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# A Pre-Censal Population History of Hawai‘i

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**ABSTRACT**

The population history of the Hawaiian Islands from the time of initial Polynesian settlement to the first reliable census in 1831–1832 is estimated using aggregate $^{14}$C age determinations. This approach to population estimation is distinct from the site census approaches previously used in Hawai‘i, is not subject to the same sources of uncertainty as the site census approaches, and yields different results. Estimation results indicate that the Hawaiian population stayed relatively small, with no net growth after the fifteenth century. The results lend plausibility to density independent hypotheses of culture change in prehistoric Hawai‘i.

*Keywords*: PALAEODEMOGRAPHY, RADIOCARBON, DENSITY DEPENDENCE, ARCHAEOLOGICAL INFERENCE.

## INTRODUCTION

The history of Hawai‘i's prehistoric population and the size of the archipelagic population at the time of first recorded contact in 1778 are topics of vigorous debate. Proponents of the idea that the human population growth curve is sigmoidal because of density dependent factors, as it is for many other insular species, have been accused of underestimating the role of culture in regulating human affairs. Supporters of the long-promoted hypothesis that the population in 1778 was between 200,000 and 300,000 have been reproached as apologists for Europeans whose diseases are conjectured to have killed some 90 percent of a contact era population that was near a million.

Here we estimate the population history of Hawai‘i from the time of initial settlement to the first accurate census, a period that Schmitt (1971) labels "pre-censal." Using aggregate $^{14}$C age determinations, we build upon and extend a population estimation method described by Rick (1987). Annual population estimates and confidence intervals that take into account the primary sources of internal uncertainty (Mosteller and Tukey 1977) are derived from 598 $^{14}$C age determinations. Sources of supplementary uncertainty are identified and data are presented to support the hypothesis that their effect is likely to be small; ad hoc assessments of estimated population parameters do not contradict this hypothesis. Results indicate that the pre-censal population of Hawai‘i stayed relatively small with no net population growth after the fifteenth century.

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## BACKGROUND

Cook's officers published the only population estimates for Hawai'i that were based on observations made before diseases introduced by the crews of *Resolution* and *Discovery* in 1778 and 1779 devastated the Hawaiian people. These population estimates varied from Bligh's 242,200 to King's 500,000, which he later revised to 400,000 (Schmitt 1968). The basis for Bligh's estimate is not known, but King described his observations in detail, along with assumptions that he used to extrapolate an estimate of the archipelagic population. King's observations have served as the primary source of data on the size of Hawai'i's 1778 population for over two centuries. Scholars who have examined King's assumptions have generally arrived at lower population estimates of their own, with most arguing for a 1778 population between 200,000 and 300,000 (Schmitt 1968, 1971; Nordyke 1989). Recently, Stannard charged that these lower population estimates are based on "flagrant errors of fact and judgement" (1989: 142) and that they are politically important to "Westerners who caused the suffering" of Hawaiians through the introduction of fatal diseases, and to "colonizers...[who] would prefer the colonized not know about their pasts" (1989: 143). He provides a number of arguments to support an estimate of between 800,000 and 1,000,000 for the 1778 population.

Estimates made after King's and before the first missionary census in 1831–1832, though uneven in quality, appear to chart a decline in population (Table 1). Schmitt (1968, 1971), Stannard (1989), and Nordyke (1989:17 ff) review these estimates.

TABLE 1

ESTIMATES OF THE POPULATION OF HAWAI'I, 1787–1823

| Estimator | Date | Estimate | Source |
|---|---|---|---|
| Dixon | 1787 | 200,000 | Dixon (1789: 267) |
| Golovnin | 1818 | 200,000 | Golovnin (1979: 215) |
| Youngson | 1803–5? | 264,160 | Freycinet(1978: 66) |
| Tyerman and Bennet | 1822 | >200,000 | Montgomery (1832 (II): 35) |
| Mathison | 1822 | ≤150,000 | Mathison (1825: 439) |
| Missionaries | 1823 | ≈142,000 | Stewart (1828: 25–27) |

The first census of the Hawaiian people began in 1831, when missionaries attempted a head count on all but the sparsely populated small islands of Lāna'i and Kaho'olawe. Although marred by various inconsistencies and an apparent failure to complete the count on Moloka'i, the census, which was completed in 1832, provides "a generally accurate and complete picture of the Hawaiian population" (Schmitt 1973: 6). The archipelagic total was variously reported as 129,814 and 130,313, though missionaries at the time and scholars later concluded that this was an overenumeration (Schmitt 1973: 6–7). Schmitt places the figure at 128,713 (1971).

