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Research Article

American sweet potato and Asia-Pacific crop experimentation during early colonisation of temperate-climate Aotearoa/New Zealand

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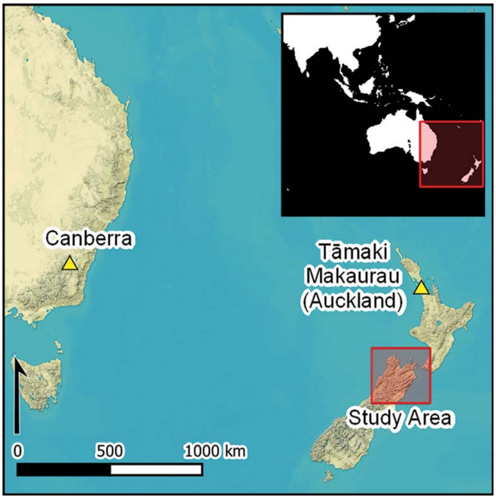

The American sweet potato (*Ipomoea batatas*) is a globally important comestible crop that features prominently in Polynesian lore; however, the timing and mode of its Oceanic transplantation remain obscure. New research from the Māori cultivation site M24/11 in Aotearoa/New Zealand, presented here, offers a re-evaluation of evidence for the early use and distribution of the sweet potato in southern Polynesia. Consideration of plant microparticles from fourteenth-century archaeological contexts at the site indicates local cultivation of sweet potato, taro and yam. Of these, only sweet potato persisted through a post-1650 climatic downturn it seems, underscoring the enduring southern-Polynesian appeal of this hardy crop.

Keywords: Oceania, Te Waipounamu/South Island, ancestral Māori colonisation, radiocarbon dating, sweet potato/*kūmara*, yam/*uwhi*, *taro*

Introduction

The historical distribution of the American sweet potato (*Ipomoea batatas*) crop across Oceania, an area where Asia-Pacific vegetables were otherwise dominant, is noteworthy (Yen 1974; Hather & Kirch 1991: 887; Ballard *et al.* 2005). Hardy, quick-growing *I. batatas*, now a globally significant comestible, was first transferred into the Pacific in separate events to open up dry, marginal environments for productive agriculture (Ballard *et al.* 2005; Iese *et al.* 2018). One early modern sweet potato journey into western Oceania revolutionised pre-nineteenth-century economics in cooler montane New Guinea (Yen 1974: 104–26; Ballard *et al.* 2005; Kirch 2017: 114–15). In Eastern Polynesia, *I. batatas* arrived directly

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from the Americas to be dispersed widely sometime after initial human settlement, *c.* AD 900, from a central island ‘ellipse’ (Figure 1A). Asia-Pacific crops remained prominent in this ellipse historically. However, transplanted *I. batatas* became the dominant food crop in southern Polynesia—as *kumara* on dry, sub-tropical Rapa Nui, and as *kūmara* for Māori in temperate-climate Aotearoa/New Zealand (Yen 1974; Ballard *et al.* 2005; Green 2005; Kirch 2017: 198–203, 208–10, 236, 238, 241–42, 265; Kirch *et al.* 2017: 172–73).

