Suggested Best Practices for the Application of Radiocarbon Dating to Hawaiian Archaeology[1]

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Preface (by Robert J. Hommon)

Ongoing studies (Duarte 2012; Rieth et al. 2011; Rieth personal communication) show that fully 90 percent of 2,334 radiocarbon determinations reported from archaeological contexts on Hawai‘i Island, Maui, and portions of O‘ahu have been from samples of wood charcoal of unspecified taxa or plant parts. Some unidentifiable portion of these dates are unrelated to, and older by as much as a century than, archaeological events of interest because, among other factors, they derive from the heartwood of one or more long-lived trees of unknown in-built age (Dye 2000). The fact that, in the absence of the samples' botanical sources, accurate dating results cannot be distinguished from inaccurate ones renders such unidentified samples poorly suited to the task of supplying the level of reliable chronometric accuracy required to understand processes in the brief and recent span of the Hawaiian archaeological record at any scale, from individual hearth use to multi-island agricultural expansion. The remaining ten percent of examples reviewed in the above-mentioned study are those reported by researchers who have avoided the problem of in-built age by dating only samples from individual, identified short-lived plants or plant parts such as seeds or twigs, an approach rooted in Murakami's (1983a, 1983b) charcoal identification research that began three decades ago.

Discussions with colleagues and a review of the literature show that, for unspecified reasons, some archaeologists working in Hawai‘i still choose not to apply well-documented, effective chronology-building strategies including radiocarbon analysis of short-lived samples, other improved chronometric methods, and the event-focused selection of dating samples (Dye 2010, 2011; Rieth et al. 2011).

At the annual business meeting in October, 2010, the membership of the Society for Hawaiian Archaeology passed a resolution I had drafted that was intended not as fruitless criticism of past omissions but rather in support of best practices in future research. The resolution observed that "the neglect of available, effective chronological techniques can be wasteful of effort and funding and, worse, can lead to erroneous conclusions about Hawaiian history and culture" and recommended the establishment of "a special committee to evaluate absolute and relative dating methods that are available for use by archaeologists conducting research in Hawai'i" and to "prepare a draft written report to include … a succinct description and evaluation of the various dating procedures discussed, [and] a list of recommended actions by the Society for Hawaiian Archaeology." In response, Tim Rieth and Stephen Athens volunteered their time to prepare the following report focusing on radiocarbon dating, a major contribution to chronology-building in Hawai'i for which they deserve the thanks of the archaeological community.

Introduction

Developing precise and accurate temporal information for archaeological remains is a cornerstone requirement for nearly all archaeological research. A high level of confidence in the relevance and accuracy of a chronology is necessary to address substantive issues such as initial island settlement, the development of social complexity, agricultural intensification and expansion, population growth, the appearance of introduced cultigens and other plants and animals, and resource exploitation, to name a few. The lack of reliable chronological placement leads only to a "muddling" of the record and endless arguments about who is right. We have seen this problem repeatedly in Pacific archaeology, of which the difficulty of dating the earliest human arrivals in Hawai'i is a particularly prominent example. Chronometric hygiene, sparked by the concerns of Spriggs and Anderson (1993), has been one response for making the past less opaque through the evaluation of problematic dates (see also Anderson 1991 [New Zealand], Hunt and Lipo 2006 [Rapa Nui], Liston 2005 [Palau], Rieth and Hunt 2008 [Sāmoa], Smith 2002 [West Polynesia]; also related efforts by Rieth et al. 2011 [Hawai'i Island], Wilmshurst et al. 2011 [East Polynesia]). However, there needs to be a much better effort to avoid generating problematic radiometric dates to begin with.

Certainly some of this chronological muddling can be attributed to a rather lengthy learning curve Pacific archaeologists have had in figuring out how to properly use radiocarbon dating technology since it first became commonly available in the early 1970s (though the earliest date in the Pacific goes back to Kenneth Emory's work at the Kuliʻouʻou site in 1950—Emory et al. 1959; see Kirch 1985:15–16; Kirch 2011; Libby 1951). Also, relatedly, over the years there have been improvements in the dating technology itself (e.g., more rigorous sample pretreatment, the Accelerator Mass Spectrometry [AMS] method, calibration, and calibration refinements). Unfortunately, however, much of the lack of clarity in Hawaiʻi's dating record is simply due to poor archaeological practice, and that is what concerns us here.

A number of major deficiencies seem clear and widespread. One, at the most basic level, is that archaeologists, be they at the PhD level or the field technician level, need to keep up with dating advances—the dating literature needs to be read and absorbed. Another big problem is that far too many samples in contract archaeology reports and academic publications have poorly documented (or poorly reported) provenience and association information. A third problem is that poor decisions are sometimes made in determining what contexts are the most appropriate for dating or would give the most reliable results concerning the event the sample is intended to date. Finally, there are issues about the choice of materials that are selected for dating and the processing protocols that should be used. Providing the right answers to all of these concerns is essential, but perhaps the biggest question one must ask is, "why should this object, feature, or provenience be dated?" In other words, "what am I trying to learn and why does it matter?" Even with all of the advances of isotope dating technologies, answering the seemingly simple question of "how old is this?" is often neither simple nor straightforward.

In this presentation, we will only address best practices concerned with radiocarbon dating, leaving aside other important dating topics such as relative chronologies derived from stratigraphic superposition (both in the sense of layers and levels of excavation units and the order of construction of architectural elements—e.g., walls; see discussion in Dye 2010), and seriation of stylistic traits (e.g., fishhooks, adze types, *heiau* architecture). Relative chronologies derived from oral accounts, histories, and chiefly genealogies also can be informative, especially in the rare instances that these can be tied to celestial events (e.g., Masse and Tuggle 1998, Tuggle 2010). All of these techniques have the potential for contributing valuable information to the overall understanding of chronological relationships, and also to contribute to the formulation of research issues for consideration, and should be applied whenever there is an opportunity. Although these often stand-alone techniques sometimes generated robust relative chronologies for certain areas, the creation of empirically based absolute chronologies relating to observable archaeological remains that could be correlated to calendar years was mostly problematic until isotopic dating became widely available. As indicated above, absolute chronologies are critical for addressing in one way or another almost all of the important processual and methodological issues in archaeology.