In the 1970s and through most of the 1980s, archaeologists collected and analysed information on the temporal distribution of dated habitation sites and calculated life tables for skeletal populations in order to develop models of the prehistoric population. Cordy (1981) reconstructed absolute population figures for eight land units on the dry, lava-covered leeward coast of Hawai'i Island by counting the number of sleeping houses per land unit, estimating their duration of use by dating pieces of volcanic glass found within them, and assigning six persons to a house. He arrived at a maximum total population of 240 for the eight land units, with the number of people per land unit ranging from 6 to 66, but did not attempt to extrapolate an archipelagic population estimate. Hommon used information on the duration of occupation at 51 volcanic-glass-dated habitation sites in leeward Hawai'i Island and 655 features on Kaho'olawe Island to investigate site population curves for these regions, but did not attempt to estimate absolute numbers of people (1976, 1980). Hommon's work was followed by Kirch, who augmented the leeward Hawai'i Island sample with information from 62 other sites, most of them dated with the volcanic glass hydration method (1984). Data from leeward Hawai'i and Kaho'olawe both yielded sigmoidal growth curves, with site populations reaching a maximum in the sixteenth or seventeenth centuries and either remaining static or declining thereafter.

Kirch (1984: 114) constructed life tables for skeletal populations excavated at Pu'u Ali'i, Hawai'i Island and Mōkapu, O'ahu Island. Although the Mōkapu site has not been dated, Kirch suspected that since the windward coast was a locus for early settlement, the "Mōkapu series could be of some antiquity" (Kirch 1984: 113). The Pu'u Ali'i series was more confidently dated to the last two centuries before European contact. The life tables for these populations showed that survivorship ($l_x$) was lower at Pu'u Ali'i than at Mōkapu, and that child and infant mortality ($q_x$) was higher at Pu'u Ali'i than at Mōkapu. Kirch found these data "tantalizing in their suggestion that... [Hawaiian] populations were responding to certain density-dependent effects" (1984: 115–116) and found in them support for the sigmoidal population curves constructed for Leeward Hawai'i and Kaho'olawe.

Criticisms of the site census approaches used by Cordy, Hommon, and Kirch call into question reconstructions of pre-censal population parameters (Cordy 1984; Clark 1988). Some years ago Cordy pointed out that occupation spans are reliably estimated for relatively few habitation sites (Cordy 1984: 23). This observation retains its force today, especially in considerations of the archipelagic population. Clark (1988) summarised several potential sources of uncertainty in the site census approach. They include the use of volcanic glass for dating at many sites, indiscriminate census of temporary and permanent habitations, variations in household size, spatial and temporal biases deriving from the small size of the dated sample of habitation sites, and use of volcanic glass age determination standard deviations to estimate occupation spans. Although Clark does not estimate the error introduced by these potential sources of uncertainty, so that his conclusion that they represent "serious" or "major" flaws is premature, the intensity of fieldwork that their estimation requires suggests that successful application of the site census approach in Hawai'i might be a long way off. These criticisms were factors in our decision to pursue a separate line of analysis.

The palaeodemographic data cited by Kirch, with the addition of a series from Keōpū, Hawai'i, have been analysed by Sutton and Molloy (1989). Using recent advances in palaeoanthropology that recognise the interdependence of life table parameters, their sensitivity to the stable population assumption, and the effects on various parameters of the frequent under-representation of infants in skeletal populations, Sutton and Molloy show that adult life expectancies at Pu'u Ali'i and Mōkapu were virtually identical, but were exceeded at Keōpū. They also show that birth rates at Mōkapu and Pu'u Ali'i were not significantly different, but were substantially higher than at Keōpū. They conclude convincingly that Kirch's results are "an artefact of his methodology" (1989: 32) and do not support the sigmoidal population curve derived from the site census data. However, they note that "the implications of [the palaeoanthropological data] for population growth cannot be adequately assessed" (1989: 35), so questions about Hawai'i's pre-censal population curve remain open.

Discriminating between alternative hypotheses on the pre-censal population growth curve and the absolute size of the contact era population requires data that support reliable estimates of the pre-censal population. Given the current inability of palaeodemographic data to inform on matters of population growth and the unlikelihood of major additions to the palaeoanthropological database in the face of current opposition to osteological analysis by native Hawaiian groups, the many potential sources of uncertainty in the site census approach and the amount of fieldwork needed to derive credible archipelagic population estimates, a more direct approach is desirable. A method described by Rick (1987) which uses $^{14}C$ dates as data provides the basis for this approach.