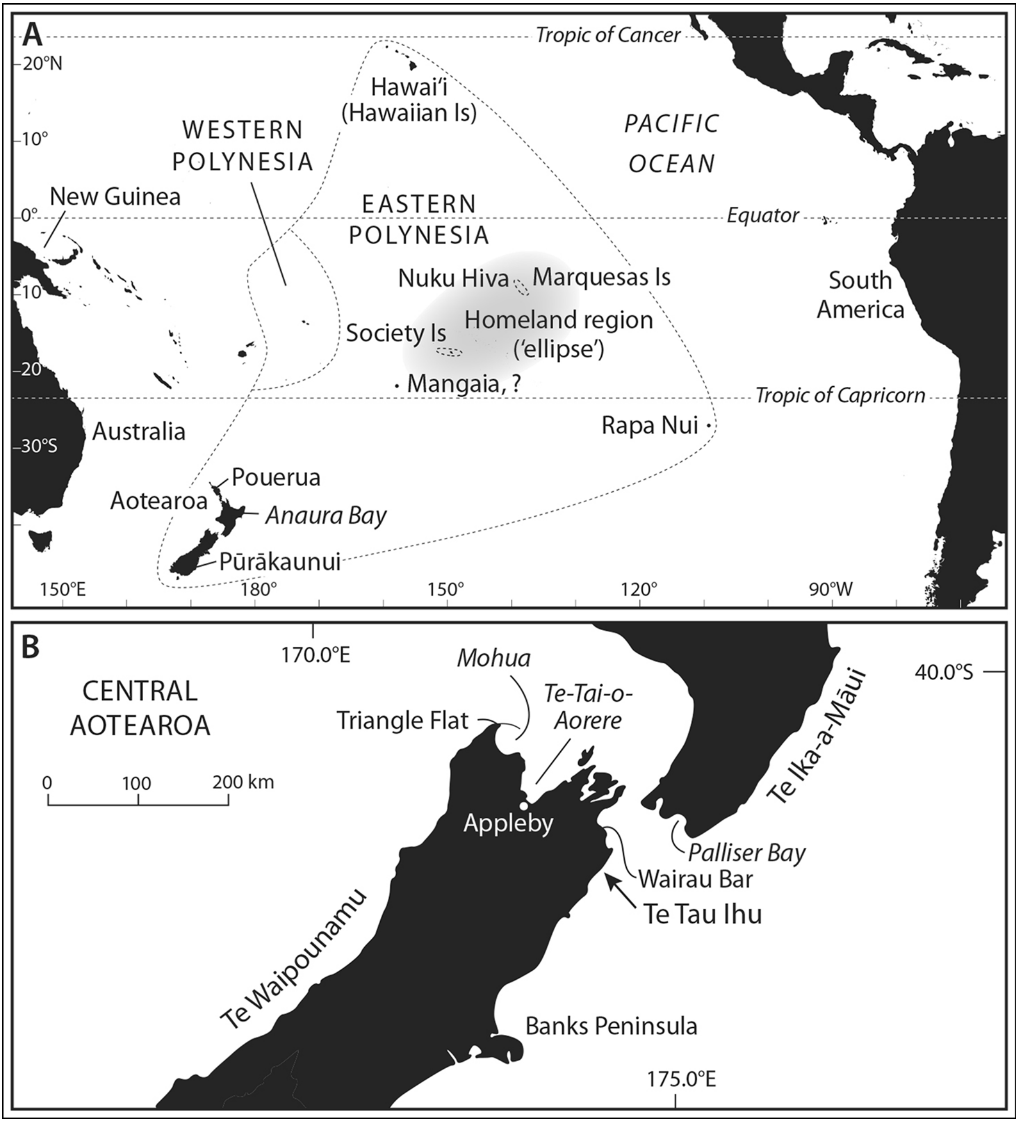

Figure 1. Location maps for places and regions of this study: A) Polynesia, including Eastern Polynesian homeland ‘ellipse’ region identified in grey fill (after Yen 1974; Green 2005); B) central Aotearoa (base data CC BY 4.0) (figure by Les O’Neill).

Māori grew annual single-season *kūmara* up to the crop's cool-climate limits on the leeward coast of Te Waipounamu/South Island (Figure 1B). From warmer localities across Aotearoa, semi-subterranean storage pits (*rua kūmara*) supplied dormant tuberous roots into winter months (Barber & Higham 2021). Māori also cultivated the Asia-Pacific geophytes *Dioscorea* yam/*uwhi* (probably *D. alata*) and semiaquatic *taro* (*Colocasia esculenta*), but less widely. *Taro* and *uwhi* required longer growing seasons and deeper, wetter and more fertile soils than *kūmara* (Yen 1974; Leach 1984: 17–32, 58–72; Barber 2012a; Kirch 2017: 200; Heider *et al.* 2021).

Debate persists around Polynesian sweet potato origins. Some scientists cite theoretical mechanics of ocean drift, seed resistance to salinity and modelled pre-human American-Polynesian genetic separation to argue that *I. batatas* became naturally transpacific (Muñoz-Rodríguez *et al.* 2018; Pereira *et al.* 2020; Temmen *et al.* 2022). Many anthropologists propose instead that South American or returning Polynesian voyagers introduced *I. batatas*, probably alongside the American gourd/*hue* (*Lagenaria siceraria*). They cite comparable Indigenous South American and Pacific names for sweet potato, which pivot around Proto-East Polynesian **kūmara* (Figure 2; see also reviews in Scaglion 2005; Kirch 2017: 210; Anderson & Petchey 2020: 351, 370; Temmen *et al.* 2022). The absence of recorded native (beyond feral) *I. batatas* populations anywhere in the Indo-Pacific area, despite a well-documented natural Oceanic distribution of other *Ipomoea* spp. (Yen 1974: 223–30, 261–63; Green 2005: 48; Ladefoged 2005: 363; Muñoz-Rodríguez *et al.* 2018; 2022: 68–70), is also notable. This fits with a genetic model of pre-Columbian human *I. batatas* transfer into Polynesia (Roullier *et al.* 2013).

