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Measurement of Population Growth and Decline During California Prehistory

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The distribution through time of radiocarbon dates is an important source of information about regional population fluctuation. However, a number of factors affecting distributional patterns must be considered when inferring changes in relative population size. Because these factors often are difficult to control, fluctuation in a date distribution is best considered a source of hypotheses about population growth and decline that should be tested against other sources of data. Three date distributions pertaining to the Santa Barbara Channel mainland coast, the northern Channel Islands, and the Vandenberg region exemplify the potential of this approach. These areas show similarities that may be linked to the impact of environmental events affecting broad geographic areas, as well as to differences that appear to reflect the impact of differing environments on cultural development. Future use of radiocarbon date distributions will be enhanced if archaeologists make every effort to obtain dates for every site investigated, take greater care in selecting samples, and report dating results in a systematic format.

CHANGE over time in the size of prehistoric regional populations has been an abiding interest among archaeologists practically since archaeology emerged as a discipline. Most often, determining such change has been based on casual evaluation of the archaeological record, taking into consideration such characteristics as changes over time in the number of sites or volumes of midden deposits. Within the last 30 years, however, the methods for identifying change in regional population size have become increasingly more explicit and formalized, in part because of greater use of quantitative analysis and in part because of growing interest in implications of changes in population numbers (Cohen 1977:71-84; Hassan 1981).

Discerning change in regional population size is difficult in California for a variety of reasons. First, contemporaneity of sites within a region is difficult to establish because abundant and ubiquitous time-sensitive artifacts are not found on the ground surface. Second, houses or habitation rooms, numbers of which bear a close relationship with population size, generally are not observable in the course of regional survey or test excavations. Third, the degree of mobility, that is, the number of sites used by a social unit, may have fluctuated through the course of prehistory, thus precluding the use of simple site counts, even if these sites could be easily dated. As a result of these difficulties, archaeologists in California generally have not attempted to estimate actual population numbers and their change through time, and instead have been content with assessing relative changes in population size based on admittedly less-than-representative samples of dated sites.

Despite these difficulties, there are important reasons why California archaeologists should be interested in ascertaining change in the relative size of regional populations. In particular, knowledge of population changes is necessary for addressing some of the theories important to contemporary archaeology. A broad realm of theory, for instance, posits that population growth is a determinant of culture change; that is, that population pressure on food supplies underlies shifts in the importance of specific food resources or changes in subsistence technology or social organization. Population pressure arguments became popular in the late 1960s and continued throughout the 1970s, primarily in the context of efforts to explain origins and development of agricultural subsistence systems (Binford 1968; Smith 1972; Cohen 1977:18-70). These arguments lost favor in the 1980s, seemingly as a result of sometimes sharp criticisms (Cowgill 1975a, 1975b; Hassan 1981:161-163). As a result, many contemporary archaeologists have opted to avoid deterministic arguments by proposing only that population size and aspects of culture such as subsistence practices are strongly correlated, or that population growth is both a dependent and independent variable.

More recently, some arguments about the relationship between population and resources have been couched in the context of optimal foraging theory, particularly the diet breadth model, thus circumventing some of the criticisms of the population pressure model. Optimal foraging theorists might argue, for example, that lower ranked resources are added to the diet as regional population grows or removed from the diet as regional population declines (Bettinger 1991:101). Arguments based on optimal foraging theory, or similar theoretical formulations, appear to be gaining popularity in California archaeology, and change in regional population size is a necessary component of such arguments, at least as they concern dietary change.

Knowledge of change in regional population size is also of interest to archaeologists concerned with the impact of paleoenvironmental change on cultural development. Although many arguments about the nature of this relationship avoid consideration of population issues, paleoenvironmental change often is proposed to result in population growth or decline. In simplest terms, some archaeologists have argued that during periods when paleoenvironmental change resulted in increasing productivity of food resources, regional population size increased; conversely, if the change resulted in decreasing productivity, regional population declined. For instance, Glassow et al. (1988) proposed that population in coastal southern California declined after about 7,000 B.P.[1] as a result of the onset of the Altithermal climatic interval. In general, it may be argued that population, environment, and culture are closely related to each other and that changes in both population and environment are important factors to consider in developing explanations of cultural change.

EFFORTS TO RECONSTRUCT POPULATION FLUCTUATIONS IN CALIFORNIA AND BEYOND

Tainter (1977) was the first archaeologist to attempt a reconstruction of the course of population growth in the various regions occupied by the Chumash at the time of European contact. Based on distributions of sites and analogs with historical Chumash and other hunter-gatherer populations, Tainter (1977) proposed population sizes for two prehistoric times: 7,500 B.P. and 3,000 B.P. He then developed a simulation model of exponential growth to fit these estimates and the size of Chumash population at the time of European contact (based on village size estimates proposed by King [1971]). To produce his reconstruction, Tainter made a series of assumptions about the nature of the archaeological record and chronology that are unwarranted from today's perspective. For instance, he assumed that most of the sites identified by Rogers (1929) as having been occupied by "Oak Grove People" dated to about 7,500 B.P. and were contemporaneous, that Rogers had identified all sites of this age within the area under consideration, and that these sites were the principal foci of settlement systems at that time (Tainter 1977:40-41).

Tainter's reconstruction of population growth is within the realm of expectation, but it is no more than that. Because the methodological basis for his estimates is questionable, his reconstruction has little utility in exploring what the nature of population growth in the Chumash area actually was. Furthermore, there is no justification for assuming that regional population growth conformed to a smooth exponential growth curve. Tainter's approach highlights the need for a stronger empirical and methodological basis upon which to base population reconstruction.

Contrary to Tainter's (1977) regular exponential growth assumption, Glassow et al. (1988) argued that, based on radiocarbon date frequency distributions, Santa Barbara Channel populations declined after 7,000 B.P. and remained low until about 5,500 B.P. (also see Glassow 1997). For Glassow et al.'s (1988) reconstruction of relative population change, the dates were tallied by 500-year intervals for the period between 10,000 and 3,000 B.P., giving a count of one to the set of all dates for a site falling within one interval. Although the frequencies of dated site components per time interval were quite low, the depression in date frequencies between 7,000 and 5,500 B.P. was so pronounced that Glassow et al. (1988) felt reasonably confident that the depression reflected low population levels.

Gerber (1992) elaborated this approach by using a technique for constructing frequency distributions of radiocarbon dates developed by Kintigh (1994). Her analysis was based on the radiocarbon dates listed in Breschini et al. (1996) for Ventura, Santa Barbara, and San Luis Obispo counties, as well as the Channel Islands. In addition to addressing many of the assumptions underlying the use of radiocarbon date distributions to infer population fluctuations, Gerber (1992:23) confirmed the depression between roughly 7,000 and 5,500 B.P. and identified another depression centering around 3,000 B.P.

Several archaeologists working in coastal California have proposed that fluctuations in radiocarbon date distributions reflect settlement shifts from one locality to another within a region. Warren and Pavesic (1963), perhaps the first archaeologists in California to use radiocarbon date distributions to document settlement shifts, proposed that occupation shifted away from the large lagoons of coastal San Diego County between 3,000 and 1,500 B.P. With a much larger sample of radiocarbon dates, Gallegos (1985:2, 1992:206) found support for Warren and Pavesic's (1963) original proposal, although he used a date of 3,500 B.P. for the beginning of the interval. Warren and Pavesic (1963) and Gallegos (1985, 1992) believed this settlement shift was the result of depletion of shellfish and fish resources brought about by closure of lagoon mouths and siltation.