## METHODS

The usual archaeological method of estimating prehistoric populations involves taking a census of dated food remains, portable artefacts, or architectural units whose number or aggregate size corresponds to population size (Hassan 1981; Ramenofsky 1987). Rick's approach differs by using $^{14}C$ dates as primary data rather than as a means to assign an age to some other class of archaeological remains. The conceptual basis of Rick's method is summarised by the assertion that "if archaeologists recovered and dated a random, known percentage of the carbon from a perfectly preserved carbon deposit to which each person-year of occupation contributed an equal and known amount, they could estimate the number of people who inhabited a region during a given period" (1987: 56). These conditions will quite obviously never be satisfied in an archaeological situation and, in practice, frequency distributions of $^{14}C$ age determinations are interpreted as reflecting relative changes in population within a region over time. Rick specifies three assumptions that must hold for a frequency distribution of $^{14}C$ age determinations to be isomorphic to a population growth curve. They are: 1) the $^{14}C$ age determination sample is representative of the extant archaeological carbon deposit; 2) the extant archaeological carbon deposit is representative of the original carbon deposit; and 3) the amount of carbon added to the original deposit *per capita* per unit time is constant over the period of interest. Rick denotes deviations from these assumptions as investigation biases, preservation biases, and creation biases, respectively. A fourth assumption is that numbers of $^{14}C$ dates are an unbiased estimator of the amount of carbon in the deposit, an assumption that seems reasonable given the fairly standard amount of carbon required for $^{14}C$ age assay and the fact that this standard sample size is, in most cases, a minute fraction of the extant carbon deposit of a region.

A frequency distribution of $^{14}C$ age determinations that is relatively free of investigation, preservation, and creation biases can be used to estimate absolute population numbers if the amount of carbon added to the archaeological carbon deposit *per capita* per unit time is known or can be estimated. In situations where the period covered by $^{14}C$ dating includes a census year, this variable can be estimated for the census year by equating $^{14}C$ age frequency to the enumerated population. If creation biases are not strong then the estimated mean *per capita* amount of carbon added annually to the archaeological carbon deposit can be extrapolated over the rest of the frequency distribution to yield an absolute population estimate for each year.

## THE $^{14}C$ AGE DETERMINATION SAMPLE

The 598 $^{14}C$ age determinations used in this analysis were selected from the Hawai'i archaeological $^{14}C$ database which, at the time of the analysis, included complete lists of $^{14}C$ age determinations 1) returned by dating laboratories to archaeologists at Bishop Museum, 2) reported in sources found in Spriggs and Tanaka (1988), and 3) contained in archaeological excavation reports on file at the State Historic Preservation Office in the summer of 1989. We believe this to be a substantially complete list of archaeological $^{14}C$ age determinations for Hawai'i to 1988. The $^{14}C$ ages of 495 age determinations differ significantly from the modern standard; 103 do not. Since the statistical treatment of these two types of dates differs, we have found it convenient to note the distinction terminologically. We refer to the former as 'B.P.' dates and the latter as 'modern'.

To minimise the error introduced by creation biases, the archaeological context of a selected age determination supported the inference that the dated charcoal was produced by a daily activity such as cooking, lighting, or some other routine household chore. Most of the sample consists of age determinations from temporary or relatively permanent habitation sites, located both in the open and in shelter caves. Also included are age determinations from isolated underground ovens that were probably used to cook food for gardeners.

Inferred activities that were rejected because of the strong possibility of creation biases include agriculture, aquaculture, and religious and burial rites. Although there does not appear to have been any radical change in Hawaiian agricultural practices over time (see Kirch 1985: 88; *pace* Handy 1930; Buck 1959: 258–259), there is a high probability that more charcoal was produced during the initial clearing of virgin forest than during subsequent clearings of second growth. Similarly, fishponds, which have been dated frequently in the last few years, are believed to have been independently invented in Hawai'i relatively late in the prehistoric sequence (Kikuchi 1976). Age determinations associated with religious rites and burial are suspect because Hawaiian traditions claim that religious practices went through revolutionary changes in the early centuries of this millennium (Fornander 1969 (II): 59 ff.). In contrast, there is no evidence for changes in the *per capita* amount of charcoal produced by daily activities in prehistory. Buck describes traditional Hawaiian cooking, lighting, and fire-making as variants on widespread Polynesian techniques (1964: 17 ff., 107). The hearths, firepits, and earth ovens of the earliest Hawaiian sites are similar to those from late prehistoric contexts (Kirch 1985: 67 ff.). Since it is unlikely that there were changes in the food resource base that would have altered cooking patterns significantly, and since average day length and climate, which determine the need for lighting and heating fires, remain relatively constant from one year to the next, it is likely that age determinations associated with daily activities in the prehistoric period are relatively free from creation biases.

This appears to be the case for the early historic period as well. The half century of the historic period between Cook's visit and the first census was a period during which traditional practices were still the rule in the countryside. Up until 1819 the *kapu* system was in force and the lifestyles of the common people changed little. Although the sandalwood trade of the 1820s greatly increased contact with the outside world, chiefs rigorously controlled trade so that commoners had little access to most Western goods until the 1830s and 1840s, when imported items begin regularly to appear in the archaeological record (Kirch 1985: 314). There are little data with which to estimate the effect of creation biases in the early historic period, but we find little reason to suppose such effects will be great.

