# Chapter 15
# Palms for the Archaeologist

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## 1 Introduction

If your historical/cultural/linguistic past harks back to temperate Europe or colonial North America, and you speak English, when you think of *trees* you might envision apple (*Malus*), ash (*Fraxinus*), beech (*Fagus*), birch (*Betula*), cedar (*Juniperus*), chestnut (*Aesculus*), elm (*Ulmus*), hemlock (*Tsuga*), maple (*Acer*), oak (*Quercus*), olive (*Olea*), or pine (*Pinus*). Trees give shade, sugar, fruit, and nuts; trees underpin our material realm, providing studs, shingles, clapboards, rafters, keels, and masts. Trees serve as rich symbols, as metaphors for knowledge and life (the two trees of Genesis), death and afterlife (Calvary, Revelation 22), and a host of relationships (family trees, phylogenetic trees, cladograms). Nations often choose trees for symbolic representation: in Wikipedia's Listing of National Trees (accessed 2020); 17 out of 86 in the sample are members of the genus *Quercus*, the most named genus, associated with mainly European nations, English speaking or not. Four countries designate *Pinus*. *Pinus* is classified as neither monocot nor dicot sensu *lato*, as is also the case for cedar and hemlock, but rather as gymnosperms, aka Acrogymnospermae. The USA is one of the 17 nations that goes with oak; Canada opts for maple. Six countries (Cambodia, Columbia, Cuba, Haiti, Maldives, Saudi

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Arabia) picked palms—monocots—but by far the international leaning is toward dicot trees.

Palms also figure symbolically, not only in ancient Mesopotamian religions, but also in the Near East and in the Mediterranean, particularly making reference to one of the arguably oldest cultivated plants, the date palm (*Phoenix dactylifera*). Worldwide, palm symbolism plays important roles in the Bible, in Christianity's rituals of Palm Sunday and Holy Week, and in Judaism's prayers of the feast of Sukkot. Symbolic referents include peace, victory, and eternal life. Many of these symbolic referents are to leaves, as in the palm crosses of Palm Sunday. In North America above the normal ecological range of palms, we often have observed two types of palms—one of artificial materials such as plastic, and the other of transplanted palms that might only survive the summer season, especially when planted in temperate regions. Both types of palms decorate pleasure destinations like casinos, water parks, miniature golf courses, and the ubiquitous Tiki bars and restaurants. The symbolic intent: to create the aura of a tropical paradise, often associated with but not solely coastal areas. Hundreds of palm individuals grown in nurseries in the southern USA travel by the truck load to more northern destinations every spring. We know of one Chincoteague Island, Virginia (USA), miniature golf course owner who successfully beats the winter kill by wrapping his palms in clear plastic (and therefore protecting the only apical meristem characterizing palms). Another miniature golf course just across the street displays plastic palms. Not far away, a restaurant on Chincoteague Bay buys replacement palms every year for its outdoor dining area. The latter may reflect how inexpensive palms have become in nursery centers in the past two decades.

We would suggest that in the temperate European and North American subconsciousness, the culturally assigned attributes of trees in the dicot and the gymnosperm genera mentioned above include endurance, solidity, strength, durability, connectedness, and transcendence. Part of the conceptualization also embraces such basic attributes as bark, branching, grain, tree rings, and roots (as in root metaphor—Google "root metaphor" and see what you get!). If you think of trees in this folk taxonomic way, and then you project that schema onto palms, you may inadvertently make some dissonant assumptions about palms. If your cultural image of "treeness" morphs to palms, you might expect palms to branch above (which occurs naturally only in the palm genus Hyphaene) and below (roots) ground, to be solid through and through, to float, to build watercraft, and perhaps to exhibit inbuilt age.

## 2 Monocot/Dicot sensu *lato* (Including Early Angiosperms and Eudicots)/Gymnosperm

We begin with a comparison of monocot and dicot sensu *lato* characteristics, and then will add commentary on conifers, classified among gymnosperms. Monocots and dicots sensu *lato* are Angiosperms (Angiospermae) or flowering plants. Cotyledon (as in cot- or -cot) refers to the first embryonic leaf or the seed leaf in plants.

Dicots sensu *lato* (Class *Magnoliopsida*) have two cotyledons in the embryo; the resulting plants are labeled dicotyledons. Characteristics of dicots sensu *lato* include pollen with three or four furrows, multiples of four or five flower parts, reticulated leaf veins, vascular bundles arranged in a ring, and roots that emerge from the radicle in the lower part of the embryo, and the phenomenon of secondary growth in stem diameter, with cambium present (Monocots versus dicots 2020). Examples include trees mentioned above such as oaks, maples, beech, and birch (excepting cedar, hemlock, pine), and also other plants like roses, cacti, lettuce, tomatoes, and legumes like peas and beans.

Monocots have a usually single cotyledon in the embryo, single pore or furrow, multiples of three flower parts, parallel rather than reticulate or branched leaf veins, vascular bundles (issued from a primary meristem called procambium) dispersed in the stem rather than located in a ring, adventitious roots emerging from the basal regions of the stem, and the lack of secondary growth, with cambium absent. Examples include palms, wheat, and also corn (maize), sugar cane, bamboo, grass, tulips, and onions. For a useful summary of differences between Monocotyledonae and Dicotyledonae (in modern classifications further split into early divergent angiosperms and eudicots or true dicots), see Tomlinson (1990: 133-135).

Conifers, in the USDA classification system (USDA plants database, n.d.), members of the division Pinophyta, aka Coniferophyta or Coniferae, include cedars (Genus *Juniperus*), pines (Genus *Pinus*), and hemlocks (Genus *Tsuga*) (all three exemplified here are of the family Pinaceae). These share many general “treeness” characteristics with dicot trees such as tree rings, grain, branching limbs and roots, and compact, solid interiors. Unlike angiosperms, double fertilization (producing the embryo and the endosperm) lacks in this group. As gymnosperms, the seeds are described as naked and in the Pinaceae are produced in cones. The Pinaceae are monecious (male and female cones present in the same individual), are resinous, and have needle-like leaves. In material culture terms, conifers like cedars, pines, and hemlocks can be used for timber just as with dicot trees—including masts, beams, flooring, clapboards, studs, and shingles.

