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Long-term rhythms in the development of Hawaiian social stratification

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A R T I C L E I N F O

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A B S T R A C T

The tempo plot, a statistical graphic designed for the archaeological study of rhythms of the long term that embodies a theory of archaeological evidence for the occurrence of events, is introduced. The graphic summarizes the tempo of change in the occurrence of archaeological events using the model states generated by the Markov Chain Monte Carlo routine at the heart of Bayesian calibration software. Tempo plots are applied to the archaeological record of Hawai'i to expose rhythms of i) *tradition* in taro pond-field construction, ii) *innovation* in temple construction, and iii) *fashion* in the harvest of branch coral for use as a religious offering. Rhythms of the long term identify a hitherto unrecognized transformation of religious practice in Hawai'i, establish temporal coincidence in temple construction in leeward sections of Maui and Hawai'i Islands previously described as regionally idiosyncratic, suggest shallow temporal limits to the use of the direct historical approach in Hawai'i, and disclose processes at work in the political economy recorded at the time of western Contact.

1. Introduction

Many of the rhythms of life in contact-era Hawai'i are well known. The cyclical rhythms imposed by nature—the daily routine and the seasonal round—and those imposed by society as status transformations through the life cycle are recorded in Hawaiian traditions and imprinted on modern practices (Chun, 2011; Malo, 1996; Pukui et al., 2001; Handy and Pukui, 1972). Less well known are rhythms of the long term, the working out of multi-generational projects of labor and innovation whose details typically fall outside the scope of Hawaiian traditional accounts, but whose remains characterize the archaeological record of Hawai'i. Like their shorter-term counterparts, rhythms of the long term can reflect cyclical processes or instead be linear, a rhythm theorized to reflect processes of inter-group alliance (Lefebvre, 2004). The study of rhythms of the long term in Hawai'i thus complements the long-standing anthropological investigation into the development of Hawaiian social complexity, which arguably created "states" or "archaic states" prior to the advent of sustained Western contact in CE 1778 (Hommon, 2013, 1976; Kirch, 2010a).

Three factors have slowed archaeological study of rhythms of the long term in Hawai'i. Foremost among these is Hawaiian archaeology's struggle to establish accurate and precise chronology (Dye, 2015), which is slowly being resolved by more frequent application of chronometric hygiene (Dye, 2000; Spriggs and Anderson, 1993) and Bayesian calibration (Athens et al., 2014; Dye, 2011). A second factor, closely related to the first, is an inclination among Hawaiian archaeologists faced with an uncertain and changing chronology to privilege social scientific explanations over historical ones (Trigger, 1989). Recent book-length treatments of social stratification in Hawai'i that take a social scientific stance posit universal cultural traits, then illustrate them with interpretations of a selective body of oral traditions kept by the Kamehameha dynasty, which ruled a unified Hawaiian kingdom through most of the nineteenth century (Hommon, 2013; Kirch, 2010b). A third factor has to do with the limited tools available to archaeologists who wish to measure rhythms of the long term. The "mainstay of time-series analysis of archaeological trends" (Williams, 2012, 578) is the summed calibrated probability distribution (SCPD). Archaeological practice has shown that interpretation of an SCPD is complicated by several factors: i) there are different ways to construct an SCPD that yield different results (Weninger et al., 2011); ii) their formal statistical meaning is the probability of the data of one of the events chosen at random, rather than the probability of the event itself; iii) as typically constructed, an SCPD lacks an estimate of uncertainty (cf. Steele, 2010); iv) much of the structure is due to the ^{14}C calibration curve; v) very

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large sample sizes are needed to detect changing frequencies of events, assuming a Poisson distribution of counts; and vi) the SCPD, as it is typically constructed, works directly with the dated events and not with target events of interest (Bayliss et al., 2007; Chiverrell et al., 2011; Culleton, 2008; Wood, 2015). These factors have contributed to recommendations that SCPD's be used in concert with other measures to check for errors and guide interpretation (e.g., Williams, 2012).

This paper describes the tempo plot, a statistical graphic designed for the archaeological study of rhythms of the long term. A tempo plot summarizes the joint posterior distribution of events specified in a chronological model using output from the Markov Chain Monte Carlo (MCMC) routine at the heart of Bayesian calibration software. It is applied to four chronological data sets from Hawai'i that have been calibrated with chronological models that distinguish dated, reference, and target events (Dean, 1978). Three distinct trajectories are identified in the resulting tempo plots and, as described below, these are interpreted as representing tradition, innovation, and fashion. Together, the tempo plots measure with archaeological materials rhythms of long term history in Hawai'i. They identify a hitherto unrecognized transformation of religious practice, establish temporal coincidence in temple construction in leeward sections of Maui and Hawai'i Islands, suggest temporal limits to the use of the direct historical approach in Hawaiian archaeology, and expose developmental processes in the political economy recorded at the time of western Contact.

