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THE TRANSFER OF KŪMARA (*IPOMOEA BATATAS*) FROM EAST TO SOUTH POLYNESIA AND ITS DISPERSAL IN NEW ZEALAND

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ABSTRACT: Whether kūmara 'sweet potato' (*Ipomoea batatas*) arrived in South Polynesia with initial colonisation or later is discussed in the light of recent evidence from East Polynesia and by examination and statistical modelling of radiocarbon ages associated with kūmara arrival and dispersal in New Zealand. Largely unresolved difficulties in radiocarbon dating of horticultural sites preclude reaching a secure conclusion about the relative timing of kūmara introduction, but strong evidence emerges of delayed dispersal southward and inland of kūmara cultivation. In the short New Zealand chronology this may have been more significant than the date of arrival for the role of kūmara cultivation in economic and political change.

Keywords: kūmara (*Ipomoea batatas*), sweet potato dispersal, South Polynesia, Māori gardening, ^{14}C calibration models, New Zealand

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The Oceanic history of the arrival and dispersal of the South American sweet potato (*Ipomoea batatas*) or *kūmara* in Polynesia has been discussed since the mid-eighteenth century but never resolved satisfactorily (Ballard 2005). In fact, resolution seems further away than ever in uncertainty about whether kūmara reached Polynesia by natural or cultural agencies (e.g., Muñoz-Rodríguez *et al.* 2018) and, if the latter, whether by Amerindian seafaring or Polynesian return voyaging (Anderson *et al.* 2007; Green 2005). Leaving those matters aside, there is an equally unresolved issue about the history of kūmara within Polynesia, especially in Hawai'i, Rapa Nui (Easter Island) and New Zealand, which were not only the most remote islands where kūmara was cultivated but also the only island groups where it became "a food product of importance" (Dixon 1932: 49). How kūmara cultivation influenced the emergence of different societies at the vertices of the Polynesian triangle is a topic that has been explored in East Polynesia

(Kirch 2010; Vitousek *et al.* 2004) but not so much in New Zealand (Anderson 2016), where kūmara was even more the dominant crop but had less favourable growing conditions.

Of a small range of cultigens in New Zealand, taro (*Colocasia esculenta*), *uwhi* 'yam' (*Dioscorea alata*), *tī pore* (*Cordyline terminalis*) and *aute* 'paper mulberry' (*Broussonetia papyrifera*) could be grown in about 15 percent of the land area (without regard to elevation or soils), but kūmara, and to some degree *hue* 'bottle gourd' (*Lagenaria siceraria*), extended cultivation potential to about 45 percent of the area (Anderson 2014: 119). How far such potential could be realised depended *inter alia* upon when kūmara arrived and how rapidly cultivation expanded. In New Zealand, late arrival of kūmara had been advocated (Duff 1956: 6, 12–21, 253–54; Ferdon 1988; Green 1970 thought so initially) and also rebutted (see Barber 2004). By the late twentieth century it was accepted that all the introduced cultigens had been present since the beginning of colonisation (e.g., Anderson 2014: 82; Furey 2006: 6–16; Leach 1984).

That was also the accepted conclusion in East Polynesia until Hather and Kirch (1991) argued that kūmara arrived in central East Polynesia at AD 1000, which made it significantly later than proposed colonisation ages (Kirch 1986). The gap diminished as colonisation ages became progressively younger with critical analysis of radiocarbon chronologies (Anderson 1991, 1995), and then disappeared with ages of AD 1000–1200 for East Polynesia (Allen 2014; Anderson *et al.* 2019; DiNapoli *et al.* 2020) and AD 1230–1315 for South Polynesia (Schmid *et al.* 2018; Walter *et al.* 2017; Wilmshurst *et al.* 2011). However, new radiocarbon ages for East Polynesian kūmara suggest that its chronological *pas de deux* with the arrival of people might return to separation in East Polynesia, with important implications for South Polynesia (Anderson 2000).

In considering this problem we propose, on the basis of East Polynesian data, that kūmara might not have reached New Zealand until around AD 1400 and seek to test that hypothesis by analysis of radiocarbon ages, particularly from significant cases in historical and recent research. We review East and South Polynesian radiocarbon ages associated with kūmara in their archaeological contexts and on the capacity of samples to provide reliable ages, then model trends in the timing of kūmara cultivation in New Zealand, regionally and by coast and interior.

KŪMARA ARRIVAL IN EAST POLYNESIA

Human colonisation of central East Polynesia during the first millennium AD is thought to have involved cultivation of west Pacific cultigens until East Polynesian voyagers sailed to Ecuador, bringing back kūmara around AD 1000–1100, which then spread to Mangareva, Rapa Nui, Hawai'i and New

Zealand (Green 2005: 46–47, drawing substantially upon Buck 1954: 321–24). Green's model, "close to the last word" according to Yen (2005: 185), took its key radiocarbon data for kūmara arrival from Tangatatau rockshelter, Mangaia (Cook Islands). In the main excavation there, carbonised *Ipomoea batatas* occurred to level E30/11 of zone SZ-4A but was not radiocarbon dated. Instead, from level E30/13 below, largely unidentified charcoal was assayed (1σ) to AD 988–1115 (Beta-32826), and from F30/10 above, to AD 1409–1440 (Beta-32818). Charred kūmara tissue in excavation F10 was bracketed by charcoal ages of AD 1162–1280 (Beta-32828) and AD 1327–1428 (Beta-32829). The results were seen as "unequivocally establishing the presence of *Ipomoea batatas* in central eastern Polynesia by around AD 1000" (Hather and Kirch 1991: 892). Although that date was at the oldest error margin of the oldest age, from below the lowest kūmara occurrence, and unrepresentative of the assay range (Wallin 1999), it was said to be supported "by many additional, although not yet published ^{14}C ages" Green (2005: 50; they remain unpublished) and widely cited as "a crucial piece of new evidence that anchors all present reconstruction of prehistoric sweet potato transfer in Oceania" (Ballard 2005: 5).

In a new Tangatatau dataset (Kirch 2017), kūmara parenchyma from zone SZ-8 is dated AD 1463–1625 (UCIAMS-164896), and the age of kūmara in SZ-4 is estimated from Bayesian boundary estimates (HPD) for overlying SZ-5 (AD 1416–1483 and 1460–1492) and underlying SZ-3 (AD 1365–1405 and 1395–1446) which date the earliest kūmara to after AD 1400 (Kirch 2017: 82–86). Thorium isotope (^{230}Th) ages on coral abraders from SZ-3 and SZ-5 (Niespolo *et al.* 2019: 24) also indicate that SZ-4 is early fifteenth century.

At present, all Hawaiian samples date to the fifteenth century or later (Coil and Kirch 2005: 74; Ladefoged *et al.* 2005), with one exception. Carbonised plant tissue from Kohala trench 50, dated AD 1290–1430 (B-208143), has characteristics of *Ipomoea batatas* but cannot be distinguished from yam or an indigenous species of *Ipomoea* (Ladefoged *et al.* 2005: 368). Research at Kealakekua in the Kona field system indicates that agriculture began after AD 1400, with continuous cultural burning beginning about AD 1450 (McCoy *et al.* 2017), and that swiddening was underway in the Kohala system "certainly by AD 1400" (Ladefoged *et al.* 2020: 13). Kūmara starch grains in Kona soil samples dated "possibly as early as the fifteenth century AD" (Horrocks and Rechtman 2009: 1118). McCoy *et al.* (2017: Supplement) notes that one type of starch found at Kona could be either kūmara, giant taro or arrowroot, although it was assigned to kūmara on contextual evidence.