Although not considered here, there are a number of other methods beside radiocarbon that can be used for obtaining absolute dates in archaeology. These include 230-Thorium dating, cosmogenic dating, obsidian hydration dating, paleomagnetism dating, thermoluminescence dating, optically stimulated luminescence, and dendrochronology (and there are some others—see Taylor and Aitken 1997). At present only a few of these have rare application for Hawaiian archaeology, though use of 230-Thorium eventually could have wider applicability and archaeologists should be familiar with its use (see Kirch and Sharp 2005; McCoy et al. 2009; Weisler et al. 2006; see also Sharp et al. 2010). Use of hydration dating for Hawaiian volcanic glass was a common practice in Hawaiian archaeology during the late 1970s and 1980s, but its use was discontinued when it eventually became apparent that the technique produced highly unreliable results (Tuggle 2010:176–178).

We are not concerned here with the science behind the radiocarbon technique (e.g., Taylor 1987, 2000; Guilderson et al. 2005) or statistical treatments of dates through the use of Bayesian models (Buck et al. 1991, 1992, 1996; see also Dye 2010:110–140, 2011), but rather the *acquisition* of radiocarbon dates in Hawaiian archaeology. In particular, we wish to compile "Best Practices" guidelines for radiocarbon dating so that much of the previously discussed problems with the application of radiocarbon dating can be reduced and the results of each dating effort will positively contribute to a better understanding of Hawaiian archaeology. Considering the amount of cultural resource management (CRM) and academic archaeology that occurs yearly in Hawai'i, and the consequent amount of money spent on radiocarbon dating, the importance of producing reliable radiocarbon determinations that contribute to research cannot be underestimated.

Methodological Issues

The biggest dating pitfalls for archaeologists relate to 1) failing to logically link the dated archaeological object with the archaeological event of interest, and the related issue 2) of failing to select the radiocarbon dating sample that most accurately references the archaeological target event. At issue here is provenience and material.

Bridging Arguments: Linking the Radiocarbon Event and Archaeological Target Event

A bridging argument is a logical statement that links the radiocarbon-dated object (dated event or radiocarbon event) with the archaeological target event (Taylor 1987). Simply stated, the dated event is the time when the organism ceases to take in ^{14}C from the environment, and the radioactive "clock" begins ticking through beta decay. Ideally, the dated event and the archaeological event (e.g., a hearth, a midden layer, a house floor, etc.) are synonymous. Thus, for example, an annual shrub is cut and used as fuel in a hearth within a short period of time of the cutting event. In this case the difference in time between the cutting event and the archaeological event (use of shrub for fuel in the hearth) is so minimal that the charcoal remains of the shrub fairly date the hearth feature. Typically, a bridging argument to link the dated object with the archaeological target event has two components: 1) provenience, and 2) sample material. It is worth noting that most often the bridging argument is not explicitly stated but remains implicit in the analysis, which can result in problems interpreting the radiocarbon dating results.

Sample Selection: Provenience and Material

Provenience

As one component of a bridging argument, the provenience of a potential radiocarbon dating sample must be assessed. Particularly, in most instances, the sample should be from a primary context. Charcoal from hearths, *imu*, and structural posts burnt in place are ideal examples because the integrity of the feature insures original (or primary) deposition. However, it is more common to recover potential dating material dispersed in a midden deposit (as opposed to a feature). Soil analysis, specifically aimed at assessing the rate and mode of deposition, can provide the information needed to understand the context of a potential sample. Dynamic colluvial, alluvial, and coastal deposits increase the chance that dating material has been redeposited and mixed. Certain archaeological features, particularly *ʻauwai*, increase the likelihood that the dated material does not directly relate to the construction or use of that feature. Additionally, post-depositional processes may result in the mixing of materials with differing ages from different strata (e.g., crab burrowing, digging of post holes, excavation of pits by site occupants into earlier deposits, etc.). Small particles, such as charcoal, can be susceptible to downward movement particularly in loose or porous sedimentary matrices. So along with an assessment of the primary mode of deposition, an assessment of post-depositional factors should be considered.

An example of the importance, and sometimes difficult process, of determining provenience and association is nicely illustrated by a limestone sinkhole excavation in the Barbers Point area of Oʻahu. This involved the dating of a hearth in which extinct avian remains were found "in and around [the] hearth" (Olson and James 1982:31). A charcoal sample from the hearth provided a presumably reliable age for the feature of AD 1205–1299. To the investigators, it appeared that the avian bones were directly associated with the hearth, perhaps representing the remains of a long ago meal. It was thereby implied that these extinct birds had survived well beyond what at the time was considered the initial period of Polynesian colonization, and that human predation was perhaps a factor in their extinction. In point of fact, the bird bones may be unrelated to the hearth given uncertainties about their depositional context as noted by the excavator (discussed in Athens et al. 2002:72). As a result of what is now known about sinkholes and avian remains in the Barbers Point area, it seems likely that the hearth was placed within or on top of sinkhole soils that contained older avian remains as a result of natural depositional processes.

The uncertainty of the Barbers Point case misled archaeologists and avian paleontologists for a long time until cumulative research in the area made the initial interpretation unlikely in our view. The point here is not to criticize the excavators for what would have been a very reasonable inference at the time, but to point out how easily misinterpretation of the archaeological record can be made through overly facile assumptions and conclusions regarding associations and depositional context, and then the subsequent extreme difficulty in recognizing and correcting these interpretations.

It is incumbent upon archaeologists to develop logical bridging arguments through the careful articulation of why and how a potential dating sample directly relates to the archaeological target event. To be sure, a great deal of archaeological experience and training are often necessary to fully evaluate the possibilities and to make the correct decision. In the case of the Barbers Point hearth excavations, we would now take it for granted that both the charcoal and the bird bone (if it was truly found within the charcoal matrix) would have to be radiocarbon dated and determined to be coeval if there was to be a claim that ancient Hawaiians were hunting and consuming these now extinct birds.

Sample Material

Any organic material that is up to 50,000 years old can be dated using radiocarbon dating (and this limit is being pushed to ~60,000 years in some cases). Each type of material used for radiocarbon dating has its own benefits and challenges that must be assessed.

