# Temporal Systematics The Colonization of Rapa Nui (Easter Island) and the Conceptualization of Time

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## Temporal Systematics

### The Colonization of Rapa Nui (Easter Island) and the Conceptualization of Time

CARL P. LIPO, TERRY L. HUNT, AND ROBERT J. DINAPOLI

> The real problem in speech is not precise language.
> The problem is clear language.
>
> *Richard Feynman (1965)*



All aspects of measuring the archaeological record involve numbers, and a knowledge of mathematics is essential for any counting and subsequent statistical evaluation. While we often associate mathematics with numbers, the *values* in an equation are not central to its purpose. Instead, mathematics provides a *language* that carefully distinguishes concepts and explicitly states their relations with other concepts. *Pi,* for example, is the ratio of the circumference of the circle to its radius squared. Values are then assigned to these concepts and can be explained due to the definitions and their properties. This framework uses a metaunderstanding of mathematics but the logic points to one of the reasons that mathematical structures (whether they are equations, chemical formulas, Feynman diagrams, and so on) provide the basis of language for most sciences: *explicitly defined ideas are kept distinct from empirical values.* It is this language that allows scientists to explain topics that lie outside of our common sense. Math provides the language that defines what is "true" in a conceptual sense, regardless of how we assume the world "must be" from our limited personal experiences.

Mathematics is not the only way in which logical structures are formalized and defined. In evolutionary biology and the practice of archaeology, the domain that effectively serves as math is *systematics*. For archaeologists, *archaeological systematics* is the set of rules with which units of meaning are constructed and applied in the explanation of the archaeological record. While attention is given to the role of theory, systematics forms the measurement basis for all our knowledge generation since units are needed to meaningfully describe the archaeological record. Units require theory to stipulate meaning but are also used to measure the empirical world. Thus, they provide a vital link between the empirical and the conceptual—in the same way as mathematics.

It follows then, that the greater the degree to which the process of unit construction is explicit, the more powerful the explanations that can be created. In the emergence of physics and chemistry as scientific disciplines in the late seventeenth century, it was creation of systematics that permitted researchers to go beyond medieval alchemy with its notions of fire, air, earth, and water as the basic elements.[1] In archaeology, measurable success as a discipline has come whenever we are able to incorporate explicit and meaningful units of analyses. The degree to which culture history has been an unqualified success in producing falsifiable chronologies, for example, is largely due to the degree of rigor of formation and testing of archaeological systematics (Dunnell 1986; Lyman et al. 1997). Success as a science is intrinsically linked to systematics.



In archaeological practice, systematics is limited to the construction of classes of discrete-object scale artifacts—for example, "types" of pottery or bifaces. Nevertheless, all our units, conceived at any scale and of any composition, must be considered within the context of systematics. Unlike other scientific disciplines, we lack a mathematical formalization providing an inherent means to distinguish the conceptual from the empirical. Yet, keeping units of measurement separate from the phenomena we are attempting to explain is key to science. In the case of archaeology, our work investigates classes of phenomena intrinsically linked to the past actions of our own species. In this way, our launching point for inquiry is often based on ethnocentric commonsense observations. Thus, the units share their form and meaning with their role as nouns and verbs in one's native language. Though we borrow some concepts and terms from other sciences (for example, radiocarbon), our basic units are derived from common sense. Of course, there have been attempts by some to concoct new terms that are supposed to provide conceptual tools such as Binford's (1962) "technomic" or "ideo-technic" and Schiffer's (2011) "techno-community." But these neologisms are versions of English nouns serving as fancy labels for empirical generalization that are derived from common sense. These terms are jargon, or as Service (1969) has aptly called it, "mouthtalk." With common sense providing the meanings for our basic units, it is not difficult to understand why some of our discipline struggles to produce scientific products. Fundamentally, we work under the tyranny of our native-language nouns that often make no distinction between the definition of a concept and the thing identified as a member of that concept. Our innate languages constrain our ability to construct a means of explaining the archaeological record outside of the limited realms of common sense. Thus, the use of our native language as the sole basis for justifying measurement units effectively traps us in an era analogous to prescience alchemy.

Systematics enables us to move beyond common sense. Culture historians used systematics to develop tools that allowed them to measure and track change through time and across space in the archaeological record (Dunnell 1971, 1986; Lyman et al. 1997). Modes, types, phases, traditions, and horizons are all purposefully constructed units for measuring the archaeological record across time and space.

Unfortunately, a lack of attention to systematics has progressed over time, given a general misunderstanding of the important distinction between theoretical concepts and empirical record. While the recognition of the artificial nature of unit construction was strong at the point in time in which units were built (for example, Phillips et al. 1951), over time the usefulness of the units resulted in them being treated as real (O'Brien et al. 2005). As a consequence, units are now often rationalized using common sense and ad hoc justifications. A means of avoiding this quagmire and moving forward is a renewed emphasis on unit construction and the expansion of archaeological systematics (Dunnell 1971, 1986).

One area where this issue is particularly problematic is island colonization, where our commonsense notions of how the process of initial settlement possibly occurred became conflated with measuring colonization in the archaeological record.

Here, we discuss an example of how careful construction of systematics can substantially change our understanding of the archaeological record using our research in the eastern Pacific and on Rapa Nui (Easter Island) (Figure 3.1). This example is intended to demonstrate how concepts with English language origins result in incorrect conclusions and how these can (and must) be reconstructed into meaningful and useful measurement units. It also highlights the need to consider systematics beyond the construction of classes of discrete-object scale artifacts and into the usage of more general types of nouns. In this example, we explore aspects of a unit related to time: colonization.

