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Long-term rhythms in the development of Hawaiian social stratification

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ABSTRACT

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

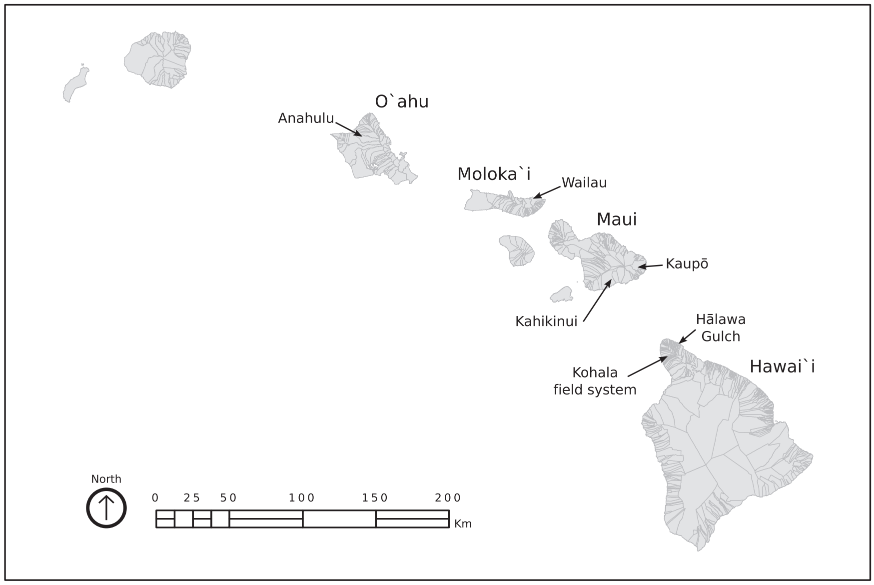

Fig. 1. The Hawaiian Islands, showing territorial divisions of the islands and places mentioned in the text.

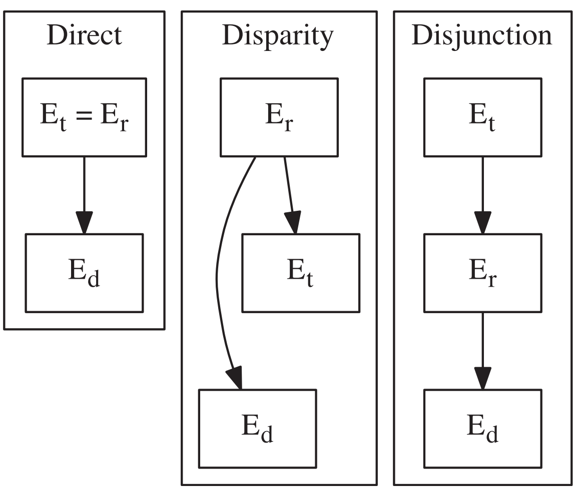

Fig. 2. Associations and discontinuities in archaeological dating identified by Dean (1978). Arrows point from a younger event to an older event. E_t = target event; E_r = reference event; E_d = dated event. Note that direct, disparate, and disjunct associations are distinguished by the relationship of the reference and target events. The dated event is drawn lower than the target event for the disparate association to emphasize the possibility that temporal relationships might be confounded due to in-built age and residuality.

of unidentified charcoal from alluvium underlying a pond-field soil exposed in a stream cut in Anahulu Valley, O‘ahu (Spriggs and Kirch, 1992, 123). The strategy of isolating charcoal stratigraphically inferior to a pond-field was later applied routinely at Wailau Valley, Moloka‘i (McElroy, 2012) and in Hālawa Gulch on Hawai‘i Island (McCoy et al., 2013) where excavations adjacent to pond-field bunds took care to collect materials from beneath a basal facing stone of the bund and identified short-lived materials for dating.

The chronological model used to estimate the age of the pond-field construction event in each case establishes a dry phase that pre-dates construction of the pond-field (Supporting Information). The dry phase is defined by an early boundary, α_{dry}, and a late boundary, β_{dry}, from which one or more ^{14}C dates were determined on materials collected below the pond-field, Θ_{dry}. In addition, β_{dry} is constrained to be later than the date Polynesians discovered and settled Hawai‘i (Athens et al., 2014). The chronological model can be expressed algebraically as follows:

$$\alpha_{pre} > \Theta_{pre} > \beta_{pre} = \alpha_{post} > \Theta_{post} > \beta_{post} \quad (1)$$