We will briefly note here in this classification section that preferred trees for Polynesian canoes such as *Alphitonia zizyphoides*, *Elaeocarpus raratongensis*, and *Acacia koa* are dicots in the USDA classifications system.

## 3 Structural Differences

What are some of the structural differences involved, trees of the dicots sensu *lato* and gymnosperms persuasion versus monocots? From this point on, we will use the term “DG” trees to refer to the dicots sensu *lato* and gymnosperm tree contingent and “AP” trees to refer to palms in the order Arecales and the family Arecaceae or Palmae (187 genera, 2600 species), as in the genera *Cocos*, *Jubaea, Juania*, *Roystonea*, and *Syagrus*.

DG trees grow by adding rings of xylem (usually dark colored, in which water and nutrients are transported up; xylem position is inner in respect to phloem) and phloem (usually light colored, and which conduct sugars and metabolites down or up; phloem position is outer in respect to xylem) which are separated by cambium. The cambium generates the xylem and phloem, and is shielded on the outside from the elements by cortex or outer bark. As the DG tree develops, newly generated xylem and phloem rings surround the former rings with the old rings becoming sapwood—or what might be called dead carbon. In temperate regions, DG trees usually add a xylem/phloem ring set each year. Typically, but not without exception, a faster growing, lighter colored part of the ring develops in the early season (early wood) followed by a darker colored part of the total ring (latewood). Complications: false bands may be generated, and in tropical regions, multiple rings sets may be generated within a year.

But what we wish to emphasize here is that temperate or tropical, the sapwood in DG trees is relatively hard, compact, and consistent from periphery to center. Rings are visible in cross section in the stem, and vertically, are perceptible as grain when split or sawn. As the DG tree grows, the tree expands in width and height by adding rings issued from secondary growth. Because of this phenomenon of internal consistency, a DG tree can make a serviceable beam, stud, clapboard, or shingle for a building, or a gunnel, lapstrake plank, keel, or mast for a vessel.

AP trees differ substantially in their structure from DG trees. Here we will focus mainly on the stem (vs. the DG trunk), but major differences occur also, for example, in the adventitious root system, in leaf development from the apical meristem, and in the general lack of branching (with the exception of the genus *Hyphaene*, or originated by injury of the stem). For a convenient summary of differences, see Hodel (2009). For extensive information, see Tomlinson's volume *Structural biology of palms* (1990).

In cross section, AP trees possess an outer cortex surrounding a central cylinder. Hodel describes it this way:

> In cross section, the palm stem has two distinct regions, the cortex and central cylinder (Fig. 15.3) (Tomlinson 1990). The cortex, a very narrow band on the outside of the stem, has a thin outer covering or skin composed primarily of thick-walled, sclerified (hardened) cells, which is sometimes referred to as pseudobark, although it has no relation to bark of dicotyledonous and coniferous trees. Relatively unspecialized parenchyma cells, which may become larger, more numerous, and lignified (woody) with age, compose most of the remainder of the cortex. [Hodel 2009: 678]

The pseudo bark and cortex represent a relatively small proportion of the total stem diameter, but the cortex can be quite hard and also brittle. Unlike DG trees, there is no peripheral cambium supporting secondary growth as most of the vascular tissue will develop from a primary meristem procambium and be characterized by its limited growth. What is really in stark contrast to DG trees is that the central cylinder, which occupies most of the area of the palm stem, is composed almost entirely of vascular bundles—not tree rings. The vascular bundles contain the phloem and xylem and each of these vascular bundles is partially or entirely enclosed by "a strong, hard, fibrous sheath" that provides efficient resistance to the palm stem. Much of the support for the palm stem derives from these bundles (Hodel 2009: 678). The vascular bundles are

> embedded in a mostly homogeneous, light colored ground tissue made up of largely unspecialized parenchyma (Dransfield et al. 2008; Tomlinson 1990). The parenchyma cells which store water and carbohydrates such as starch, tend to become woody with age, especially those toward the outer part of the central cylinder, while those toward the center of the central cylinder are mostly spongy and unlignified (Tomlinson 2006). [Hodel 2009: 678]

The proportion of cortex to central cylinder is quite small. William Liller observed *Jubaea chilensis* in Las Campanas, a Chilean National Park, and inspected two dead palms. Gurley and Liller report schematic densities ranging from 210 to 540 kg/m$^3$ (1997:83) and the thickness of “the tough outer bark, or pericarp which averaged 5 millimeters in thickness and with a density of from 1300 to 1640 kg/m$^3$.” This density they state is similar to that of bone or ivory and is “denser even than *lignum vitae* or ironwood” (Gurley and Liller 1997: 84). In their Figure 3, “Schematic density distribution in a mature *Jubaea chilensis*” they illustrate a transition zone between the “pericarp” and the “fibrous” interior of 20 millimeters. Flenley and Bahn repeat the 5 millimeter figure for the “outer bark” (2002: 124), accompanied by ill. 34, a photograph, “A cross-section of a Chilean wine palm, showing the thin, hard rind and fibrous interior” (they cite Gurley and Liller 1997). Note that the term pericarp usually and technically relates to the fruit and corresponds to the outer layers of the fruit wall, in turn divided into the three regions endocarp, mesocarp, and exocarp, but in Gurley and Liller, it refers unconventionally to the outer bark. Later we will return to Gurley and Liller (1997) and Flenley and Bahn (2002) in respect to the possibility of using palms for rollers under the *moai*.

Whereas DG trees have a continuously hard, solid, and dry interiors, AP trees like *Cocos nucifera* and *Jubaea chilensis* (and likely the extinct *Paschalococos disperta*) possess relatively soft interiors compared to the outer cortex. First, we would call attention to the AP cortex which represents quite a small proportion of the total diameter. In Figs. 15.1 and 15.2, we show cross sections of fresh cut coconut palm and royal palm stems, respectively, kindly donated to us by a road crew on Molokai. A knife marks where it is very easy to insert the blade as the denser cortex is approached. There is no apparent tissue border here; rather, it is a simply a matter of increasing density of the vascular bundles as the outer edge is approached. As Tomlinson (1990:126) writes about palms in general, “The boundary between cortex and central cylinder is represented only by an abrupt transition in texture of ground tissue and density of vascular bundles; there is no limiting endodermis or other specialized boundary layers.”