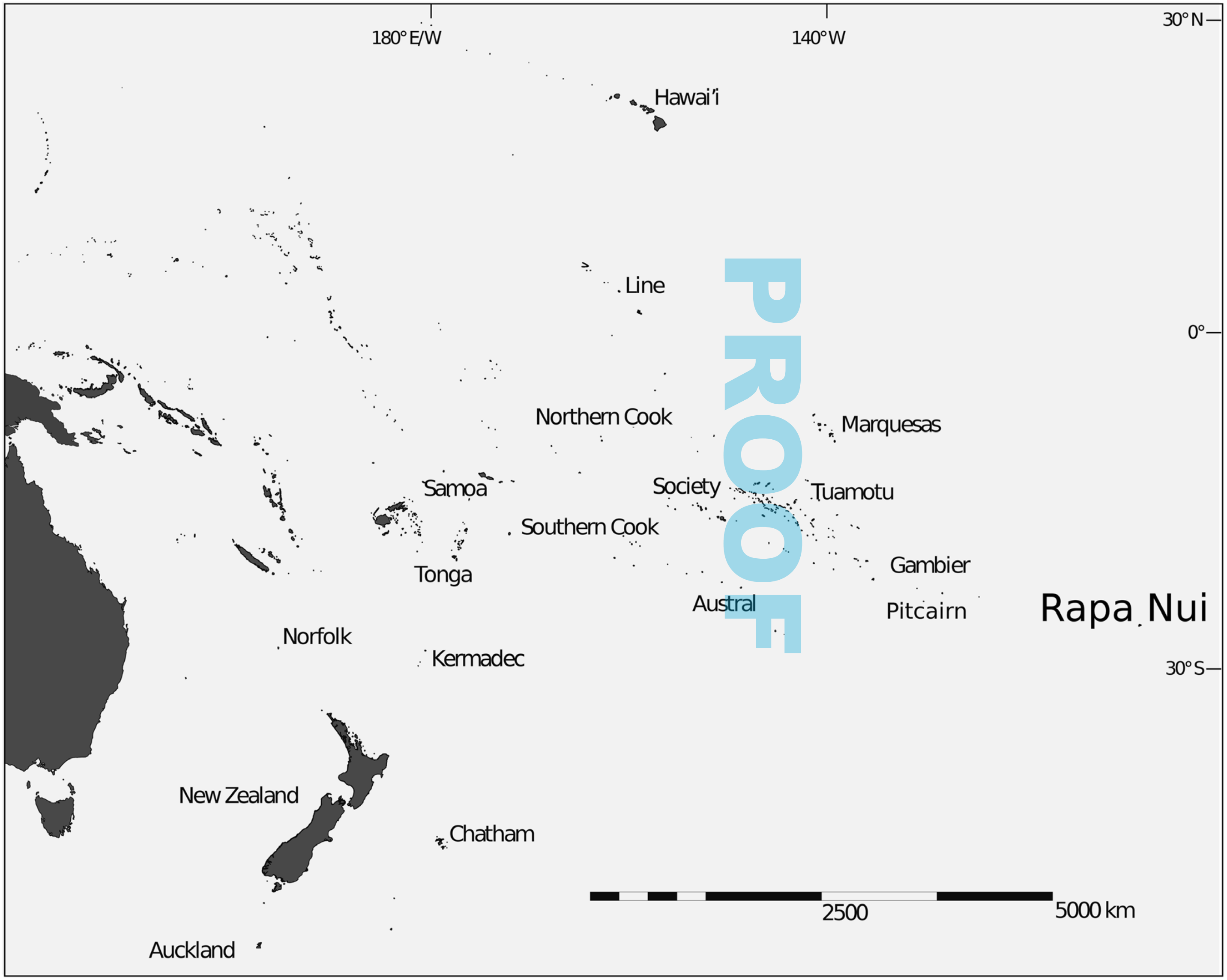


Figure 3.1. The islands of the eastern Pacific.

## Units of Time

Time is a slippery dimension for archaeologists (Ramenofsky 1998). We are interested in the archaeological record because it provides information about what occurred in the past, yet the past is not directly observable. The archaeological record has two dimensions, and *only* two dimensions: form and space (Spaulding 1960). Empirically speaking, *what we study has no time dimension;* instead, it only exists in the here and now. The lack of a temporal dimension is true for all of human experience: time is removed from our senses. Instead, time exists only as a calculation we make based on sets of observations in the present. While this statement seems absurdly simple, it is vitally important for understanding the archaeological record. Temporal facts are always based on units that we construct and depend on the questions we ask. Thus, we require an understanding of "temporal systematics." To facilitate our discussion, Table 3.1 consists of a list of terms and their definitions as used in this chapter.

The crux of a temporal systematics is the understanding that time can be usefully conceived as a relationship between events. Our common sense tends to distinguish between "events" and "things," where events are something "fleeting," but things are "stable." But this is an arbitrary distinction since things are only stable with respect to our point of view in time. When viewed over long stretches, we can easily see that any one "thing" has coherence over some duration, where that duration is longer than casual observation. "Things" only have coherence as identifiable discrete chunks of matter over the duration of time in which all the constituent ingredients are together. Imagine a chair: a chair only becomes a chair once the leg, seat and back are physically arranged. It no longer meets the definition of a chair once its parts are no longer physically associated. Thus, in the long-term view, things are events. We only distinguish them as "things" due to our own evolution and the scale of our lifespan (or attention span).

It is important to note that "thingness" or "eventness" are ideational classes that form a *classification,* not an empirical property (compare O'Brien and Lyman 2002). Being able to explicitly construct and manipulate this classification is critical to archaeologists because, while we deal with things, we are often interested in events. Differentiating between things and events depends solely upon common-sense conventions, so for the time being we want to talk about the units of the empirical world as *instances* or "uniquenesses" and not get tangled up in the thing-and-event stuff.

Thus, events are simply concoctions of classes, classes with a certain set of attributes that form a unique combination of features and arrangements of phenomena in time (Dunnell 1971). For example, an event might be a particular point in time at which a biface is deposited in a refuse pit. In this way, temporal units are defined on the basis of events. Events are simply configurations of classes and attributes observable in the present, but explicable in terms of time. We know time has passed, for example, by comparing sets of events. The difference between sets of events is then attributable to the passage of time.

To create units of time, we must specify the combination of classes or attribute sets that are necessarily linked to the event of interest. We are most familiar with object-scale events in which we select a set of attributes of an object to use in calculating the amount of time passed for the attributes to be as they are presently measured. Examples of these events include those measured through radiocarbon and luminescence dating. Radiocarbon-age events, for example, are identified through a classification consisting of the abundance of $^{14}C$ atoms within organic material relative to the $^{14}C$ content of the atmosphere at the time when the organism was alive. Using these attributes, we can calculate when the organism ceased respiration. Luminescence-age events, in contrast, are measured by classes that consist of the abundance of light released from crystalline forms of some minerals, the amount of ionizing radiation in the local environment, and the rate at which luminescence increases with these minerals as a



Table 3.1. Definition of terms used in the chapter

| **Term** | **Definition** |
|---|---|
| *Empirical unit* | Any specified identified portion of the measurable world |
| *Theoretical units* | Conceptual rules for measuring the world |
| *Object-scale events* | The point in time when a set of attributes becomes physically associated with a discrete object |
| *Aggregate-scale events* | The point in time when a set of discrete objects becomes physically associated |
| *Target event* | The event of interest for the investigator (Dean 1978) |
| *Dated event* | The event that is physically measured (Dean 1978) |
| *Commonsensical colonization* | The imagined point in time that represents the arrival of people in a new location |
| *Archaeological colonization* | The first measurable observation in the archaeological record that can only be explained as the result of human activity |

*Source*: Authors, unless otherwise indicated.

function of radiation. Using these dimensions of measurement, we can then calculate the amount of time that has passed for these samples to accumulate the measured amount of luminescence.

Less intuitive are aggregate-scale events that are composed of sets of events at lower scales (Dunnell 1971). Occupation is an example of an aggregate scale event since it consists of the set of all the events that comprise a deposit. At this scale, we must carefully define the events of interest since choices can vary from the determination of when the first member of the set was added to, when the last member of the set was added to, when the modal events became a set—or any other combination. The choice depends on the question asked. Duration is a calculated property of aggregate-scale events as are any questions related to the first measured event (that is, arrival), last event (that is, termination), and rates of change (that is, change of intensity of occupation). Infinitely more attributes of aggregate-scale events can be calculated depending on the question.