Three uncontrolled sample biases contribute to the supplementary uncertainty of population estimates: differences in the treatment of sample composition factors, in particular isotopic fractionation, over the four decades that Hawaiian archaeologists have used $^{14}C$ age determinations; preservation biases, which violate the assumption that the extant archaeological carbon deposit is representative of the original carbon deposit; and investigation biases, which violate the assumption that the $^{14}C$ age determination sample is representative of the extant archaeological carbon deposit. Here we marshal evidence to estimate the effects of uncertainty introduced by these biases. Although it is difficult to derive precise estimates of supplementary uncertainties, as is often the case in non-experimental situations, it is sufficient to compare the likely magnitude of uncertainties against the magnitude of internal uncertainty. If the largest source of supplementary uncertainty is likely to be smaller than the internal uncertainty, then the estimates of population and their confidence intervals can be judged relatively reliable. It is also important to note that we have used all of the available $^{14}C$ dates, so that the resulting population estimates are the best that can be made with present evidence. We believe that efforts should be made to identify systematic archaeological collection biases and we lament the lack of previous investigations of this important topic in Hawai'i. If future investigations identify significant collection biases, it will be a simple matter to add their effects to the confidence intervals of our population estimates.

Two hundred and fifty-one age determinations, comprising 42 percent of the sample, were not corrected for isotopic fractionation. The contribution of this bias to uncertainty can be estimated by extrapolating from the distribution of $^{14}C$ measurements for the 347 age determinations for which this information is available (Fig. 1). The range of $\delta^{13}C$ values is −8.36 to −30.91‰ (wrt PDB), which exceeds at the upper end the world-wide range for 2,843 $\delta^{13}C$ measurements on plant materials (including wood and charcoal) of −8.7 to −33.2‰ (Burleigh *et al.* 1984). The distribution of $\delta^{13}C$ measurements is bimodal, with a primary mode for $C_3$ pathway plants centered at −26‰, and a smaller, but unexpectedly large (cf. Burleigh *et al.* 1984: Fig. 5), mode for $C_4$ pathway plants at −12‰. Dividing this distribution at −16‰, a value suggested both by Figure 1 and by the distribution of 1155 $\delta^{13}C$ values from wood (Burleigh *et al.* 1984: Fig. 6), yields an average value of −24.23‰ for 285 measurements on $C_3$ pathway plants, which corresponds to a correction factor of about 10 $^{14}C$ years, and an average value of −12.36‰ for 62 measurements on $C_4$ pathway plants, a correction factor of about 200 $^{14}C$ years. If the distribution of $\delta^{13}C$ values for the 251 unmeasured age determinations were similar to Figure 1, then 206 require an addition of 10 $^{14}C$ years to the $^{14}C$ age, which would have negligible effects on the results. Forty-five would require an addition of 200 $^{14}C$ years. The effects of this bias on the results would depend on the $^{14}C$ ages of these 45 age determinations, which comprise under 8 percent of the sample, and cannot be estimated with confidence.

Preservation biases in the sample almost certainly exist. On a small scale, most hearths, firepits, and earth ovens were used repeatedly. Frequent cleaning would have dispersed older carbon, making it less likely to be collected than the remains of later fires. On a larger scale, cultural deposits in coastal environments, thought by many prehistorians to include a high proportion of early sites, have been extensively disturbed, in the past through the instability of many coastal sand deposits and, in some areas, catastrophic tidal waves, and in this century by development activities that have affected several of the major islands (Kirch 1985: 67 ff.). In general, these processes tend to decrease the relative probability of collecting an early sample. Given our method of estimating population sizes by anchoring the curve at a census estimate, this bias would lead to an underestimate of the size of the

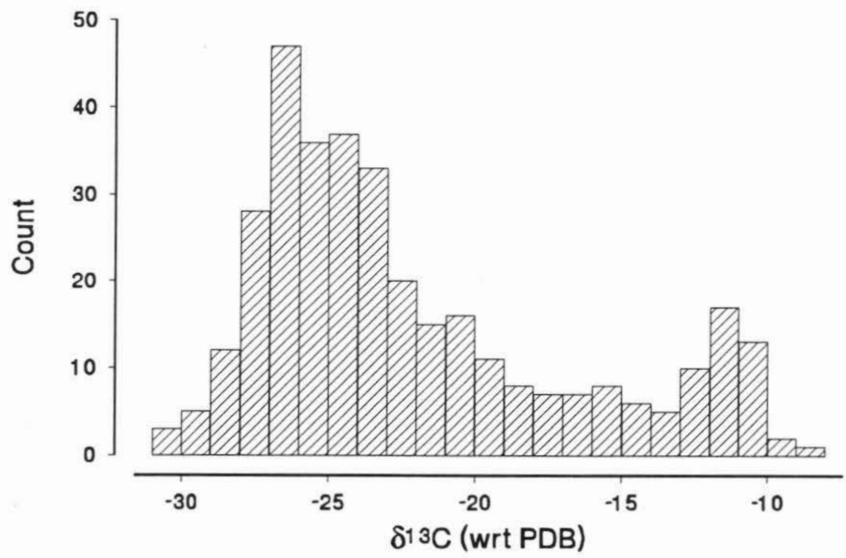


*Figure 1:* The distribution of stable carbon isotope ratios for 347 age determinations in the sample. Note the bimodal shape of the curve.

early prehistoric population, but would have little effect on later periods. Without some prior knowledge of the chronological distribution of the original carbon deposit we can find no way to estimate the effects of this bias.