The Old Wood/Inbuilt Age Problem

Wood charcoal is the most common material used for radiocarbon dating in Hawaiʻi. But even during the infancy of radiocarbon dating in the archipelago, potential problems were suggested by seemingly anomalous dates (Emory and Sinoto 1969). This "old wood" or "inbuilt age" problem was first systematically discussed in relation to New Zealand archaeology (McFadgen 1982), and has subsequently been noted as a source of significant error elsewhere in the Pacific, including Hawaiʻi (e.g., Allen and Wallace 2007; Dye 2000; Rieth et al. 2011; Wilmshurst et al. 2011). The old wood problem derives from the dating of wood or charcoal from long-lived trees, which results in the radiocarbon date being much older than the archaeological target event.[2] It can also be a result of dating charcoal derived from trees growing near volcanic vents because the trees can absorb and metabolize ^{14}C -depleted carbon dioxide (Taylor 1987:131–132).

The old wood problem is a model example of the potential disjunction between the radiocarbon event and the archaeological event of interest. In Hawai'i this problem is not only the result of the aging process of local trees, but also can be caused by the documented practice of burning in hearths beached driftwood that derives from the Pacific Northwest of North America (Emory and Sinoto 1969; Strong and Skolmen 1963; Murakami 1983b, 1992). Vancouver (1798:886–887), in fact, described "the finest canoe we had seen amongst these islands" as being made of "pine." He was informed that the log from which the 61 foot vessel had been constructed "was drifted by the ocean," the source of which he believed was probably "the northern parts of America." Some of these drift logs can be quite old, and the amount of time they spend water-logged and drifting before finally becoming beached in Hawai'i represents a further extension of their inbuilt age. Even wood from the heart of a mature native *koa* or *'ohi'a* tree can date as much as two centuries prior to its use as a fuel.

While extreme divergences between inadvertently dated pine or other driftwood charcoal samples and the archaeological event can sometimes be easily recognized if unintentionally dated, the inbuilt age offset is often difficult to recognize in most radiocarbon determinations. For example, if the charcoal from which the radiocarbon date was obtained consisted of both *koa* heart wood and outer growth wood such as might occur if wood chip debris from canoe construction were later burned as fuel in a hearth, then the date of the archaeological event might be unrecognizably too old. The same is true when woods of different longevities are combined in a single dating sample. The older woods will increase the temporal distance between the material dated and the archaeological event, but it will be next to impossible to recognize that the archaeological event will appear to be 50 or 150 years older than it really is. The result is an inaccurate documentation of the archaeological record. There is no way to determine that these dates are definitely incorrect except through a laborious process of various forms of chronometric hygiene or redating using taxonomically-identified samples from the same provenience. In such situations, money spent to obtain dates on unidentified wood has been wasted. But more importantly, there is an incalculable cost in terms of wasted research time and effort by archaeologists and others trying to understand the past.

Recently, Peter Mills and colleagues (2011) obtained first-hand knowledge on the impacts of inbuilt age on research. These investigators completed a geochemical analysis of a curated lithic assemblage from a Kahalu'u habitation cave in Kona, Hawai'i Island. Paul H. Rosendahl, PhD, Inc. (PHRI) had excavated the cave in the 1980s. Initially lacking grant funding and using the original radiocarbon dates obtained from bulk, unidentified charcoal samples, the assemblage appeared to have two components: an early deposit dating between ~1400–1650 AD, and a later component dating between 1650–1800 AD. Intriguingly, the proportion of Mauna Kea Adze Quarry basalt increased dramatically in the later assemblage. Prompted by a reviewer of their journal manuscript and with the receipt of grant monies in the middle of the project, Mills et al. obtained three new dates from *kukui* endocarp fragments (short-lived plant parts). These revealed that the entire deposit dated between ~1650–1800 AD—the earlier component was simply an artifact of the inbuilt age problem. Of course, this significantly changed the interpretation of the results. The silver-lining to this anecdote is that through grant funding and peer review, it was possible to correct a dependence on inaccurate dates before the article was published. Unfortunately, this is not always the case or even possible if samples are no longer accessible.[3]

This old wood problem is easily resolved through the taxonomic identification of wood charcoal and the selection of short-lived plants or plant parts for dating (Table 1). By selecting short-lived plants or plant parts (seeds, seed cases, twigs) a researcher will maximize the statistical accuracy of the radiocarbon date for determining the age of the archaeological event. Additionally, wood charcoal identification can identify the presence of historically-introduced plant taxa, which provides a *terminus post quem*[4] date for the deposit, albeit one that is historic. It also could be that the presence of historic plant taxa in a potential dating sample indicates that the archaeological deposit is disturbed. In either case, the expense of a radiocarbon date is avoided, and a more accurate assessment of the true nature of the archaeological deposit is gained.

Taxonomic identification of charcoal samples, especially those derived from habitation combustion features, is also a valuable means of generating paleoenvironmental data concerning the type of plants that were available in the local environment. They may also provide important information for refining the chronology for Polynesian plant introductions (e.g., breadfruit and sweet potatoes—see Dye 2011; Ladefoged et al. 2005; McCoy et al. 2010).

Finally, review of all dating samples by a qualified wood anatomist positively determines if the dating sample is, in fact, carbonized wood. It has happened on occasion that radiocarbon dated "charcoal" yielded a date much too early for humans in Hawai'i. When the origin of the sample was reviewed, it turned out to be most likely anaerobically blackened wood from wetland deposits and not charred wood. The two can be difficult to distinguish. At least for O'ahu and Kaua'i, the presence of prehuman charcoal is limited to lightning strikes (which is not true for some parts of Hawai'i Island and east Maui where there has been active volcanism throughout the Holocene).[5]

Marine Shell and Other Marine Invertebrates

Marine shell and other invertebrate remains comprise another domain of potential archaeological radiocarbon dating samples, which are often more abundant in an archaeological deposit than charcoal. As with any potential dating sample, the bridging argument must substantiate the association of the marine shell with the

Table 1. General Ages/Lifespans for Common Hawaiian Plants (adapted and modified from Rieth et al. 2011)*

Species	1 to ~ 10/15 years	1–~50 years	>50 years
Acacia koa			x
Aleurites moluccana nutshell	x		
Aleurites moluccana			x
Artocarpus altilis			x
Bidens spp.	x		
Bobea spp.		x	
Chamaesyce spp.	x	x	
Chenopodium oahuense	x		
Cocos nucifera nutshell	x		
Cocos nucifera		x	x
Coprosma spp.	x	x	
Cordyline fruticosa		x	
Diospyros sandwicensis			x
Dodonaea viscosa			x
Fern caudex		x	
Ipomea batatas	x		
Lagenaria siceraria	x		
Metrosideros polymorpha			x
Myoporum sandwicense			x
Nototrichium spp.		x	
Osteomeles anthyllidifolia		x	
Pipturus albidus		x	
Pritchardia spp.			x
Psychotria spp.		x	
Railliardia spp.= *Dubautia*		x	
Rauvolfia sandwicensis		x	
Santalum spp.			x
Senna sp.		x	
Sida fallax	x		
Sophora chrysophylla			x
Styphelia tameiameiae		x	
Wikstroemia spp.		x	