## Colonization



On the Pacific Islands, one common temporal question relating to the archaeological record is, "When did human populations arrive on a particular island?" Accurate and precise answers to this question are critically important as the timing of arrival forms the basis for all other questions regarding the islands' human history (for example, Allen 2014; Anderson 1995; Burley et al. 2015; Dye 2015; Rieth and Cochrane 2018; Rieth and Hunt 2008; Sear et al. 2020; Spriggs and Anderson 1993). The question of earliest arrival is usually asked in terms of the concept of "colonization." As is unfortunately common in anthropological practice, the term "colonization" is often based on an unanalyzed, intuitive connotation referring to the process wherein people arrive to "live in a new land." Given the word's English origins, colonization is assumed to be an empirical event where a group of people leaving one location with all of their traditions and belongings travel to a new location to take up residence. The assumption that colonization is an empirical event means that it is something we can "find."

While the intuitive "living in a new land" notion appeals to an imagined (that is, *reconstructed*) set of events, colonization does not exist in the archaeological record. As a result, *commonsensical* colonization has no necessary attributes for identification. In its commonsense form, "colonization" is a concept in search of evidence with no necessary and sufficient criteria that can be specified. When conceived this way, notions of colonization tend to lead some to grasp for observations that *might* show human occupation. The determination of commonsense colonization leads to a futile search for something akin to the first human footprint on an island beach. Is the first step of an individual onto the wet sands of the island the ultimate indicator of colonization? Or is the first cooking fire? Or is the first deposited artifact? Or the first sighting of land? Or the first house constructed? Or the first tree cut down? Or the first persistent settlement occupation? Since our research is limited to what is observable in the archaeological record, such a definition often assumes that the "real" colonization evidence is somehow missing, resulting in a quest for *imaginary* evidence of a fabricated story.

In this way, poorly defined notions used to study the archaeological record lead to assertions of mere plausibility, rather than relying upon empirical standards. Evidence is evaluated on how *plausible* it is relative to archaeological tradition and existing lore that exists about the chronology. A fragment of charcoal found below areas of clear deposits of artifactual material, for example, *could* be evidence related to early colonization. Other material might be rejected simply because it is "way too old" (that is, does not fit current thinking). However, with plausibility as the only criterion for consideration, false positives are more likely to become part of the "evidence" for colonization. Any bit of information that suggests some "reasonable" possibility of early occupation becomes the basis for making claims about colonization. As we will see shortly, due to measurement error and uncertainty, as well as choice of statistical approach, chronologies made under such conditions tend to become older, sometimes significantly so.



In the Pacific, for example, the quest for elusive "footprints" has dominated much of the discussion of colonization for the past 60 years—ever since radiocarbon dating made it possible to provide ages of organic material (for example, Heyerdahl and Ferdon 1961). Given the revolution represented by radiocarbon dating in terms of its ability to stipulate quantitative values for the degree of antiquity of materials, archaeologists enthusiastically pursued collecting and dating samples as means of specifying "colonization" dates. This enthusiasm coupled with the quest to find the "earliest" examples led to largely uncritical acceptance of samples throughout the discipline (Dean 1978). In the Pacific, this effect is demonstrated by the fact that once radiocarbon dating was introduced, arguments for the timing of human occupation of eastern Polynesia shifted from estimates of the thirteenth century AD (Buck 1938) to about 1,000 years earlier (for example, Hunt and Holsen 1991; Kirch 1986; Kirch and Ellison 1994; see Anderson 1995; Spriggs and Anderson 1993).

Archaeologically, however, our efforts at learning about the timing of the arrival of people must consist of identifying the *set of earliest observable events that can only be explained by human behavior.* Thus, "colonization" is not something

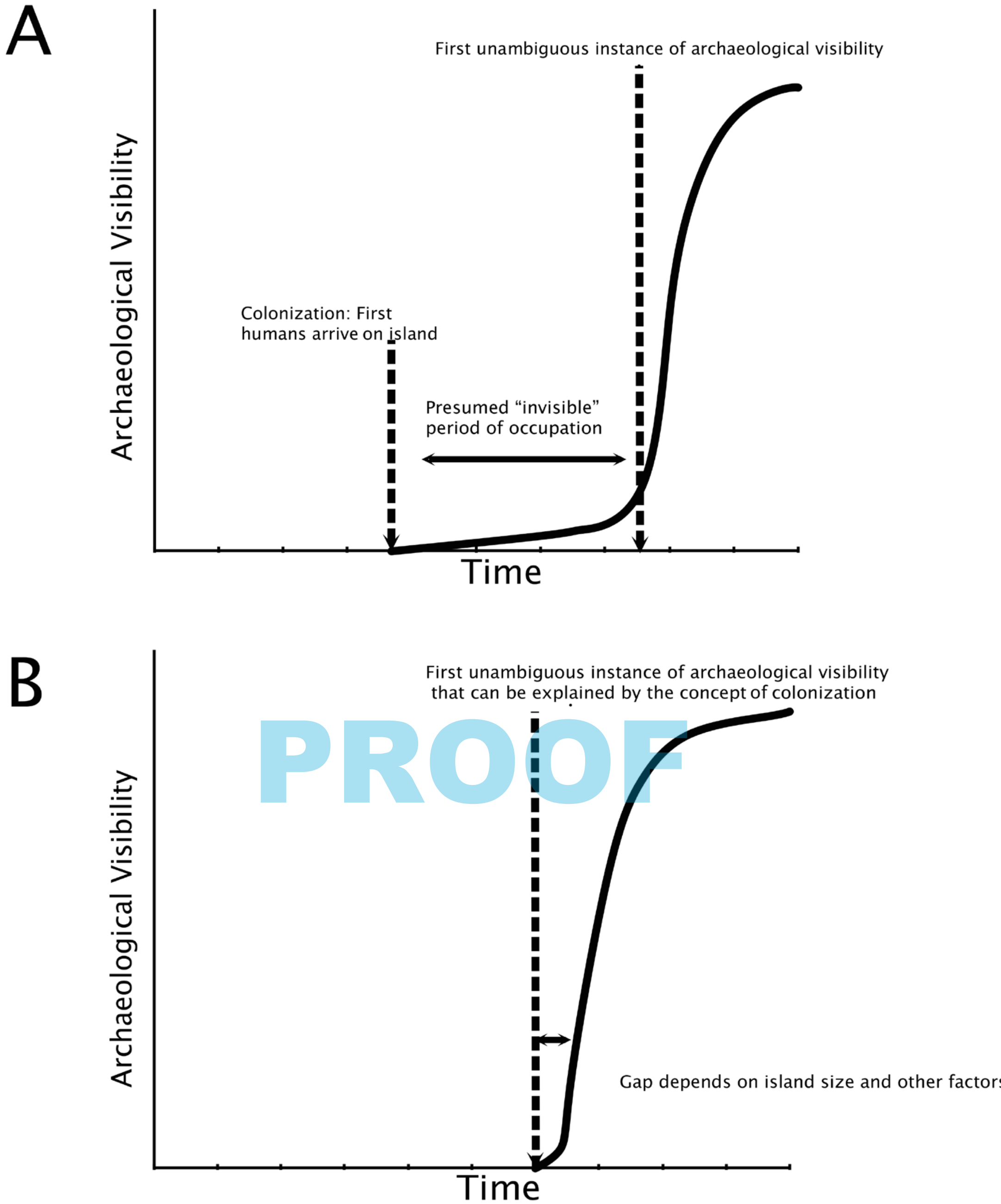



Figure 3.2. Common-sense colonization (*A*) versus archaeological colonization (*B*). Note that “invisible” period of occupation prior to archaeological visibility in the common-sense notion of colonization assumes low population–growth rates, low environmental impacts, low-density settlements, and/or large landmasses that would take significant time to result in abundant archaeological remains. From empirical evidence, none of these conditions holds true in cases when humans enter a previously unoccupied landscape. Birth rates often exceed 3% (Birdsell 1953, 1957), small populations tend to live in nucleated settlement patterns, and even large landmasses show impacts almost immediately after arrival. In the case of New Zealand (268,671 km$^2$), e.g., human visibility took only several years to spread across the entire island (Wilmshurst and Higham 2004). In cases with far smaller islands (e.g., Rapa Nui is just 160 km$^2$), any possible lag between “arrival” and archaeological visibility must be negligible.