Investigation biases are of two types: spatial and temporal. If spatial coverage is spotty then it is difficult to discriminate archipelagic population changes from regional migrations. The age determinations selected for analysis are from eight islands, with the majority from the islands of Hawai'i and O'ahu, where the coincidence of relatively strong historic preservation laws and extensive land development in the last two decades led to intensive archaeological exploration (Table 2). Two islands lack age determinations in the sample: Lāna'i, where modern archaeological research has just begun; and Ni'ihau, a privately owned island with restricted access. An index of sampling density, derived by dividing the number of age determinations by the length of the general coastline (Beckerman 1977), shows considerable variation between islands. The wide geographic distribution of the sample, however, mitigates against the uncertainties introduced by migrations. Migration hypotheses might be tested in the future when more dates from under-represented regions are available or when the number of age determinations makes regional comparisons worthwhile.

TABLE 2

DISTRIBUTION OF AGE DETERMINATIONS ASSOCIATED WITH DAILY ACTIVITIES

| | N Samples | | | Indices | | |
|---|---|---|---|---|---|---|
| Island | B.P. | Modern | Coastline km | B.P. | Modern | Total |
| Necker | 1 | 1 | 3.5 | 0.29 | 0.29 | 0.57 |
| Nihoa | 2 | 0 | 5.0 | 0.40 | 0.00 | 0.40 |
| Kaua'i | 18 | 0 | 145.0 | 0.12 | 0.00 | 0.12 |
| O'ahu | 176 | 18 | 180.0 | 0.98 | 0.10 | 1.08 |
| Moloka'i | 18 | 9 | 142.0 | 0.13 | 0.06 | 0.19 |
| Kaho'olawe | 49 | 39 | 47.0 | 1.04 | 0.83 | 1.87 |
| Maui | 35 | 7 | 193.0 | 0.18 | 0.04 | 0.22 |
| Hawai'i | 196 | 29 | 428.0 | 0.46 | 0.07 | 0.53 |
| **TOTAL** | **495** | **103** | **1143.5** | **0.43** | **0.09** | **0.52** |

Note: General coastline measurements for the Main Hawaiian Islands are taken from Armstrong and Bier (1973). Necker and Nihoa coastlines were measured on 1:20,000 scale nautical charts with the aid of a digitising tablet and measurement software.

The changing goals of Hawaiian archaeologists over the last four decades suggest that two contradictory temporal investigation biases can be distinguished, although these biases are probably less severe than they are in regions where periods are clearly marked by index fossils. During the Traditional Excavation period (1950–1966), archaeologists emphasised the excavation of sites believed to belong to the earliest culture of Hawai'i (Kirch 1985; Dye 1989: 15–17) and thus, to the extent that they were successful, probably produced a sample of age determinations biased toward relatively early dates. The Empirical Excavation period (1966–present) is closely linked to the practice of settlement pattern archaeology in Hawai'i which, with its emphasis on surface survey and determining the function of surface features through excavation, has probably produced a bias toward the collection of relatively late dates. Fifty-four (11%) of the B.P. age determinations are from the Traditional Excavation period and 441 (89%) are from the Empirical Excavation period.

The effect of investigation biases in one or both periods is suggested by the fact that the 'average' $^{14}C$ age of a B.P. age determination collected during the Traditional Excavation period is about 1.5 times older than a comparable sample from the Empirical Excavation period (Fig. 2). Without independent information on the age distribution of the archaeological carbon deposit it is difficult to decide if this difference is due to investigation bias in one or both periods. The fact that potential investigation biases from one period offset those from the other suggests, however, that their combined effect will be small.

These data support the hypothesis that the effects of supplementary uncertainty from differences in the treatment of sample composition factors and preservation and investigation biases are small. Below, the results of the analysis are used in an ad hoc assessment of supplementary uncertainty.