* Age bracket categorizations are intended only as approximations as precise data on the longevity of many taxa are not well known and may be variable depending on the local environment where particular plants grow. Also, different species within the broader taxonomic designations can range from subshrubs to small trees with very different longevities. Finally, notwithstanding their age categorizations, all of these taxa produce short-lived plant parts, including seeds/fruit cases, nuts, and small twigs or branches.

archaeological remains that one is attempting to date. Thus, it is always important to first establish that the shell sample is contemporaneous with the target archaeological event you wish to date. If the shell has a weathered appearance and rounded edges, this may indicate that the shell is (or was) part of a natural deposit and therefore would not be a reliable candidate for dating. If, on the other hand, it can be identified as a food source and/or raw material, then its association with the archaeological target event may be more secure, in which case its dating potentially could contribute to a chronological understanding of the archaeological target event (however, see Rick et al. 2005 for a discussion of the "old shell" problem).

As has been known for a long time, marine shells and other marine organisms have an "apparent" ^{14}C age, which means that they date older than their true age. This is because of the marine reservoir of carbon in the ocean. As explained by Petchey (2009),

> The surface ocean (down to around 200 m depth) has an apparent ^{14}C age that is, on average, 400 years older than the terrestrial (atmospheric) reservoir. This is known as the marine reservoir effect, and is caused by a delay in the ^{14}C exchange between the atmosphere and the ocean, and by the mixing of surface waters with upwelled, ^{14}C-depleted deep ocean water (Stuiver et al. 1986:982).

The use of a marine calibration curve provides a general correction, which typically must be further amended by the application of a local marine reservoir correction factor termed delta-R (ΔR). However, calibration is not so simple as there are significant local variations in marine reservoirs due to a number of causes. Dye (1994) provided an early review of the various ΔR values in Hawai'i, which he calculated from shells of known age in Hawai'i (collected live prior to nuclear bomb testing), along with an assessment of the suitability of certain marine mollusks and their habitats and feeding strategies for radiocarbon dating. He proposed several ΔR values, noting substantially different marine reservoir corrections for molluscs living on coral substrates of likely middle Holocene age and/or likely exposure to ^{14}C-depleted carbon in shallow water in the vicinity of near-shore Pleistocene limestone (upraised reefs). Even in locations without significant coral or any Pleistocene limestone (i.e., volcanic coasts), there can be the need for significant marine reservoir correction values due to varying exposures of the organisms to upwelling of ^{14}C-depleted water. Dye (1994:54–55) offers ΔR values for shells obtained from coral coastlines and volcanic coasts, plus a ΔR value for *Tellina palatam* bivalves. While acknowledging the uncertainties involved in dating marine shell, he believes his newly derived ΔR estimates "should prove useful in certain archaeological situations."

More recently, Petchey (2009) completed a review of dating marine shell, coming to similar conclusions as Dye (1994). Like Dye, she discusses the great importance of dietary and habitat preferences for particular mollusk taxa in determining the magnitude of the effect of the marine reservoir on them, and also the variable exposure of near shore areas to the upwelling of ^{14}C -depleted water around the islands. As Petchey (2009:166) notes, "it seems likely, therefore, that ΔR values for Hawaii will be highly variable depending on the coast in question." In fact, current ΔR values from throughout the archipelago range from -500±120 to 3820±100 (Petchey 2009:160–161) (Table 2). She concludes (Petchey 2009:167) that, "the most problematic values are those for deposit-feeders and other species that may incorporate sediment in their diets. These deposit-feeding shellfish should be avoided for both routine ^{14}C dating and ΔR studies."

To summarize, Dye (1994) and Petchey (2009) have highlighted two extremely important issues regarding mollusk sample selection for radiocarbon dating: 1) certain deposit-feeding taxa are unreliable for dating regardless of the reliability of a local ΔR value, and will remain so for the foreseeable future (F. Petchey pers. comm.), and 2) other taxa may be locally unreliable due to the feeding habits on specific substrates (e.g., limestone).

Weisler et al. (2009) have taken a novel approach for determining ΔR using 230-Thorium and AMS dating of *Pocillopora* spp. coral samples. The 230-Thorium dates provide a precise measure of the age of the coral, which was compared with an AMS determination from the same samples, thereby allowing calculation of ΔR. The benefit of this method is that numerous samples can be analyzed from across the archipelago, with the limiting factor being the abundance and age-range of branch corals. Such an approach could address the high variability in ΔR identified by Dye (1994) and Petchey (2009). Caution is still required, however, since this method does not account for the feeding habits of marine mollusks found in archaeological deposits, which are used for radiocarbon dating. Additionally, further research is needed to determine if *Pocillopora* spp. corals and various mollusk taxa from the same shoreline differentially sequester ^{14}C from ocean water due to biology/life history and/or environmental factors (e.g., rocky shore/splash zone mollusks compared to coral at several meters below the surface along a reef edge).

Radiocarbon dating marine shell in Hawai‘i requires forethought and consideration. If a reliable ΔR has been established for a local area and suitable mollusk taxa are present in an archaeological assemblage, the use of these taxa for radiocarbon dating can produce reliable results. Radiocarbon dating of marine shell should be avoided 1) in areas subject to significant upwelling of deep ocean water (e.g., southern Hawai‘i Island), 2) areas where the local ΔR value has not been reliably determined, 3) at locations with exposed limestone substrates when dating grazing herbivorous taxa , and 4) if deposit-feeding taxa are the only available dating samples. An additional caveat would be the dating of marine shell from inland deposits or features since the original collection locale, and therefore the appropriate ΔR, cannot be determined. A useful avenue for further research is for archaeologists in Hawai‘i to date additional charcoal-shell pairs to better understand

Table 2. ΔR Values for the Hawaiian Islands, Primarily from the Marine Reservoir Corrections Database (http://calib.qub.ac.uk/marine/) (adapted and modified from Petchey 2009)