The timing of pre-Columbian *I. batatas* movements into and across Oceania is also debated. A once widely accepted *c.* AD 1000–1100 radiocarbon chronology on unidentified charcoal from Tangatatau rockshelter on Mangaia bracketed finds of *I. batatas* parenchyma at the site (Hather & Kirch 1991; Green 2005: 50). But more recent modelling of shorter-life radiocarbon plant ages for this context supports uranium-series dating of coral to AD 1361–1466 (Kirch *et al.* 2017: 172; Niespolo *et al.* 2019: 22–23, 31; Anderson & Petchey 2020: 352–53). From northern Polynesia, the earliest plausible radiocarbon report is AD 1290–1430 (95% probability) on a poorly preserved carbonised root at Kohala, Hawaiʻi, identified "in favour" of *I. batatas* (Ladefoged *et al.* 2005: 367–68). From south-eastern Polynesia, macrobotanical *I. batatas* remains on Rapa Nui are no older then the thirteenth century AD, at most (Green 2005: 51; Anderson & Petchey 2020: 353–54; Muñoz-Rodríguez *et al.* 2022: 70–73, 78). And, in south-west Polynesia, the earliest reported radiocarbon age (AD 980–1280) on a carbonised *I. batatas* root from Pouerua, northern Aotearoa, represents an outlier from a post-1500 context (Anderson & Petchey 2020: 360).

Purported pre-Columbian palynomorphs cf. *I. batatas* have also been dated across Polynesia. These are primarily starch granules and occasionally pollens (see online supplementary material (OSM) Methods and Materials (OSM Methods hereafter). However, it is not always clear whether these palynomorphs have been, or even can be, differentiated from native Pacific *Ipomoea* spp., some of which are edible (Anderson & Petchey 2020: 353, 354, 360; Muñoz-Rodríguez *et al.* 2022: 69, 71–72, 74–76). Moreover, the disturbance or mobility of palynomorphs within sediments is indicated in core samples from