that is discovered, but rather is an *explanation* for events that are defined and observed in the archaeological record. This statement simply means that we cannot look for "evidence" of colonization with the assumption that it is real and somehow "out there." Instead, we account for observations (that is, identified instances of artifact classes) that can only be explained as the result of human behavior.

Maintaining the subtle but distinctive nature of these aspects of the concept of colonization is vital. The use of commonsense colonization often assumes that the "real" colonization date must be older than the earliest archaeological evidence and thus results in an endless unfalsifiable quest for the first footprint. *Archaeological* colonization, in contrast, is associated with the identification of the earliest observations that can only be explained as the result of human activity (Figure 3.2). Based on this archaeologically defined class, the investigator begins by acquiring chronological information for the deposition of the earliest case of identified artifactual material. This conceptual approach is fundamentally distinct as it is falsifiable and amenable to continuous testing. As additional information is produced through excavations and other archaeological studies, the challenge in research is to iteratively evaluate archaeological evidence, typically with statistical modeling, in order to refine the chronology of colonization.



### *Uncertainty in Events*

If colonization serves as a potential explanation for empirical observations (that is, a hypothesis), uncertainty comes from two primary sources: (1) linking the events we observe with the events of interest and (2) inherent measurement error. First, we must link our observations to claims about human behavior that occurred in the past. Our interest is in describing events, which are descriptions of a point in time when a set of attributes came to co-occur. In the case of colonization, we want to temporally distinguish events related to human activity. However, we cannot study human activity directly in the archaeological record. Instead, we describe phenomena in the present in terms of physical mechanisms that create them. Bridging arguments are necessary to connect these physical events with human behavior.

Consider radiocarbon ages, for example. Radiocarbon ages are determined based on the removal of an organism from the carbon cycle and the decay of $^{14}C$ over time. Whether that organism came to be removed from the carbon cycle (that is, died) must be reasoned through additional attributes such as physical features (for example, cut marks), association (with other artifacts), or composition (that is, non-native commensal species). Even with multiple attributes used to link a radiocarbon age with human behavior, direct relatedness cannot be guaranteed since the death of the portion of organism from which a radiocarbon age has been determined may have occurred long before the point at which the other attributes became associated. For example, the inner parts of long-lived tree species are often removed from the carbon cycle hundreds of years before they end up as fuel in an earth oven.

Dean (1978) demonstrated that we could resolve this confusion by distinguishing two kinds of events involved in establishing a "date": the *target event* and the *dated radiocarbon event*. The dated event is the point in time in which the physical attributes that are measured come together, such as the point at which the organism is removed from the carbon cycle. The target event is the event of interest to archaeologists, such as any observation that can be explainable as a consequence of human activity. These may be effectively the same event as is the case in luminescence dating where the firing of the ceramic vessel is the dated event and (often) the target event. In the case of radiocarbon ages, however, there may be a substantial difference between the two events, depending on the material used.

The second area of uncertainty in establishing the timing of an event comes from the inherent error terms involved in making measurements from *aggregate-scale events*. In the case of radiocarbon dating, there are two sources of error. The first, common to all dating techniques, comes from basic laboratory error that depends on the accumulation of imprecision of each of the measurement steps. This error is typically normally distributed and thus amenable to statistical evaluation. The second source of uncertainty, in the case of radiocarbon ages, comes from the calibration process, where calibrated ages are a function of the history of atmospheric radiocarbon and do not follow a regular distribution. There is thus a finite probability that the dated event will occur at each point in time, and we can only be 100 percent certain of the date if we consider the entire range of non-zero probabilities. For particular portions of the calibration curve, these distributions can be quite complicated and include multiple sets of possible durations (for example, Jacobsson et al. 2018; Lipo et al. 2005; Ramenofsky 1987).

### *The Selection of Samples*

Given these sources of uncertainty, it is necessary to evaluate each dated event included in a set that meets the definition of archaeological colonization—the earliest observations that can only be explained as the result of human activity. The choice of samples used to generate the assemblage of events is perhaps the most significant step in the analysis. The better the association between the target event and the event of interest (that is, early human activity), the better the results. Including questionable dates (that is, unknown degree of divergence from target events) means that conclusions are also necessarily going to be questionable. No degree of statistical machinations can compensate for including samples that bear ambiguous association with the event of interest. Radiocarbon dates have to be carefully evaluated to ascertain that the events are appropriate for inclusion. This is not to say that any particular date is "wrong," but rather it may poorly link the dated event to the targeted event.

Such evaluation takes place whether one acknowledges it or not. It is not uncommon, for example, for researchers to reject dated events "obviously too old" on unspecified criteria. In the inclusion of materials that can be explained as related to colonization, however, particular and explicit evaluation criteria must be applied. Simply put: one must be able to definitively state the necessary and sufficient criteria used to sort dates into "acceptable" and "unacceptable."

## An Example from Rapa Nui



Estimating the arrival of humans on Rapa Nui provides a useful example of the steps required for selecting samples and calculating probabilities as well as highlights the problems that emerge from commonsense notions of colonization. We initially conducted these analyses in 2006 and concluded that Rapa Nui was first colonized in the early part of the thirteenth century AD (Hunt and Lipo 2006; see also Wilmshurst et al. 2011 for the larger region). Despite attempts to invalidate our analyses (Shepardson et al. 2008), or outright rejection (for example, Bahn and Flenley 2017; Kirch 2017), our estimates of colonization have yet to be falsified (for example, DiNapoli et al. 2020; Schmid et al. 2018). Certainly, falsification of our hypotheses is possible: all that is required is at least one sample (and preferably more) that is unambiguously associated with human occupation and demonstrates earlier human presence.