Island	Location	Sample Material	Calendar Age (Date collected)	ΔR	Lab No.	Reference	Comment
O'ahu							
	?	*Trochus intextus*	1840	139±50	L-576J	Dye 1994	Exact location unknown
	Waikane	*Tellina palatum*	1925	229±40	Beta-14024	Dye 1994	Deposit feeder; lagoon-unknown influence
	Kane'ohe	*Macoma (Scissulina) dispar*	1918	-479±120*	Beta-13805	Dye 1994	Lagoon-unknown influence
	Kane'ohe	*Conus distans*	1947	44±60	Beta-15794	Dye 1994	Lagoon-unknown influence
	Waimanalo	*Conus distans*	1936	502±70	Beta-12749	Dye 1994	
	Pearl Harbor	*Trochus intextus*	1936	3842±100*	L-576D	Dye 1994	Questionable species in limestone region
	Pearl Harbor	*Tellina palatum*	1927	-21±60	Beta-15793	Dye 1994	Deposit feeder; questionable species in limestone region
	Kualakai	*Nerita picea*	1930	776±80	Beta-54333/ CAMS-3219	Dye 1994	Questionable species in limestone region
	Barbers Point	*Cellana exarata*	1914	822±80	Beta-54332/ CAMS-3218	Dye 1994	Questionable species in limestone region
	Barbers Point	*Cypraea caputserpentis*	1915	532±80	Beta-54331	Dye 1994	
Moloka'i							Questionable species in limestone region
	Puko'o	*Tellina palatum*	1905	-38±60	Beta-12903	Dye 1994	Deposit feeder; questionable species in limestone region
	West coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	39±36*	OZJ963	Weisler et al. 2009	
	West coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	64±42*	OZJ964	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	8±42*	OZJ965	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	29±39*	OZJ966	Weisler et al. 2009	
	North coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	58±36*	OZJ967	Weisler et al. 2009	
	North coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	56±37*	OZJ968	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	115±53*	OZJ954	Weisler et al. 2009	

Table 2 (cont.)

Island	Location	Sample Material	Calendar Age (Date collected)	ΔR	Lab No.	Reference	Comment
Moloka‘i							
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating		OZJ955	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	56±53*	OZJ956	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	69±51*	OZJ957	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	34±55*	OZJ958	Weisler et al. 2009	
	South coast	*Pocillopora* sp. (coral)	Archaeological sample subject to U-Th dating	57±53*	OZJ959	Weisler et al. 2009	
Hawai‘i Island							
	Keauhou	*Porites lobata* (coral)	1923	-28±4	UCI 3172-4432	Druffel et al. 2001	
	Kaulana	*Cellana exarata*	1923	290±100	Beta-54336/ CAMS-3222	Dye 1994	
	Kaulana	*Cypraea caputserpentis*	1923	280±80	Beta-54334	Dye 1994	
	Kea‘au	*Nerita picea*	1924	159±80	Beta-54335/ CAMS-3221	Dye 1994	

* Denotes ΔR calculated using the Marine04 calibration curve, the remaining values were calculated using the Marine09 calibration curve.

local variations in the marine reservoir. However, extreme care is needed to ensure that the paired samples are actually contemporaneous. Additionally, calculation of $\delta^{18}O$ and $\delta^{13}C$ isotope values for dated marine shell samples, in combination with ΔR values, can provide useful data on marine environments, specifically as indicators of changes to water temperature, salinity, water source, and marine productivity (Culleton et al. 2006; Petchey et al. 2008; Petchey and Clark 2011).

Bone

Faunal bone is another sample material that is commonly used for radiocarbon dating. Similar bridging arguments as those applied to charcoal and marine shell are applicable. Assuming there is a suitable candidate sample for dating, the big dating challenge is to remove all contaminants from the bone (soil humates and other soluble organics) to insure the isolation of endogamous bone collagen for dating. The difficulty of radiocarbon dating bones has been well known for a long time. Stafford et al. (1988:2257) summarize these problems:

> The majority of bones that are used for radiocarbon dating and stable isotope analyses have undergone moderate to severe diagenesis and are often contaminated with substantial amounts of humates and other foreign organic matter (Table 1 [not shown here]). As diagenesis proceeds, chemical properties of bone protein are lost and it becomes increasingly difficult to separate endogenous organic carbon from humates and other foreign organic matter. Time, temperature, and burial conditions contribute in a complex manner to alter bone organic matter; however, major categories of fossil bone are distinguishable by their physical-chemical characteristics (Table 1 and 2 [not shown here]).

By isolating individual amino acids in collagen, reliable AMS dating of bone is possible (Stafford et al. 1991). There are currently two pretreatment protocols that can effectively and reliably isolate contaminant-free collagen. The older of these methods relies on the XAD-2 resin protocol (Stafford et al. 1988, 1991). The more recently developed method is that of ultrafiltration (Bronk Ramsey et al. 2004). Most commercial laboratories are now using this technique, but it is important to find out specifically what pretreatment protocol is used prior to submitting a sample. Both are accepted techniques for dating bone, and have demonstrated a very high level of reliability. One of us (JSA) has used the XAD-2 resin protocol extensively in his research in a wide variety of contexts, and has even performed his own independent evaluations (Athens 1995:99–100, 1999:179–182). His results have been consistently excellent for bone dates. These techniques allow the accurate dating of even the smallest bird bones. Note, however, that dates obtained from bones subject to ultrafiltration or XAD-2 pretreatment are not automatically reliable. A suite of quality control data must accompany all bone dates, or the dates cannot be properly evaluated. These include %N and %C, with C:N and %yield also valuable measures.

An added twist that must be considered in the calibration of radiocarbon dates obtained from bone samples is the possibility that the organism had obtained its diet either exclusively from the marine environment (e.g., seabirds), or from a mixture of atmospheric and marine reservoirs. For the latter, it can be assumed that pigs, dogs, and chickens could have been fed the scraps of a traditional Hawaiian diet consisting of starches (atmospheric reservoir) and sea food (marine reservoir).[6] Isotope measurements ($\delta^{15}N$ and $\delta^{13}C$) can differentiate the varying components of the organism's diet, and if a marine fraction is identified, the ΔR problem needs to be addressed. For animals that fully subsisted on terrestrial resources (e.g., forest birds), this would not be an issue.