In Rapa Nui, unidentified charcoal from an earth oven, about which were found charred remains of kūmara and sugar cane, was radiocarbon dated to AD 1437–1619 (K-522) by Smith (1961). A charred kūmara, excavated beside a *moai* ‘megalithic statue’ (specifically no. 156) at Rano Raraku, dated to AD 1458–1635 (Beta-447618; Sherwood *et al.* 2019). Eight samples containing kūmara starch grains from a garden at Te Niu were associated with ages of AD 1400 or younger, and two were older at AD 1214–1436 and AD 1286–1399 (Horrocks and Wozniak 2008: ^{14}C Lab unreported), while very degraded possible kūmara pollen was recovered beneath an *ahu* ‘ritual structure’ where obsidian dated to about AD 1450 (Cummings 1998). Kūmara starch in human dental calculus from Rapa Nui, however, is not clearly associated by Tromp and Dudgeon (2015) with the oldest dated calculus sample (RH 11: AD 1321–1412). Probable starch grains found on five shell tools in radiocarbon dated stratigraphy beginning AD 1200–1400 at Anaho Bay, Nuku Hiva (Marquesas), provide a stronger case (Allen and Ussher 2013: 2800).

There is nothing in these data to preclude kūmara having been taken on initial colonisation passages. However, neither do the data rule out the possibility of secondary introduction to Hawai‘i and Rapa Nui a century or more later.

KŪMARA ARRIVAL IN SOUTH POLYNESIA

At the outset it is worth noting an independent source of comment on kūmara arrival: Māori tradition. Archdeacon Walsh (1902: 13) recorded a widespread understanding that “not finding the kumara on their first arrival in the country, the Maoris made an expedition back to their old home among the Pacific islands to secure a supply for cultivation”. One account refers to an origin ancestor, Toikairakau (Toi the wood-eater, from his lack of cultivated foods), who was living at the mouth of the Whakatāne River when two travellers arrived from Hawaiki. They found his foraged food disagreeable and offered, instead, sweet paste from powdered kūmara (*kao*) they were carrying. The local people then sailed *Horouta* to Hawaiki to obtain kūmara plants (Turei 1912). Toikairakau is positioned between the thirteenth and fifteenth centuries in Bay of Plenty *whakapapa* ‘genealogy’ (Simmons 1976: 71–72, 100). Ngāti Awa, similarly apprised of kūmara, sailed to Hawaiki and returned with it to Whakatāne on the *Mataatua* canoe (Simmons 1976: 148–52), 16–17 generations before about 1850 (Best 1904: 131). The median length of whakapapa for *Mataatua* descent is 17 (range 12–21), i.e., about AD 1390 (Fenner 2005; Simmons 1976: 307). These data are late in the colonisation period of AD 1270–1430 estimated on canoe whakapapa (Anderson 2014: 63–64), implying kūmara introduction broadly around AD 1400.

The traditional transfer of kūmara differs from that of other Polynesian plants. In Bay of Plenty traditions, hue long preceded taro and kūmara (Best 1904: 130; 1925: 245), with taro arriving on the *Mataatua* and *Nukutere*, uwhi on the *Māhuhu* and aute on the *Ōtūrereao* and *Tainui* (Best 1925;

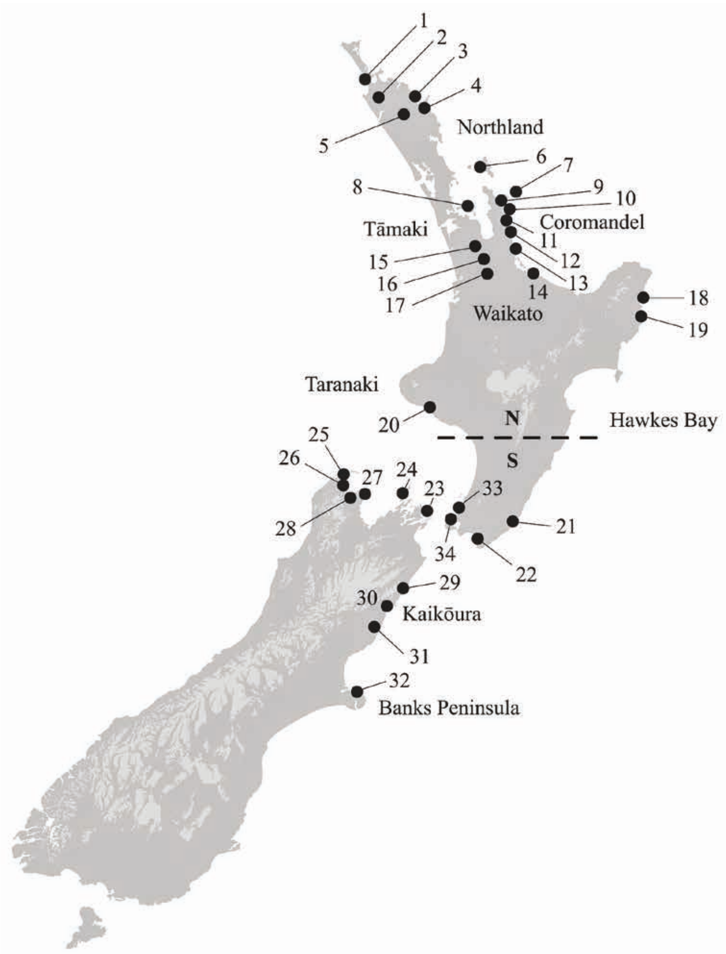

Figure 1. New Zealand places and archaeological sites referred to in the text (N = Northern, S = Southern) 1. Motutangi, 2. Awanui, 3. Rangihoua Bay, 4. Hahangarua, 5. Pouerua, 6. Harataonga, 7. Ahuahu, 8. Sunde, 9. Sarah's Gully, 10. Skipper's Ridge, 11. Cook's Beach, 12. Hahei, 13. Whangamatā, 14. Papamoa, 15. Taupiri, 16. Horotiu, 17. Kirikiriroa, 18. Anaura Bay, 19. Tolaga Bay, 20. Waverley, 21. Okoropunga, 22. Palliser Bay, 23. Cattleyard Flat, 24. Greville Harbour, 25. Triangle Flat, 26. Parapara, 27. Takapou, 28. Tata Beach, 29. Clarence River, 30. Avoca Point, 31. Pari Whakatau, 32. Panau, 33. Pauatahanui, 34. Makara.