The first step in evaluating colonization is to choose the samples for analyses that meet the definition of archaeological colonization. This process has to be accomplished explicitly rather than intuitively. For example, in a review of early radiocarbon dates related to the colonization of Rapa Nui, Martinsson-Wallin and Crockford (2002) reject a radiocarbon date from a sample of charcoal from Ahu Akivi by William Mulloy with an age of 2216 ± 96 BP (Mulloy and Figueroa 1978). Simply stating that the date is "questionable" (Martisson-Wallin and Crockford 2002: 250), they eliminate it from consideration as the earliest acceptable date. No rationale is given, but it can be assumed the rejection comes from the notion that the date is “too old” as it predates preconceived notions for colonization of the island. Following this strategy, one might argue that “obvious” outliers can easily be excluded from analysis, but as one approaches assumed target events, dates are accepted on tacit criteria because they appear to “fit” or be “consistent with” other results. The reasoning is entirely circular: “obvious” outliers simply reinforce a priori assumptions, and the a priori assumptions determine what makes an “outlier.”

The use of these criteria (that is, implementing chronometric hygiene) means that we did not include all possible samples in our original analyses; we included those that could reliably inform us about the chronology of human behavior. We excluded samples for which there was not a strong link between the removal from the carbon cycle and a human-attributed event—for example, material from unknown floral taxa (that is, the old wood problem) and samples that contained mixed earth and charcoal. We also excluded samples of mixed isotopic fractionation (for example, mixed charcoal and soil) that would necessarily provide a problematic relation between the dated and target events.

Significantly, we also excluded samples from marine contexts such as coral and marine mammals. Marine samples must always be carefully considered since old carbon in the form of dissolved carbon dioxide is sequestered in deep water to create a global marine reservoir effect of circa 400 years, and local offsets (ΔR) can also substantially deviate from this global average (Alves et al. 2018; Mangerud 1972; Stuiver and Braziunas 1993). Marine samples can, therefore, produce dates that are highly variable due to mixing between shallow and deep water (Alves et al. 2018;; Anderson 1995; Spriggs and Anderson 1993). While this value can be adjusted using a ΔR correction, there can often be high intraisland variation in ΔR, and choosing a reliable correction for some highly mobile marine fauna (for example, sea birds, marine mammals) or samples with mixed terrestrial/marine dietary contributions (for example, humans, commensal species) can be highly complex and difficult to resolve (for example, Cook et al. 2015). In similar cases, such as on the Island of Hawaiʻi, modern samples taken from the same bay reveal correction values that differ by several hundred years, explained by local effects of deep water inconsistently mixed with shallow sources (for example, Petchey 2009). Rapa Nui has a limited reef environment and deep waters lie immediately offshore (Friedlander et al. 2013). Consequently, there is unknown and likely substantial variability in sources of marine carbon for certain organisms we may want to date (for example, marine mammals). For the purposes of narrowing down the timing of archaeological events, then, such inconsistency makes some marine samples potentially problematic. For this reason, we excluded three marine mammal (dolphin) bone/tooth samples from excavations conducted by Steadman and colleagues (1994; see also Lipo and Hunt 2016). While a marine reservoir correction has been estimated for one nearshore location on Rapa Nui (Beck et al. 2003; Burr et al. 2009), we do not know the appropriate age corrections for deep-sea, widely ranging dolphins, among others.

For a related reason, we also exclude coral dates. Beck et al. (2003: 93–111) report radiocarbon dating of 27 abraded coral artifacts, many identified as statue eye fragments, from Anakena Beach. As Beck et al. (2003: 100) correctly point out, the coral may have been collected live or used long after the death of the coral. Another problem with coral is that it secretes a hard, external skeleton as it grows. This growth can take place over 1,200 years for any particular cluster of coral (Glynn et al. 2003). Thus, some parts of coral may be significantly older than other parts, with no way of distinguishing the difference: coral death ages are likely systematically older than the manufacturing events by unknown and potentially great amounts. Thus, these coral dates must be considered ambiguous in terms of their relation to the archaeological events we seek to measure.

We also exclude lake-core sediment dates on Rapa Nui for estimating colonization events. Lake-core dates from sediments associated with changes in vegetation are often provided as evidence for early arrival of humans on Rapa Nui, but these are significantly problematic. For example, in recent publications Flenley and colleagues (for example, Butler and Flenley 2010) suggest human presence on Rapa Nui as early as AD 100 based on sediment cores taken from Rano Kau. Similarly, Cañellas-Boltà et al. (2013) and Rull (2019; Rull et al. 2013) argue for a colonization date of 400 BC based on vegetation changes in sediments from Rano Raraku lake cores.



There can be several potential problems using lake-core sediment samples for estimating colonization events. First, while coring evidence in the form of fecal biomarkers (for example, Sear et al. 2020) or commensal plants or animals (for example, Prebble and Wilmshurst 2009) would constitute reliable samples for archaeological colonization—as they are clearly related to human arrival on Rapa Nui, samples taken from cores are often argued as associated with human events, given sedimentary changes in microcharcoal, pollen, and/or other vegetation changes. Vegetation change and variation in microcharcoal, however, may not necessarily be linked to human impacts, though this is one possibility (for example, Gosling et al. 2020). More problematic in the case of Rapa Nui is the tendency for mixing to occur in the sediment profiles whereby older and younger material become associated. As Butler et al. (2004) have clearly shown, radiocarbon results from lake-core samples on Rapa Nui have produced wildly unreliable dates, explained by problems with bulk samples (that is, including unknown materials with potentially great inbuilt age), mixing of sediments and the dated constituents collected from them, and serious problems reliably relating materials dated with definitive evidence of human presence. Thus, with samples taken from Rapa Nui lake cores, there is no necessary relation between the radiocarbon and archaeological events. Instead, lake-core radiocarbon dates must be explained *in terms of* archaeological events where alternative explanations are possible or even likely. Using *only* this ambiguous lake-core evidence to infer the settlement history of Rapa Nui, as done by Flenley (for example, Butler and Flenley 2010) or Cañellas-Boltà et al. (2013), has little logical basis, as others have argued (Larsen and Simpson, 2013).

Our criteria for the analysis of Rapa Nui colonization also included dates with laboratory error terms less than 10 percent of the mean radiocarbon age. This criterion simply served to minimize the ambiguity of dates with a large degree of measurement error. As the amount of error increases, the less certain the radiocarbon age is for *any* value. In our original approach, dates with low precision limited our ability to specify any detail in the timing of colonization. Our use of 10 percent as the maximum acceptable was an arbitrary choice designed to include samples with precision great enough to contribute to resolution of the event of interest. In the case of the Rapa Nui, where our goal is to at least specify the century of colonization and where colonization has generally been thought to be no earlier than AD 500, explicitly limiting samples to those with a 10 percent maximum radiocarbon measurement error provided a restriction that ensured greater precision in our event estimation. While Hamilton and Krus (2018) argue that limiting samples to those with small error terms is not strictly necessary when using Bayesian models, especially if there are only a few dates with larger error terms, the choice of 10 percent gave us the best possible set of dates for our analyses.

Lastly, we removed dates from the Gakushuin lab, which are known to be problematic (Blakeslee 1994). Following these steps left us with 14 samples that meet all of the requirements for archaeological colonization. We distinguished these classes of samples as those that provide the most direct age estimates for defining chronology (that is, "Class 1" dates after Wilmshurst et al. [2011]).