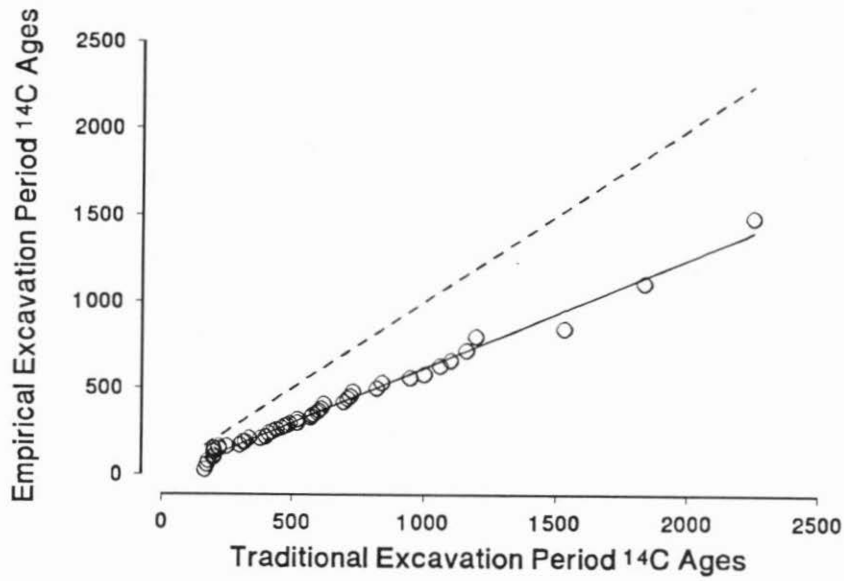


*Figure 2:* Empirical quantile/quantile plot of $^{14}C$ ages from the Traditional Excavation period (1950–1966) and the Empirical Excavation period (1966–present). The solid regression line ($y = -24.74 + 0.65x$) fits the points very closely ($r^2 = 0.99$) and very nearly intersects the origin. This suggests that the distributions of $^{14}C$ ages from the two periods are similar in shape, but differ by a multiplicative constant. The dashed line ($x=y$) indicates the regression line that would result if $^{14}C$ ages from the two periods were equal. Chambers *et al.* (1983: 48 ff.) describe the construction and interpretation of empirical quantile/quantile plots.

## RESULTS

A line graph of the annual frequency distribution (Dye and Komori, this volume) was constructed from the 598 $^{14}C$ dates in the sample (Fig. 3). Gaussian curves were constructed for the 103 modern dates with the computer program UNCALIB. The 495 B.P. dates were calibrated with the computer program CALIB. The resulting Gaussian and relative probability distributions were summed with the computer program SUM$^{14}$C. The annual frequency distribution of these data yields values between 0.0071 and 0.8952 for the interval A.D. 1 to 1832, with a mean of 0.2371. Sample densities are converted to absolute population estimates (Fig. 3, heavy line) by setting the sample density of 0.7144 at the census year 1832 to 130,313, the largest figure reported for the census.

The first order annual frequency distribution is sigmoidal, though second order deviations from the sigmoid grow steadily after A.D. 1100 and are marked after A.D. 1600. Three first order regions of the estimated population curve can be distinguished: an initial period of small, fluctuating populations to A.D. 1150; a rapid increase to A.D. 1441 that corresponds to the 'take-off' portion of a logistic curve; and a final four centuries of no growth marked by episodes of rapid decline and partial recovery. Estimated populations range from a low

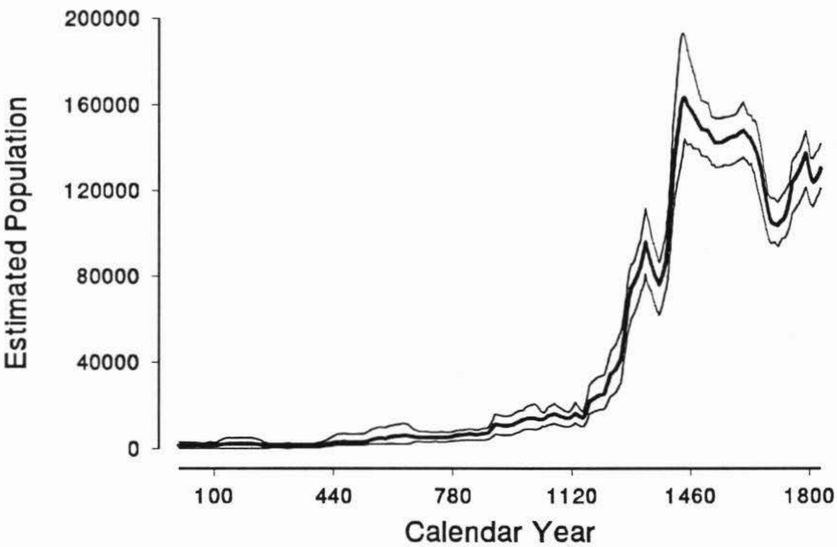


*Figure 3:* An estimate of the pre-censal population history of Hawai'i, A.D. 1–1832. The estimate is shown with 95% confidence intervals. Y-axis values are based on an 1832 population of 130,313.

in A.D. 332 of 1,295 with a 95 percent confidence interval of 365–2,280, to a high in A.D. 1441 of 163,293 (141,787–192,606). The estimated population at the time of Cook's visit in 1778 is 132,338 (116,797–141,750).