Similarly, Jones and Waugh (1997) compared distributions of radiocarbon dates from sites in the vicinities of Elkhorn Slough of Monterey County and Morro Bay of San Luis Obispo County to show that these localities had population peaks that differed significantly in time as a result of the differing chronologies of evolution of estuary/wetland environments. Through an analysis of the geographic and temporal distribution of sites associated with radiocarbon dates, Mason et al. (1997) identified a series of settlement shifts over the course of several thousand years involving the upper and lower ends of Newport Bay, the nearby ocean coastline, and the interior hills. They believed that these settlement shifts were the result of changes in the availability and distribution of bay and open coast resources, as well as an emphasis late in prehistory on a collector form of settlement system.

The different approaches California archaeologists have used to reconstruct population fluctuations reflect a significant contrast in geographic scope. On the one hand, Glassow et al. (1988), as well as Gerber (1992), attempted to view population change over a large geographic region, such as Santa Barbara County or all of coastal southern California. On the other hand, Warren and Pavesic (1963), Gallegos (1985, 1992), Mason et al. (1997), and Jones and Waugh (1997) compared the population histories of small, environmentally discrete, geographic areas. There is little question that fluctuations in radiocarbon date frequencies often are the result of shifts in food resource productivity restricted to relatively small geographic areas, such as a specific coastal estuary or interior wetlands. Many of these shifts probably were not related to large-scale environmental changes, although some undoubtedly were. It would seem that the smaller the area to which a set of radiocarbon dates pertain, the greater the chance that date frequency fluctuations reflect changes in strictly local environmental conditions. Conversely, the larger the geographic area, the more likely that date frequency fluctuations reflect large-scale environmental changes, driven by climatic fluctuation.

Quite a number of archaeologists working in other parts of the world also have been interested in documenting population fluctuations. Such efforts have been especially popular in the American Southwest, where the focus has been on reconstructing population histories of environmentally discrete localities such as a watershed area (e.g., Plog 1974:88-97; Kintigh 1985:85) or even an individual archaeological site (Dean 1969). On a much larger geographic scale, however, Berry (1982) attempted to reconstruct the population histories of the whole Colorado Plateau on the one hand and the southern basin and range province on the other. However, his methods and results have been severely criticized (Dean 1985). Such efforts in the Southwest have been based on a wide variety of data: architectural evidence of room additions tied to tree-ring cutting dates in the case of individual sites, site or room counts tied to ceramic chronologies in the case of small geographic areas, or frequency distributions of radiocarbon and dendrochronological dates in the case of large geographic areas. Perhaps nowhere else in the world are chronometric and archaeological data as useful for discerning population fluctuations as in the American Southwest, yet aside from Berry's (1982) work, Southwestern archaeologists typically have relied on general knowledge rather than formal analysis in their attempts to reconstruct population fluctuations in regions the size of the Colorado Plateau (e.g., Dean et al. 1985:542).

Examples from elsewhere in the world include Erlandson et al.'s (1992) use of a distribution of radiocarbon dates grouped by 500-year intervals to identify broad trends in population fluctuations along the southern Alaskan coast and Smith's (1992) use of changes in radiocarbon date frequencies to discern gross patterns of population growth during the Late Upper Paleolithic and Mesolithic of the British Isles. Rick (1987) also used radiocarbon date frequency distributions to identify population growth trends, his interests including temporal and geographic patterns in population fluctuation during the preceramic prehistory of Peru.

THE USE OF RADIOCARBON DATES TO MEASURE REGIONAL POPULATION CHANGE

Considering the 9,000-plus years of California prehistory and the popularity of radiocarbon dating for establishing the antiquity of site occupation, it makes sense to formalize procedures for using date distributions to infer changes in regional population. At the same time, the potential of this approach needs to be assessed. In working toward these objectives, this article builds upon the efforts of Rick (1987). Of particular significance is Rick's explication of the basic assumptions one must make in using radiocarbon date frequencies as a measure of relative population size. A careful consideration of such assumptions clearly is important to any use of radiocarbon date frequency distribution to discern population trends. Reworded for present purposes, Rick's (1987:56) assumptions are: (1) the size of a regional population is correlated with the volume of production per time interval of organic material useful for radiocarbon dating; (2) the volume of datable organic material that survives until the time of archaeological collection is proportional to the volume of production; and (3) archaeologists' selection of organic samples for radiocarbon dating is proportional to the surviving volume of datable material per prehistoric time interval.

As Rick (1997:56-57) pointed out, biases occur at every juncture indicated by each of these three assumptions. For instance, regional populations during one time interval may have produced more organic material, such as shell or charcoal, per capita population than was the case during other time intervals. Furthermore, such factors as shoreline transgression or seacliff erosion may have differentially affected earlier as opposed to later sites, and archaeologists prior to about 1975 frequently obtained radiocarbon dates only for basal deposits of sites. Pointed out above was a biasing factor of particular concern to California archaeologists, that being the number of sites produced by a population unit of a given size, which may vary from one time period to the next depending on the degree of mobility of the population. Because Rick (1987) recognized that particular sources of bias may be quite significant in the radiocarbon date record for a region, he argued that evaluation of frequency distributions of dates should include exploration of these sources of bias so that they may either be eliminated or controlled.

Obviously, however, many sources of bias cannot be eliminated or controlled, and so evaluations of radiocarbon date distributions must be governed by a series of rules that take into account the existence of unknown and uncontrollable sources of bias.

PROCEDURES FOR INFERRING POPULATION FLUCTUATIONS

Of course, the simplest approach to using radiocarbon date distributions to infer population fluctuations is to count the number of dates per time interval, for instance, the 250-year intervals used by Breschini et al. (1996) to produce county-by-county frequency distributions. This relatively crude approach does reveal some interesting trends, even though the intervals are broad and the distributions are clearly biased by such factors as a lack of correction of most dates derived from marine shell. The frequency distribution of approximately 4,700 California dates reported in Breschini et al. (1996) implies that California population growth was exponential through more than 9,000 radiocarbon years of prehistory, although inference of population growth was not the reason why this frequency distribution was produced. Despite an overall exponential trend, the distribution exhibits both depressions and plateaus that are of interest.

Several procedures may be employed to reduce some of the biases in the raw date distributions presented in Breschini et al. (1996). First, those dates deemed suspect might be eliminated from consideration. Second, all dates derived from marine shell might be corrected to make them comparable to dates derived from charcoal. For those shell dates lacking correction for fractionation effects, one might use the average of fractionation corrections for dates reported in the local archaeological literature. Third, two or more dates obtained from one site or stratigraphically discrete site component might be evaluated to determine whether the differences between them are statistically significant. If there is reason to believe that the differences are not significant, they might be averaged or otherwise combined and counted as one. This procedure would reduce the bias resulting from variations in the intensity of dating programs from one site to another. Each of these three procedures may be implemented in a variety of alternative ways.

In preparing the radiocarbon date frequency distributions for the analysis presented below, the date list for Santa Barbara County in Breschini et al. (1996), along with several dozen dates not included on that list, were used. Also included are the northern Channel Islands date lists (Santa Cruz, Santa Rosa, and San Miguel islands). Dates that were listed as suspect or were obtained from bone were eliminated from consideration. As well, any dates earlier than 9,600 B.P. in the Santa Barbara County date list and earlier than 11,000 B.P. in the Channel Islands date lists were eliminated on the grounds that these are of questionable archaeological significance.