In this vein, it is of considerable interest that recent dating research on bones of the Dark-rumped Petrel (*Pterodroma phaeopygia*) found almost no marine reservoir variation. This is certainly the result of this seabird's exclusively pelagic and wide ranging feeding habits (as opposed to feeding near shore and in areas of upwelling where the marine reservoir can be highly variable). A ΔR value of 54±20 years was calculated from 28 pre-bomb petrel bone museum specimens from Hawai'i (Welch et al. 2012:3731, A. Welch pers. comm.). Because of the demonstrated low variance of ΔR values in these samples, it is now possible to correct for the marine reservoir with a high degree of confidence for archaeological specimens. Thus, with the use of proper bone dating protocols (XAD-2 or ultrafiltration pretreatment), archaeological petrel bones should produce radiocarbon determinations at the same level of accuracy as properly pre-treated charcoal samples run on short-lived plant taxa or plant parts.

To summarize, bone dates are reliable only if either the XAD-2 resin or ultrafiltration pretreatment protocols are used. Without use of one of these protocols, the bone date will always be subject to question due to potential contamination. In science, of course, even the best methods must be subject to continual evaluation, re-evaluation, and refinement, and perhaps XAD-2 resin or ultrafiltration will be modified or supplanted by better techniques in the future. But for now, we know that lack of proper pre-treatment of bones leads to dates that are inherently unreliable to a high degree and only serve to confuse our understanding of the past.

Bulk Soil

Bulk soil samples are occasionally dated in the absence of other more suitable samples. Except perhaps in very special circumstances, the dating of bulk soil should be avoided since the origin of the organic material in the soil is uncertain (probably incorporating a range of organics of different ages and from different sources), and there is no way to know if these organics are contemporaneous with the archaeological event one wishes to date. For example, the dating of a bulk sample from a paleosol that is a cultural deposit will produce an averaged age for the development of the soil. However, the formation of the soil may pre-date the use of this surface for cultural activities, which in turn are documented in the archaeological record.

A special case of dating bulk soils occurs in the dating of soils derived from wetland or lake sediment cores. This work is often undertaken for paleoenvironmental studies. While dating soils in cores generally should be avoided in favor of wood, seeds, or plant parts (except roots), it is sometimes the case that such materials are not present. Fortunately, however, the dating of bulk soil in wetland or lake cores is often not as perilous as dating bulk soils from archaeological sites. This is primarily because wetland or lake core soils are often highly organic, with the organics mostly deriving from biological processes within the wetland or lake. After the death of the various micro and macro organisms, their organic remains fall to the bottom of the wetland or lake and accumulate over time, eventually forming a potentially lengthy stratigraphic record.

While most of the organic materials in wetland and lake soils usually derive from biological processes within the wetland or lake (endogenous), some exogenous organics may enter the aquatic system through alluvial and colluvial processes (and to a more limited extent, by aeolian means). These exogenous materials eventually become deposited in the wetland or lake sediments along with the endogenous organics. Pollen from terrestrial plants growing in the watershed of the lake or wetland is one type of exogenous organic material that enters these aquatic systems. The pollen will be essentially contemporaneous with biological processes occurring within the wetland or lake, and it is eventually deposited with the organic remains. However, there is always the possibility that some of this exogenous material may have eroded from earlier terrestrial deposits and hence would not be contemporaneous with other organics from the wetland or lake. Thus, in theory, there is the potential that radiocarbon dates performed on bulk sediments in cores could have an older age than the actual time of deposition, depending on the amount of older exogenous material that entered the wetland or lake. In actual practice, however, this problem is not usually a real concern, probably because the quantity of the older material that may enter the lake or wetland tends to be extremely low and is overwhelmed by the contemporaneous organics.[7]

Thus, unlike terrestrial soils, there tends to be little opportunity for the admixture of significant exogenous organics to wetland and lake sediments. But, if there is reason to suspect that a great deal of soil has been carried into the wetland or lake by alluvial and/or colluvial processes, then the investigator should be wary about the accuracy of bulk soil dates in the affected core intervals. This may be the problem with the Mangaia Island core records, which were based entirely on the dating of bulk sediments, described as "organic detrital muds" (Kirch et al. 1992:175; see also Kirch and Ellison 1994). These records clearly document the advent of Polynesians on the island, though the analyzed cores suggest this happened at a time too early to be compatible with local and regional archaeological records (Anderson 1994:847). According to Kirch (pers. comm. 2011), this "error" in the core dating records may be a result of the massive erosion of the island that occurred with Polynesian settlement, which then loaded the wetlands surrounding the island with older organic carbon derived from these sediments. Alternatively (or in conjunction), it also could be, to a greater or lesser extent, the result of the dissolution of ^{14}C-depleted makatea reef limestone that surrounds the coastal wetlands on Mangaia.

The problem is that makatea limestone (or any limestone) gradually dissolves due to exposure to water, which may derive from its exposure to water in a bordering lake or pond, and also from rain water that falls on the makatea limestone and drains into the basin. Upon entering the wetland or lake, the ^{14}C-depleted carbon from the limestone is metabolized by algae and other organisms. As the remains of these organisms constitute the bulk of the detrital organics in wetland or lake sediments, a radiocarbon date on them will result in an age that can be significantly older than their true calendar age. A graphic example of this problem may be seen in the Ordy Pond core at Barbers Point on O‘ahu (Athens et al. 1999:63–65; see also Uchikawa et al. 2008). The algal dates in this core are 1,000 to 1,500 years older than their calendar ages, and show some inversions. Subsequent radiocarbon dating of terrestrial plant seeds in the core, which documented the expected progression of age with depth, proved the inaccuracy of the algal dates, which were also inconsistent with chronologically sensitive pollen types (e.g, Polynesian plant introductions).

Recently, the dating of biogenic sedimentary particles from coastal deposits on Guam (Carson and Peterson 2012) and the Marshall Islands (Weisler et al. 2012) has been successful at determining the timing of beach deposit formations and their temporal relationships with archaeological strata. The utility and success of dating algal bioclasts and/or foraminfera by archaeologists in Hawai‘i has yet to be determined, although in theory they should prove beneficial.

Ash

Ash is the residue remaining from oxidized (combusted) organic remains, although less than 20% of ash may be extremely small particles of non-incinerated wood (Etiegni and Campbell 1991). The majority of wood ash, ranging from 13.2 to 98.4%, is calcium carbonate (Vance 1996), with potash, phosphate, and trace elements present in varying amounts depending on the combustion temperature (Demeyer et al. 2001).