The tape measure in Fig. 15.1 of the coconut palm stem shows about 0.5 inches (ca. 13 mm) thickness of cortex in a stem diameter of about 8 inches (ca. 20 cm). The cortex would thus represent about 12–13% of the radius or the diameter. The remaining ca. 87–88% of the central cylinder is much softer and less tightly packed. In Fig. 15.2 of the royal palm, the cortex measures from about 0.75 to 1 inch (ca. 19 mm to 25 mm) in width, in a diameter of about 13.5″ (ca. 34 cm), representing

**Fig. 15.1** Stem segment of coconut palm, Molokai (Hawaii). The scale is inches, 2.54 cm/inch, The knife marks the easy insertion point, at ca ½” or about 10 mm, between the cortex and the central cylinder. Photograph by authors, 2012

**Fig. 15.2** Stem segment of royal palm, Molokai (Hawaii), showing loose vascular bundles. Photograph by authors, 2012

about 14% of the radius or diameter. Compare these proportions to those of Gurley and Liller's *Jubaea chilensis* stem transition zone (roughly equivalent to where the knife blade is located in Figs. 15.1 and 15.2) of 40 mm (20 × 2) out of 1 meter stem diameter: about 4%. The illustration of a complete cross section of an actual 0.6 m *Jubaea chilensis* stem, shown in Guzman et al. Fig. 3a (2017:188) we suggest, shows proportions of cortex to central cylinder similar to our Figs. 15.1 and 15.2 coconut and royal palm examples.

When freshly cut, the palm stem central cylinder is rich with moisture and carbohydrate like starch and sugars—in the fundamental parenchyma, in the vascular bundles—perhaps especially in the case of the wine palm, *Jubaea chilensis* (see output values later in this chapter). In our 2012 Molokai experiments, when son-in-law Jon Smith and we put newly cut royal and coconut palm stem segments in a barrel full of freshwater, we were surprised when the segments sank. The same test applied to dry segments of royal and coconut palm: the segments floated but initially with only about 1/8 of their diameter above the surface; over the next few days, the segments absorbed water and were barely breaching the surface.

In 2009, we may have experienced a premonition of this phenomenon: when snorkeling in a restored Molokai fish pond, we observed palm logs underwater. We wondered at the time, why were they sunken? In 2012, we conducted a survey of several miles of Molokai's west and south shores. Although we saw lots of palms by the shore, we saw no palm driftwood except immediately in front of two eco-camps where they had been cut down but had not traveled very far. The lesson we learned: those vascular bundles which comprise such a massive volume of the palm stem central cylinder can retain or lose massive volumes of moisture; we also suspect that the fundamental parenchyma is able to retain substantial amounts of water. Unlike the hard and dry interiors of DG trees, the central cylinders of palms are like thousands of liquid-filled pipes while the palms are alive. When newly cut and fresh, the palms we tested had a specific gravity greater than fresh or ocean water.

An index of how much moisture a palm stem can harbor is in the amount of sap. According to Bork and Mieth, a medium-sized trunk of *Jubaea*, about 10 m in height and about 0.5 m in diameter could have "nearly 2 $m^3$ of trunk wood." Bork and Mieth report possible volumes of sap from 300 to 400 liters (citing Darwin 2001; Rundel 2003–04; Grau 1998; and Orliac 2003) for the central region of Chile. For their purposes, Bork and Mieth estimate 50–150 liters (Bork and Mieth 2003: 120, 121). Delhon and Orliac repeat the approximately 400 liter volume in a subsequent publication (2007:97). Incidentally, the usual method reported for obtaining sap involves felling the palm rather than tapping it like in other African (*Borassus*, *Elaeis*, *Hyphaene*, *Raphia*) or Asian palms (*Arenga*), or in dicots sensu *lato*, such as the maple tree, removing the fronds, making a cut at the apical meristem, and capturing the drip. In other parts of the world, palms are repeatedly climbed to tap their inflorescences (*Arenga*, *Caryota*), which the palms can survive (Dalibard 2009). Felling was the means reported by Darwin (1845: Chapter XII, August 16th), who noted the palm would be felled up slope rather than down slope.

One cubic meter equals 1000 liters; if the high value of 400 liters derives from about 2m$^{3,}$ of stem volume, that is about 20% of the stem volume. We recommend that you visit the link for Darwin (1845) for a fascinating description of his palm sap comments.

When dead and dried out, however, the vascular bundle tubes are as dry and flexible as broom straws. In Fig. 15.2, this condition is especially visible in a dry stem segment of royal palm. The vascular bundle tubes can easily be drawn out by hand like straws. With the blow of an axe, these palm stems, both in the royal and coconut segments, are surprisingly brittle and can be readily split in the vertical dimension. Notice the already existing cracks in the cortex in Fig. 15.2. Remarkably, once split open, we found that the vascular bundles in coconut and royal palms could be removed by hand, no tools needed, thus totally evacuating the central cylinder. Granted, coconut and royal palms are not *Jubaea chilensis*, but in Fig. 3a in Guzmán et al. (2017), the *Jubaea chilensis* cross section although larger in diameter appears similar in central cylinder vascular bundle arrangement and proportion. The fact that all three genera are phylogenetically related may suggest a common stem structure, particularly visible through the density and the arrangement of vascular bundles in the stem.

One implication of the moisture and nutrient-rich vascular bundles of the central cylinder includes the propensity for rapid decay. In a very short time, a downed palm (coconut we think) can look like the one shown in Fig. 15.3, at Anakena. Here, not only is the central cylinder in a state of advanced decay, but so is the cortex. Incidentally, it has observed the paucity of palm charcoal on Rapa Nui (Delhon and Orliac 2007: 99; Rull et al. 2010:58). Could it be palm's tendency to rot rapidly? On

**Fig. 15.3** Rotting coconut palm at Anakena (Rapa Nui). Photograph by authors, 2010

arid western Molokai, following the suspension of irrigation at a golf course and at an eco-camp, we noted subsequent death and toppling of substantial palms followed by rapid decay; the time frame was two to three years. Indeed, a large majority of palms need high ground water, whereas only a limited number of palm genera (i.e., *Hyphaene*, *Medemia*, *Washingtonia*) are truly adapted to xeric conditions.