Hiroa 1950: 51–63). In contrast, kūmara is said to have arrived on the *Aotea*, *Arawa*, *Horouta*, *Kurahaupō*, *Māhuhu*, *Māmari*, *Mataatua*, *Tainui* and *Tokomaru* canoes. Whether kūmara arrived on such a broad front is questionable, however, and for a good reason. Kūmara was a tapu plant: "The offspring of Rangi and Papa [was] first the Kumara, which came from the face of Heaven", as noted by Taylor (1855: 18). It embodied *mana* 'prestige, authority, power' and was embedded in ritual belief. Consequently, competing descendants refused to agree that their canoe had failed to bring the kūmara exclusively or before others. The acrimonious debate between Taranaki and East Coast authorities, recorded in the 1880s by John White, makes this very clear. Mohi Turei, for Ngāti Porou, proposed a compromise: "This is what I would say to you: you possess your *kumara*, and your own ancestor, and your *kumara*-cultivations; and I have my *kumara*, my ancestors, and my *kumara* cultivations" (White [1888] 2011: 5). It was not a context in which a later arrival of kūmara was likely to be conceded. Nevertheless, that idea was implicit in the contest and more generally.

Turning to the archaeological evidence, we have compiled a database of 118 ^{14}C radiocarbon dates that are older than, or overlap, AD 1400 and which have been associated with kūmara gardening. They are grouped into Northern (74) and Southern (44) regions divided approximately by a line from southern Hawkes Bay to Taranaki (Fig. 1). Cultivation of all or most cultigens was possible to the north, but kūmara was wholly dominant to the south, with hue a minor crop, and taro possibly reaching Golden Bay. Northern cultivation is likely to be older, but it cannot be assumed *ipso facto* as having been of kūmara, while kūmara can be assumed generally as the object of southern cultivation, but possibly younger because of adaptational issues (Leach 1984: 61). In the discussion of regional gardening chronology below, the ages have been calibrated from the conventional radiocarbon ages (CRA) and are reported at 68% probability to enhance visibility of differences between them. The 95% probability ranges are listed in Tables S1 and S2.

Northern Gardening

The subtropical Kermadecs and Norfolk Island are important to the South Polynesian kūmara narrative because they were colonised in the early fourteenth century from New Zealand (Anderson 2000). Excavations on Raoul Island have uncovered candlenut (*Aleurites moluccana*) but no other introduced plants (Johnson 1995: 56). Amongst plants recorded historically, taro, tī pore and several weeds, including *Oxalis corniculata*, might have been introduced prehistorically (Sykes 1977: 123, 152–56; cf. Prebble 2008), although Johnson (1995: 57–59) suggested that taro and tī pore arrived with nineteenth-century Polynesian settlers. *Ipomoea batatas*, grown historically on Raoul Island, seems to have been a whaling-era cultivar (Sykes 1977: 98).

Sedimentary coring on Norfolk Island indicated that *Cordyline* spp. was present before human occupation and that *Phormium tenax* (New Zealand flax), absent in the cores but recorded in the eighteenth century, had come with Polynesian colonists (McPhail *et al.* 2001: 133). Johann Forster, in 1774, recorded *Oxalis* and *Sonchus* spp., and a banana (*Musa* spp.) grove was seen by Europeans in AD 1788, but no other Polynesian cultigens were recorded historically or archaeologically (Anderson and White 2001). No evidence of pre-European occupation of Lord Howe Island has been recovered (Anderson 2003), and no kūmara cultivation has been recorded on the Chatham Islands. The evidence is thin, but it suggests that kūmara was not available for transfer from New Zealand when Māori migrants colonised Raoul and Norfolk Islands in the early fourteenth century, and therefore that it was not brought to New Zealand by the first Polynesian colonists.

Turning to mainland New Zealand, formative fieldwork in the 1950s brought Māori agriculture in the Coromandel to the forefront of archaeological concerns. Exposure of complex pit architecture, the proximity of the pits to settlement sites of Archaic East Polynesian provenance, and arguments for stratigraphic connections between the two encouraged confidence that kūmara gardening began with initial colonisation. Golson (1959: 45) put it like this: "We know that underground storage was normally reserved for *kumara* at the time the Europeans came to New Zealand and it is possible that the Archaic structures at Sarah's Gully were such *kumara* stores." The pit–kūmara association was strengthened by Yen's (1961) model for kūmara adaptation to New Zealand, and soon supported by radiocarbon ages from two sites in particular.

Storage Pit Ages. At the Sarah's Gully *pā* 'fortified site', bell-shaped pits were assigned to the first phase of occupation (Parker 1962). One is dated to AD 1280–1390 (NZ-1080) on an unidentified charcoal sample. Material of the same sample was examined recently by Wallace (2018) and discarded as unsuitable for radiocarbon dating. This leaves no reliable age for the first occupation at the site; four pit ages of sixteenth century or later refer to subsequent occupations of the pā. The Sarah's Gully settlement, midden and pā might be a single site established in the thirteenth century (Davidson 2018: 112), but the initial age of pit construction remains unknown.

At Skipper's Ridge, a large pit from the first occupation dates to AD 1180–1300 (NZ-1740). This charcoal sample (Davidson 1975) was identified as *Pseudopanax* spp., and on that basis was thought to have little inbuilt age. However, *Pseudopanax* contains species that can live for several hundred years, and the NZ-1740 sample was considered as the remains of a post or beam. On those grounds the date was rejected by Anderson (1991). Pits excavated further up Skipper's Ridge also varied in form but dated eighteenth century to modern, and Bellwood (1969:

204) argued that Parker's (1962) succession of pit types was weak and contradictory, concluding that "*kumara* storage pits have never been satisfactorily demonstrated to belong to the Archaic period". Charcoal dates on short-lived species from site T10/777 south of Skipper's Ridge (Gumbley and Hoffman 2007) are from a possible *umu* 'oven', AD 1460–1630 (Wk-37543); a probable bin pit, AD 1480–1630 (Wk-37544); and a bell-shaped pit (Wk-37547), AD 1500–1630 (Bickler 2014: 148).

Fire scoops above rectangular and oval pits at Hahei Beach produced radiocarbon ages (Table S1) reaching into the thirteenth century (Harsant 1984). As NZ-4950 (AD 1500–1800) and NZ-4951 (AD 1320–1460) were from the same fire scoop and, together with NZ-4952 (AD 1390–1460), were below the oldest age (NZ-4953, AD 1280–1400), vagaries of inbuilt age can be suspected. Tōtara (*Podocarpus totara*), kauri (*Agathis australis*), māhoe (*Melicytus ramiflorus*) and *Metrosideros* spp. were prominent in all samples. At nearby Cooks Beach, horticultural evidence is radiocarbon dated to AD 1500 and later (Maxwell *et al.* 2018), and on Ahuahu (Great Mercury Island) a series of pits of varying shape and size were radiocarbon dated (Wk-42270–42274) on five samples of *Coprosma* spp. charcoal to about AD 1350–1400 (Prebble *et al.* 2019: Table S3; see Table S1). As some *Coprosma* species can grow to 10–12 m with lifespans in decades, there is a possibility of some inbuilt age.

In the western Bay of Plenty, storage pits date fifteenth century and later (James-Lee 2014: Table 5.7), and Law (2008: 63) concluded that cultivation in the region dates no earlier than the fifteenth century. There are few relevant radiocarbon data further south, but extensive deforestation on the East Coast after about AD 1400 is thought related to horticultural activity (Jones 1988). Taranaki also had sustained deforestation occurring around AD 1500 with pā construction and gardening (Prickett 1983; Walton 2000: 14). In South Taranaki, charcoal including punga and fern from storage pits at site Q22/77 near Waverley (Walton 2000: 61) produced ages later than AD 1400 (Table S1).