### *Measuring Colonization Events*

Once suitable samples are identified, decisions remain about specifying radiocarbon events to measure the timing of colonization. To convert conventional

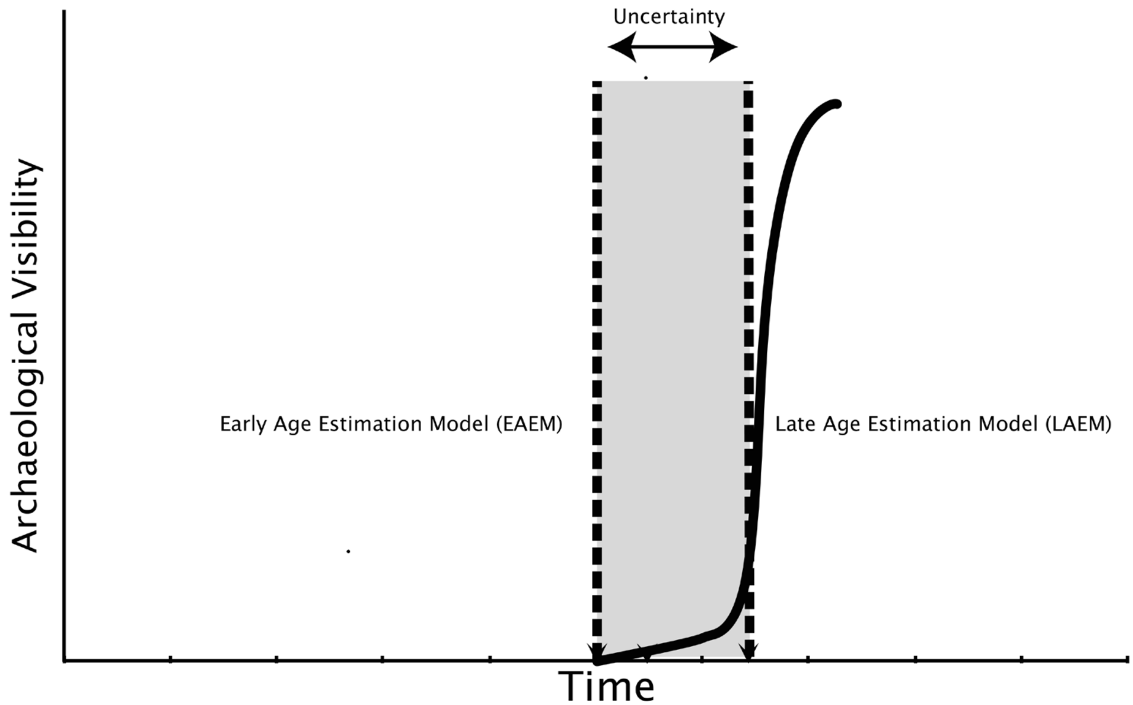


Figure 3.3. Two models for ascertaining the event of colonization. The Early Age Estimation Model (EAEM) is the point in time after which the event of colonization must have occurred. The Late Age Estimation Model (LAEM) is the point in time after which we are reasonably certain (i.e., $p>0.50$) that colonization has already occurred. In the case of Bayesian analysis, the process identifies range of ages that are statistically most likely to reflect the earliest date. This range is effectively the same as the EAEM.



radiocarbon ages (CRAs) into calendrical dates, the values must be calibrated, resulting in a series of time-specific probability distributions for each dated radiocarbon event. Since the values of these distributions are composed of probabilities usually not normally distributed, but reflect historically idiosyncratic $^{14}C$ levels in the atmosphere, it is difficult to specify the timing of the radiocarbon event with any great precision. To better specify timing, information from multiple, independently dated events can be combined and statistically analyzed to isolate a point in time when the colonization event *most likely* occurred (Figure 3.3).

### *Statistical Analyses*

The two most common statistical approaches for estimating the colonization of Rapa Nui have been summed probability distributions of radiocarbon dates (SPD) (for example, Hunt and Lipo 2006; Lipo et al. 2016; Wilmshurst et al. 2011) and, more recently, Bayesian modeling (DiNapoli et al. 2020; Schmid et al. 2018). Shepardson and colleagues (2008; see also Contreras and Meadows 2014) have challenged our previous conclusions of a circa–thirteenth century colonization based on our use of SPD modeling (for example, Hunt and Lipo 2006; Wilmshurst et al. 2011; see Figure 3.4) and suggested a better statistical means for estimating colonization. In their proposed method, the probability of any date being the earliest is conditioned by the other probability distributions that are represented across all valid samples. Shepardson and colleagues use this approach for calculating the "earliest" date and find 900 AD to be more likely than our thirteenth-century conclusion. Shepardson et al. (2008) provide a useful illustration of the need to appropriately define and measure archaeological colonization rather than operate from common sense. Their problem is related to both the choice of the samples used, which do not meet the definition of archaeological colonization, and their method of estimating the point of colonization, particularly the inability to objectively account for potential outliers or large error terms. Nine out of 11 samples selected by Shepardson et al., including the 4 earliest CRAs,