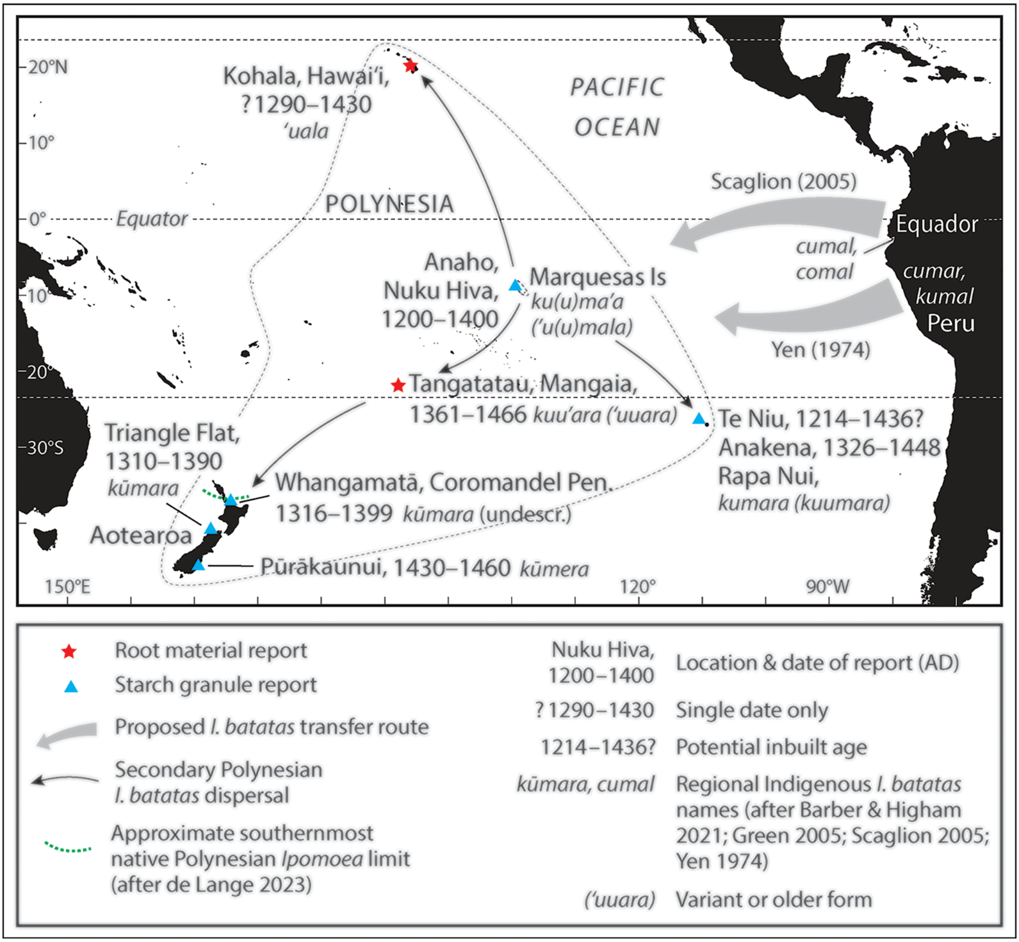

Figure 2. Location map of modelled and unmodelled chronometric ages for plausible reported pre-Columbian Polynesian I. batatas *remains including related data and crop names. Report sources by location are: Anaho, Allen & Ussher (2013); Anakena, Berenguer* et al. *(2024); Kohala, Ladefoged* et al. *(2005); Pūrākaunui, Barber & Higham (2021, modelled); Tangatatau, Niespolo* et al. *(2019, modelled); Te Niu, Horrocks & Wozniak (2008); Whangamatā, Gumbley & Laumea (2019, modelled) (figure by Les O'Neill & Chris Jennings).*

Aotearoa and a Rapa Nui crater lake (Horrocks *et al.* 2012: 190, 192, figs. 2–4, tab. 1; Anderson & Petchey 2020: 360–62).

A few pre-Columbian *I. batatas* starch reports appear to have more reliable contexts. Mollusc tools dated generally to AD 1200–1400 from Anaho, Marquesas Islands, preserve starch granules attributed to *I. batatas*, discriminating *I. pes-caprae* (Allen & Ussher 2013: 2804, 2805, 2808, 2811, tabs. 2, 4–6). Intriguingly, South American human DNA may also arrive in the Marquesas group *c.* AD 1200 (Ioannidis *et al.* 2020). Coastal cultivation soils incorporating starch granules cf. *Ipomoea* from Te Niu, Rapa Nui, plausibly date to AD 1214–1436 (95% probability), although this radiocarbon estimate is on unidentified wood from "major forest burning" (Horrocks & Wozniak 2008: 130, tab. 1). Along this same coast at Anakena, starch granules on obsidian tools from a basal archaeological deposit are attributed to *I.*

batatas with a modelled probability >90%. There are various radiocarbon determinations for this deposit, among which calibrated short-life palm endocarp dates are reported as AD 1326–1448 (Berenguer *et al.* 2024). In Aotearoa, a short-life Bayesian radiocarbon model dates a boundary transition for archaeological deposits with 'sweet potato' and *taro* starch to AD 1316–1399 (95% probability) at coastal Whangamatā, north-eastern Te-Ika-a-Māui/ North Island (Gumbley & Laumea 2019: 103, 131–32, 206). Whangamatā also lies around the indistinct southern natural limit of *Ipomoea* in Oceania (Figure 2; OSM Methods). Well south of that limit, Polynesia's southernmost archaeological starch granules cf. *Ipomoea* are reported from midden-capped *rua kūmara* deposits in a coastal dune at Pūrākaunui, south-eastern Te Waipoumanu. These assumed *I. batatas* deposits are dated to AD 1430–1460 in a short-life Bayesian radiocarbon model, also at 95% probability (Barber & Higham 2021).