Early archaeological assumptions about pits as kūmara storage features have been questioned by Helen Leach (1979b: 246; 1984: 58–59), who argued that pits were used to store both yam and kūmara, perhaps especially the former at first because of its longer period of seasonal dormancy in New Zealand (Leach 1984: 60). Pits were used also to store taro (Matthews 2002; Prebble *et al.* 2019), processed *Cordyline* stems, karaka berries and fern-root (Best 1916: 91, 107), amongst many other products that were unsuited to open-air storage and forbidden within houses. In addition, bell-shaped pits of a kind occurring in early Coromandel sites were built to store water or to catch rats and, "as they much resemble in form the smaller food-pits used for storage purposes, the one may well be mistaken for the other" (Best 1916: 86). We are not obliged to interpret pits as storage for kūmara.

Garden Soils and Planting Pit Ages. Identification of garden soils is seldom an exact science. Soil modification by adding gravel or other materials is scarce in the north and northeast of the North Island in areas which, on other grounds, had probably been gardened (Furey 2006: 47). Conversely, soils on alluvial fans or plains often contain natural layers or lenses of sand or gravel despite not being cultivated (Furey 2006: 68–69; Jones 1986; McFadgen 2003: 37). At Hahangarua Bay, Bay of Islands, radiocarbon ages as early as AD 800 (Groube 1967), and later about AD 1230, were obtained for layers 5 and 6 of a garden soil, recognised by its stratigraphic perturbation (Peters 1975: 178–79). The latter samples were on short lifespan material, now calibrated as AD 1400–1620 (ANU-543) and AD 1320–1420 (ANU-542), but Robinson *et al.* (2019: 52–53) observed that the samples could have incorporated charcoals from earlier natural fires before gardening began in the late fifteenth century. In any event, whether the gardening involved kūmara cultivation is unknown, and taro was grown historically in made soils (Groube 1967; Walton 1982).

The Sunde site, Motutapu Island, provided tephrochronological evidence of early garden soils and pits, possibly involving kūmara (Nichol 1988). The Rangitoto Ash that covered Motutapu Island erupted first at AD 1398 ± 7, and again at AD 1446 ± 5 (Lindsay *et al.* 2011). At the Sunde site, a shell sample beneath the ash dated AD 1210–1430 (NZ-6956A), and no cultigens were noted among leaf impressions in the base of the ash. Between ash layers there was evidence of digging and introduction of sand. A bin pit cut into the ash below a made soil (Nichol 1988: 371) dates AD 1480–1640 (NZ-6954). The data suggested gardening beginning in the fifteenth century.

That conclusion seems generally valid for substantial research on Māori horticulture, assumed as mainly kūmara cultivation, in the Tāmaki district (Furey 2006: 30). In Bulmer's (1994: 62–67) recalibration of the radiocarbon data, 20 of 23 (87%) age ranges on storage pits and garden walls from 14 sites were later than AD 1400, and the remaining three overlapped that date. In the Bay of Plenty, cultivation soils at Papamoa date AD 1400–1700 (Phillips 2016).

It could be expected that horticulture might have developed later in inland regions, and that seems to be so in the middle Waikato basin. Forest clearance on charcoal samples of short-lived taxa date to AD 1430–1630 (Wk-7928) at Kirikiriroa Stream (Gumbley and Hoffmann 2013) and at Horotiu (Wk-32467) to AD 1510–1660 (Campbell 2012: 41). Additional research on forest clearance and horticultural features in the Horotiu district has produced 13 radiocarbon ages (Table S1), all of them younger than AD 1400 and most suggesting sixteenth- or seventeenth-century activity (Gumbley and Hoffman 2013: 141–47). Similar evidence has come from the southern part of the Waikato Basin (Campbell *et al.* 2016). Overall, inland Waikato data suggest that settlement and gardening began in the sixteenth century (Campbell and Harris 2011; Gumbley and Hoffmann 2013). The latest data (Gumbley, pers. comm., 7 July 2020) indicate gardening began close to the river at AD 1500–1650 and 2.5–3.0 km away from the river near Cambridge at AD 1650–1750.

Preserved Kūmara Ages. Carbonised kūmara were excavated from a rectangular raised-rim pit (pit O) at pā P5/228, Pouerua, inland Bay of Islands. Leahy and Nevin (1993: 44) argued that "the burning of the pit structure and the carbonising of the kūmara [was] a single event". Nine kūmara specimens were radiocarbon dated as effectively modern. Later excavations (Yen and Head 1993) produced an additional 28 radiocarbon dates on kūmara, 23 being modern. The remaining five kūmara samples came from a short stretch of drain on the pit floor (Table S1), but the ages are from AD 980–1280 (ANU-4753) to AD 1650–1950 (ANU-4736). The age spread was taken to imply "antiquity and continuity of the use of the pit for kūmara storage" (Yen and Head 1993: 63), and Sutton (1993: 99) combined the three oldest ages on kūmara to conclude that pit O was made AD 1257–1393. Conversely, the construction history of pit O appears late in the pā history, all the radiocarbon-dated kūmara came from the floor of the same pit and 34 of 37 radiocarbon ages (92%) do not suggest deposition before AD 1400. Later, Sutton *et al.* (2003: 198) conceded that the argument for a long period of kūmara storage in pit O "was promoted to support the widely varying radiocarbon results and was not based on archaeological evidence".

Kūmara Microfossil Ages. Microfossils of kūmara, particularly starch grains, have been identified, but comparative collections are largely from cultivated plants, and, given the potential variety of indigenous plant starches with overlapping granule morphology, starch identification remains problematic (Prebble *et al.* 2019: S4; Wilson *et al.* 2010). There are species of Convolvulaceae in New Zealand, the microfossils of which have yet to be characterised definitively, including native *Ipomoea cairica* and *Ipomoea pes-caprae* in the northern North Island. They may not produce much starch, but Horrocks (2004: 328) was unable to rule out *I. cairica* as the *Ipomoea* starch in sites at Rangihoua Bay (Bay of Islands) and Harataonga (Great Barrier Island). Kūmara xylem was identified in coprolites at the latter site (Horrocks *et al*. 2004: 155), and it is dated by association with short lifespan charcoal to AD 1420–1620 (NZA-12591). In wetland garden ditches at Motutangi there is *Ipomoea* starch, but while it is likely to be from kūmara, that conclusion "is complicated by the presence of ... *I. cairica*" (Horrocks and Barber 2005: 113). At Cooks Beach, starch grains, c.f. kūmara, were found on obsidian tools dated to the sixteenth century (Maxwell *et al.* 2018).

Radiocarbon ages put the lower layers (including bin and storage pits) of the Cabana site at Whangamatā into the fourteenth century (Table S1). In

2007, kūmara starch was identified in four samples (two being coprolites) and taro in three (Gumbley 2014: 138–44). In 2016, taro was identified in two coprolite samples but no kūmara (Gumbley and Laumea 2019: 103, 184–85). There is a potential case of fourteenth-century kūmara consumption, but coprolites only circumvent the issue of microfossil mobility (below) if they are taken from interior material (not mentioned in the reports). Fourier-transform infrared spectroscopy, which can identify degraded starch (Horrocks, Appendix in Gumbley and Laumea 2019) did not identify any as kūmara. Starch of kūmara and yam has been identified in association with garden features at Horotiu, and kūmara and taro at Taupiri, suggesting that gardening was diverse in the Waikato by the sixteenth century, if the microfossils are dated by the radiocarbon ages (Campbell 2012: 41).