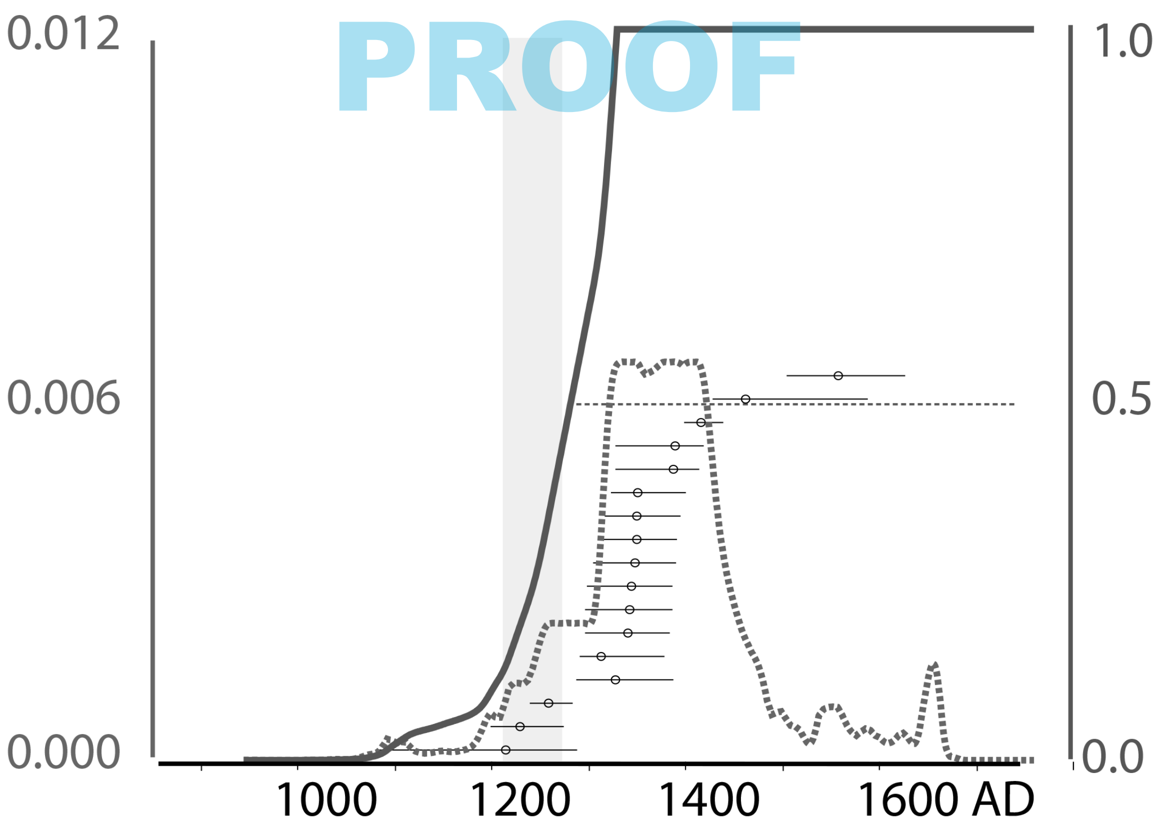



Figure 3.4. Rapa Nui colonization event as indicated by Class 1 radiocarbon ages and summed probability distribution modeling based on analyses in Hunt and Lipo (2006) and Wilmshurst et al. (2011). The gray bar indicates the area of uncertainty between the EAEM and the LAEM. For Rapa Nui, therefore, based on this analysis and the evidence used, colonization can be said to have taken place between AD 1200 and AD 1253.

derive from unidentified charcoal, and the 2 oldest CRAs have substantial error terms associated with the radiocarbon ages (>10 percent). The early values obtained through their analyses are entirely the product of the limitations of their statistical model and choice of samples: simply including values that are early, but bear unknown relations to the target events of interest, results in earlier estimates of colonization. Furthermore, their claim that "the *true* colonization date for Rapa Nui (which archaeologists will probably never know for sure) is likely to be earlier than any random, or even the earliest recovered, evidence of human occupation" (Shepardson et al. 2008: 98, emphasis added) highlights the fundamentally unfalsifiable character of commonsense notions of colonization. Defining archaeological colonization as the earliest secure and unambiguous evidence of human activity, however, results in hypotheses that are continually testable as new data and methods arise.

To address the potential statistical problems with our previous analyses raised by Shepardson et al. (2008) and others (for example, Contreras and Meadows 2014), we recently tested our previous colonization estimate by reanalyzing a suite of radiocarbon dates meeting the definition of archaeological colonization (DiNapoli et al. 2020) with a technique that is now common in the Pacific: Bayesian modeling using OxCal (for example, Athens et al. 2014; Bronk Ramsey 2009a, 2017; Burley et al. 2015; Clark et al. 2016; Dye 2015; Schmid et al. 2018; Rieth and Athens 2019).

In our model, each CRA is combined into a single unordered phase and calibrated based on prior information about other dates in the group, and the result is a 95.4 percent probability estimate for the beginning of this phase (that is, colonization). All samples were calibrated using the SHCal13 calibration curve (Hogg et al. 2013). To focus on colonization events, we chose dates sufficiently early so that the radiocarbon probabilities inform on the likelihood of earliest human arrival. Strictly speaking, this is not a necessary step. One can include dates that most likely postdate colonization, though the degree to which they help confirm the earlier portions of probability distributions is a matter of contention (Mulrooney et al. 2011). For our analyses of Rapa Nui, we arbitrarily chose dates with a CRA greater than 650 BP. This procedure simply isolates those dates that provide the most information about the earliest portion of the radiocarbon probability distributions. Given recent advancements in Bayesian modeling of radiocarbon dates, in particular the ability to objectively handle potential outliers and large error terms (for example, Bronk Ramsey 2009b; Hamilton and Krus 2018; Dee and Bronk Ramsey 2014; Schmid et al. 2018), we ran two colonization models for Rapa Nui: one that only included 9 short-lived plant samples, and another that also included 19 unidentified charcoal samples modeled using a Charcoal Outlier parameter (Dee and Bronk Ramsey 2014). These unidentified charcoal samples come from archaeological contexts with secure stratigraphic relationships between the sample and the target event (that is, human activity). The Charcoal Outlier model allows us to account for the other potential source of uncertainty between the dated event and the target event that Sheppardson et al. (2008) could not account for—inbuilt age.

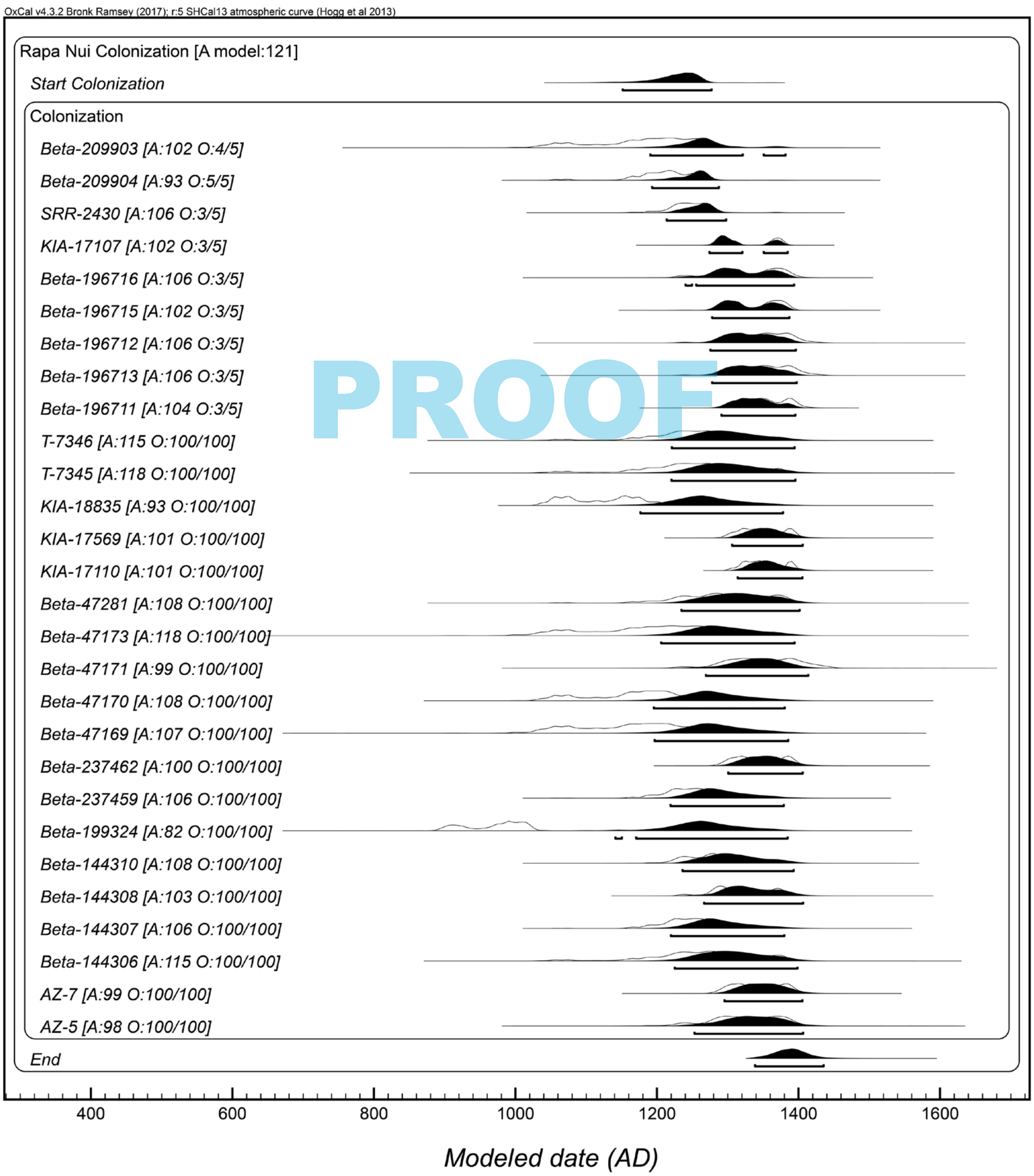



Figure 3.5. Single-phase Bayesian colonization model for Rapa Nui (figure adapted from DiNapoli et al. 2020).