> As for the commonly asked question as to how the discoverers [of Rapa Nui] did not witness the traces of thousands of collapsed trunks that would have resulted from extermination we have found an answer in the fact that the author once revisited a palm orchard after a 60 period, where hundreds of cut palms once covered the ground. Surprisingly, there were no traces of them (Fig. 9). The putrefaction process that goes from inside out is the answer. The process starts in the fiber-vascular tissue and advances toward the bark (Grau 2005:32)

The trunks Grau mentions were massive *Jubaea chilensis* trunks about a meter in diameter, felled for their sap, in a palm forest where he camped as a youth all those years ago (Grau 1997: 124). Compare this outcome to long-dead (since ca. 1915), blight-killed American chestnut (*Castanea dentata*) trees one of us observed in the Quabbin Reservoir (central Massachusetts, USA) which were still being taken to sawmills to make barn timbers in the early 1970s. Similarly, Holmes (1981:17) cites foresters stating fifty to seventy years might be required for the decomposition of *koa*. In terms of archeological evidence, much of palm stem biomass, unless perhaps charred, would seem likely to be lost, excepting phytoliths.

## 4 Canoes? Rollers and Sledges? Lumber?

### *4.1 Canoes?*

Because in the majority of AP trees, the central stem cylinder is composed of vascular bundles and is not solid and compact compared to DG trees, we suggest that the AP stem in general is not a good candidate for canoe keels, planks, or ribs. On the one hand, because the central cylinder vascular bundles can be very wet, rendering the total stem mass of greater specific gravity than water, the palm would not float if fresh. On the other hand, if the vascular bundles have become desiccated, then the risk is a sponge-like effect of water absorption, waterlogging the craft. If the mass of flexible vascular bundles is removed in the central region of the trunk, only the thin brittle cortex remains. This cortex would not be a suitable material for the keels of an ocean going double voyaging canoes, in part, because palm stem cortex could not be shaped or carved in the manner of DG trunks, as in the Hawaiian case (Jones 2007: 307, 2011: 86–87; Holmes 1981:8) where the keels were carved from solid logs and then plank sides were built up, or a large tree provided the entire hull. If the cortex is split longitudinally into planks for lapstrake (clinker built) or non-lapped (carvel-built) hull application, the challenge of dealing with the latitudinal curvature of the cortex planks presents itself. Constructing a canoe hull by sewing curved planks together in the manner of the Rapa Nui canoes observed by Europeans like Forster or de la Pérouse (see Flenley and Bahn 2002:37, Fig. 14, and Boersema 2015:17, Fig. 2.5) would be difficult. Over 20 years ago, Hunter-Anderson, in a long passage citing several sources and individuals, addressed disadvantages of palm for watercraft: "…it does not float well… impossible to shape by adzing… it sinks…it swells and contracts with heat and cold… (1998: 87-88). Whistler, in his book, Plants of the Canoe People: An Ethnobotanical Voyage through Polynesia comments "Undressed coconut timber is very strong and is used over much of Polynesia for posts and fences, in the framework of houses, and in many other ways, but is too heavy for planks or canoes" (2009: 74).

In the literature on world watercraft, Hunter-Anderson (1998 footnote 2, p. 97) found one example: "The only recorded case of palm wood being used for a canoe is on tiny Arorae, a low coral island in the and [sic] southern Gilberts (Kiribati) (Alexander 1902: 727). It is unknown if these canoes were used in the open ocean, or whether they were sailing canoes." We found another example (Ingersoll and Ingersoll 2016) of a type of canoe made by the Iquitos in the Peruvian Amazon of large palms (*Iriartea deltoid*ea), used to carry people and cargo downstream. The canoes were made quickly in a day or two (easy to hollow out!), took the downstream journey, and were then abandoned and not used for anything else such as fishing (Johnson and Mejía 1998: 208). They wrote "[p]alm canoes are temporary watercraft." They emphasized the vulnerability of the bow and stern, and noted that keeping the canoe in the water was needed to prevent drying and cracking. Our search through the Pacific watercraft literature in sources such as Hornell (1936) and Pâris (1843) for palm watercraft hull construction of palm yielded no examples; however, palm sennit lashings and coconut outrigger booms in the Tuamotus (Hornell 1936: 21, 59) and leaf use (Pâris 1843) were reported. Although one observer (1839) cited by Hornell had claimed that small Napuka canoes had been made by sewing coconut strips together, Hornell wrote "Wilkes is presumably in error regarding the timber employed. The coconut palm is never used in the Tuamotus for canoe planking" (1936: 55). The use of *Borassus aethiopum* to make canoes has been reported in West and South Africa (Acheampong 2014:11, Balami et al. 2016: 59, Salako et al. 2018:7, and Zongo et al. 2018: 69). Salako et al. illustrate a small canoe (Benin) in their Figure 3.

If not ocean going double canoes, could palm rafts have been fashioned on Rapa Nui? Certainly, sailing rafts are well documented in the Polynesian Pacific. Green (2001: 70) wrote in his article on sailing rafts: "Van Tilburg (1998:144) also makes a sensible suggestion that palm log rafts may have once been present in Easter Island before the Chilean oil palm of that island went extinct, leaving only *nga 'atu (totora)* reeds from which to manufacture a small float type raft-like vessel seen at contact." We predict that a palm raft would 1) not float if made of fresh palm stems and 2) would soon become waterlogged and unnavigable after launch if made of desiccated palm stems. Personally, we would not board such a raft.

## *4.2 Rollers and Sledges?*

In the 2003 BBC documentary, *The Mystery of Easter Island*, the dialogue includes a line by David Steadman: "By the time palm trees got scarce on Easter Island everybody on the island knew they were in trouble. They loved palm trees, that's what, how they made their good canoes, that's how they rolled their statues. No palm trees equals we can't move our statues anymore." We have already reviewed canoe possibilities, but what about rollers and sledges for the *moai*? An extensive literature addresses a number of means of transporting the *moai*. How was it done is the question? Some of the transport models call for rollers—of palm.

