOST, AND BM.AGE AS VARIABLES
DEFINE RM.BM.SET AS A FIFO SET
INHIBIT LIST ROUTINES

THE SYSTEM OWNS A RM.SET, AN UNUSED.RM.SET, AND A BM.PILE.SET
DEFINE BM.PILE.SET, RM.SET, AND UNUSED.RM.SET AS FIFO SETS
PRIORITY ORDER IS POP.CHANGE, DESTROY.ROOM, REPLACE.BEAM,
REUSE.ROOM, BUILD.ROOM, ABANDON.ROOM, AND IO
DEFINE YEARS TO MEAN DAYS
END

MAIN
RESERVE RM(*) AS 100 AND BM(*) AS 1000
FOR I=1 TO 100 DO
   LET RM(I) = I
END

FOR I=1 TO 1000 DO
   LET BM(I) = I
END

LET CM.ID.ROOM = 0
LET POPULATION = 0
LET CM.ID.BEAM = 0
LET REMAINDER = 0
LET TIME.S = 0
SCHEDULE A POP.CHANGE AT TIME.S + 1.0
START SIMULATION
END

ROUTINE SNAP.R
PRINT 4 LINES WITH POPULATION, CM.ID.ROOM, AND
CM.ID.BEAM THUS

THE POPULATION AT TERMINATION WAS ****
THE TOTAL NUMBER OF RIGMS BUILT WAS ***
THE TOTAL NUMBER OF BEAMS CUT WAS ****
PRINT 1 LINE AS FOLLOWS
HERE ARE THE ATTRIBUTES OF THE ROOMS IN THE ROOM SET:
FOR EACH ROOM IN RM.SET, DO
   LET AGE(ROOM) = TIME.S - TM.CREATED(ROOM)
   LIST ATTRIBUTES OF ROOM
FOR EACH EEAM IN RM.BM.SET(ROOM), DO
   LET EM.AGE(EEAM) = TIME.S - TM.TCUT
   LIST ATTRIBUTES OF EEAM
END

PRINT 1 LINE AS FOLLOWS
HERE ARE THE ATTRIBUTES OF THE ROOMS IN THE UNUSED ROOM SET:
FOR EACH ROOM IN UNUSED.RM.SET, DO
   LET AGE(ROOM) = TIME.S - TM.CREATED(ROOM)
   LIST ATTRIBUTES OF ROOM
FOR EACH EEAM IN RM.BM.SET(ROOM), DO
   LET EM.AGE(EEAM) = TIME.S - TM.TCUT
   LIST ATTRIBUTES OF EEAM
EVENT IO
PRINT 12 LINES WITH TIME,S,CM,ID,BEAM, N,RM,SET, N,UNUSED,RM,SET, AND POPULATION AS FOLLOWS

---MEAT-TRAY PUEBLO YEARLY REPORT---

HERE'S A SUMMARY OF ACTIVITY IN YEAR ***:
TOTAL BEAMS CUT TO DATE ***
TOTAL NUMBER OF ROOMS PRESENTLY OCCUPIED IS ***
TOTAL NUMBER OF DISUSED BUT INTACT ROOMS IS ***
TOTAL NUMBER PEOPLE WHO LIVE HERE AT PRESENT IS ***

IF TIME,S GE 40
PRINT 1 LINE AS FOLLOWS
NORMAL PROGRAM TERMINATION CALLED FROM IO
CALL SNAP,R

ALWAYS
IF POPULATION LE 0
PRINT 1 LINE AS FOLLOWS
EVERYONE GONE; SIMULATION ENDED THROUGH CALL TO SNAP,R
CALL SNAP,R

ALWAYS
RETURN
END

EVENT POP,CHANGE
DEFINE ROOM,CHANGE,ROOMS,REUSED,AND NEED AS INTEGER VARTABLES
DEFINE XBAR AS A REAL VARIABLE
IF TIME,S LE 1
   LET NUMBER = 10
   GO TO NEWPOP
ALWAYS
LET NUMBER=INT.F(NORMAL.F(6.0,6.0,1))
IF TIME.S GE 21.0
    LET NUMBER=-NUMBER
ALWAYS
'NEWPOP' LET POPULATION=POPULATION+NUMBER
LET ROOM.CHANGE=TRUNC.F((NUMBER+REMAINDER)/5)
LET REMAINDER=MOD.F(NUMBER+REMAINDER,5)
PRINT 3 LINES WITH TIME.S, NUMBER, ROOM.CHANGE, AND
REMAINDER AS FOLLOWS