Seemingly, sweet potato invisibility in the earliest, unequivocally pre-1300 deposits of these island sequences supports persistent suggestions of delayed Polynesian *I. batatas* dispersal (Green 2005; Ladefoged *et al.* 2005; Anderson & Petchey 2020). In Aotearoa, the foundational food economy (*c.* AD 1300–1450) included native vegetables, shellfish and finfish, marine mammals and birds, especially the flightless *moa* megaherbivores (Aves: Dinornithiformes, extinct by *c.* 1450–1500). Polynesian foods introduced to the islands were domestic dogs (*kurī*, *Canis familiaris*), commensal rats (*kiore*, *Rattus exulans*) and crops (Anderson *et al.* 2014: 76–86). Among the latter, sweet potato has been seen as influential (Leach 1984: 54–63; Barber 2004, 2012a), but a recent study has called for a "critical review of nearly all" reported pre-1400 Aotearoa *I. batatas* dates (Anderson & Petchey 2020: 371). Pre-1400 cultivation becomes Asia-Pacific crop production primarily, with *I. batatas* deemed unimportant, if present (Anderson & Petchey 2020: 356–64, 371–72; see also Prebble *et al.* 2019, 2020).

These problems inform our study at Te Tau Ihu/northern Te Waipounamu, a colonisation-era distribution hub for meta-argillite adzes (*toki*). In this region, with no native *Ipomoea*, pre-contact *kūmara* evidence is diverse and potentially early (Barber 1996, 2010, 2012a, 2013, 2017). Our focus is a multi-century Māori cultivation complex (Barber 2013). Short-life radiocarbon ages are modelled and diagnostic palynomorphs targeted in light microscopy (see OSM Methods for details). We ask, when were *I. batatas* and other Polynesian crops transplanted to Te Tau Ihu and how might this transplantation inform our understanding of southern Polynesian colonisation?

Te Tau Ihu study region and site

Eastern Polynesian *toki* and *moa* and seal bones characterise Aotearoa's earliest *papakāinga* (home base) at Wairau Bar, eastern Te Tau Ihu (radiocarbon dated AD 1320–1360), as well as scattered sites further west (Barber 1996; Anderson *et al.* 2014: 77–79; Jacomb *et al.* 2014). Post-1500 earthworks (*pā*) across the region signal later Māori occupation. *Māra* (cultivations) are dated to the sixteenth–seventeenth centuries from floodplain soils modified by gravel additions around Appleby, southern Te Tai-o-Aorere/Tasman Bay. In neighbouring Mohua/Golden Bay, potentially earlier coastal *māra* are identified in eastern dunes and at the coastal Triangle Flat in the north-west (Barber 1996, 2010, 2012a & b, 2013, 2017).

Figure 3. Triangle Flat site M24/11 from: A) western hill looking east over woolshed (cf. Figure S1); B) inland shelly ridge edge looking south over N21 E5 (by arrow) (photographs by Ian Barber; figure by Les O'Neill).

Triangle Flat site M24/11 spreads across low sandy-shelly ridges behind Mohua's soft shore, approximately 1km north-east of a defended headland (*pā*). Site components include stratified *māra* soils and features, midden deposits, *hāngi* (earth ovens), burials and stone artefacts, consistent with a sustained *papakāinga* (Figures 3 & S1; Barber 2013, 2024). The stratigraphy at M24/11 is capped by black sand layer 1 (L1 etc. hereafter) that incorporates post-contact farm materials (Figures 4–6A, S1–S3; Barber 2013). In many places L1 overlies redeposited bivalve shells (mostly *Austrovenus stutchburyi*) from beach sediments. This shelly deposit which incorporates occasional Māori materiality (only) is differentially mounded and caps black sand *māra* soil. Together, the capping shell and *māra* soil become L2. Substrate depressions (labelled SD) from L2 soil extend roughly 200mm into natural, C-horizon shelly sand (L5). Small intrusions (<100mm) may be *kūmara* root moulds (e.g. Figure S3). L1 or L2 overlie discontinuous midden deposits of marine molluscs (primarily *Paphies* sp. and Myitilidae), finfish, cetaceans, smaller birds, *kurī* and *kiore*, designated L3. A lower, intermittent, anthropic black sand A-horizon base is designated L4. This fills a natural subsurface channel which is expanded in one area. As in L2 soil, substrate depressions are cut below beach shell caps from L4 soil into L5 substrate (Figures 4 & 5B; Barber 2013, 2024).

The rounded to asymmetric substrate depressions at M24/11 resemble 'planting pits' on Rapa Nui that vary in size and crop use, and are so designated hereafter (Figures 4–6A cf. Stevenson *et al.* 2006: 934, figs. 9–12; Horrocks & Wozniak 2008; Barber 2010, 2012a, 2013). Durable lithic and beach mollusc sediments above archaeological Rapa Nui and M24/11 planting pits, respectively, preserved garden moisture and soils in place. This has facilitated cultivation reuse to the present on Rapa Nui (Barber 2010, 2013).