$$\alpha_{dry} > \Theta_{dry} > \beta_{dry} \quad (2)$$

$$\beta_{pre} > \beta_{dry} \quad (3)$$

where: i) α_{pre} and β_{pre} are the early and late boundaries of the pre-Polynesian phase, respectively; ii) Θ_{pre} represents the true ages of the reference events for ^{14}C dates confidently assigned to the pre-discovery phase, which in each case is deposition of the dated material; iii) α_{post} and β_{post} are the early and late boundaries of the post-discovery phase, respectively; iv) Θ_{post} represents the true ages of the reference events for ^{14}C dates confidently assigned to the post-discovery phase, which in each case is deposition of the dated material; v) $>$ means “is older than”; and vi) β_{pre} and α_{post} represent the date of Polynesian discovery.

The best estimates for the pond-field construction dates are the marginal posterior densities for β_{dry} (Fig. 3).

2.2. Temple construction events

Two recent investigations provide data on the tempo of temple construction in leeward locations where rain-fed cultivation of sweet potatoes was the dominant crop.

Excavations at eleven temples in the leeward Kohala field system collected short-lived wood charcoal from contexts beneath the basal stones of the temple structures (McCoy et al., 2011). Here, the reference event, which is deposition of the dated material at its collection location, is in disjunct association with the target event, which is construction of the temple’s stone architectural elements. The ^{14}C dates were subsequently calibrated with a chronological model similar to the one used for the taro pond-field construction events, which considers the reference event in each case to be a *terminus post quem* for temple construction (Dye, 2012). Like the construction of taro pond-fields, the temple construction events are constrained to be later than Polynesian discovery of Hawai‘i, but

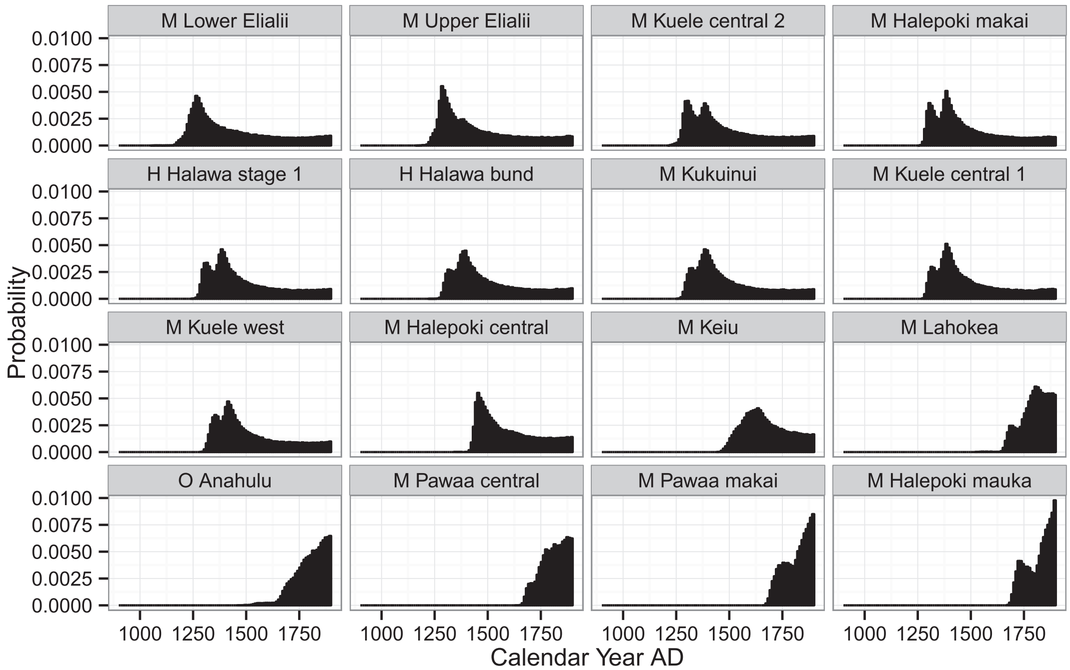

Fig. 3. Construction date estimates for 16 taro pond-fields on Moloka'i (M), O'ahu (O), and Hawai'i (H) Islands.

in this case there is the additional constraint that the temple must have been built before the overthrow of the traditional Hawaiian religion in 1819 (Kamakau, 1992, 219–228). This chronological model uses (1) and

$$\alpha_{pre-lkfs} > \Theta_{pre-lkfs} > \beta_{pre-lkfs} > \text{AD } 1819 \quad (4)$$

$$\beta_{pre} > \beta_{pre-lkfs} \quad (5)$$

where: i) $\alpha_{pre-lkfs}$ and $\beta_{pre-lkfs}$ are the beginning and end of the pre-construction phase; and ii) $\Theta_{pre-lkfs}$ are the calendar ages of the ^{14}C date reference events, which in each case is deposition of the dated material. In this model, the best estimate of the temple construction date is $\beta_{pre-lkfs}$ (Supporting Information). The Bayesian calibration yields construction date estimates ranging from the early sixteenth to the early nineteenth century (Fig. 4).