Annual rates of increase, calculated with the formula $r=(P_{y+1}-P_y)/P_y$ where $P$ is population size and $y$ is calendar year, vary from −2.53% to 2.75% and average 0.25% over the entire period. If the summary period ends in A.D. 1778 and the date of initial settlement is assumed to be A.D. 400, rather than A.D. 1, then the mean annual rate of increase is 0.32%, with a range of −1.1% to 2.75%.

## AD HOC ASSESSMENT OF THE EFFECTS OF SUPPLEMENTARY UNCERTAINTY

Ideally, the combined effects of internal and supplementary uncertainty are estimated, but this is rarely possible in practice, especially in non-experimental situations. Evidence presented above led to the hypothesis that the effects of supplementary uncertainty are relatively small, so that internal uncertainty, as measured by bootstrap confidence intervals, provides a reasonable estimate of the total uncertainty in the estimates. Nevertheless, it is best to guard against unexpected effects. Two ad hoc assessments of supplementary uncertainty are made. Estimated population sizes are compared with inferences about the size of the initial population based on studies of Polynesian voyaging capabilities, and estimated growth rates are compared with rates estimated for other parts of the world over the same period of time. Unfortunately, comparable data are not available for other Pacific Islands, where palaeodemographic data have so far yielded spurious values (e.g., Brewis *et al.* 1990: 352) and estimates based on size of contact period population require assumptions not only on the size of the founding population and date of initial settlement, but on the population growth function as well. Since there is no guarantee that either growth rate estimates for other parts of the world or inferences on the size of the founding population are correct, the object of the ad hoc assessments is to determine if our estimated population parameters fall within ranges considered reasonable by population scholars.

Population estimates for the period of initial settlement, *c.* A.D. 1–400, vary from 1,295 to 2,280, thus greatly exceeding the few tens or hundreds of people often estimated to comprise the founding population (e.g., Earle 1978: 162; Kirch 1985: 286; Stannard 1989). The lower 95 percent confidence interval for this period ranges from 109 to 584, with a mean of 248, so conventional estimates are not excluded. Recent experiments suggest that Polynesian exploratory voyaging techniques were fully capable of prospecting for islands over distances as great as the 4,000 km from the central eastern Polynesian homeland to Hawai'i (Irwin 1989; Irwin *et al.* 1990), and thus that initial colonisation of Hawai'i might have involved many more people than has been conventionally estimated. A central feature of a successful exploratory voyaging strategy would have been the ability to return home at the end of a voyage, whether or not the voyage resulted in the discovery of new lands. This return voyage presumably provided an opportunity to confirm observations made on the initial voyage of discovery and to fix the paths of sea routes between the homeland and newly discovered islands. Handy and Handy cite traditional Hawaiian accounts of first settlement as evidence for such a process of deliberate colonisation (Handy and Handy 1972: 267).

The estimated average rate of growth for the prehistoric period is 0.32% per annum, which is quite a bit lower than the rates of 0.63% deduced by Schmitt and Zane (1977), 0.64% assumed by Hommon (1976, 1980), and 0.52% adduced by Stannard (1989). These latter rates are low compared to the growth rates of most modern nations, a fact that helped Stannard label them conservative (1989: 33 ff.). On the face of it, this makes our estimates seem unreasonably low. However, annual growth rates of 0.5% or 0.6% are higher than pre-modern growth rate estimates for most regions of the world (Table 3). Excluding the period A.D. 14–350, when Hawai'i might not have been settled, the estimated average annual rate of increase for Hawai'i is greater than the estimated world average in 7 of 11 periods, falling below it only after population estimates peak in A.D. 1441. In the four periods ending A.D. 600, 1000, 1340, and 1500, Hawai'i's estimated population grew faster than any of the 16 regions for which estimates are available. Thus, while it is likely that subregions of the regions in Table 3 grew faster than Hawai'i at various times (cf. Grigg 1980: 51 ff.), it is still possible to argue, as Stannard has for a postulated average annual growth rate of 0.52%, that these modest estimated growth rates reflect the behaviour of a population growing in an "extremely healthful environment" (Stannard 1989: 36 ff.).

These ad hoc assessments show that estimated population parameters fall within reasonable ranges. Previous estimates of the size of the founding population, which may require upward revision on the basis of Irwin's recent voyaging experiments, nevertheless fall within the lower 95 percent confidence intervals of our estimates. Comparison of estimated growth rates with 16 regions of the world shows that Hawai'i's population was capable of relatively rapid growth, but was otherwise unexceptional. These assessments strengthen the hypothesis that supplementary uncertainty contributes little to the overall uncertainty of the population estimates.