Previous palynomorph reports from M24/11 identified pollens, spores, starch granules, vascular materials, biogenic silica and calcium oxalate (CaOx) crystals in light microscopy, including micro-particles cf. *I. batatas* and *C. esculenta* (OSM Methods; Horrocks 2004: 328; Horrocks *et al.* 2004: 155; Barber 2024: app. 1). L2 pollens include intrusive post-contact pine (*Pinus* sp.) and ribwort plantain (*Plantago lanceolata*), a single *hue* (*Lagenaria siceraria*) grain, and edible, native sow thistle (*Sonchus* sp.) (the latter often considered an indicator of disturbance; cf. Prebble *et al.* 2019). Secure L4 sediments at N70 E31 incorporate native palynomorphs only (Figure 6A). These are dominated by forest pollens and

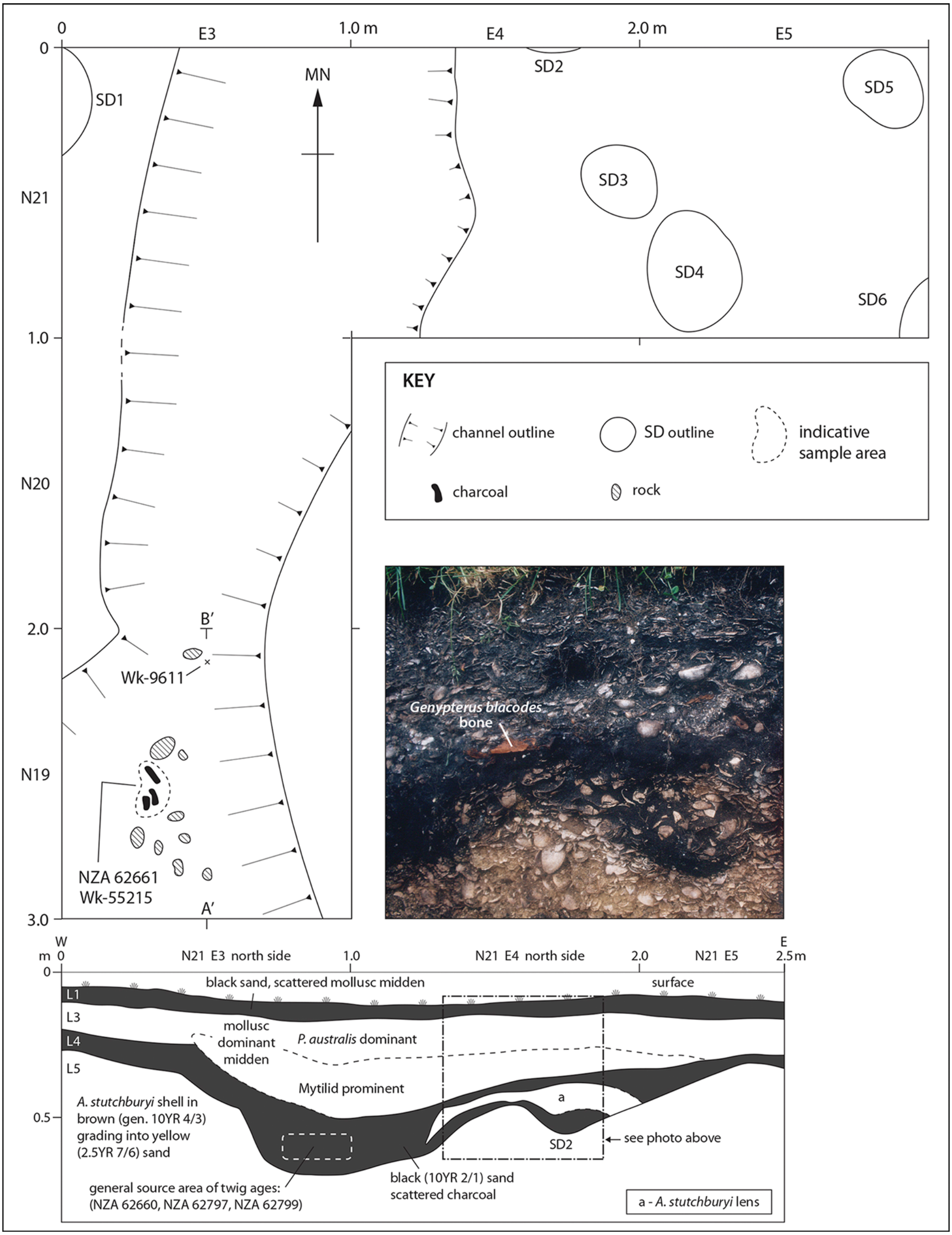

Figure 4. M24/11 excavation plan for units N19 E3–N21 E5 (from Figure S1), with lower section A'–B' (below, see also Figure S2) and inset photograph for N21 E3–E5 north (photo by Ian Barber; figure by Les O'Neill).