The second project, in the dry Kahikinui lands on Maui Island, collected and dated pieces of branch coral from architectural fill contexts at 11 temples identified by the excavator as "architecturally integral" (Kirch et al., 2015). Here, there is a direct association between the reference event and the target event, which in both cases is construction of the architectural element from which the dated branch coral was collected. The branch coral pieces were dated with the ^{230}Th method, which yields precise age determinations with typical errors of less than a decade. A Bayesian model designed to estimate temple construction dates in Kahikinui is slightly different than the one used to calibrate the ^{14}C dates from beneath the temples in the leeward Kohala field system (Supporting Information). Because the branch coral pieces were harvested, they must all be younger than the colonization event. The model includes (1) and

$$\alpha_{pre-kahikinui} > \Theta_{pre-kahikinui} > \beta_{pre-kahikinui} > \text{AD } 1819 \quad (6)$$

$$\beta_{pre} > \alpha_{pre-kahikinui} \quad (7)$$

where: i) $\alpha_{pre-kahikinui}$ and $\beta_{pre-kahikinui}$ are the beginning and end of the pre-construction phase; and ii) $\Theta_{pre-kahikinui}$ are the calendar ages of the ^{230}Th dated reference events, which in each case is deposition of the branch coral. In this model, the best estimate of the temple construction date is $\beta_{pre-kahikinui}$. The Bayesian calibration yields estimates that start in the mid-sixteenth century and run to the early nineteenth century (Fig. 5).

2.3. Branch coral harvest events

Forty-six ^{230}Th dates on branch coral pieces chosen for dating to minimize the hiatus between coral death and harvest (Fig. 6) have been reported for Maui Island (Kirch et al., 2015, Table 1). The dates provide a high resolution record of branch coral harvest associated with ritual offerings on temples from Kahikinui and Kaupō districts of Maui Island (Supporting Information). The dates range from CE 1099 ± 8 to CE 1794 ± 4, with most falling between the mid-sixteenth to seventeenth centuries.

3. Results

Tempo plots for the pond-field construction events, coral harvests, and temple construction events at the leeward Kohala field system and Kahikinui are shown in Fig. 7. The tempo plot indicates that pond-field construction began early and that new pond-fields were added steadily well into the historic period. In contrast, branch coral harvest on Maui starts early, is practiced frequently from CE 1550 to 1700, and then declines. The sigmoidal shape of the branch coral harvest tempo plot contrasts strongly with the linear shape of pond-field construction tempo plot. Finally, construction of temple foundations in the leeward Kohala field system and at Kahikinui starts late—after sweet potato was introduced to Eastern Polynesia from South America (Green, 2005; Yen, 1974), transferred to Hawai'i sometime before CE 1290–1430 (Ladefoged et al., 2005), and procedures for its optimal production were developed (Kagawa and Vitousek, 2012)—and expands rapidly until the overthrow of the traditional religion in 1819, when temple construction stopped throughout the islands.