Aside from the small particles of non-incinerated wood, ash deposits in archaeological sites are far from being pure ash as they are usually “contaminated” with organic remains absorbed from their depositional environments (e.g., soil humates). Along with the small particles of non-incinerated wood, extremely fine charred material (e.g., soot) may be present that is not detectable by the naked eye. Because the AMS method can date milligram-sized samples, the organic contaminates, miniscule non-incinerated wood particles, or soot in the ash can be dated. The wood particles and soot will give the date of a burn event, though it is up to the archaeologist to establish that the soot actually is associated with the archaeological target event. As a practical matter, it may be difficult to separate the tiny wood particles from exogenous organics, making soot a better choice of dating material. While there is some risk that the wood particles and soot do not necessarily derive from the burn event that produced the ash, this is probably a minimal concern in most situations. However, there is still the risk of dating material that derives from unidentified wood, which could possibly have a significant inbuilt age. Non-soot exogenous organics would not be appropriate for dating since they could derive from almost anywhere.

Regarding the dating of the ash itself, if the calcium carbonate ($CaCO_3$) in the wood ash formed at the same time as the burning event (by the formation of burn-residue lime [CaO] reacting with overlying atmospheric CO_2), then the date would represent the burn event (e.g., the date of the hearth feature). The caveat is that the hearth temperature that produced the ash has to reach 600°C for this chemical reaction to occur. With respect to the practicalities of dating calcium carbonate in wood ash, we have not been able to find any experimental literature that empirically demonstrates the value and/or limitations of this approach (see Taylor 1987:63–64; also Nawrocka et al. 2005 for discussions of dating $CaCO_3$ in lime mortar, based on the principles just described, but with some potential complications not associated with wood ash).

Our advice at this time is that ash samples should be avoided. Even if microscopic charred material is present, it cannot be taxonomically identified and thus the potential for inbuilt age cannot be assessed. The confounding issues of dating non-soot ash described above add further justification for avoiding this sample material.

Evaluating Radiocarbon Dating Results: Reporting and Synthesis

Obtaining reliable dates is one half of the process of addressing specific research questions as well as contributing to local and regional chronologies. The second half of this process involves evaluating and reporting the results. If this second step is adequately addressed, the task of developing a cumulative synthesis of radiocarbon dating information that could address a variety of research issues is greatly aided. Ideally, the archaeology community in Hawai‘i would develop an easily accessible, interactive on-line database for posting the dating results of their projects.

The most important step in the acquisition of reliable radiocarbon dating results should have occurred with sample selection. Once that is done, all pertinent information relating to sample provenience, material, dry weight, processing, and other details (catalog number, method of collection, etc.) should be carefully documented when reporting radiocarbon dating results. An example of the kind of table we like to see in both contract archaeology and academic technical reports and publications is shown in Table 3. Note that the table includes a column for specifically describing the archaeological event that the sample is intended to date, which in this case is the burned floor. In this example the determination will be a *terminus ante quem* date since the charcoal was not actually in contact with the floor but slightly above it. Thus, the floor should date *before* AD 1285–1401 (2σ), though presumably only slightly in this instance. There should be some explicit discussion in the text of the report or paper as to how the radiocarbon sample relates to the archaeological event that is to be dated.

Table 3. Radiocarbon Determination, Hacienda Zuleta Mound EE, GPR Grid 1, Floor Feature

Cat. No.	Lab. No.* Beta Analytic	Provenience	Event Dated	SubmittedWeight g/material	Age BP	$^{13}C/^{12}C$ ‰	Conventional Age BP	Calibrated Age AD**
Zul-09-14	279098	Layer I, 80 cmbs. (under vessel frags; ca. 1 cm above burned floor)	*terminus ante quem* date for burned floor	1.60 unidentified charred plant substance	370±40	-9.0	630±40	1285–1401

* AMS procedure used to date sample.

** Calibration from OxCal v. 4.1.7 (Bronk Ramsey 1995, 2001) using the IntCal09 Northern Hemisphere curve (Reimer et al. 2009).

The results of all radiocarbon dates must be accompanied by a determination of isotopic fractionation, represented as the $^{13}C/^{12}C$ ratio, which is used to calculate a "conventional" age for the sample (i.e., an adjustment of the "measured" age). Without correction for isotopic fractionation, the sample age may incorporate an error factor. Use of calibration routines on a non-conventional ("measured") date is inappropriate.

Calibration software (e.g., Calib and Oxcal) corrects for natural changes in the level of atmospheric ^{14}C that are known to have occurred over time. These changes are the result of variation "with the sun's solar activity and fluctuations in Earth's magnetic field" (Balter 2006:1560). Dendrochronology has provided a means to obtain precise information on past ^{14}C levels in the atmosphere, thereby allowing radiocarbon ages to be "calibrated" to their true calendar ages. Initially it was possible to calibrate dates only as early as about 12,400 years ago, but recent advances have extended the calibration curve back to 50,000 years (Fairbanks et al. 2005; Reimer et al. 2009). Calibration software is available as a free download, which allows users to easily calibrate "conventional" radiocarbon dates to calendar dates within the constraints of statistical probabilities. Calibrated results may be presented at one or two standard deviations (1σ [68.2%] or 2σ [95.4%]). It is advisable to discuss dating results at 2σ, as 1σ ranges are inaccurate nearly 33% of the time. When presenting calibrated dates, it is important to always cite the source of the calibration results.

Depending on one's research problem, further evaluation and analysis of radiocarbon dating results may be warranted using one or more methods, such as chronometric hygiene (e.g., Spriggs and Anderson 1993), date classification (e.g., Rieth et al. 2011; Wilmshurst et al. 2011), and Bayesian statistics (Buck et al. 1991, 1992, 1996; Dye 2010, 2011). Calibration software packages (e.g., Calib and OxCal) also allow pooling of dates, calculation of depositional rates, graphical presentation of data (Figure 1), and other analyses.