Excavations in historical Māori gardens at Anaura Bay produced probable kūmara starch, but it was mixed with microfossils of *Pinus* sp. and white potato. Coring produced possible taro and yam microfossils but no kūmara tissue (Horrocks *et al.* 2008). Excavation of a coastal site at Cook's Cove, Tolaga Bay, disclosed microfossil remains of probable kūmara and taro in the lower occupation level (Phase II). In this (Horrocks *et al.* 2011; Walter *et al.* 2011: 10–13), Layer 5B samples date to AD 1320–1410 (Wk-23490) and AD 1430–1580 (Wk-23489), and Layer 5a samples to AD 1460–1630 (Wk-24847) and AD 1500–1630 (Wk-24846). Kūmara cultivation, therefore, might just have extended back to about AD 1400, but *Pinus* sp. pollen also occurred in Phase II deposits, and Horrocks *et al.* (2011: 248) noted that "pollen is deposited on the ground surface and carried downwards through the soil by percolating groundwater", and that the process is complicated by digging and other disturbance of sedimentary profiles.

Implicit concern about trans-stratigraphic mobility of microfossils is warranted. Sedimentary remixing brought horticultural microfossils into association with a mid-Holocene radiocarbon age at Rangihoua Bay (Horrocks *et al.* 2004: 154) and taro and kūmara starch into Pleistocene levels in cores from Motutangi and Awanui (Horrocks *et al.* 2007: 277). The porosity of many sediments to post-depositional redistribution of microfossils by gravity or groundwater, and the disruption of original microfossil deposition patterns by bioturbation and human activity, create significant uncertainty about associations of microfossils with stratigraphic order and chronology. Moreover, it is exceedingly difficult to radiocarbon date microfossils directly, and if continuing uncertainty about taxonomic specificity is added, as in *Ipomoea* (e.g., Horrocks *et al.* 2017), then it is apparent that there are fundamental difficulties still to resolve. Coring and excavations in dense, damp, fine-grained sediments which restrict microfossil mobility provides the most useful results, as at Ahuahu, although even there some down-core microfossil contamination was recorded (Prebble *et al.*

2019: S3: 9–10). At Ahuahu, taro pollen enters the record in two sequences, Tamewhera and Waitetoke, after AD 1425 and is not recorded later than AD 1500. At about that point it is replaced in one sequence by kūmara starch.

In summary, the problems of defining the age of Northern kūmara arrival are formidable, and many individual results considered here are open to debate. The pit ages at Ahuahu, if pits were for kūmara, and the basal ages at Cabana, if demonstrably associated with kūmara, might sustain a fourteenth-century age, but otherwise kūmara gardening does not seem clearly older than the fifteenth century.

Southern Gardening

The case for early Southern kūmara gardening was made emphatically by Helen Leach. Referring to Yen's (1974) hesitancy to declare kūmara a proven early introduction to New Zealand, she argued (Leach 1979b: 248) that gardening in Palliser Bay, "under circumstances which preclude other Polynesian cultigens except gourd, by communities bearing the stamp 'New Zealand East Polynesian' and at a time (from about the 12th century AD) close to the settlement of New Zealand, is as close to proof of Yen's contentions as may ever be obtained". The first point remains valid: for climatic reasons only kūmara could, and would, have been grown extensively as far south as Palliser Bay. The second, that gardening dated to the colonisation era, soon became debatable, and Anderson (1991: 788–92) proposed that the early Palliser Bay material culture seemed a better fit for the fourteenth century. Of 18 radiocarbon ages for the Palliser Bay gardens (B. Leach 1979; H. Leach 1979a), 11 are later than AD 1400 and 7 strongly overlap it (Table S2). All the radiocarbon ages were on unidentified charcoal samples. Twig charcoal had been chosen for some samples, but "it is difficult to distinguish between twigs and branches that have had the outer rings burnt off" (McFadgen 2003: 76). Gumbley (pers. comm., 7 July 2020) examined 160 Waikato radiocarbon ages on charcoal and found that 50% of those with twigs from podocarps or other large trees were comparatively too old.

Neither the sequence of beach ridges over which the gardens extended nor the type or stratigraphy of garden structures provided a means of relative dating against which the radiocarbon ages could be compared. McFadgen (2003: 78) used marine shell samples from three of the Palliser Bay garden sites to assess the plausibility of their charcoal ages. For the NZ-1311 site (AD 1290–1400), a calibrated shell age was AD 1470–1640 (Wk-7457), and for the other two sites the shell samples were also much younger. It is a small comparative sample and it is possible that the charcoal and shell samples had different contexts, but the shell ages suggest that part of the

Palliser Bay chronology on charcoal samples could be offset too early at a centennial scale. Okoropunga, another Wairarapa garden site, dated AD 1270–1390 (NZ-3116) on a charred and possibly old tōtara root (*Podocarpus totara*), but AD 1400–1460 (NZ-3115) on mainly *Coprosma* sp. charcoal. On the Wellington west coast, NZ-1877 (AD 1430–1610) dates a garden soil at Makara and NZ-1878 (AD 1460–1630) another at Pauatahanui (McFadgen 1997: 18–40).

Compounding potential old wood influences in unidentified charcoal samples are additional problems in radiocarbon dating of gardens, especially in the southern region. In New Zealand there was natural forest firing in drier areas throughout the late Pleistocene and Holocene and then massive deforestation by burning early in the colonising era, especially in eastern districts (McWethy *et al.* 2014). This activity pre-loaded soils with non-gardening charcoal which, by gardening, could become incorporated in archaeological contexts. The potential problem is less evident in humid northern regions, where forest firing and gardening began later and together (Newnham *et al.* 2018).

At the small scale of particular garden complexes, as well, where sediments and charcoal have idiosyncratic disturbance histories, determining the strength of a chronological association between a radiocarbon sample and a cultural event is difficult. It is recommended currently that dispersed charcoal in agricultural soils should be rejected for radiocarbon dating (Higham and Hogg 1997), and also unidentified charcoal because inbuilt age cannot be determined retrospectively. Marine shell has the advantage that, in most situations, the shell is likely to have been culturally collected and deposited, but as construction of garden features could easily incorporate midden that preceded the horticultural activity, the problem remains.

Research on garden features in Golden Bay yielded four ages on marine shell, for a midden directly above planting pits at Triangle Flat (Wk-17250, Wk-8052, Wk-9611 and Wk-11542), suggesting cultivation around the sixteenth century (Barber 2013: 47). There are similar ages on shell from garden soils at Parapara (NZ-4505, NZ4506), Takapou (Wk-24251) and Tata Beach (Wk-9607, Wk-9608), with a supporting short lifespan charcoal date from an associated pit (Wk-4912). In western Tasman Bay (Barber 2010: 78), shell ages NZ-7900 and Wk-2278 and an age on carbonised bark from the base of a borrow pit (Wk-1776) date fifteenth century and later (Table S2). Another borrow pit at Motueka dates AD 1180–1290 (NZ-3307), but it was on charcoal from the long-lived rimu, *Dacrydium cupressinum*. Barber's research and earlier results (Challis 1991: 129–34) describe a consistent district chronology indicating a fifteenth century or later advent of horticulture.