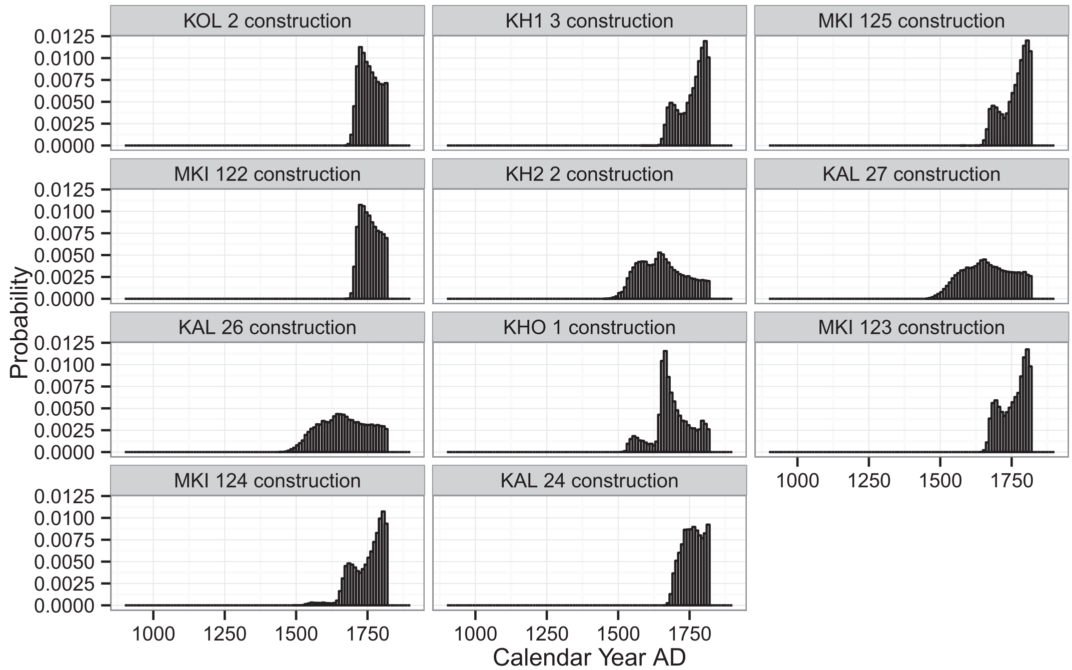

Fig. 4. Construction date estimates for 11 temples in the leeward Kohala field system. *Source*:Dye (2012, 1204).

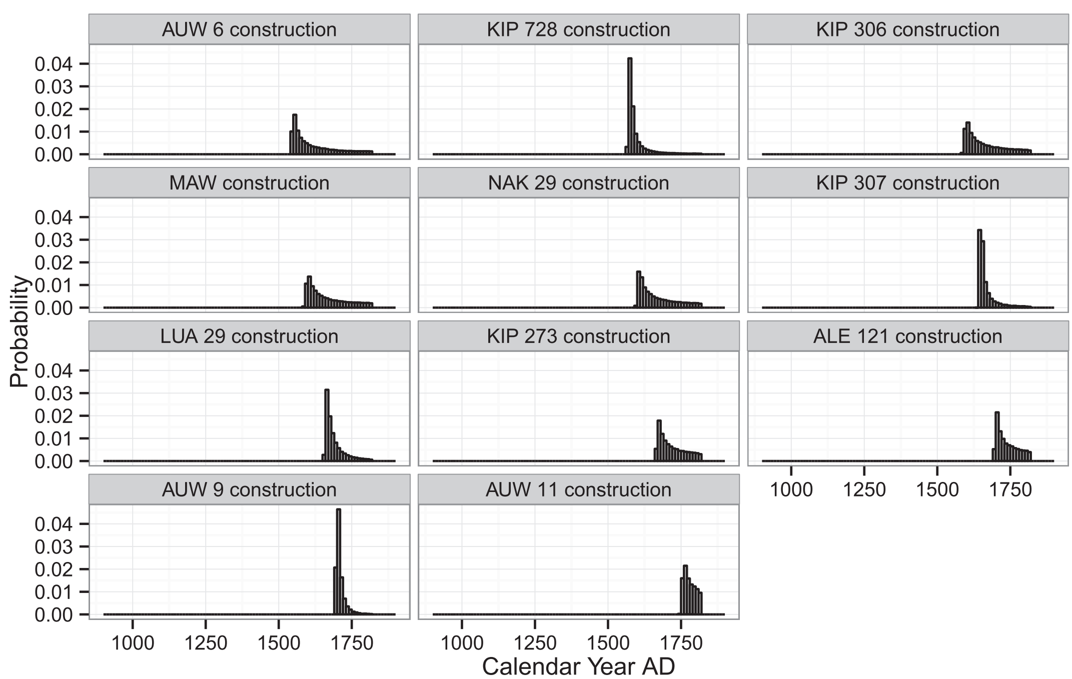

Fig. 5. Construction date estimates for 11 Kahikinui temples.

Uncertainty in the estimates shown in Fig. 7 is directly tied to sample size and to the underlying uncertainty of the age determinations. This can be seen most clearly in the tempo plot of branch coral harvest, which summarizes 46 event estimates with standard deviations mostly less than 10 years. The irregular shape of the tempo plot of the Kahikinui temple foundations compared to the smooth tempo plot of the leeward Kohala temple foundations is due to the relative precision of the ^{230}Th dates from Kahikinui.