The date lists in Breschini et al. (1996) do not include the fractionation corrections for dates derived from marine shell, but they do indicate whether a reported date might already be corrected for fractionation effects. Of course, many shell-derived dates, particularly those obtained prior to 1980, were not corrected for isotopic fractionation. For reasons that remain unclear, the average fractionation correction appears to vary somewhat between the Vandenberg region and the Santa Barbara Channel. The average fractionation correction of 24 Vandenberg dates derived from marine shell is +413 years, and the average correction of 15 Santa Barbara Channel dates reported by Erlandson (1988:27) is +432 years. Because Erlandson's (1988) published correction has some local popularity, a fractionation correction of +430 years was used for all shell dates considered in this analysis.

Marine shell dates also must be corrected for the reservoir effect, which in the Santa Barbara Channel area is thought to be approximately -625 years (R = -402 years plus ΔR = -225 years, as reported by Stuiver and Braziunas [1993:152-156]). The fractionation correction must be added to the raw radiocarbon date, and the reservoir correction must be subtracted. The difference between the two corrections, 195 years, was subtracted from all reported marine shell dates that were not already corrected for fractionation effects, while 625 years was subtracted from those that were (e.g., dates obtained with accelerator mass spectrometry [AMS], which include correction for isotopic fractionation).

A possible source of bias in the date lists used for this analysis is geographic variation in the value of the reservoir effect. On the basis of archaeologically derived dates brought to their attention, Stuiver and Braziunas (1993:153) pointed out that the reservoir correction may not be uniformly 625 years (specifically their ΔR of 225 years) along the whole length of the California coast, and Ingram and Southon (1996) demonstrated that the reservoir effect does, in fact, increase north of Point Conception (also see Kennett et al. 1997:1052). Furthermore, some variation in the reservoir effect within a segment of the California coast would be expected to be the result of such microenvironmental characteristics as nearshore upwelling in submarine canyons.

Temporal variation in the reservoir effect also is expected (Stuiver et al. 1986:980). Recently, Kennett et al. (1997) investigated this possibility through evaluation of shell and charcoal date pairs from two sites on San Miguel Island. They found that the reservoir effect varied substantially between 7,800 and 9,200 RCYBP, and they also found that the reservoir effect appears to be 255 to 275 years less than 625 years at about 3,100 to 3,200 RCYBP (i.e., a ΔR of -30 to -50). Such variation in the reservoir effect means that shell dates could vary as much as a few hundred years from true radiocarbon age if the standard ΔR of 225 years were used. Consequently, the accuracy of a shell date must be assumed to be potentially a few hundred years in error unless the temporal variation in the magnitude of the reservoir correction associated with the date is sufficiently well established. The analysis carried out by Kennett et al. (1997) was based on only 10 shell-charcoal date pairs distributed between 9,200 and 3,100 RCYBP, too few to determine the nature of variation in the reservoir effect through time. Furthermore, two of their pairs with nearly identical charcoal dates were associated with shell dates that differed by 130 radiocarbon years, which implies that multiple pairs will be necessary to determine the reservoir correction for a narrow time interval.

For the present, there is little choice but to continue using the reservoir correction based on radiocarbon dates obtained from historic shells collected before hydrogen bomb explosions began to contaminate the world's radiocarbon reservoirs. Nevertheless, any dates falling within the two intervals of time during which Kennett et al. (1997) found departures from the modern reservoir correction should be questioned until the nature of the fluctuation in the reservoir effect is better understood. The most recent dating of such "pre-bomb" shells, summarized by Kennett et al. (1997:1052), implies that the ΔR correction for the Santa Barbara Channel is more likely to be about 233 years rather than the 225 years used in the analysis presented here.

Dates derived from wood charcoal also are subject to bias. Some of the wood collected by prehistoric fire-builders may have been a few hundred years old at the time of collection (Schiffer 1986). Kennett et al. (1997:1054) attempted to minimize the "old wood" problem by selecting carbonized twigs, which presumably are a product very few years of plant growth that took place no more than a few years before the wood was collected. However, Breschini and Haversat (1996:104) noted that a number of California radiocarbon dates derived from charcoal "are almost certainly erroneous" because of "old wood" bias, and they suggested that in many instances marine shell may produce more reliable dates. Because the existence of this bias cannot be ascertained without careful consideration of other chronological information, no correction of dates derived from charcoal was attempted herein.

Combining dates close in time from the same site or site component has always been a difficult problem for archaeologists. Over the years, much has been said about appropriate statistical approaches to deciding whether dates may be combined, and some fairly elaborate statistical procedures have been proposed (Ward and Wilson 1978; Wilson and Ward 1981). Many archaeologists have combined dates, or have argued that differences between dates are not statistically significant if their counting errors (one sigma standard deviation) overlap. However, a variety of strictly archaeological considerations also may be appropriate to consider in deciding whether to combine dates. For instance, the earlier date of a pair that is only one hundred years apart may be from a distinct stratum below that of the later date. Because of stratigraphic differences in chronologically sensitive artifacts, an archaeologist may decide that the dates indeed do indicate a temporal difference, even though on statistical grounds the difference between the dates may be considered nonsignificant.

A related problem arises when three or more dates from a site are distributed through time in such a way that the difference between any two temporally adjacent dates in the suite may be statistically nonsignificant, but the difference between the earliest and latest dates in the suite is statistically significant. This pattern in suites of dates is not uncommon in California archaeology. Which of the dates in a suite, if any, may be combined is largely a matter of archaeological judgment, often based on the stratigraphic contexts of the dates.

Combining dates from a site or a physically discrete site component for the distributions used in this analysis entailed obtaining the average of two or more dates whose counting errors overlapped, and in most cases the dates (as opposed to the intervals defined by the counting errors) were less than 100 years apart. In those cases in which counting errors of three or more dates sequentially overlapped but whose earliest and latest dates did not, the dates were divided into 150- to 200-year intervals, taking into consideration the largest gaps between dates and the span of time between the earliest and latest dates. In one instance, 12 dates for one site formed a continuous series spanning 540 years; these were combined into three groups.

In using radiocarbon date frequency distributions to measure population fluctuations, the potential bias resulting from possible (indeed likely) variations in settlement mobility through time, which affects the number of sites created by a social unit, was not addressed. Erlandson (1997: 105) attempted to reduce this bias in his estimates of Middle Holocene population change along the western Santa Barbara Channel by differentially weighting sites he classified as campsite/activity areas, secondary villages, and primary villages. However, this approach implies that types of settlement have been objectively defined and that the relative weighting of different site types is consistent with the duration and frequency of site use. Smith (1992) used a geographic approach to compensate for changes in settlement mobility. In his consideration of Late Paleolithic/Mesolithic population change in the British Isles, he divided the area of the isles into 10 x 10 km. grids, under the assumption that a discrete settlement system would have encompassed an area of about 1,000 km.^{2} To construct a date distribution, he combined into a count of one all dates within one grid and within a 1,000-year interval. Smith (1992) had the benefit of a very large sample of radiocarbon dates, so the reduction in the total caused by this counting procedure still left him with a sample sufficiently large to discern patterns.