We were skeptical, given the nature of palm cortex, that palm rollers could stand the stress and in that we were not alone. In a book review of Cotterell and Kamminga (1990), the review states that in reference to Mulloy's proposed method, the authors offer that the "rollers would have been squashed" (Recent Publications, Rapa Nui Journal 4(1): 3). Similarly, MacIntyre (1999:36) states that "palms are not known as good canoe material, and I would not move *moai* on rollers (although palms might make adequate pylons at the quarry) . . .". Even John Dransfield (2010), noted palm expert, wrote "there is absolutely no evidence that trunks of the extinct palm were suitable and could have been used in that way" (as rollers for the *moai*). Van Tilburg writes:

> The trees of Rapa Nui's prehistoric palm forest had a theoretical ability to attain smooth, cylindrical but uneven trunks more than 1 m in diameter. There is no evidence, however, that they ever attained this maximum size, nor is it clear that, if they did, their trunks would have been useful in statue transport. Rather, many "prints" of palm trunks embedded in hardened lava on the northwest coast of Rapa Nui (as documented by G. Figueroa) measure a less unwieldy 30 to 40 cm in diameter or less. [2009 np]

However, Van Tilburg (2009 np) conducted an experiment in a California construction yard with a pair of concrete Jersey road barriers set on a steel plate, barriers and plate combined yielding an approximate average statue weight, estimated at the time at about 12.5 m tons (Paro, the largest known *moai*, has an estimated weight of 75 m tons). These were placed on a pair of 7 m long 33 cm diameter palm trunks arranged in a V-shaped sledge form. Then the sledge was placed on rollers or sliders and then pulled by a fork lift truck. The "Results clearly demonstrate that palm wood is fully capable of bearing the requisite experimental load." Not specified is distance of travel, but even if palm stems eventually collapsed, more could be supplied; also not specified is the genus and species of palm, which could be important, as for example, the characteristics of date palm trunks would not be the same as *Roystonea* trunks. The experiment was then successfully repeated with eucalyptus logs. Without experimental evidence like Van Tilburg's, Gurley and Liller argued that mature palm trunks would make excellent rollers, "since the cylindrical form of the outer hardwood would support an estimated six tons before yielding, while the softer interior wood would provide a resilient inner spring" (1997:83). Previous studies in *moai* transport not by Van Tilburg reported *toromiro* for walkers, rollers, or sledges (Bahn and Flenley 1992:135, Love 2000:12). Grau thought that the palms would function as rollers for dorsally oriented *moai*, but over long distances *toromiro* trunks tied into a platform could be used to roll on top of palm trunks (1997:123). A reviewer of this chapter, an expert on Rapa Nui vegetation, disagreed with the suitability of *Paschalococos disperta* for rollers, given the stem structure of the palm deemed by many to be the most similar to it, *Jubaea chilensis*. The reviewer wrote "I have seen and touched transverse sections of *Jubaea chilensis*: the stem has an exceptional extensive very spongy part. I do not believe in the use of these stems as rollers for the moais. However, stem consistence of *Paschalococos disperta* might have been different."

Van Tilburg's experimental data argue that palms could function as rollers and sledges to move at least the average *moai*. Our next comment relates to palm supply and demand. If 19.7 million palms (Mieth and Bork 2018: 42) initially populated Rapa Nui and at least 887 documented *moai* were (Van Tilburg 2009) (additional *moai* may be located within ahu or covered by earth, etc.) created between about 1100 and 1680, an approximate 580 year time span, that translates into about 1.5 *moai* per year. Alternatively, if the palms were mostly gone within a 450 year time frame (Bork et al. 2019:153), that would be about 2 *moai* per year. Although Lee wrote of palms that

> [t]he land was cleared for crops, and the huge palm forests were cut down. The trunks of these trees likely were used as rollers to move the great statues, further decimating the groves of trees. By AD 1500, the population had spread over the island, the land was cleared (causing erosion and loss of productivity), and food resources were scarce. This is the Rapa Nui that we know the most about. [2004:113]

We suggest, conversely, that at about 1.5 to 2 *moai* per year, the specific draw on the palm population for *moai* transport rollers would be relatively minor, not approaching the level of decimation, whose historical meaning is to reduce by the tenth part.

### *4.3 Lumber?*

This section addresses how palm sourced stems might be employed for lumber with a focus on the cautionary challenges of the material. A substantial commercial literature exists which deals with palm as a building material source. We will briefly examine one such source, Killmann and Fink (1996) which examines production of lumber from coconut palm stems. This exploration helps to suggest what might or might not have been feasible with *Paschalococos* stem material on Rapa Nui. When coconut palms reach about 60 years of age, their productivity declines—at this point the aging palms become a lumber potential. Killmann and Fink discuss production of such items as rafters, fence posts, utility poles, wall paneling, and furniture.

> *Timber exposed to weather must be chemically treated (for example, with pentachlorophenol) —this would include fence posts, utility poles, and siding (Section 2.1). Section 7.2 discusses application of wood preservatives
>
> * "Coconut palm wood has an initial moisture content ranging from 60% (high density) up to 230% (low density)." (Section 6, p. 75). To manage moisture, seasoning or drying is "essential" before processing
>
> *Killmann and Fink outline palm removal practices (stem, canopy, roots) to reduce the substantial disease risks from insects and fungi (Section 3) to the remaining palms. Leaving palms to rot in place is highly inadvisable. After milling or sawing, waste must be removed (Section 4.8). Among the risks are rhinoceros beetle (*Oryctes rhinoceros*) and palm weevil (*Rhynchophorus schach oliv*.) (see Ingersoll and Ingersoll 2018 for a review of palm disease and insect threats). Coconut wood, classified as "non-durable," should be dipped before storage to prevent fungi, mold, or insect attack (Section 7). Special stacking and storage procedures are outlined.
>
> *Cutting advice: special steels are recommended for sawing palms by whatever method, especially with Stellite tipped blades/teeth or tungsten-carbide (Section 4.7). Frequent re-sharpening is a must. Split boards are rough but can be used for shed rafters or trusses (Section 4.3.1) The sclerenchymatous vascular bundles often containing silica cause the dulling.
>
> *Because of inherent density variation between the cortex and the central cylinder, with much of the central cylinder too soft for lumber, sawing patterns typically square off the outer cortex, thus excluding a large proportion of the central cylinder (Section 4.1 and Figs. 19-22).
>
> * Many products made from palm wood, to achieve usable mass, require lamination, mortising and tenoning, or gluing (Sections 8.2.5, 8.6.8, 8.7). The fibrous vascular bundles can be used for particle board manufacture (Section 4.7).