4. Discussion

The tempo plot was designed to contribute to an historical interpretation of the Hawaiian archaeological past. Like the historic turn in the human sciences that developed in response to the universalizing goals of social scientific research (McDonald, 1996, 1), historicism in Hawaiian archaeology is developing in response to the neo-evolutionary approach that has dominated Hawaiian

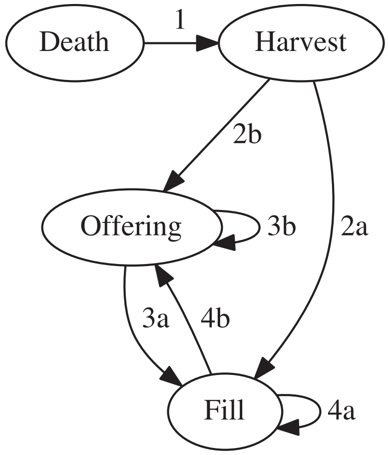

Fig. 6. A model of potential discontinuities in the process by which branch coral is introduced to the archaeological record. The nodes indicate events starting with the death of the branch coral, through its harvest, and deposition at a temple, either as an offering or a component of the architectural fill. The numbered arcs represent potential hiatuses in the process. See the text for a full discussion.

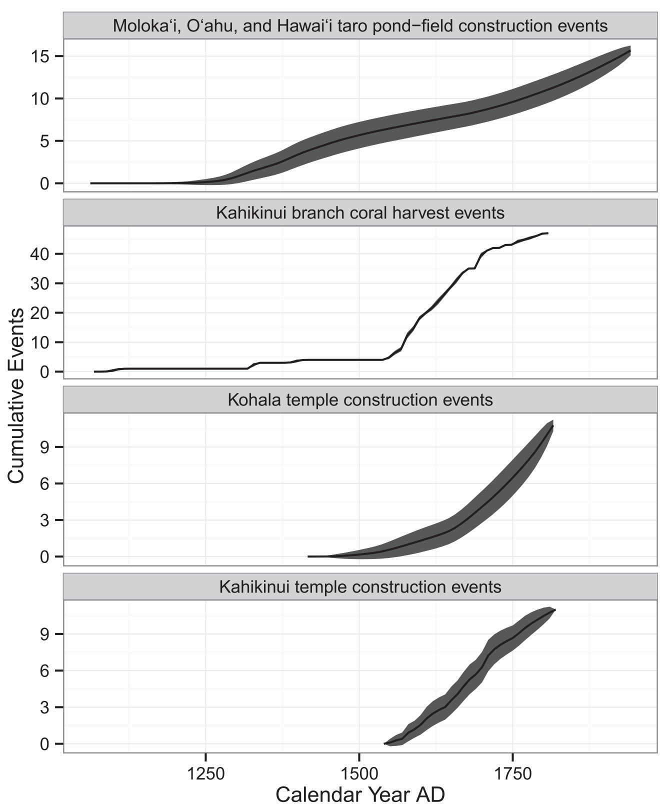

Fig. 7. Tempo plots of pond-field construction, temple construction at Kahikinui and the leeward Kohala field system, and coral harvest events plotted with 1 s.d. confidence intervals.

archaeology since the rise of the New Archaeology in the 1960’s and 1970’s (Trigger, 1989). The tempo plot is designed to encourage the acquisition and interpretation of fine-grained chronologies of change as an antidote to the fuzzy archaeological chronologies produced by the neo-evolutionists, a circumstance that has arguably led to over-interpretation of traditional historical accounts (Dye, 2014).

Central to the tempo plot is the event, which is specified precisely with a Bayesian chronological model. The event has been widely disparaged in social scientific research as idiographic or unimportant, but historicism’s local scope and embrace of contingency has renewed interest in the analysis and interpretation of events. There are two main lines of event-based research. Historical sociologists have a long history of compiling and interpreting event catalogs to explain social change during times of unrest (Tilly, 2008, 46–54). More recently in anthropology, Marshall Sahlins has theorized the event as the unit of practice responsible for generating social change, using historical case studies from Hawai‘i and Fiji (Sahlins, 1981, 1985, 1991). Sahlins’ ideas have been elaborated by the political scientist William H. Sewell, Jr (Sewell, 2005) and this analytic framework is being explored by archaeologists, most of whom are interested in how material events articulate with the ideal notion of structure at the center of Sahlins’ and Sewell’s work (Beck Jr. et al., 2007; Bolender, 2010). In contrast to these studies, which theorize the role of events in particular pasts, the tempo plot embodies a theory of the evidence, based on the distinctions among dated, reference, and target events (Dean, 1978).