Consistent with the logic presented by Rick (1987), one could argue that archaeologists inevitably select samples for radiocarbon dates in proportion to the volume of deposits that were produced within a given interval of time. If this is close to being true, it should make relatively little difference whether this volume is distributed among a few large sites or many smaller sites. In fact, within the last two decades, California archaeologists have become increasingly more eclectic with regard to the size of the sites they investigate and from which they select samples for dating, in large part because of the cultural resource management context of most of California archaeology during this time. It is reasonable to make the assumption, therefore, that settlement system variation through time does not profoundly affect the patterning in the distribution of radiocarbon dates. In fact, one could argue that an approach that counts only relatively large sites most likely having served as main residential bases, or gives such sites greater weight relative to smaller sites, could introduce bias greater than an approach that treats all sites equally, regardless of size. For instance, if settlement systems shifted from occupation of a few large sites during an earlier time period to many small sites during a later time period, it is possible that the small sites would not be counted or that the weighting given to them would not be consistent with the size of the population occupying them. The result would be a spurious inference of population change.

It is nonetheless possible that small residential bases with relatively low densities of cultural remains and datable organics have been selectively omitted from dating programs. The prejudice that some archaeologists have toward such sites is widely recognized, if not well documented. For the purposes of this study, it is assumed that the omission of such sites from dating programs is not so significant as to obscure the more obvious fluctuations in regional population size.

Another source of bias is not so much a bias as a "random noise" factor. Many of the dates are derived from organic samples collected from relatively gross proveniences, often from a level of a test unit. If the sample consisted of one discrete lump of charcoal or one shell, the sample is likely to represent one discrete point in time. However, if a number of pieces of shell or charcoal from a unit level comprise the sample, the resulting date may be an average of the dates of the individual pieces deposited over a period perhaps hundreds or even thousands of years long. Rodent disturbance surely has mixed deposits of widely differing ages at many mainland Santa Barbara County sites, and the degree of rodent disturbance is not always obvious in a unit level from which the shell or charcoal pieces were collected. In recent years archaeologists working in coastal southern California have become a good deal more careful in selecting samples for radiocarbon dating, in part because AMS dating may be performed on one small piece of shell or charcoal that otherwise would have to be combined with other pieces for a conventional date. In any regard, radiocarbon dates derived from multiple shell or charcoal pieces of divergent ages tend to blur whatever patterns might exist in a distribution rather than create false patterns. Eliminating dates from consideration based on multiple pieces of organic material would avoid this "noise" factor, but the number of pieces comprising a sample frequently has not been reported.

A final consideration is the nature of radiocarbon dates as they are reported by a dating laboratory. Each date has a 67% probability of falling within the interval specified by the counting error. In the date lists used for this analysis, for example, counting errors range from 50 to 350 years, which means the 67% probability intervals range between 100 and 700 years. In other words, the reported date is only the most likely date for the sample given the inherent inaccuracy of the radiocarbon dating technique, and there is the possibility that this date is in error by as much as a few hundred years. Calibration of radiocarbon dates—that is, conversion from radiocarbon years to calendar years—adds other sources of error, which, of course, also adhere to uncalibrated dates if they are taken to be representative of calendar time.

Various approaches have been used to address the issue of counting error. Rick (1987:61), for instance, tallied radiocarbon dates on a 600-year sliding scale, in which 600-year intervals overlap adjacent intervals by 200 years. In essence, then, each radiocarbon date contributes to three adjacent 200-year intervals, and the resulting 600-year interval therefore embraces most of the date's counting error. Berry (1982:32) used a similar approach by giving a count of one to all 25-year intervals into which the one-sigma error interval of a date extended. As Rick (1987) pointed out, however, Berry's method results in dates with large counting errors contributing more to the distribution than dates with small counting errors.

Kintigh (1994) proposed the most sophisticated method for addressing the counting error issue. He treated each radiocarbon date not as a discrete point or an interval but instead as a normal distribution. In constructing a frequency distribution, therefore, a date would be a normal curve with an area under the curve equal to that of every other date in the distribution. The normal curve for a date with a small counting error would have a tall peak and narrow tails, whereas the curve for a date with a large counting error would have a low peak and broad tails. Therefore, a date might contribute to more than one time interval, as a result of its normal curve spanning more than one time interval. That portion of the area of the date's normal curve in each interval would be added to the other normal curve area segments falling within that interval. If the interval used in the date distribution is small, say 25 years, a date with a large counting error, say 150 years, may contribute relatively small normal curve segments to several intervals.

The advantage of Kintigh's (1994) approach to constructing a date distribution is that it more truthfully represents each date than if only the reported date, representing the peak of a normal curve, is used for the distribution. However, because the relatively large interval of 200 years was used for the frequency distributions that are the subject of this analysis, only a slight advantage is gained by the technique, given that the 67% probability interval is generally between 100 and 150 years. Gerber (1992:27) discovered this in the course of her use of an earlier version of Kintigh's (1994) approach for her analysis of radiocarbon date frequency distributions. One might argue, in fact, that using the "most likely" date for constructing a distribution, that is, the discrete date as reported, increases the chances for patterns to be discerned. Nevertheless, Kintigh's (1994) approach to constructing frequency distributions certainly is more sensitive to the actual characteristics of a radiocarbon date.

A 200-year interval was selected for this analysis because of the low prospects of discerning meaningful patterns in a distribution with smaller intervals, given the sizes of the date samples and the various sources of potential bias and noise. This interval is consistent with Taylor's (1987: 141) conclusion that radiocarbon dating generally does not allow one to "distinguish temporal increments in units of less than 2-3 centuries at reasonable levels of precision." This interval size largely precluded the need for sophisticated techniques for combining similar dates, or the characterization of dates as normal distributions. The possible effects on a frequency distribution of shifting the starting point for defining 200-year intervals was not considered. For instance, if the starting point were at 50 or 100 years rather than zero, a somewhat different pattern of fluctuation may be produced. Because the focus herein was on the peaks and depressions in the distribution spanning more than one interval or repeated across at least two distributions, shifting the starting point should have no appreciable effect.

The 200-year interval used in this analysis compensates to a large extent for variations through time in the magnitude of the reservoir effect, but if the reservoir correction departs on the order of 100 to 200 years from the correction used here (especially if the fluctuation occurs within a few hundred years), then the patterning in radiocarbon date distributions will be affected. That is, clusters and gaps could be created or accentuated by such fluctuations in the reservoir effect. This possibility is considered in the analysis below.

Uncalibrated dates were used for the distributions because of difficulties calibrating both charcoal and shell dates and because patterns in the distributions should be just as obvious using either uncalibrated or calibrated dates. Through the course of evaluating the patterns described below, however, it was kept in mind that radiocarbon years are shorter than calendar years during some periods of time and vice versa during other periods (see Stuiver and Becker 1993:Fig. 2). This variation is important, as some peaks in the radiocarbon date frequency distributions may be a product of radiocarbon dates being distributed through a period when radiocarbon years are shorter, and some depressions may occur during a period when radiocarbon years are longer.

To summarize, a relatively simple approach to constructing date distributions, considering the various biases and "noise" factors, was used. All dates derived from marine shell were corrected using a standard procedure, given that many such dates were not originally associated with fractionation corrections. Furthermore, dates from a site that are close in time were combined, and a 200-year interval was used for the distribution in light of both the typical counting error of the dates and uncertainty in reservoir effect variation and the temporal integrity of the samples from which many of the dates were generated.