TABLE 3

ESTIMATED POPULATION GROWTH RATES[§] IN HAWAI'I AND AROUND THE WORLD, A.D. 14–1800

| Date | Sixteen Regions[†] | | | | |
|---|---|---|---|---|---|
| A.D. | Minimum | Maximum | Mean | World | Hawai'i |
| 14–350 | -0.31 | 0.15 | -0.02 | 0.00 | -0.02 |
| 600 | -0.21 | 0.39 | -0.03 | -0.03 | 0.52 |
| 800 | 0.00 | 0.38 | 0.11 | 0.05 | 0.09 |
| 1000 | -0.11 | 0.28 | 0.07 | 0.03 | 0.41 |
| 1200 | -0.20 | 0.36 | 0.10 | 0.16 | 0.28 |
| 1340 | -0.49 | 0.65 | 0.14 | -0.01 | 0.93 |
| 1500 | -0.39 | 0.30 | -0.03 | 0.08 | 0.32 |
| 1600 | -1.00 | 0.50 | 0.06 | 0.15 | -0.01 |
| 1650 | -0.80 | 0.80 | 0.07 | 0.07 | -0.14 |
| 1700 | 0.00 | 0.80 | 0.28 | 0.43 | -0.55 |
| 1750 | 0.00 | 0.69 | 0.25 | 0.26 | 0.35 |
| 1800 | -0.10 | 1.00 | 0.36 | 0.39 | 0.08 |

[§] Average annual rate of increase in % since preceding date.

[†] Regional and world population growth rates derived from Clark (1967). The sixteen regions include Egypt, China, India, Japan, Asia Minor (including Syria and Cyprus), Other South West Asia, Asian U.S.S.R., Other East Asia, South West Europe (Spain and Portugal), British Isles (England, Wales, Scotland, and Ireland), North West Europe (France, Belgium, Netherlands), Italy, South East Europe (including Greece), Northern Europe (Scandinavia, Germany [excl. Eastern Provinces], and Austria), East Europe (Russia in Europe, Poland, Czechoslovakia, etc. and Hungary), and America.

## DISCUSSION

To the extent that the annual frequency distribution is isomorphic with population growth, the population peak in the fifteenth century and subsequent cessation of long term growth support the conclusions of Hommon and Kirch, based on equivocal data, that the archipelagic population growth curve was sigmoidal (Hommon 1976; Kirch 1984). However, the decline of population growth rates was not necessarily density dependent. On the basis of a sigmoidal population curve for West Hawai'i whose peak population was reached in the latter half of the seventeenth century, Kirch argued that density dependent population control mechanisms, such as infanticide, celibacy, abortion, *coitus interruptus*, sea-voyaging, and war might have tempered population growth in Hawai'i (Kirch 1985). Such an explanation, whose reliance on presumed pressures on food supplies and "limitations of agricultural land" (Kirch 1985: 287) is difficult to reconcile with Handy and Handy's and Yen's assertions that the agricultural resources of Hawai'i were not fully developed (Handy and Handy 1972; Yen 1973), requires modification if it is to be plausibly applied to the present estimates, which reach a maximum some two centuries earlier. Here an argument for density dependent population growth might contend that population grew too rapidly in the fourteenth and early fifteenth centuries for agricultural development to keep pace, and that evidence for the intensification of production that is a "hallmark" of the sixteenth and first half of the seventeenth centuries (Kirch 1985: 305), was an effort to create a stable productive base for an essentially static population. Other density dependent arguments are, of course, possible and worth exploring. But in our view the population estimates developed here enhance the plausibility of density independent explanations for culture change in Hawai'i.

A density independent hypothesis of Hawaiian cultural change was offered by Earle, who proposed that agricultural intensification was an "outcome of political competition and *not* of population pressure" (Earle 1978: 183; emphasis in original). In Earle's view, which builds on Goldman's (1970) interpretation of the importance of status rivalry in the development of social stratification in Polynesia, "agricultural intensification was a strategy to increase *local* population as a means to increase surplus production" (Earle 1978: 183; emphasis added). This hypothesis accounts neatly for the intensification of agricultural production and of warfare (Hommon 1976: 279–280, 315–331) during a period of net population stasis. More detailed tests of the density independent hypothesis, in particular the investigation of local population changes in a regional context, might be possible in a few years given the rapid growth of the $^{14}$C database.

To the extent that the bootstrap confidence intervals encompass the total uncertainty of our population estimates, questions about absolute numbers of people in the pre-censal period have been answered. The maximum population estimate of 163,293 (141,787–192,606) at A.D. 1441 and the estimated A.D. 1778 population of 132,338 (116,797–141,750) are both less than half the size of King's estimate of 400,000 for the A.D. 1778 population, and between a quarter and a fifth the size of Stannard's (1989) hypothesis of 800,000 to 1,000,000. This supports the conclusions of generations of scholars, culminating with Schmitt (1971), that King's estimates were too high. The maximum population estimate, the sigmoidal annual frequency distribution, and the estimated annual growth rates all count against Stannard's hypothesis, which must now be seen as highly improbable. Estimates of a contact era population between 200,000 and 300,000 were not motivated by a desire to keep Hawaiians from knowing their past, as Stannard imagines. Given the data presented here, the humdrum hypothesis that population scholars were motivated by an interest in knowing and sharing knowledge of the past seems most plausible.

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