Application of the tempo plot to Hawaiian archaeological data has implications for previous research results and presents an opportunity for an interpretation of the long-term rhythms of Hawaiian history.

4.1. *Implications for previous research*

The theory of the evidence embodied in the tempo plot is important because dating evidence is often misinterpreted in Hawaiian archaeology. For example, dates collected from beneath pond-field bunds have sometimes been interpreted as if they represent vegetation clearance immediately preceding construction (e.g., McElroy, 2012, 138), but all that can be said with confidence is that materials beneath the bund face are older than the pond-field construction event; the magnitude of the disjunction can’t be estimated confidently given the evidence. Nevertheless, the dates from the Wailau pond-field systems were calibrated absent the constraints of a stratigraphic model and the resulting age estimates—for the growth of plants in the region prior to pond-field construction—have been interpreted as estimates of construction events (e.g., Kirch, 2010a, 145). This tactic potentially yields age estimates for pond-field construction that are too old because there is no guarantee that dated materials are not much older than the construction event.

Similarly, the tempo plot for temple foundation construction in the leeward Kohala field system can be compared to an ad hoc interpretation of the dating evidence that postulated an early chronology that dated two construction events to CE 1474–1522, four to CE 1522–1647, four to CE 1647–1680, and one subsequent to CE 1680 (McCoy et al., 2011, 935–936). The conclusion that 10 of the 11 temple foundations were constructed before CE 1680 contrasts strongly with the tempo plot, which indicates 2–4 construction events by that time. The decline of temple construction postulated by the ad hoc chronology, in which only one temple was built between CE 1680 and 1819, is contraindicated by the tempo plot, which shows that the pace of temple construction quickened during this period.

The theory of the evidence embodied in the tempo plot has several implications for the chronology of temple construction at Kahikinui. The Kahikinui dating projects pioneered the ^{230}Th dating of branch coral from Hawaiian archaeological sites (Kirch and Sharp, 2005; Kirch et al., 2015). The lure of ^{230}Th dating is its precision; the standard deviation of age estimates is typically less than a decade and often less than five years. However, the interpretation of the initial ^{230}Th results by Kirch and Sharp (2005) was widely criticized because seven of the eight dated branch coral pieces were collected from surface contexts that post-date the temple construction event by an unknown interval (Dye, 2010; Kolb, 2006; Weisler et al., 2005).

Subsequently, another 40 ^{230}Th dates were processed, mostly from surface contexts but also including 18 from "architecturally integral" contexts in disjunct association with the construction event (Fig. 6). The model Kirch et al. (2015) use to interpret these dates stipulates that a long discontinuity between coral death and harvest (Fig. 6, hiatus 1) is implausible at Kahikinui where the high energy marine environment purportedly thins standing dead corals; this stipulation can be extended to low energy marine environments because dead coral becomes encrusted with algae fairly rapidly, and algae encrusted pieces would not be selected for ^{230}Th dating. Thus, the dating protocol for selecting pristine coral pieces ensures that a discontinuity between coral death and harvest is minimized. Kirch et al. (2015, 171) go on to argue that similarities in the age distributions of the surface and architecturally integral corals support a model in which discontinuities between the harvest event and deposit of the coral at the temple (Fig. 6, hiatuses 2a and 2b), discontinuities due to re-deposition of coral offerings (Fig. 6, hiatuses 3a and 3b), and discontinuities due to re-deposition of corals in fill material (Fig. 6, hiatuses 4a and 4b) are also negligible.

Kirch et al. (2015, 172–173) note that a model in which freshly harvested corals are deposited on or in newly-built temples does not fit the dating results from KOU temple where: i) a difference of nearly 300 years separates two architecturally integral coral pieces, indicating a discontinuity between coral harvest and deposition in the fill (Fig. 6, hiatuses 2a, 3a, and/or 4a); and ii) ages of surface corals range over 145 years, indicating a discontinuity between coral harvest and deposition of offerings (Fig. 6, hiatuses 2b, 3b, and/or 4b). The poor fit of data to model is treated as an exception that "demonstrates the complications that can arise with complex, monumental architecture on a site used over an extended time period" (Kirch et al., 2015, 173).