THE NATURE OF THE DATE DISTRIBUTIONS USED IN THE ANALYSIS

A major aspect of this analysis considers the more obvious differences and similarities among three radiocarbon date distributions, each consisting of radiocarbon dates from sites in a discrete region of Santa Barbara County (Fig. 1). The Santa Barbara Channel mainland distribution is based on 195 dates from 67 sites located along the coast from the eastern boundary of Santa Barbara County to Point Conception and inland to the crest of the Santa Ynez Range. Combining multiple dates for some of the sites resulted in 141 dates actually in the distribution. The northern Channel Islands distribution is based on 186 dates from 50 sites located on Santa Cruz, Santa

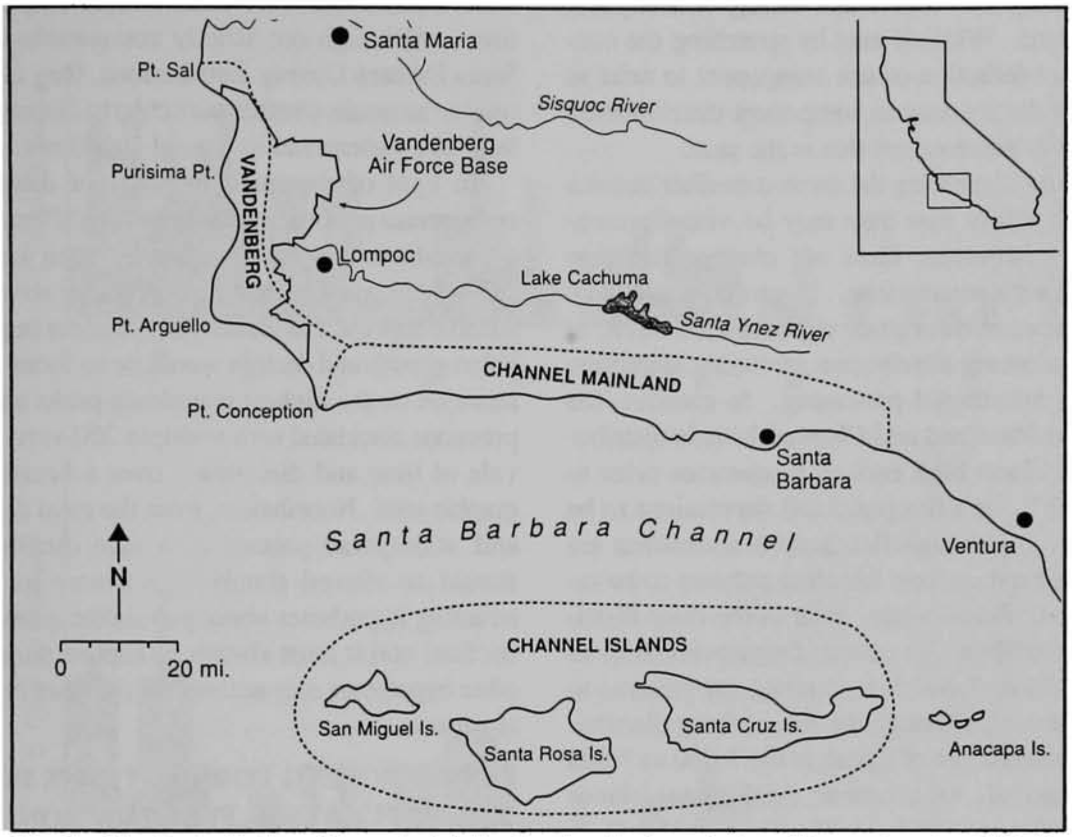

Fig. 1. The Santa Barbara Channel vicinity showing the boundaries of the regions to which the three radiocarbon date distributions pertain.

Rosa, and San Miguel islands (but not Anacapa Island). Combining dates resulted in 121 dates actually included in the distribution. The Vandenberg distribution is based on 189 dates from 55 sites located within a few miles of the coast north of Point Conception, nearly all coming from Vandenberg Air Force Base. Combining dates resulted in 135 dates included in the distribution. Too few dates exist for sites in the interior of Santa Barbara County to discern any meaningful patterns. Each of the three regions has a number of distinctive environmental characteristics; however, the prehistoric populations living in all three participated in cultural traditions with many commonalities. Consequently, their date distributions should exhibit both similarities and differences.

One might argue that the date distributions may be considered site component distributions instead. Because similar dates from a site were combined, the set of dates from one site are, in essence, dates of occupations. In some instances, dates from a given site falling into sequential 200-year intervals actually may be dating a continuous, long-term occupation at the site. Nevertheless, in many instances, the dates are separated by enough time to imply that they are associated with separate occupations. Archaeologists usually consider a site component to be a discrete occupation at a site discernible as a distinct stratum of deposits. However, rodent disturbance at many sites has blurred what probably were discrete strata, and the separateness of occupations generally must be determined through radiocarbon dating or some other dating or analytical procedure. While it may be stretching the conventional definition of site component to refer to the date distributions as component distributions, at least to some extent this is the case.

Figure 2 presents the three date distributions in such a way that they may be visually compared. However, there are obvious limits to making such comparisons. In particular, the low frequencies of dates prior to about 2,800 B.P. in the Vandenberg distribution precludes identification of meaningful patterning. In contrast, the Channel Mainland and Channel Islands distributions do have high enough frequencies prior to 2,800 B.P. for a few peaks and depressions to be identified, although fluctuations sometimes are too rapid and extreme for clear patterns to be recognized. Furthermore, none of the three distributions exhibits high enough frequencies prior to the 7,400 to 7,600 B.P. interval for patterns to be discerned, although the Vandenberg distribution exhibits a hint of a peak at the 7,600 to 7,800 B.P. interval. Of the three, the Channel Islands distribution potentially has the highest resolution, given that site components generally are not as contaminated by earlier or later deposits, a problem quite prevalent in coastal mainland sites. Moreover, periods of population decline may be more obvious on the islands due to a narrower range of food resources and more limited freshwater sources. However, date frequencies are too low in the Channel Islands distribution to determine whether these expectations actually resulted in more distinct peaks and depressions.

Supplementing the three Santa Barbara County distributions in the analysis are date distributions pertaining to coastal California counties from San Francisco Bay southward to the Mexican border (Fig. 3). Taken without modification from Breschini et al. (1996), these distributions are simply of reported radiocarbon dates grouped into 250-year intervals. Included are dates derived from shell that are both corrected and uncorrected for fractionation, as well as every individual date from a site, regardless of how close they are in time. Although not strictly comparable to the Santa Barbara County distributions, they may be used to ascertain whether particularly distinct patterns are widespread in coastal California.

In light of the small numbers of dated site components per time interval and the different vagaries affecting the association between a radiocarbon date and a prehistoric event, the most reasonable approach to identifying patterns in population growth and decline would be to focus more attention on the highest magnitude peaks and depressions associated with multiple 200-year intervals of time and discernible over a broad geographic area. Nonetheless, even the most distinct and widespread pattern in a date distribution should be viewed simply as a source for constructing hypotheses about population growth or decline, and it must always be kept in mind that other hypotheses may account for the distributional pattern.