Some of the observations drawn from Killmann and Fink about coconut above should be applicable in general to other related palms like *Jubaea*, and we would expect, *Paschalococos* (see below), for example, that the softer central cylinder material of coconut does not make for solid lumber, or that felled coconut stems tend to succumb to rot rapidly. If the extinct *Paschalococos* shares such capabilities and drawbacks, we might predict that it would not make for optimal architectural materials exposed to the weather, or for enduring canoes or canoe ladders.

## 5 Age, Dendrochronology, and $^{14}$C

How long do palm trees live? Hunt and Lipo (2007:92) question Flenley and Bahn's lifespan claim for *Jubaea chilensis* of up to 2000 years as "unfounded" (Flenley and Bahn 2007a, b), but allow that an age of 400 years on Rapa Nui for *Jubaea* sp. or *Paschalococos disperta* might be possible. Hunt and Lipo (2007:92) quote Tomlinson's cautious position (2006:10): "[t]he age of the palm can only be determined accurately from knowledge of its seed planting date." Tomlinson provides an example, a *Jubaea chilensis* planted at Temperate House at the Royal Botanic Gardens, Kew, in 1843. This palm, 163 years old (presumably in 2006), can be observed in Tomlinson's Figure 1 (2006:6), where the caption states "It is said to be the largest and oldest single stemmed palm cultivated under glass outside its natural habitat." On the topic of palm lifespan, Tomlinson adds:

> Other examples, as summarized in Uhl and Dransfield (1987), are based on extrapolated values that range from 100 to 740 years. In trees traditionally thought to be thousands of years old, as in conifers [e.g. *Pinus longaeva* D.K. Bailey, *Sequoiadendron giganteum* (Lindl.) J. Bucholz], most of the tree's tissue is nonliving and phloem cells remain conducting for quite short periods. [Tomlinson 2006: 10]

This quote above by Tomlinson comparing palms to conifers brings us to a crucial difference: that conifers have growth rings and palms do not. Lacking growth rings, AP trees are not dateable by dendrochronology. There is likely some general age relationship between the series of leaf scars and age, but the whole stem would be needed, from root to apex, as well as an estimate of how many leaves (fronds) were on average generated and coexisting at any point in time to furnish the crown (leaf scars are visible in Figs. 15.1 and 15.3). Lack in Lack and Baker (2011:17) writes:

> Despite the lack of growth rings, it is possible to estimate the age of a palm by measuring the plastochron, the interval between the development of two subsequent leaves. By multiplying the plastochron with the sum of the number of leaf scars on the trunk plus the number of leaves in the crown, at least a rough age estimation can be obtained. With a measured age of 720 years, the Australian *Livistona eastonii* is one of the palm Methuselahs.

Note that the term "annular rings" has been applied to palms (Jones 1995: 23), but the above quote should make clear the differences between AP and DG trees' annular rings and tree rings, respectively. In reference to the above quote, we would emphasize the "rough age estimate" point, that due to variation in wet or dry years, the yearly production of leaves would vary, and that the counts would relate to *living* leaves in the crown (see quote above).

If the whole AP tree is needed for a rough age estimate, very few opportunities for dating will occur in archaeological contexts, which brings us to $^{14}$C dating. Because DG trees contain massive volumes of nonliving material which can vary greatly in age of carbon deposition, with progressively older material moving toward the center from the bark, and downward in the trunk from the top. Where in the DG tree a radiocarbon sample comes from is highly relevant in regard to what besides the wood or charcoal sample is targeted to be dated by association. The phenomenon of inbuilt age presents serious challenges to developing chronologies, often leading analysts to the revision of prior technologies by seeking sample sources such as leaves, flowers, twigs, or seeds which avoid high inbuilt age problems and sidelining wood samples (see Wilmhurst et al. 2013).

The concept of inbuilt age has been applied to palms, as Hunt and Lipo (2007:89) write in reference to a palm wood charcoal date reported by Orliac and Orliac (2005:31): "However, dating palm wood is certainly problematic given its high-inbuilt age (Taylor and Higham 1998)." But in the source cited, Taylor and Higham do not actually seem to argue for high inbuilt age in palms (here the date palm, *Phoenix dactylifera* L.) but mention that "Zeuner considered the question of ‘inbuilt’ age.” F. E. Zeuner (1960) did make an estimated age adjustment based on the sample’s characteristics:

> Zeuner noted that palms show no annual growth increments (tree rings). The full thickness is formed first and then the tree grows upwards. For the tree to be high enough to be useful for ceiling rafters, it would have had to have been between 15 and 85 years old. [Taylor and Higham 1998:90]

This mention of lack of growth rings by Zeuner we wish to pursue here, because it may relate to the way inbuilt age and radiocarbon dating applies to palms. To further illustrate the relevance of palm structure, we supply some quotes from Tomlinson’s *The Uniqueness of Palms*. He writes: “In contrast to the conducting elements of dicotyledons, however, palm vascular elements retain their conductive ability throughout the total life span of the tree” (Tomlinson 2006: 10), and

> The hydrosystem is massive in terms of water storage capacity, both in parenchyma and axial metaxylem, which remains permanently functional (Holbrook and Sinclair, 1992). [Tomlinson 2006: 9]
>
> Within the palm stems, both the sheathing fibres of the vascular bundles and the parenchyma cells of the ground tissue retain metabolic activity seemingly throughout the life of the palm (Figs. 2–10, 11–19). This is exhibited in continuous cell changes throughout the palm stem, those cells at the base of the trunk being oldest. This leads to a distinctive secondary diffuse thickening that is measurable (Schoute 1912). Metabolic activity is demonstrated structurally in several different ways. [Tomlinson 2006: 10]
>
> Perhaps the most distinctive property of palm stems is the ability of mature differentiated stem cells to retain their viability for centuries. [Tomlinson 2006: 13]

To the comments above, we would add Tomlinson’s descriptions of the operation and schematics of the vascular system of palms (1990: 141–156). To see in detail how the vascular system connects to the leaf traces, see Tomlinson’s section “Vascular system of *Rhapis*” and especially Fig. 6.12 (1990: 141–156) published in his comprehensive manual *The Structural Biology of Palms*. *Rhapis* is a genus of palms thought to be an appropriate model for palm vascular systems. Notable in all palms is the vascular continuity throughout the stem. In general how this works according to the “principle of borrowed bundles” is that “an axial bundle diverges from an outgoing leaf trace” (1990:155); as the palm grows, later that bundle continues upward through a series of leaf traces to the periphery, and heads toward the interior of the stem. Although lower leaves are lost and new ones are formed in the crown, the vascular system in a major way remains intact through the stem. An interesting phenomenon occurs of a spiraling effect of the rising vascular bundles in palms, resulting in the offset of each successive leaf placement, possibly positioning fronds for optimum exposure to light.