However, the KOU site is not the only exception to the model. Six of the nine other smaller temples from which multiple corals were dated yielded discontinuities. At the WF-AUW-359 and KIP-330 temples surface corals indicate discontinuities of about 75 and 125 years. At the AUW-9 temple, one of the architecturally integral dates is 20 years older than the other three, and at LUA-29 two architecturally integral corals that a site plan (Kirch et al., 2015, 173) shows were part of the smaller, southwest enclosure yielded dates about 45 years apart. These temples indicate discontinuities between coral harvest and deposition in the fill (Fig. 6, hiatuses 2a, 3a, and/or 4a). At the KIP-273 and KIP-306 temples, surface coral is 20–40 years older than architecturally integral coral (Fig. 6, hiatuses 2b, 3b, and/or 4b). In these smaller temples, discontinuities have cumulative effects ca. 20–125 years, an order of magnitude greater than the ^{230}Th measurement errors. If the KOU temple is not exceptional, then the cumulative effect of discontinuities is two orders of magnitude greater than the ^{230}Th measurement errors.

Evidence for "a major phase of temple construction in Kahikinui beginning ca. CE 1550 and continuing until ca. CE 1700" (Kirch et al., 2015, 166) is not apparent in Fig. 7, which indicates that temple construction began in the late sixteenth century and continued steadily through the seventeenth, eighteenth, and early nineteenth centuries. The purported surge in temple construction in the sixteenth and seventeenth centuries appears to be an artifact of an ad hoc method that ignores potential discontinuities in the processes by which branch coral is introduced to the archaeological record (Fig. 6) and that estimates construction events with disparate target events (Fig. 2). When a plausible theory of the evidence is applied, there is no credible evidence for a quickening tempo of temple construction associated with the rulers Pi‘ilani, Kiha-a-Pi‘ilani, and Kamalalawalu, whom tradition credits with unifying the districts of the island, a crucial step in state formation (Kirch et al., 2015, 174).

The theory of the evidence embodied by the tempo plot indicates that ^{230}Th dates on pieces of branch coral are, instead, associated with the coral harvest event, when the living or recently dead coral piece was broken off from the rest of the colony and removed from the sea. This association is interesting for several reasons. First, given that the dated corals were selected to minimize the effect of a discontinuity between coral death and harvest (Fig. 6, hiatus 1), and thus confidently date human activity, the oldest dated coral, KOU CS-5a, which yielded an estimate of CE 1099 ± 8, indicates that Polynesians were in Hawai‘i around the start of the 12th century, about a century earlier than a recent colonization date estimate (Wilmshurst et al., 2011). Second, at the other end of the distribution, the youngest branch coral date, KOU-CS-2, on a piece of coral collected from the surface of the KOU temple, yielded an age estimate of CE 1794 ± 4. This age estimate indicates that the practice of harvesting branch coral for deposition at temples continued to within about a generation of the overthrow of the traditional religion in 1819, albeit at a much reduced frequency and likely reduced importance. Third, the tempo plots indicate that the century and a half when branch coral harvesting was regularly practiced—from the mid sixteenth century to the turn of the eighteenth century—coincides with the early stages of temple expansion at Kahikinui and the leeward Kohala field system. Later stages in the process of temple expansion were carried out at a time when branch coral harvesting had declined. When Hawaiian traditions were recorded in the early nineteenth century, the practice of depositing branch coral as an offering within the temple was no longer remembered, but corals were still collected and placed outside the temple (Malo, 1996, 92, 256). This suggests that religious practice at the time when Pi‘ilani, Kiha-a-Pi‘ilani, and Kamalalawalu were unifying the island was one in which the harvest of branch coral offerings was important, but that this changed around the turn of the eighteenth century. Regardless of the precise nature of the transformation, which might be discovered through additional archaeological inquiry, the decline of branch coral harvest indicates a temporal limit to application of the direct historical approach to the interpretation of Hawaiian temples. In this case, the direct historical approach might be useful back to around the beginning of the eighteenth century, but is problematic for earlier times.

4.2. Long-term rhythms in Hawaiian history

Tempo plots for taro pond-field construction, harvest of branch coral, and temple construction in rain-fed agricultural regions take on three different patterns or shapes indicative of distinct rhythms of the long term. The tempo plot for taro pond-field construction starts early and rises steadily through the sequence. This shape is indicative of a *tradition* in much the same sense as this term was defined by American archaeologists in the 1950's, as "a (primarily) temporal continuity represented by persistent configurations in single technologies or other systems of related forms" (Willey and Phillips, 1958, 37). If taro pond-fields can be considered a single technology and the long-term practice of their construction a "persistent configuration," then the label can be seen to have a more or less consistent application from the culture-historical framework of the mid twentieth century through to the practice and event based framework advocated here. Persistence of the taro pond-field construction tradition implies an extension of cyclical rhythm in Hawaiian practice, where the impetus for pond-field construction arises at semi-regular intervals to create space for the cyclical production of taro at the center of Hawaiian practice.