SEARCHING FOR PATTERNS IN POPULATION FLUCTUATION

This analysis of date distributions begins with a consideration of trends that may indicate population growth or population peaks. The most obvious trend is that date frequencies do not reach their highest levels until after about 1,600 B.P., implying that population growth accelerated within a few hundred years after this date. This pattern also may be seen in other coastal county distributions for which samples of dates are relatively large—specifically, those for Monterey, San Luis Obispo, Orange, and San Diego counties.

Another trend that is not so obvious is the presence of a small peak in date frequencies centering around 7,000 B.P. This is obvious in the Channel Mainland distribution as well as in the distributions for Monterey, Orange, and possibly San Diego counties. This peak may indicate that population sizes rose significantly beginning sometime around 7,200 B.P. but declined again within a few hundred years after 7,000 B.P.

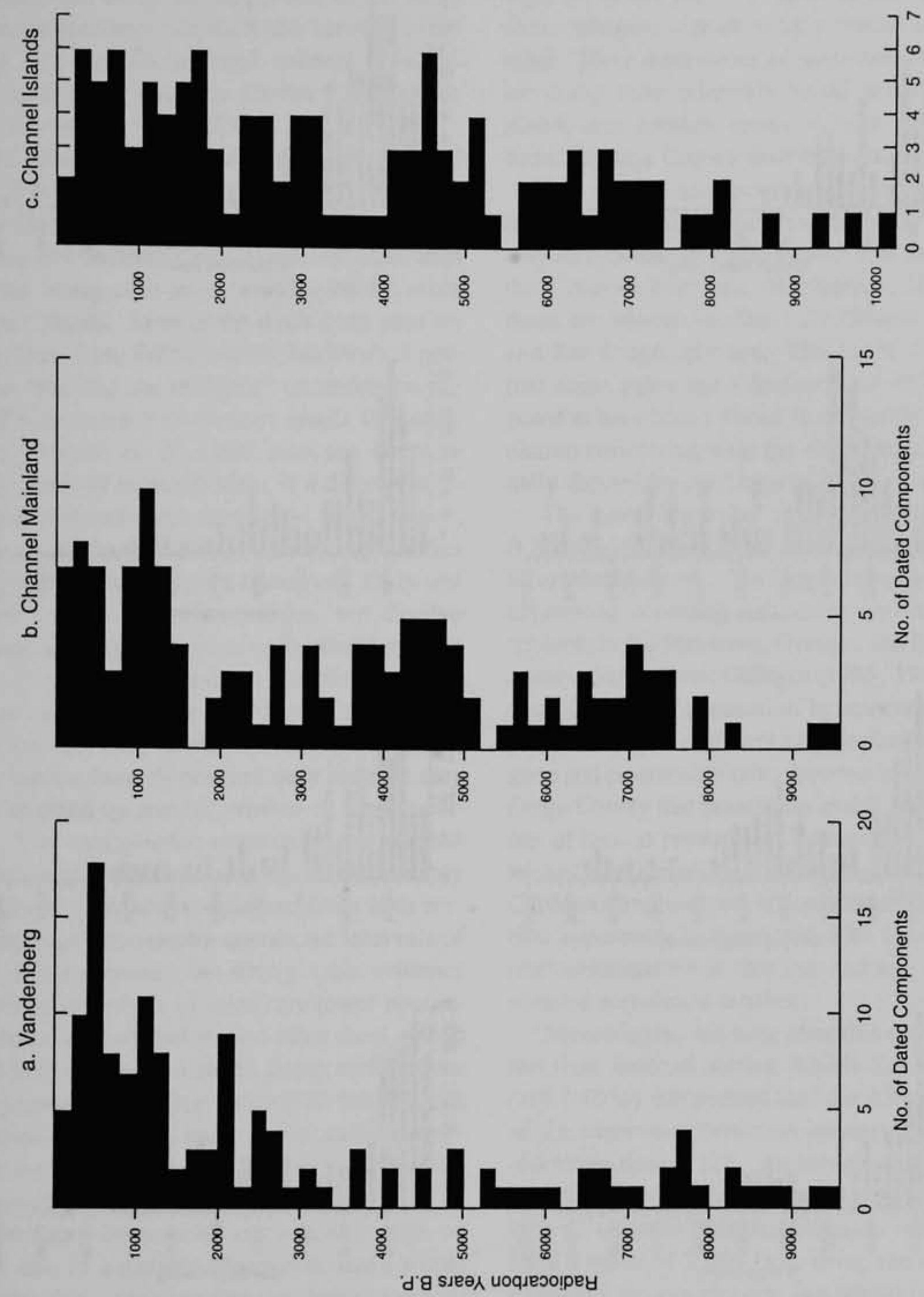

Fig. 2. The Vandenberg, Channel Mainland, and Channel Islands radiocarbon date distributions.