In the Marlborough Sounds, a soil layer at Greville Harbour (Wellman 1962: 62–63) is dated AD 1280–1400 (NZ-481) on unidentified charcoal from a buried log and AD 1030–1210 (NZ-482) on marine shell. There is no evidence that the ages refer to a garden. A shell date from a mound at Cattleyard Flat (NZ-4499) is AD 1490–1660. Stone rows and garden soils near Clarence River, Kaikōura, have been thought contemporary with shell middens there dating as early as the thirteenth century (Furey 2006: 92), but charcoal of mixed-age taxa from a made soil beneath a garden row (McFadgen 1980) dates AD 1460–1630 (NZ-3113) and a buried soil at the base of a borrow pit AD 1500–1640 (NZ 3397). At Avoca Point, Kaikōura, purported garden structures dated to the fifteenth–sixteenth centuries were later identified as natural features (McFadgen 1987). A post in a large rectangular pit at Pari Whakatau dated (NZ 133) AD 1500–1640 (Challis 1991: 134), and other rectangular pits are associated with post-AD 1500 pā or settlement sites throughout the Marlborough Sounds and along the Kaikōura coast (Law 1969).

Gardens and storage pits on and near Banks Peninsula, none of them radiocarbon dated, are associated with traditional pā sites occupied in the seventeenth or eighteenth centuries (Tau and Anderson 2008: 117). The Panau village site has a late pre-European settlement upon which some enigmatic garden lines had been constructed (Jacomb 2000). It is possible that they and other such features on Banks Peninsula are traces of nineteenth-century potato gardening (Challis 1995: 28) or for varieties of kūmara introduced in the early nineteenth century. In any event, kūmara cultivation was precarious in this district (Law 1969). Southern pits, oval or circular with raised rims, generally prove to be *umu tī* 'ovens for cooking *Cordyline australis*' (Fankhauser 1992).

CALIBRATION MODELS

Bayesian modelling is employed here to average out the impact of error sources, such as inbuilt age, and should produce more accurate age ranges than had been obtained earlier. As the modelling uses the same radiocarbon data used to produce the original CRA results, individual Bayesian results may not improve significantly upon the original calibrations, but the younger ends of their modelled age ranges are likely to be closer to the true age. Ideally, new radiocarbon measurement of the same samples, or of new samples, should be obtained to validate, or not, the individual dates and provide more precise age ranges. The value of the Bayesian models, however, lies in their identification of trends, and the objective here is to define trends in the distribution of ages between Northern and Southern groups, and between coastal and inland localities. The inland ages are marked with an asterisk in Table S1. As aggregation of the dates refines the age ranges, conclusions using 95% probability are both statistically more robust and, in this instance, more useful than individual dates.

In origin, 14 of the Northern ^{14}C dates are marine and 60 terrestrial, with 33 of the latter on short-lived materials such as seeds, twigs or kūmara. Sixteen of the Southern ^{14}C dates are of marine origin and 28 on potentially long-lived terrestrial materials. Dates on marine and long-lived taxa are often not included in chronological assessments (e.g., Anderson *et al.* 2019; Wilmshurst *et al.* 2008) because they are less reliable or difficult to interpret. Yet, removing these material categories reduces the number of dates available for modelling and introduces sample selection and material biases that could skew chronologies (Blauuw *et al.* 2018; Hamilton and Krus 2018). A more objective method of chronological analysis is to include those materials and use Bayesian statistical methods that downweigh problematic samples, in line with overall model parameters.

Using the outlier methodology in OxCal, charcoal samples unidentified, or identified as having 10+ years of growth, are modelled using the Charcoal Outlier command (Bronk-Ramsey 2009). We have treated all charcoal samples as having inbuilt age unless the sample material was manifestly short-lived (a category also containing eggshell and terrestrial bone), and in those cases ^{14}C dates were tagged with the General T-type Outlier command. The dates can then be slightly too young or too old, without disproportionally effecting the overall model. Each material was assessed and assigned an outlier code (supplementary file available from authors). The Bayesian Sequence Analysis option in OxCal (Bronk-Ramsey 1995) was used to generate HPDs for the most likely age interval for initial evidence of kūmara gardening in each region. HPDs are constrained by prior information of association with kūmara gardening, within a single-phase Bayesian model suitable for unordered groups of ^{14}C dates that are unconstrained by stratigraphy (Bronk-Ramsey 2009).

The orthodox method for calibrating marine ^{14}C dates uses the marine calibration curve, Marine20 (Heaton *et al.* 2020), of global changes in average ^{14}C at the ocean surface. A ΔR (Delta R) offset to the calculation corrects for regional variation (Stuiver *et al.* 1986). Using pre-AD 1950 marine values (from http://calib.org and references therein), we have calculated a New Zealand ΔR value of -154 ± 38 ^{14}C years. The individual results of this method (global calibration curve with ΔR value of -154 ± 38) can be found in the Supplementary Information (Tables SI-1 and SI-2, http://thepolynesiansociety.org/Anderson_Petchey_SI.pdf), while the Bayesian modelled trends are presented in Table 1 and Figure 2B.

This method (i.e., Marine20 with regional ΔR offset) shows southern moa-hunting (the 2A sample consists of 112 South Island moa eggshell dates taken collectively as a proxy age of early foraging; details from authors) as more or less contemporaneous with an early fourteenth century start for kūmara gardening in coastal Northern areas (2B), and the end of moa hunting coinciding with kūmara gardening beginning to move inland in the early fifteenth century AD (2B). In the Southern region, kūmara cultivation starts in the late fourteenth to mid fifteenth centuries (2B).

Table 1. HPD start boundary ages for the three Bayesian models (see text for details).[1]

Name	Calibrated boundary ages (AD)			
	68% prob.		95% prob.	
Moa hunting start	1300	1320	1290	1340
Moa hunting end	1400	1420	1390	1420
	Marine20 with −154 Δ*R*			
Kūmara start North	1300	1350	1280	1380
Kūmara start South	1360	1450	1280	...
Kūmara start North Coastal	1290	1340	1260	1370
Kūmara start North Inland	1400	1450	1350	1460
	South Pacific Marine calibration curve[2]			
Kūmara start North	1260	1310	1240	1320
Kūmara start South	1290	1390	1240	1440
Kūmara start North Coastal	1250	1300	1220	1310
Kūmara start North Inland	1390	1450	1330	1450
	Terrestrial dates only			
Kūmara start North	1300	1370	1280	1400
Kūmara start South	1220	1310	1180	1390
Kūmara start North Coastal	1270	1330	1220	1350
Kūmara start North Inland	1400	1450	1350	1460