Labeling this pattern a “tradition” fits well with Hawaiian traditional accounts, which give great value to taro cultivation and consider the plant a genealogical ancestor of the Hawaiian people.

In contrast to the steadily rising shape of the tempo plot for taro pond-field construction, branch coral harvest starts early, persists at a low level for several centuries, then rises sharply before becoming once again infrequent. The shape of this tempo plot is indicative of a *fashion*, a practice that comes into and then goes out of style. Plotted in a different way, the data on branch coral harvest would produce a battleship-shaped curve indicative of a stylistic, as opposed to a functional, trait (Dunnell, 1978). Because the relationship between an offering and its meaning in the ritual is essentially arbitrary, harvest of branch coral for use in temples is a prime candidate for a stylistic attribute in this evolutionary sense.

Finally, tempo plots for temple construction at Kahikinui and the leeward Kohala field system exemplify a third pattern. Both plots start late and rise strongly until CE 1819, when the traditional religion was overthrown and temple construction ceased. Their late start and consistent practice over brief spans are indicative of *innovations*, linear rhythms imposed on the more cyclical rhythms of local life. When Cook arrived in the late eighteenth century, temples were used by high status men to feast on pork, a food by that time denied to women and others (Kirch, 2001). Linear rhythms such as these are “determined by the forms of alliance that human groups give themselves” (Lefebvre, 2004, 100). In this case, similarities in tempo plots for temple construction on opposite sides of the ‘Alenuihaha channel reflect the quickening pace of marriage alliances between elite families of Hawai‘i and Maui (Graves et al., 2010) and a corresponding increase in demand for pigs that might be used in gift exchanges central to alliance creation and maintenance (Dye, 2014).

5. Conclusions

Tempo plots are a potentially useful tool for archaeologists interested in the time-series analysis of trends, and are easily constructed from the raw MCMC output of Bayesian calibration software. They provide a framework consisting of a chronological model, the established methodology of Bayesian calibration, and a simple descriptive statistical graphic that reveals the rhythm of events in the long term. The graphic appears able to distinguish at least three different rhythms. The cyclical rhythms of pond-field construction and use can be characterized as a *tradition* with deep roots in Hawaiian culture that was established early and practiced steadily into the modern era. In contrast, the linear rhythm of temple construction in the rain-fed agricultural fields of leeward Maui and Hawai‘i Islands can be characterized as an *innovation* that began late in the traditional Hawaiian period and continued until the overthrow of the traditional religion in 1819. This long-term rhythm of temple construction can be divided into an early period of about a century and a half when it was the *fashion* to harvest branch coral and either offer it at temples or incorporate it in the structural fill, and a later period when branch coral harvest fell out of fashion in the century leading up to 1819.

Tempo plots shed some light on the development of Contact-era political economy, which has been investigated primarily by archaeologists working within a neo-evolutionary framework, resulting in two recent book-length treatments, both of which rely heavily on traditional historical accounts and less so on strictly archaeological data. One of these accounts hypothesizes an early development of “archaic states” in the seventeenth century (Kirch, 2010a), while the other favors a later development of “states” in the eighteenth century (Hommon, 2013). Although it is unlikely that the timing of “archaic state” or “state” formation will be determined with confidence from the archaeological record, because the state is an abstract notion that leaves no direct traces, the long-term rhythms of temple construction and branch coral harvest cast doubt on the hypothesis of early development. In particular, religious practices that supported the political aspirations of Hawaiian kings (Valeri, 1985) developed their Contact era form in the eighteenth century, sometime after harvest of branch coral for temple offerings went out of fashion.

Analysis of archaeological events with tempo plots encourages the archaeologist to move beyond the stadial view of cultural development proposed by neo-evolutionary theory and invites the theorist to hypothesize state formation as a process with an archaeological expression, rather than as an event that might be inferred from traditional accounts (Routledge, 2014). From the perspective of an historical approach to Hawaiian archaeology, rhythms of the long-term revealed by the tempo plot, including the cyclical rhythms of tradition and the linear rhythms of fashion and innovation, can be interpreted as diachronic strands that contribute to a multi-stranded cable of explanation, an explanatory form that distinguished early modern science from the scholastic tradition it eventually replaced (Peirce, 1868) and is favored by at least one philosopher who has thought deeply about archaeological explanation (Wylie, 1989).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2016.05.006.

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