2. Methods and materials

The tempo plot makes use of the raw data produced by the MCMC procedure at the heart of Bayesian calibration software, which repeatedly generates parameter values that satisfy the constraints specified by a chronological model. The chronological model sets out what is known about the relative ages of dated, reference, and target events (Dean, 1978). This information is typically drawn from stratigraphic observations, but the model is general and information on relative ages can come from any source, including expert opinion, interpretations of oral traditions, etc. The model-building step is important for the tempo plot because the events it intends to summarize must all be specified in the chronological model.

Each call to the MCMC routine produces a set of values that represent one valid instance of the chronological model. In the course of a typical calibration, the MCMC routine produces several hundred thousand of these valid instances, which in the case of a successful calibration might be thought of as having explored the state space of the chronological model. The marginal posterior for an individual event summarizes the several hundred thousand values assigned to it by the MCMC routine during the calibration process. A histogram of these values yields the calibrated age graphic familiar to archaeologists and produced by all of the calibration software applications. In addition to this standard graphic, calibration software applications also provide ways to investigate the joint distributions of two events, either by estimating the hiatus between them or by calculating the probability that one is older than the other. In these cases, the software compares the several hundred thousand values assigned to the two values by the MCMC routine to calculate the appropriate statistic. When more than two events are of interest, then some applications will calculate an SCPD, which yields a rather poor estimate of event density. However, for practical reasons, the software applications do not provide general sets of tools with which to investigate joint posteriors. Access to the raw MCMC values is needed for these more specialized analyses.

For many years, the Bayesian calibration software applications popular among archaeologists used the MCMC results internally, but did not report them. This meant that it was effectively impossible to carry out specialized analyses of three or more joint posteriors. In 2009, the OxCal software package added a function, MCMC_sample, to write out raw MCMC values, and a similar facility was added to the BCal software (Buck et al., 1999) sometime later. Raw MCMC values can also be accessed with the open-source Chronomodel application (Lanos et al., 2015). These developments make it possible to investigate arbitrarily complex relations among events specified in a chronological model.

The tempo plot is one example of a tool designed to investigate the joint posteriors of multiple events in a chronological model (see Steele, 2010, for a use of raw MCMC output to estimate event density). For each instance generated by the MCMC routine, the tempo plot calculates the cumulative frequency of specified events by calculating how many events took place before each date in a specified range of dates. The results for each date are then summarized by finding the mean and standard deviation. The tempo plot is constructed by plotting three lines, one connecting the means for each date to show the central tendency of the tempo, and two others connecting the standard deviations younger and older than the mean to indicate the dispersion of the data. An R software routine for calculating the joint posteriors for a tempo plot using the raw MCMC output from OxCal is presented in the Supporting Information.

Tempo plots are calculated and constructed for four chronological data sets from Hawai'i, including i) estimates of 16 taro pond-field construction events on Moloka'i, O'ahu, and Hawai'i based on ^{14}C dates; ii) estimates of 11 temple construction dates in the rain-fed agricultural region of Kohala, Hawai'i based on ^{14}C dates; iii) estimates of 11 temple construction dates in the rain-fed agricultural region of Kahikinui, Maui based on ^{230}Th dates; and iv) estimates of 46 branch coral harvest events at Kahikinui, Maui based on ^{230}Th dates (see Fig. 1).

2.1. Taro pond-field construction events

Taro (*Colocasia esculenta*), a Hawaiian staple native to India and mainland Southeast Asia and possibly domesticated in the western Pacific (Coates et al., 1988), was widely cultivated in pond-fields in Hawai'i (Ladefoged et al., 2010). Irrigated facilities for taro production are found throughout the Pacific, where they contrast with rain-fed cultivation of crops such as yams and sweet potatoes (Barrau, 1965; Kirch, 1994; Spriggs et al., 2012). In Hawai'i, the pond-field system has been characterized as "a set of artificially leveled planting surfaces designed to impound water, sharing a single water source, and forming a hydraulic unit for the purposes of irrigation" (Kirch, 1977, 252). Individual pond-fields are located in intermittent stream beds, on taluvial slopes, and most commonly on alluvial terraces where they impound water with an earthen bund typically faced with a veneer of stones (Earle, 1980; Kirch, 1977; Ladefoged et al., 2010).

Archaeologists in Hawai'i have dated materials with which to estimate the construction dates of 16 taro pond-fields on three islands. In each case, the dated material was collected from a context beneath the base of the pond-field bund facing. Thus, the reference event, which is deposition of the dated material at the collection location, has a disjunct association with the target event, which is construction of the pond-field bund. A disjunct association ensures that the hiatus between the dated event and reference event—the in-built age that is always present (Waterbolk, 1971)—lacks the potential to confound the relationship between reference and target events (Fig. 2).

The first project to collect dating material in disjunct association with the pond-field construction event recovered and dated a piece