Several hypotheses can be framed in regard to how these palm characteristics might act to reduce or increase the inbuilt age effect: 1) water storage in a permanently functional system might promote new carbon exchange and reduce the inbuilt age effect, 2) lifelong metabolic activity in the stem might introduce new carbon in new or replacement cells and reduce the inbuilt age effect, 3) continued possible connection to the peripheral cortex by former leaf traces even after leaves are lost might introduce new carbon metabolically or by exchange and reduce the inbuilt age effect, 4) that the central cylinder is not composed of predominantly dead and isolated matter as in DG trees might reduce the extent of inbuilt age, 5) that old carbon is systematically maintained, increasing inbuilt age effect, and 6) that once carbon is placed, and the vascular bundles become progressively lignified, no new carbon is introduced, increasing the inbuilt age effect. The resolution of this question would seem to call for experimentation, in which $^{14}$C sampling takes place at intervals along the full extent of the stem cortex, and at different depths within the central cylinder, of a recently dead palm. In short, how do $^{14}$C dates vary with location within the palm stem?

## 6 Classical Taxonomy/Genomics

The palm we would really like to know about is the extinct palm of Rapa Nui referred to in the literature as *Paschalococos disperta* (see Zizka 1991:64–65 for Dransfield's description), but in some cases also attributed to the modern taxon *Jubaea chilensis*. Both *Jubaea chilensis* and *Juania australis* (Dransfield et al. 1984; Hunter-Anderson 1998: 92) have been seen as potential predecessors of the large Rapa Nui palm. Possible evidence on Rapa Nui for the large palm includes charcoal, pollen, phytoliths, stem casts, root cylinders, and nuts. To complicate matters, there are other possible palms, also extinct, as reported by Gossen's analyses of pollen and phytoliths in cores (2011): "The discovery in this research with the most impact was the loss of not only one palm species but of at least four palm types" (2011: 58). Gossen describes four types, the one closest to *Jubaea* designated as Type 1. Type 2a is a rounded pollen, Type 3 is smaller than *Jubaea*, and Type 4 is "a distinct pointed-end pollen" (2011:159). While nearest living genera and species are not proposed for the four types (they are possibly extinct), Gossen does state that "[n]one of these are *Cocos nucifera*. In Appendix A, Gossen furnishes numerous high definition color photomicrographs from a wide range of radiocarbon dated organic micro-remains from the sediments of the KA03 core of the crater lake Rano Kao. The remains include starch, rhizomes, charcoal, phytoliths, and pollen from many life forms. Photomicrographs of Types 1–4 may be viewed in Gossen (2011): 413, 415, 416, and on other pages in Appendices and A and D. Delhon and Orliac (2007) and Rull (2019) also mention the possibility of more than one palm species on Rapa Nui.

Next we would like to review the interrelatedness of the Cocoeae, in which both *Jubaea* and *Paschalococos* are included. To illustrate potential close structural stem characteristics, we will use Dransfield et al. (2008), which is a systematic updating of Dransfield and Uhl (1986), and a brief update to Dransfield et al. (2008) in Baker and Dransfield (2016).

In some classical taxonomical systems, the order Arecales is followed by the family Arecaceae, the subfamily Arecoideae, the tribe Cocoseae, and then the subtribe Attaleinae. In the subtribe Attaleinae, Baker and Dransfiled (2016:212) show 10 genera, which include *Beccariophoenix*, *Jubaeopsis*, *Voanioala*, *Allagoptera*, *Attalea*, *Butia*, *Cocos*, *Jubaea*, *Syagrus* and *Parajubaea*. Some of these may have been successfully crossed with *Jubaea* (see below).

While on the topic of classification, we will mention some of the other palms noted in this chapter. *Juania australis*, a palm formerly considered as a possible source or relative of the Rapa Nui palm, or as a species at one time on Rapa Nui is classified as subfamily Ceroxyloideae, tribe Ceroxyleae, genus *Juania* (Baker and Dransfield 2016:211). A study by Delhon and Orliac (2007: 107), however, concluded that the

> results of the morphometrical analysis show that, in most cases, fossil phytolith assemblages from Easter Island are close to those produced in the trunks of *Jubaea chilensis*. Thus, it seems that *Paschaloccocos disperta's*[sic] trunks are responsible for most of the phytoliths preserved in the Rapanui sediments studied here. That interpretation based on morphometrical phytolith analysis is corroborated by the presence among these samples of that of Poike, which corresponds to the sediment surrounding a charred *Paschaloccocos*[sic] stem.

Grau (2001: 87) noted that, when comparing the small coconuts of *Jubaea* and *Juania*, "we see that that they are not even similar"; on the other hand, Grau saw similarities in the pollen and coconuts of *Jubaea* and the fossil pollen of the Rapa Nui palm (1996:37).

Another possible palm from Rapa Nui noted by Delhon and Orliac (2007: 108) is *Pritchardia pericularum*, subfamily Coryphoideae, tribe Trachycarpeae, subtribe unplaced Trachycarpeae (Baker and Dransfield 2016: 211). The palm from Peru described by Johnson and Mejía (1998) used to make canoes, *Iriartea deltoidea*, is in subfamily Arecoideae, tribe Iriarteeae (Baker and Dransfield 2016:212).