1 SHCal20 (Hogg *et al.* 2020) used for terrestrial samples in all cases.
2 Following Petchey and Schmid (2020).

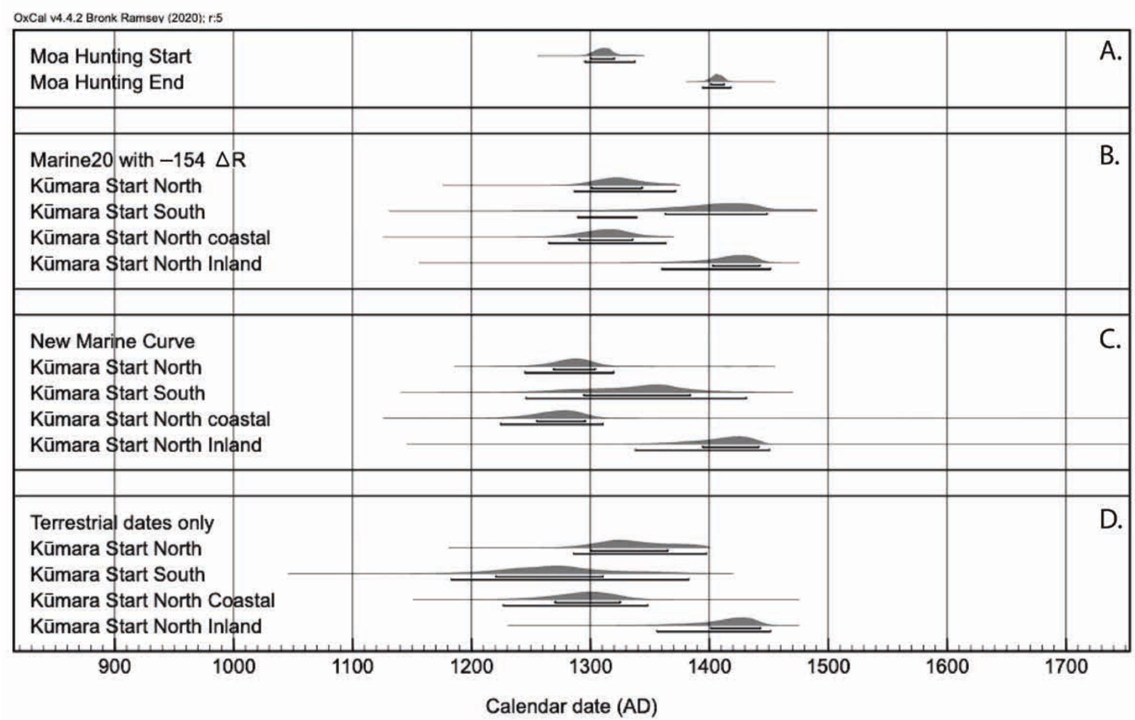

Figure 2. Comparison of HPD boundary ages for the start of kūmara gardening using different methodologies. A. Comparison of model boundary ages for moa hunting in the South Island; B. Start boundary ages using SHCal20 (Hogg *et al.* 2020) for terrestrial samples and Marine20 with a regional ΔR value of -154 ± 38 ^{14}C years applied for marine samples; C. Start boundary ages using SHCal20 and the newly developed South Pacific marine calibration curve (Petchey and Schmid 2020); D. Start boundary ages using terrestrial ^{14}C dates only.

Petchey and Schmid (2020) also identified temporal shifts in the marine reservoir around New Zealand that the global marine curve does not correct, notably a significant ΔR shift between 550 and ~600 cal BP. Although they calculated temporal ΔR corrections to adjust for this variation (see also Petchey 2020), these values are difficult to apply without a paired terrestrial ^{14}C result because the ^{14}C age of a shell living ~600 years ago will be similar to one living 300 to 400 years ago. To help in this problem, Petchey and Schmid (2020) developed a new regional calibration curve from published South Pacific marine ^{14}C ages, referred to here as the "South Pacific marine calibration curve". The individual calibrated results are graphed in Figures 3 and 4 (below) and details provided in the Supplementary Information (Tables SI-1 and SI-2). The overall modelled trends using this new calibration curve are provided in Table 1 and Figure 2C (above).

Figure 2C shows that the South Pacific marine curve makes start dates earlier overall, placing Northern kūmara cultivation just before the onset of Southern moa hunting, while Southern kūmara cultivation is entirely within the fourteenth century. The differences with 2B reflect the number of shell dates that overlap the significant marine reservoir shift noted by Petchey and Schmid (2020). The date of movement inland (2C) remains similar to 2B.

To assess whether one marine calibration method provided results more consistent with the terrestrial chronology than the other, we modelled only terrestrial materials (Figure 2D). As this reduced the number of dates to 28 for the South Island and 60 for the North Island, the precision of the calibrated results is less, and the model shows Southern kūmara cultivation starting earlier. As all but one (NZ-6496) of the Southern dates is on charcoal with inbuilt age while Northern dates mix short-lived and longer-lived materials, this result is improbable. If the Southern data are removed, then the modelled terrestrial results match the Marine20 calibration and still overlap at 68% probability with the South Pacific results; in other words, there is not much difference. Schmid *et al*. (2018) have demonstrated that the precision of HPDs within single-phase models depends not just on the number but also the distribution of dates. A higher percentage of late or early dates in models results in correspondingly older or younger age ranges, and a dominance of short-lived materials will result in a slightly younger age range because the end-member dates dominate the probability distributions.

* * *

For nearly 40 years the chronology of kūmara dispersal in East and South Polynesia has been linked to assertions that kūmara was radiocarbon dated to AD 1000 in Mangaia, and that this could stand as the arrival age for central East Polynesia, from which it was later extended to East and South Polynesia as a whole. Now that the particular age has been changed to AD 1400 we would be wise to avoid making the same loose inferences about East Polynesian prehistory from a single site and instead take the matter up explicitly for each

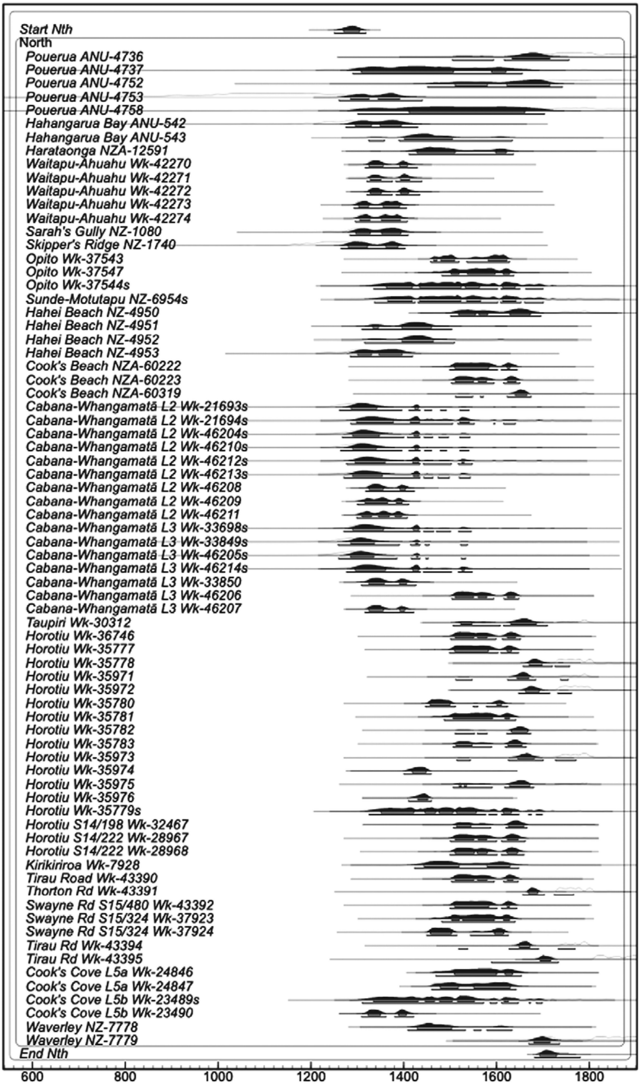

Figure 3. Calibrated results for kūmara cultivation in Northern sites using SHCal20 (Hogg *et al.* 2020) for terrestrial samples and the South Pacific marine calibration curve (Petchey and Schmid 2020) for marine samples. The outline distributions show the unmodelled calibrated ages for each sample. The black distributions show the age ranges when applying the Bayesian model constrained by the outlier parameters, as outlined in the text. Error margins of 68% and 95% are indicated by bars under each age distribution.