IN YEAR ***.* A POPULATION CHANGE OF ** NECESSITATED A ROOM
CHANGE OF ** LEAVING ** PEOPLE LEFT OVER.
LET NEED=ROOM.CHANGE-N.UNUSED.RM.SET
LET ROOMS.REUSED=MIN.F(ROOM.CHANGE,N.UNUSED.RM.SET)
SCHEDULE AN TO NOW
SCHEDULE A POP.CHANGE AT TIME.S + 1.0
IF ROOM.CHANGE NE 0
    IF ROOM.CHANGE GE 1
        SCHEDULE A REUSE.ROOM(ROOMS.REUSED) NOW
        IF ROOMS.REUSED LT NEED
            SCHEDULE A BUILD.ROOM(NEED-ROOMS.REUSED) NOW
    ALWAYS RETURN
ELSE
    SCHEDULE AN ABANDON.ROOM(ABS.F(ROOM.CHANGE)) NOW
RETURN
ELSE RETURN
END

EVENT REUSE.ROOM(H.M.AGAIN)
IF UNUSED.RM.SET IS EMPTY PRINT 1 LINE WITH TIME.S AS FOLLOWS
    ATTEMPT TO REUSE RCCM IN YEAR ***.* CANCELLED; NO VACANCIES
RETURN
ELSE
    DEFINE N AND I AS INTEGER VARIABLES
    FOR I=1 TO H.M.AGAIN WHILE I LE N.UNUSED.RM.SET
    DO
        'PICKONE' LET N=BANDI.F(1,CM.ID.ROOM,1)
        IF RM(N) IS IN UNUSED.RM.SET
REMOVE RM(N) FROM UNUSED_RM_SET
FILE RM(N) IN RM_SET
GO TO JUMP
ALWAYS GO TO PICKONE
'SJUMP' IF N.RM.BM_SET(RM(N)) LE 0
SCHEDULE A REPLACE_BEAM(N) NOW
PRINT 1 LINE WITH RID(RM(N)) AND TIME_S AS FOLLOWS
REOCCUPIED_ROOM *** IN YEAR **.* BUT NEEDED TO REPLACE BEAM(S)
ALWAYS PRINT 1 LINE WITH RID(RM(N)) AND TIME_S AS FOLLOWS
REOCCUPIED_ROOM *** IN YEAR **.* WHICH NEEDED NO REPAIRS
LOOP
RETURN
END

EVENT REPLACE_BEAM(IN_WHICH_ROOM)
DEFINE J, N, AND BEAM_DESTROYED AS INTEGER VARIABLES
LET N = IN_WHICH_ROOM
PRINT 1 LINE WITH N AND TIME_S AS FOLLOWS
NOW TRYING TO REPLACE A BEAM IN ROOM *** IN YEAR **.*
IF RM(N) IS IN RM_SET
IF N.RM.BM_SET(RM(N)) GE 8
   REMOVE FIRST BEAM FROM RM.BM_SET(RM(N))
   LET TM.LOST(beam) = TIME_S
   LET BM.AGE(beam) = TM.LOST(beam) - TM.CUT(beam)
   PRINT 1 LINE WITH N, TIME_S AS FOLLOWS
   HERE ARE THE ATTRIBUTES OF BEAM DESTROYED IN ROOM *** IN YEAR **.*:
   LIST ATTRIBUTES OF BEAM
   DESTROY THIS BEAM
ALWAYS
IF BM.PILE_SET IS NOT EMPTY
   REMOVE FIRST BEAM FROM BM.PILE_SET
   FILE THIS BEAM IN RM.BM_SET(RM(N))
   GO TO HERE
ALWAYS CREATE A BEAM CALLED BM(CH_ID.BEAM + 1)
LET TM.CUT(BM(CH_ID.BEAM+1)) = TIME_S
FILE BM(CH_ID.BEAM+1) IN RM.BM_SET(RM(N))
LET CM_ID.BEAM = CM_ID.BEAM + 1
GO TO HERE
ALWAYS
IF RM(N) IS IN UNUSED.BM.SET
    REMOVE FIRST BEAM FROM RM.BM.SET(RM(N))
    FILE THIS BEAM IN BM.PILE.SET
    *HERE* SCHEDULE A REPLACE.BEAM(N) AT TIME.S + 10.0
    PRINT 2 LINES WITH N, TIME.S + 10 AS FOLLOWS
    A BEAM REPLACEMENT HAS BEEN SCHEDULED BY REPLACE.BEAM
    TO TAKE PLACE IN ROOM *** IN YEAR ***.*
RETURN
ALWAYS.
PRINT 2 LINES WITH N AS FOLLOWS
    ATTEMPT TO REPLACE BEAM IN ROOM *** CANCELLED;
    ROOM HAS BEEN DESTROYED.
RETURN
END