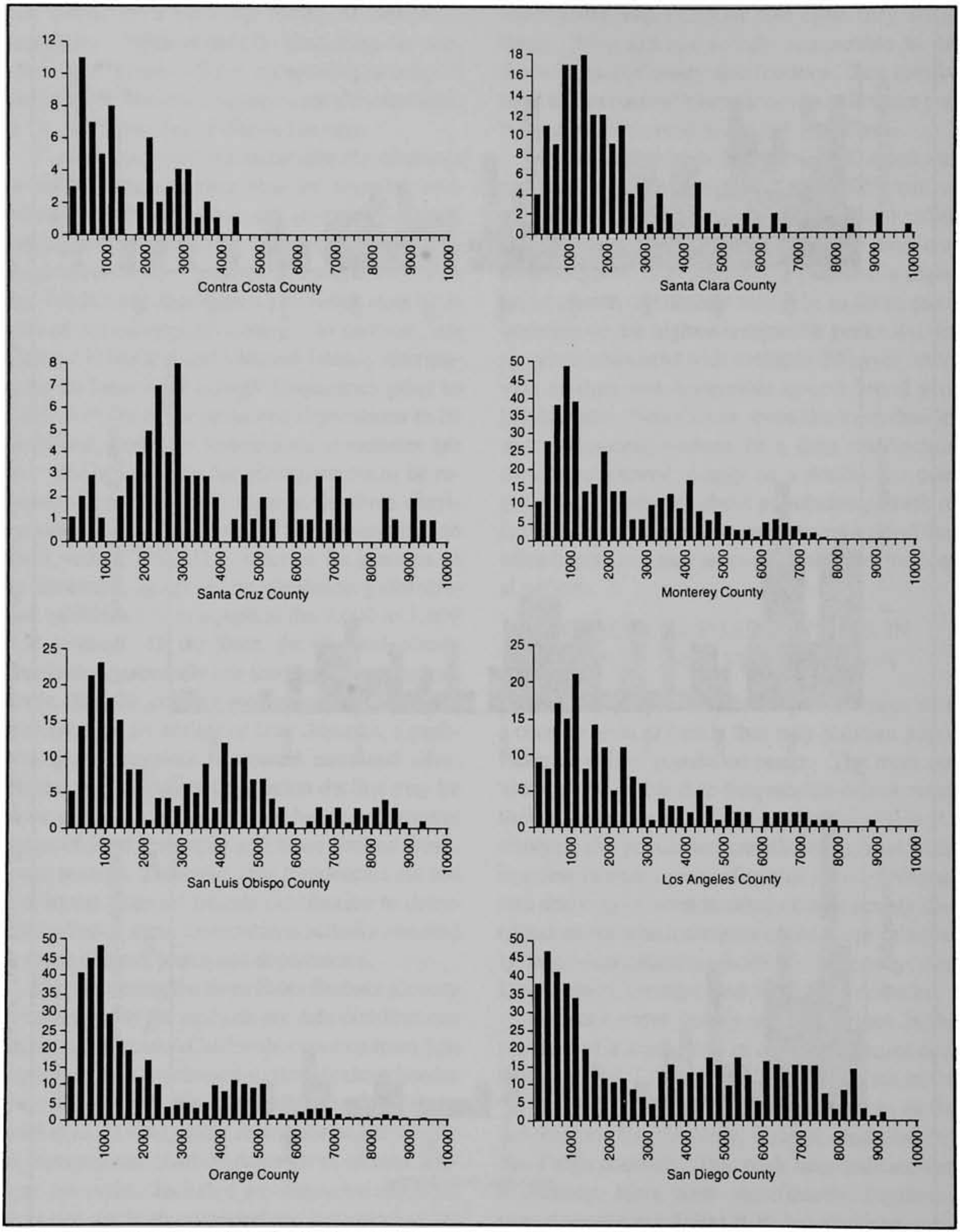

Fig. 3. Radiocarbon date distributions for selected counties in California from Breschini et al. (1996).

Dated sites contributing to this peak typically are manifestations of the initial portion of the Milling Stone Horizon, which is the earliest widespread and well-documented cultural development in coastal southern California (Wallace 1954; Glassow et al. 1988).

The relatively prominent peak between 4,400 and 5,200 B.P. in the island distribution is largely a product of my research focus on sites of this time interval on Santa Cruz Island and analogous interests of my colleagues working on the other Channel Islands. Most of the dates from sites on Santa Cruz Island falling within this interval pertain to "red abalone middens" occurring on the island's southern and western coasts (Glassow 1993; Glassow et al. 1994; also see Glassow 1997). Each of these middens is a discrete stratum generally no more than about 20 cm. thick, and many of these strata are overlain by midden deposits of a much different character. Only one is underlain by an earlier midden, but the two middens are separated from each other by strata of nearly sterile dune sand. A number of the red abalone middens are separated from later deposits, if they occur by aeolean or alluvial deposits, many having been discovered only because they were bisected by seacliff erosion or arroyo cutting. The stratigraphic contexts of red abalone middens imply that the period of occupation they collectively represent is separated from both earlier and later deposits by significant intervals of time. In other words, the stratigraphic evidence suggests that periods of relatively lower population occurred both before and after the 4,400 to 5,200 B.P. interval. A much flatter and broader peak centers on this time interval in the Channel Mainland distribution, but it is not readily apparent in the distributions for other coastal California counties.

If the date frequencies are relatively high on either side of a distinct depression, there would be reason for suspecting that the depression represents a period of lower population density. Indeed, such a depression in date frequencies probably is more meaningful than a peak, in that the vagaries in the data are likely to hide a depression, whereas a peak simply would be broadened. Three depressions of some potential interest occur over relatively broad geographic regions, and another seems evident only in the Santa Barbara County distributions.

The earliest and seemingly most obvious of these depressions centers around 6,000 B.P. and may be as broad as 1,000 years. It is manifest in the Channel Mainland distribution, as well as those for Monterey, San Luis Obispo, Orange, and San Diego counties. This is the depression that some years ago Glassow et al. (1988) proposed to have been a period of relatively low population correlating with the Altithermal as originally defined by Antevs (1955).

The next, occurring around 3,200 to 3,600 B.P., is evident in both the Channel Mainland and Island distributions. This appears to be the same depression centering a bit later in time that is apparent in the Monterey, Orange, and San Diego county distributions. Gallegos (1985, 1987, 1992) argued that this depression is associated with a period of rapid sedimentation in Batiquitos Lagoon and presumably other lagoons in coastal San Diego County that essentially ended the intensive use of lagoon resources. However, the appearance of this depression in other regions of coastal California implies that this episode of sedimentation apparently is associated with a larger scale environmental event that resulted in a period of reduced population numbers.

Interestingly, not long after this depression is the time interval during which Kennett et al. (1997:1056) determined that the ΔR component of the reservoir correction appears to be -30 to -50 rather than +225. An uncorrected radiocarbon date from marine shell of 3,000 B.P. (3,430 B.P. if corrected for fractionation only) would have a value of 2,805 B.P. using the correction procedure for this analysis, but would have a value of 3,070 B.P. if an average of their two ΔR values was used. If the time interval of this unusually small fractionation effect extends back through the period of the depression in radiocarbon date frequencies between 3,200 and 3,600 B.P., but no further, it would at least contribute to the depression.

The third depression, occurring sometime around 1,800 B.P., is more problematic. A depression in the Channel Mainland distribution occurs at the 1,600 to 1,800 B.P. interval, but in the island distribution it occurs between 1,800 and 2,200 B.P. In the more southerly coastal California distributions, there is a hint of a depression in the 1,750 to 2,000 B.P. interval. This interval is worth monitoring as more dates become available.

The fourth depression, occurring just after 1,000 B.P., also is problematic. This appears in the Channel Mainland distribution, in which it is relatively obvious, but is less evident in the other two Santa Barbara County distributions. If indeed this depression is real, it may indicate a population decline linked to the Middle-to-Late Period transition defined by Arnold (1992a, 1992b) and given attention by Raab (1994) and Raab and Larson (1997; see also Arnold et al. 1997).

The differences between the three Santa Barbara County distributions also are of some interest. Most of the differences probably are a product of the erratic nature of distributions consisting of small numbers per interval, but other factors may be in effect as well. An interesting difference between the Vandenberg distribution and the other two is that a much larger proportion of the dates in the Vandenberg distribution occur after about 2,800 B.P., implying that populations of the Vandenberg region remained relatively low until after that date.

Another interesting comparison is that the Channel Islands distribution tends to exhibit peaks and depressions about 200 years earlier than the Channel Mainland and seemingly also the Vandenberg distributions. A possible explanation for this offset is that the reservoir correction for marine shell dates may be off by about 200 years. Considering that a majority of the Channel Islands dates are derived from charcoal, whereas the majority of mainland dates (in both the Channel Mainland and Vandenberg distributions) are derived from marine shell, the implication is that the reservoir correction may be 200 years greater than the currently used 625 years. As discussed earlier, however, Kennett et al. (1997) discovered that for one interval of time during the last several thousand years, the Santa Barbara Channel reservoir correction is considerably *less* than 625 years rather than greater.

Alternatively, mainland radiocarbon samples tend to be contaminated by shell (perhaps charcoal too) from more recent, stratigraphically higher components more often than they are contaminated by earlier, stratigraphically lower components. This proposal is not as unreasonable as it may seem at first glance, but if this pattern of contamination were occurring, the offset should diminish within the last 1,000 years of prehistory. This does not appear to be the case; the 200-year offset appears as obvious in the latest prehistoric period as in the earliest.

A third possibility is that Channel Islands populations responded more rapidly to environmental fluctuations affecting food supplies than did mainland populations. Although this is likely, it seems implausible that the time difference would be on the order of 200 years. Furthermore, the greater diversity of terrestrial food resources and larger land areas on the mainland would have meant that periods of lower population numbers would have been narrower than on the islands rather than offset a few hundred years later.