Current research into phylogenetic relationships exhibits both continuity with earlier taxonomic approaches and difference (Dransfield et al. 2005). For an example illustrating this continuity, see Tomlinson et al. (2011). Note that with genetic approaches, shifts in ordering occur. For example, an analysis of 7 WRKY loci illustrated in Meerow et al. (2009, Figure 1 consensus tree) places *Jubaea chilensis* immediately below *Butia*, and above *Attalea*, then descending, *Cocos*, then *Syagrus*. In a subsequent analysis, Meerow et al. (2015) illustrate cladistics relationships using six WRKY gene family loci, showing above *Jubaea chilensis*, first *Butia,* then *Syagrus*, *Lytocaryum*, *Cocos*, and *Attalea*. *Roystonea,* an outgroup, occurs 6 clade lines down from *Jubaea* (Fig. 1, 2015:516). See Asmussen et al. (2006) and Horn et al. (2009) and for additional cladograms related to lamina evolution and plastid DNA phylogeny in related palms. We recommend consulting Fig. 7 in Baker and Dransfield (2016: 223) to see an updated schematic tree of phylogenetic relationships among palms.

Another mode of conceptualizing palm relationships is by considering hybridization results. Many nurseries report on palm hybrids. The recent list shown below is from The Desert Northwest website (2021). In hybrid cross terminology, the female source is listed first, then the male; F2 hybrids are noted by parentheses. Much of the commercial interest in hybrids is to come up with palms that can withstand temperate climate and/or to add ornamental value to the progeny. Below are listed some of several successful crosses with *Jubaea,* a palm that can withstand relatively low temperatures for palms. The Desert Northwest website shows a number of other coccoid hybrids not involving *Jubaea* but intergeneric crosses with some of the genera shown below, such as *Butia eriospatha* × *Syagrus romanzoffiana*. Altogether this site describes 11 cocoid palm hybrid crosses. These involve *Jubaea*:

> *Butia capitata* × *Jubaea chilensis*; *Jubaea chilensis* × *Butia capitata*; (*Jubaea chilensis* × *Butia capitata*) × *Syagrus romanzoffiana*; (*Jubaea chilensis* × *Butia capitata*) × *Jubaea chilensis*; *Jubaea chilensis* × *Syagrus romanzoffiana*; *Syagrus romanzoffiana* × (*Jubaea chilensis* × *Butia capitata*); *Butia eriospatha* × *Jubaea chilensis*.

A caution concerning the hybridization reports above: the crosses should be regarded as anecdotal as they derive from commercial websites and should be checked out against the specialized literature. Incidentally, the chromosome 2n numbers are 32 for *Butia capitate*, *Cocos nucifera*, *Jubaea chilensis*, *Syagrus romanzoffiana* (Dransfield et al. 2008: 62). *Parajubaea* may also be 32 as most of the Attaleinae are 2n = 32. By contrast, *Borassus flabellifer is 2n* = 36 (Dransfield et al. 2008: 60), *Iriartea deltoidea* is 2n = 32, and Roystonea is 2n = 36 (Dransfield et al. 2008: 61). We could not locate the chromosome number of *Juania australis*, but members of the tribe Ceroxyleae are 2n = 30, 32, and 36 (Dransfield et al. 2008: 55).

A website for Sea Breeze Nurseries (accessed October 9, 2016, but no longer available) listed a *Jubaea chilensis* × *Parajubaea cocoides* hybrid. We have not found verified *Cocos* crosses with *Jubaea*, although one website mulls over one questionable possibility. With *Cocos*, there are continuing intraspecies hybridizations being attempted.

We reference the information above to indicate the taxonomic and genetic closeness of the tribe Cocoeae, including Rapa Nui predecessor candidate *Jubaea*. Perhaps *Paschalococos disperta* if not directly available as a living palm would easily fit in the cladograms of analyses like Meerow et al. 2009 and 2015. It would seem that the *Paschalococos* pollen and nut shells might contribute DNA to the effort, but according to Dransfield (2021 np, webpage last modified November 12, 2013) "the pollen remains consist of the almost indestructible sporopollinin pollen cell walls, but no contents where DNA would be and the nuts consist of hard woody dead cells virtually devoid of cell contents—and hence no DNA" (also see Rull et al. 2010: 57). Maybe archaeologists will get lucky and recover some completely preserved nuts so DNA-based comparisons with tribe Cocoeae can be made.

## 7 Conclusions

Palms of the tribe Cocoeae, though magnificent donors to the production of endless cultural products—nuts, copra, oil, sap, sago, palm cabbage, palm hearts, sugar, flour, honey, wine, butter, milk, cream, water, animal feed (from sap—Dalibard 2009), cosmetics, thatch, coir, string, rope, fuel, lumber, to name a few (see Jones 1995 for an extensive discussion of palm products)—may not be the best of sources for seagoing rafts and voyaging canoes. We suggest that on Rapa Nui, when the large palm called *Paschalococos disperta*, a potential member of the tribe Cocoeae, went extinct for whatever cause or causes, the loss of the palm did not cancel the ability of the Rapanui to maintain Pacific contact with other islands. While large palms have been documented for what might be dubbed "temporary watercraft." Rather, for Pacific voyaging, large true dicots (Eudicotyledons) or gymnosperm trees would be needed. Elsewhere we have argued that the species of large trees used for Polynesian voyaging canoes actually never grew on Rapa Nui (Ingersoll and Ingersoll 2019) and thus did not have the opportunity to become extinct via deforestation. Even the small canoes seen on Rapa Nui may have been built of wood from beyond the island. Thompson wrote:

> There are no canoes in use at the present time, but we found two very old ones in a cave on the west coast, having long ago passed their days of usefulness on the water and now serving as burial cases. They were a patchwork of several kinds of wood sewed together, and though in an advanced stage of dry-rot the material was sufficiently well preserved to prove that it never grew on Easter Island, but had been obtained from the drift-wood on the beach. [1891:474]

While palms can be and are used for lumber, we think the applications, due to the lower density structure of the palm central cylinder and its high moisture and nutrient content, are somewhat limited. The relatively thin cortex limits the dimensions achievable in the lumber. Diverse sources note the susceptibility of the palm stem to rapid deterioration, thus limiting outside uses without preservatives. While we initially were dubious that palms might suffice as rollers for the *moai*, due to the low density of the central cylinders, experiments by Van Tilburg demonstrate otherwise.

Because palms exhibit very different structural characteristics from true dicots and gymnosperm trees, that is, no tree rings, dendrochronology is not possible. The degree of inbuilt age in palms we maintain should be tested by experiment rather than assumed.

We conclude with observations on the tribe Cocoeae to call attention to the close structural relationships among the members of the tribe, which may help to anticipate the characteristics of *Paschalococos disperta*.

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