EVENT BUILD.ROOM(H.M.NEW)
DEFINE I,J,K,L, AND M AS INTEGER VARIABLES
LET M = 0
FOR I=CM.ID.ROOM + 1 TO CM.ID.ROOM + INT.F(H.M.NEW)
DO
    CREATE ROOM CALLED RM(I)
    LET TM.CREATED(RM(I)) = TIME.S
    LET RID(RM(I)) = I
    LET M = M + 1
    IF N.BM.PILE.SET GE 8
       FOR K=1 TO 8 TO
            REMOVE FIRST BEAM FROM BM.PILE.SET
            FILE THIS BEAM IN RM.BM.SET(RM(I))
       LOOP
       GO SCHEDULE
    ALWAYS
    LET L = 0
    FOR J=CM.ID.BEAM+1 TO CM.ID.BEAM+8 WHILE
    N.RM.BM.SET(RM(I)) LE 8
    DO
        CREATE A BEAM CALLED BM(J)
        LET TM.CUT(BM(J)) = TIME.S
        LET L = L + 1
        FILE BM(J) IN RM.BM.SET(RM(I))
    LOOP
   END
LOOP
LET CM.ID.BEAM = CM.ID.BEAM + L
'SCHEDULE' SCHEDULE A REPLACE.BEAM(I) AT TIME.S + 10
PRINT 1 LINE WITH I AND TIME.S + 10 AS FOLLOWS
A BEAM REPLACEMENT HAS BEEN SCHEDULED FOR ROOM *** IN YEAR ***.*
FILE RM(I) IN RM.SET
LOOP
LET CM.ID.ROOM = CM.ID.ROOM + M
RETURN
END

EVENT ABANDON.ROOM(HOW.MANY.GONE)
DEFINE I AS AN INTEGER VARIABLE
FOR I = 1 TO INT.P(HOW.MANY.GONE)
DO
REMOVE FIRST ROOM FROM RM.SET
PRINT 1 LINE WITH RID(ROOM), TIME.S AS FOLLOWS
ROOM *** HAS BEEN ABANDONED IN YEAR ***.*
SCHEDULE A DESTROY.ROOM(RID(ROOM)) AT TIME.S + 1.0
FILE THIS ROOM IN UNUSED.RM.SET
LOOP
RETURN
END

EVENT DESTROY.ROOM(WHAT.ROOM)
DEFINE ID AS AN INTEGER VARIABLE
LET ID=INT.P(WHAT.ROOM)
IF RM(ID) IS IN RM.SET
PRINT 2 LINES WITH ID AS FOLLOWS
ATTEMPT TO DESTROY ROOM *** CANCELLED; ROOM HAS BEEN
REOCCUPIED.
RETURN
ELSE
LET TM.DEstroyed(RM(ID))=TIME.S
LET AGE(RM(ID))=TM.DEstroyed(RM(ID)) - TM.CREATED(RM(ID))
FOR EACH BEAM IN RM.BM.SET(RM(ID))
DO
REMOVE BEAM FROM BM.BM.SET(RM(ID))
FILE BEAM IN BM.FILE.SET
LOOP
PRINT 2 LINES WITH ID AND TIME S AS FOLLOWS
    ROOM *** WAS DESTROYED IN YEAR **.*,* AND ITS BEAMS PLACED IN
    PILE OF USED BEAMS. HERE ARE ITS ATTRIBUTES:
LIST ATTRIBUTES OF ROOM CALLED RM(ID)
REMOVE RM(ID) FROM UNUSED_RM_SET
DESTROY ROOM CALLED RM(ID)
RETURN
END