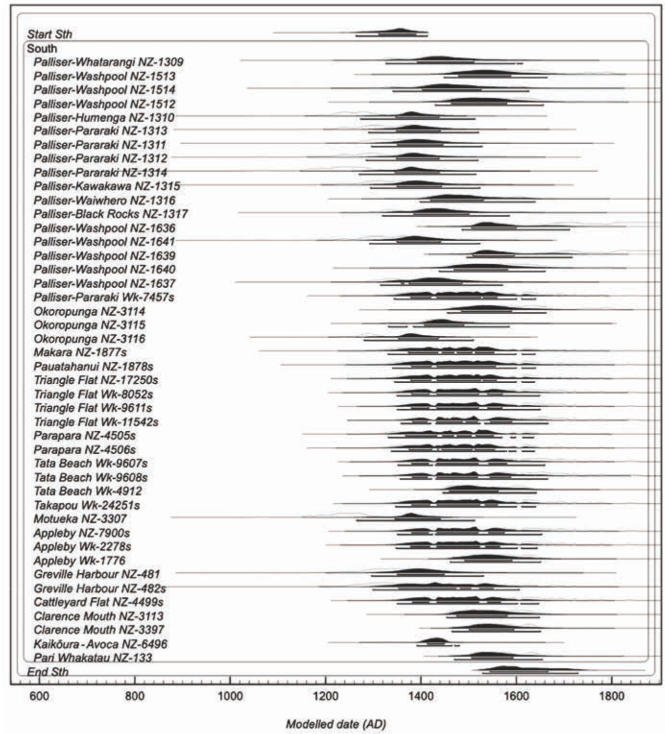

Figure 4. Calibrated results for kūmara cultivation in Southern sites using SHCal20 (Hogg *et al.* 2020) for terrestrial samples and the South Pacific marine calibration curve (Petchey and Schmid 2020) for marine samples. The outline distributions show the unmodelled calibrated ages for each sample. The black distributions show the age ranges when applying the Bayesian model constrained by the outlier parameters, as outlined in the text. Error margins of 68% and 95% are indicated by bars under each age distribution.

archipelago, especially for Hawai'i, Rapa Nui and New Zealand, where the historical implications are particularly important. One question of primary significance is whether kūmara came first into the Marquesas or Rapa Nui with the arrival of Amerindians in the twelfth to fourteenth centuries (Ioannidis *et al.* 2020) on their own sailing rafts, as has long seemed more probable than otherwise (Anderson *et al.* 2007; Wallin 2020).

As for regional dispersal, there seems to be a case, currently at least, for hypothesising post-colonisation transfer of kūmara to Hawai'i and Rapa Nui, if it did not arrive directly to the latter. While our first, exploratory, review of the New Zealand material suggested something similar, this has not emerged from the full study. We have considered the timing of kūmara introduction and dispersal in New Zealand from both ends of the scale, one being the credentials of particular samples, ages and sites. This has confirmed a scarcity of directly dated kūmara tissue in the archaeological record and numerous charcoal samples in which the extent of inbuilt age is now indeterminable. Even radiocarbon samples on short-lived taxa can remain questionable, as in cases where ages in the mid- to late fourteenth century could have some decades of inbuilt age. Elsewhere, this level of error might be trivial, but in New Zealand's short chronology, where a century is a fifth of the total span, significant questions of timing are begged at a sub-centennial level.

To answer these questions, the identification of short-life-span taxa in charcoal samples might need to go beyond most of the shrubby taxa generally accepted within it to shorter-lived taxa again (cf. Gumbley *et al.* 2003: 20), such as leaves of *Phormium* and *Cordyline*, and tussock grasses. Such samples, however, are more readily displaced in archaeological sites and demand greater assurance of original associations. That is even more the case in identifying kūmara microfossils, given that they are highly susceptible to trans-stratigraphical mobility. The exclusively cultural origin of charcoal in gardens is uncertain, as are inferential links between kūmara and pits, stone lines or other structures. Gardens were not necessarily for kūmara, and nor were storage pits. These sources of difficulty readily facilitate critical review of nearly all the pre-AD 1400 ages. Nevertheless, some early age series from Coromandel might prove robust.

That appears to be so at the other end of the research scale, where the ages for kūmara cultivation are modelled in aggregate. Excluding the terrestrial test where relatively abundant old carbon in unidentified Southern charcoal samples is suspected, an initial colonisation–cultivation link is strong for the Northern coastal region in each model. Similarly, there is a consistently late inception of Northern inland (Figure SI-1) and Southern cultivation. The modelled data are, in origin, those formerly critiqued at the sample level, but it can be argued that the application of outlier models and new calibrations to groups of ages confers more validity to the trends than can be claimed by arguing from individual ages.

If the trends are accepted and we begin thinking about why they exist, subsistence imperatives in colonising New Zealand might have been involved. When the Māori population was small, perhaps not exceeding 10,000 by AD 1400, a substantial proportion of it was attracted to hunting and foraging in the Southern region. For small dispersed colonising groups elsewhere the effort of converting heavily forested ground into kūmara gardens, especially in Northern districts, could have been delayed in favour of cultivating taro in existing wetlands (Prebble *et al.* 2019). The notion that early Northern horticulture was mainly about taro, and to a lesser extent uwhi, has some history (Ferdon 1988; Groube 1967), and taro cultivation is evident in the oldest stratigraphy on Ahuahu (Prebble *et al.* 2019).

Yet, considering the options of kūmara introduction to New Zealand, the consequences of the two modes implied here might not have been remarkably different. Kūmara arriving early in the colonisation era could have been confined for the first century or so, perhaps by lack of consumer demand, adaptational processes or the dispersal limitations of other cultigens (which helped to ensure horticultural production continuity if one species failed), to the northern North Island, and possibly to a few actual or virtual islands of premium cultivation conditions (Barber 2020; Prebble *et al.* 2019). Alternatively, kūmara arrived later and began spreading with little delay toward its latitudinal and altitudinal limits, c.f. sweet potato in the Americas (Ferdon 1988) or New Guinea (Ballard 2005). Either way, the regional dispersal, which expanded by several times the range of kūmara cultivation, occurred at about the same time. It may have been less the arrival age of kūmara than its delayed regional dispersal, and the rise of what seems to have been plantation horticulture, that had the stronger influence on population growth, pā construction, internal migration and political change (Anderson 2016). Further research might then show that the history of kūmara cultivation in South Polynesia, which has intriguing parallels with Hawai'i and Rapa Nui, was following a similar trajectory—in which surplus productivity was invested in reinforcing inherent political inequality, but in conditions of low population density and therefore later or more slowly. Time will tell.

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