Syntheses of Hawaiian radiocarbon dates have been compiled and published during

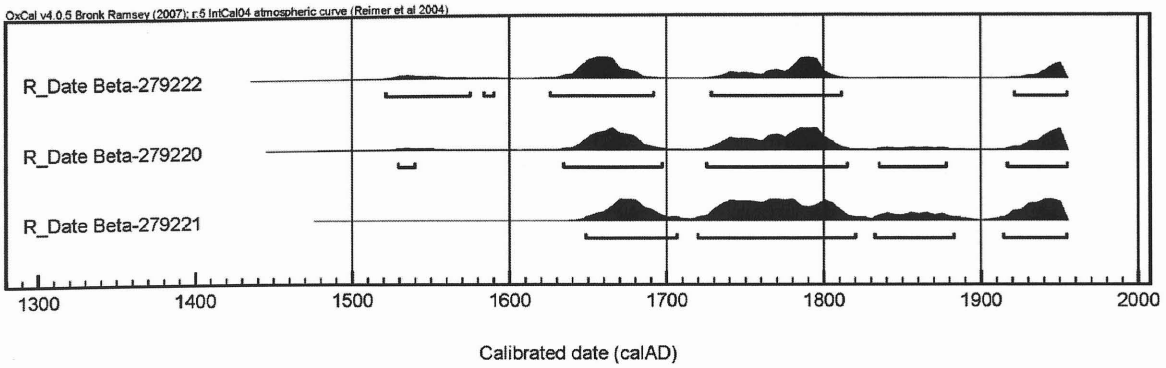

Figure 1. An example of graphics displaying radiocarbon probability distributions created using Oxcal v4.0.5.

the last several years for Kaua'i (Carson 2005), Moloka'i (McCoy 2007), Hawai'i Island (Rieth et al. 2011) and Maui (Duarte 2012). No comparable datasets have been created for O'ahu, Lana'i, Kaho'olawe, Ni'ihau, and the Northwest Hawaiian Islands. Although these published date assemblages are valuable and hard won resources, by their nature they are static. By the time these compilations are generated and published, they are already obsolete as a result of many new determinations having become available in the meantime. An interactive database, therefore, is necessary to create a dynamic dataset that can be updated by users as new dates are obtained (or at least as reports and papers are made public), thus increasing the accessibility and efficiency of the cumulative radiocarbon dating results. The Society for Hawaiian Archaeology or State Historic Preservation Division websites would be logical hosts for such a database.

Conclusion

We have presented the primary factors that archaeologists can control to maximize the value of their radiocarbon dating efforts. The "best practices" outlined in this paper serve as general guidelines when considering the selection of samples for radiocarbon dating, specifically in relation to the sample provenience and sample material. These considerations should be part of a chain of logic linking the radiocarbon event and the archaeological event of interest. We believe that these guidelines offer a sound starting point for any archaeological dating endeavor. However, this presentation is no substitute for archaeologists having first hand familiarity with the radiocarbon dating literature and keeping up to date with advances in radiocarbon dating technology and other absolute dating techniques.

Notes

1. This paper resulted from a resolution passed at the 2010 Society for Hawaiian Archaeology general membership meeting. Rob Hommon wrote the resolution and was a strong advocate for the importance of this topic.

2. McFadgen (1982:384), using the term "inbuilt age" explains the problem thusly: "Trees live several hundred years, but are dead inside, and central tree wood may be as much as several hundred years old when the tree dies (growth age). Trees may last many hundreds of years after they die before rotting away (storage age). Inbuilt age is thus growth age plus storage age. A sample of wood or charcoal used to date an event may thus be several hundred years older than the event itself."

3. As another example of the kind of wasted research effort we are talking about, consider Stannard's (1989) model of population growth in Hawai'i and the population numbers he calculates in the islands at the arrival of Captain Cook in 1778. His figures are based in part on his assumption that Hawai'i was first settled by Polynesians about 1,800 years ago (Stannard 1989:32-33), a time based on what he considered to be a conservative reading of the available radiocarbon dating evidence. We now know that Hawai'i was first settled much later, with some suggesting a time frame in the range of 950/1000-1100 AD (Athens 2009:1499; Dye 2011; Kirch 2011), and others concluding it was approximately ~1200-1250 AD (Duarte 2012; Rieth et al. 2011; Wilmshurst et al. 2011). While it is conceivable that Stannard's (1989:59) end point conclusion that "it seems likely . . . that a figure higher than 800,000" people were present in Hawai'i at contact could be approximately correct in a fortuitous manner, at least one important aspect of his analytical assumptions used to arrive at this conclusion—the initial colonization date—is seriously flawed and essentially undermines the strength of his argument (see Hommon 2010:53-57 for recent research on population size at contact in Hawai'i).

4. *Terminus post quem* is an expression indicating the earliest time an event could have happened. Thus, an historic coin in a burial indicates that the burial must date *contemporaneous to* or *after* the date on the coin. This contrasts with *terminus ante quem*. An archaeological example of a *terminus ante quem* date would be the age of a floor that underlies a wall of a known age. The *terminus ante quem* date for the floor must be *before* (not later than) the date of the wall.

5. A wood anatomist can also separate lignite from the charcoal dating sample, something that was an important concern for obtaining reliable radiocarbon dates from Palau (Liston 2005:301; Gail Murakami, pers. comm.).

6. Obviously, this applies to dating human bone, which is currently a moot issue in Hawai'i. Prior to the Native American Graves Protection and Repatriation Act (NAGPRA), the 1990 amendments to Chapter 6E, Hawaii Revised Statutes, and adoption of its implementing administrative rules (Chapter 13-300, Hawaii Administrative Rules) in 1996, dates were obtained from human bone without the calculation of isotope measurements. Therefore, the reliability of these dates will always be open to question.

7. However, we have recently learned that investigators dating soil samples from wetlands need to be cautious about this assertion. The Weli Fishpond core (Athens and Ward 2000), recovered from the now-filled wetlands of the Ft. Shafter flats area of Honolulu, provides an instructive case in point. A recent reconsideration of the chronology of this core, which was based on radiocarbon dates on bulk soil, shows that the initial appearance of forest changes and evidence for Polynesian colonization is about 200 years earlier than demonstrated by the Ordy Pond core of the ʻEwa Plain (Athens et al. 2002). Assuming that both cores should date these changes to the same time, the dating difference likely reflects the presence of small amounts of exogenous older carbon in the Weli soil samples. It was presumably derived through colluvial and fluvial processes affecting the wetland. In contrast the Ordy Pond dates were all derived from short-lived plant parts (see Athens et al. in prep. for full presentation of the argument). While the dating difference between the two cores is not huge, it is quite significant for Hawaiian archaeology.

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