DISCUSSION

One should exercise a good deal of caution in inferring population fluctuations from radiocarbon date distributions, largely because the date frequencies per time interval still are quite small. One might also argue that this rather simple approach to identifying patterning in the frequency distributions of dates should be replaced with one entailing statistical evaluation of patterning in the date distributions, although the use of statistical techniques would make more sense once samples of dates are both larger and more reliably related to discrete prehistoric events. Despite the vagaries of the radiocarbon data and the simplicity of the approach herein to evaluating patterning, several broad conclusions seem appropriate.

First, there is little doubt that populations in the three regions of Santa Barbara County, and elsewhere in California, witnessed both increases and decreases in population size through the course of prehistory. Population growth was not uniformly progressive, punctuated only by narrow plateaus. Population declines surely did occur, and some of these declines appear to have been very significant.

Second, population density appears not to have begun rising to levels approaching those of the period immediately prior to European contact until after about 1,600 B.P. in Santa Barbara County and probably elsewhere in California as well. Furthermore, it may be that populations reached levels comparable to those at the time of European contact within just a few hundred years after 1,600 B.P.

Third, although similarities in patterns of population fluctuation appear to extend over large geographic areas, regional differences may be discerned that most likely are related to environmental differences between regions. Jones and Waugh (1997) emphasized this in their comparison of date distributions for the Elkhorn Slough and Morro Bay vicinities. With regard to the three Santa Barbara county regions, the Vandenberg region stands out from the other two in having a much larger proportion of its dates within the last 2,800 years of prehistory. While population density in the Vandenberg region appears to have remained relatively low until about 2,800 years ago, relatively higher population levels were reached two or three times prior to this date in the Channel Mainland and Channel Islands regions.

Interpretations of fluctuations in frequency distributions of radiocarbon dates might focus on either the frequency peaks or the frequency depressions rather than a combination of the two. Depressions are likely to be of greater interest in relating population fluctuations to cultural development. It is not the intent of this paper, however, to explore cultural responses to such environmental changes, if they existed. Nevertheless, it is worth mentioning that new means of environmental adaptation might be expected to come into existence during periods when unfavorable environmental conditions were severe enough and persisted long enough for food resource productivity to be broadly affected. These new adaptations would become visible archaeologically in sites dating immediately after a period of depressed population.

The latest interval of apparently depressed population is of particular interest in that it correlates with the time interval Arnold (1992a, 1992b) recently defined as the Middle-to-Late Period transition. Arnold proposed that this time interval was one of subsistence stress implicated in the development of chiefdoms and economic intensification that characterized the Chumash at the time of European contact. If these cultural developments occurred during a period of depressed population, they would be most evident when population again rose to higher levels, after 600 to 700 B.P. Significantly, Arnold (1992b: 134) found evidence of abandonment during the Middle-to-Late Period transition at several of the sites she investigated on Santa Cruz Island.

It is intriguing that the patterns in radiocarbon date fluctuations identified in the Santa Barbara County distributions and elsewhere in coastal California bear some similarity to patterns in a radiocarbon date frequency distribution for the Northwest Coast (Maschner 1991:930), although there are clear differences as well. The most obvious correlation is a distinct depression centering around 1,000 B.P. in the Northwest Coast distribution (converted from calibrated dates) with the 600 to 1,000 B.P. depression on the Santa Barbara County distributions. The Northwest Coast distribution also exhibits a marked increase in date frequencies after about 2,500 B.P.

One also can find similarities with date distributions for other regions of the world. For instance, Rick's (1987) analysis of Peruvian preceramic (pre-3,500 B.P.) radiocarbon dates revealed distinct depressions between about 6,000 and 6,500 B.P. in his coastal frequency distribution and between about 4,500 and 6,000 B.P. in his sierra frequency distribution. As well, Smith (1992) noted a decline in date frequencies after 7,000 B.P. in his British Isles distribution (which includes only dates older than 6,000 B.P.). These depressions may correlate with the 5,200 to 5,600 B.P. depression in the Santa Barbara County distributions, which may extend back in time to ca. 7,000 B.P. Although the definition of such a global pattern is highly speculative, it is reasonable to suspect that some peaks and depressions (particularly the latter) are essentially global in scope.

Despite the obvious shortcomings of this analysis, it should be clear that radiocarbon date distributions have the potential to provide many insights into population dynamics and their relationship with both environmental changes and cultural development. In lieu of more direct measures, radiocarbon date distributions are our principal source of data concerning population fluctuations in regions of California. To enhance the value of this data source, the following suggestions are made.

First, we must obtain dates from *all* sites investigated, no matter how small or disturbed. Obviously, the larger the regional sample of dates, the greater the likelihood of identifying statistically significant patterns. Furthermore, to compensate for changes in the number of sites included within a settlement system, radiocarbon dates need to be obtained for all sites containing datable organics, no matter how small the pieces of organic material might be. Of course, this initiative also would help us understand the nature of and change in settlement systems.

Second, we must obtain greater numbers of dates per site or site component. It will be particularly useful to have both initial and terminal dates for a site or site component. For instance, terminal dates for a number of sites or site components in a region might correlate, thus providing a different realm of evidence of population growth and decline or major shifts in settlement systems.

Third, we must obtain dates from individual pieces of charcoal or shell, or if multiple pieces must comprise a sample, use only pieces from a provenience that unequivocally represents a single depositional episode. Selecting such samples frequently will require either small-sample or AMS dating procedures, which will increase the cost per date. This means that larger proportions of project budgets must be devoted to radiocarbon dating. Considering how important bracketing the time period during which a site was occupied is to a variety of important research problems, there is good justification for such a reallocation of funds.

Fourth, if a marine shell and charcoal from small twigs occur in a context that may be argued to represent a single point in time or at most an interval no more than several years long, we must obtain dates from both materials in order that the date pair might contribute to the investigation of geographic and temporal variations in the reservoir effect on marine shell dates. Although one pair isolated in time and space is not particularly meaningful, such efforts eventually would result in quantities of shell-charcoal pairs sufficient for the study of variations in the reservoir effect.

Fifth, we must include information about the nature of the sample and the discreteness of its provenience in tables or summaries appearing in reports and publications that present data about radiocarbon dates. Simply mentioning whether the radiocarbon sample was wood charcoal or mussel shell does not provide information useful in evaluating the likelihood that a date represents a discrete depositional episode.

Finally, we must report dates and all information pertaining to them for inclusion in future issues of *California Radiocarbon Dates* (published by Coyote Press). Most of us working in California have come to depend on this source for information about sites associated with radiocarbon dates, and the availability of the date lists in this frequently updated publication are fundamental to any analysis of radiocarbon date distributions.

CONCLUSION

The analysis of radiocarbon date distributions offers California archaeologists a potentially powerful tool for discerning changes in the relative size of populations occupying regions or localities. As well, there is the possibility of identifying population fluctuations over large geographic areas that are related to major paleoenvironmental changes. Although inconsistencies in patterns of fluctuation in the three Santa Barbara County frequency distributions leave room for doubt, there is little question that broad similarities do exist, particularly when consideration is also given to frequency distributions for other regions of California. It is obvious, however, that the only way to realize the potential of the analysis of radiocarbon date distributions is to devote more attention to the nature and context of the organic samples submitted for radiocarbon dates and to systematically obtain radiocarbon dates to bracket in time each occupation of a site.

NOTE

1. All dates, unless otherwise identified, are in radiocarbon years before present.

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