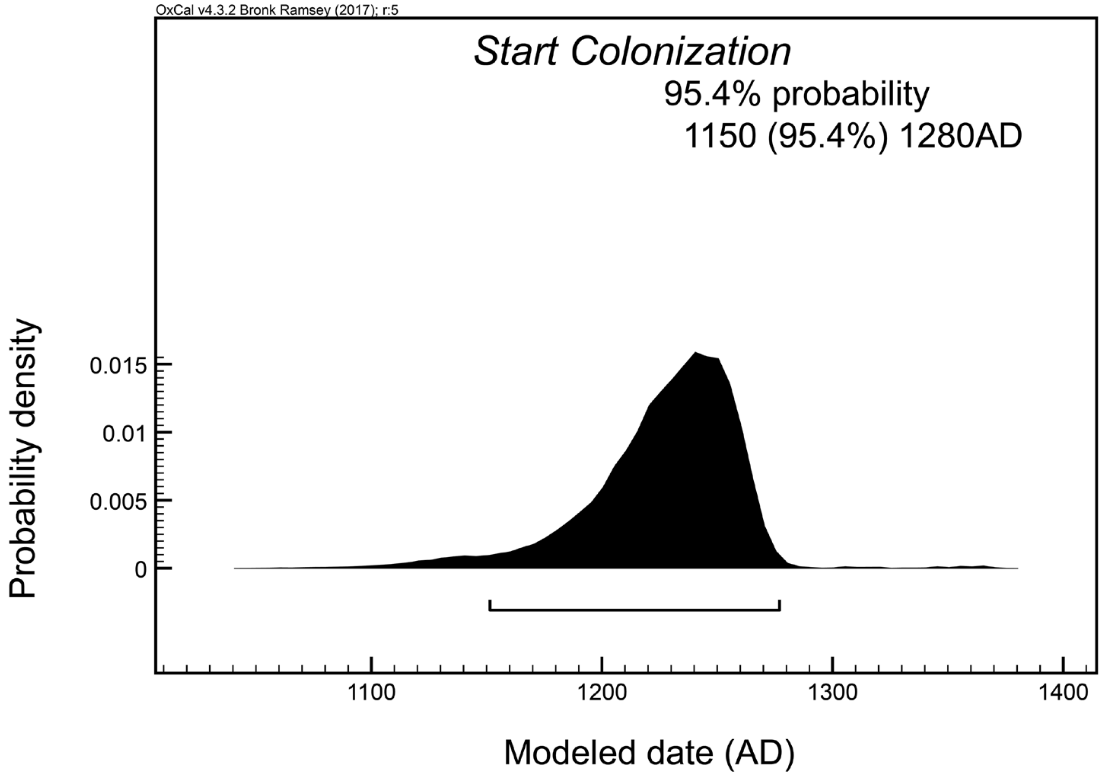


Figure 3.6. Single-phase Bayesian modeled Boundary start range for the colonization event on Rapa Nui (figure adapted from DiNapoli et al. 2020).



The results of these two models are essentially identical and suggest that the colonization event is 95.4 percent likely to have occurred between *1150 and 1280 cal AD* (Figures 3.5 and 3.6). The agreement index for each modeled date is above the commonly used threshold of 60, the model agreement is 121, and the overall agreement is 120.5. This result is consistent with the conclusions we reached with our earlier analyses (for example, Hunt and Lipo 2006; Wilmshurst et al. 2011), pointing to the fact that the current best evidence is that colonization begins sometime between the late twelfth and middle thirteenth century. This reanalysis highlights that it is crucially important that we define archaeological colonization—that is, the earliest unambiguous evidence of human activity—in selecting samples for modeling colonization.

## Conclusions

The change in our understanding of the colonization event on Rapa Nui is significant. Rather than arrival in AD 700–900, humans arrived on this tiny, remote island between the twelfth and thirteenth century. Since we know that Europeans located the island in 1722, this dramatically shortens the overall pre-contact chronology from 1,000 years or more to only about 500. This shorter chronology, among other lines of evidence, led us to question many of the popular assumptions about Rapa Nui prehistory long-term population growth with overshoot, collapse, and rebound (Bahn and Flenley 1992; Diamond 1995, 2005; Puleston et al. 2017; compare Lipo et al. 2018). With a solid chronology for Rapa Nui, we now have a firm empirical understanding of the basic phenomena that must be explained. This temporal framework has led us, for example, to see that the making and transport of *moai* were associated with behavior vital to the success of communities in evolutionary and ecological terms given the environmental and social constraints of the island (for example, DiNapoli et al. 2018, 2019).

Unfortunately, unit construction is rarely considered to be of primary importance in archaeological practice, yet there is no task that is more fundamental to our ability to generating meaningful observations. While many recognize the use of classes in the measurement of artifacts, few understand how they are constructed and even fewer are aware of the need for unit construction with *all* of our nouns and verbs. The insidious nature of commonsensical notions leads us to treat English concepts as empirically discoverable, forcing us to make implicit and cryptic assumptions about what we are studying. Nowhere is the problem more acute than in the study of time. Our inability to directly observe time means that we must use conceptual units for measuring its effect on the world. Herein lies the necessity of temporal systematics.



The use of the concept of colonization in the study of humans arriving on islands across the Pacific illustrates how clarification and careful linkage of observations with meaning can produce new understandings of prehistory. The problems illustrated in this chapter are not unique to Rapa Nui and could be usefully extended to other regions experiencing similar issues, exemplified by recent work in the Caribbean (for example, Napolitano et al. 2019), Madagascar (for example, Anderson 2019; Douglass et al. 2019), and other chapters in this volume (for example, chapters 6 and 7). With cryptic assumptions (for example, “true” colonization being earlier than the earliest evidence) and a conceptualization based on common sense, many studies of colonization have endlessly pursued elusive “footprints” that are evidence of a behavioral event. By explicitly defining the concept of colonization, we are afforded falsifiable explanations of the record with known links between hypotheses and the events we create.

## Note

1. For chemistry, Robert Boyle's publication of the *The Sceptical Chymist* in AD 1661 marked the change, while physics began to shed its alchemist roots with the AD 1687 publication of Isaac Newton's *Principia Mathematica.*

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