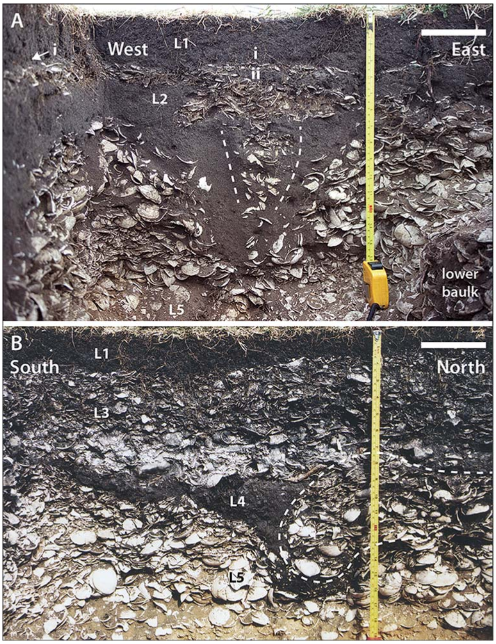

Figure 5. M24/11 sections presenting shelly mounded surfaces above planting pits filled with post-harvest beach shell (indicated within broken lines): A) lower L2 context between oblique baulk edges below discrete but disturbed beach mollusc cap (ii) and extensive mollusc deposit (i), N41 E15 (location Figure S1; also in Barber 2013: figs. 4, 6B–B'); B) L4 context at border of N21 E3–E4 (SD3, see Figure 2). Scale 100mm in each section (photographs by Ian Barber; figure by Les O'Neill).

considerably fewer grass phytoliths than L2 samples, consistent with a primary context (Barber 2024: app. 1).

Results

Light microscopy palynomorph analysis

The relatively well-preserved, semi-crystalline plant starch granules of our study were identified optically. In most cases this followed recognition of a birefringent (double refracted light) extinction cross in polarisation (Figures 7, 8, S4, S5). For species identification purposes we considered environment, context and known plant biogeography alongside specimen anatomy, allowing for limitations in Aotearoa starch granule reference work (Prebble *et al.* 2020; OSM Methods). Helpfully at M24/11, floral diversity is constrained in the predominantly young, dry, shallow, sandy topsoils, while starches of important local food plants have been documented in earlier light microscopy work (Barber & Higham 2021: 11–12; OSM Methods).

Hundreds of single, semi-compound and occasionally compound granules measuring 7–35µm in diameter, consistent with *Ipomoea*, presented in samples from L4 below dense mollusc sediments, and from L2 (e.g. Figures 6B, 7, 8, S4, S5). The granules are circular, subcircular and polygonal (multi-faceted) and present cavities or fissures at the hilum (granule origin) and on occasion, several lamellar growth rings (see OSM Methods). Granules of native, starchy Mohua plants lack cavities at hila, except in seeds from naturalised (pre-contact) *karaka* (*Corynocarpus laevigatus*) trees introduced from northern Aotearoa. However, *karaka* granules are <13.2µm and have no visible lamellae. Moreover, multiple lamellae are not diagnostic in laboratory starch contaminants that present cavities or fissures at hila (Type 1 in Crowther *et al.* 2014), nor reported in granules from *L. siceraria* rind. Large *uwhi* (Dioscoreaceae) granules and lab starch contaminants do present lamellae but are easily differentiated (see OSM Methods and discussion below). Accordingly, eight L4 granules with lamellae around vacuoles or fissures in circular, cupule or polygonal shapes, one semi-compound, are most likely *I. batatas* (Figures 7, 8 & Table S1). Individual and semi-compound granules with cavities or fissures cf. *I. batatas* from L2 suggest local persistence of cultivation (Figures 8 & S4).

In contrast, the starch granules of a deep, asymmetric, L4 planting pit in N70 E31 are predominantly smaller (<6µm), often aggregated, or enclosed in tiny (<4µm) granule masses.

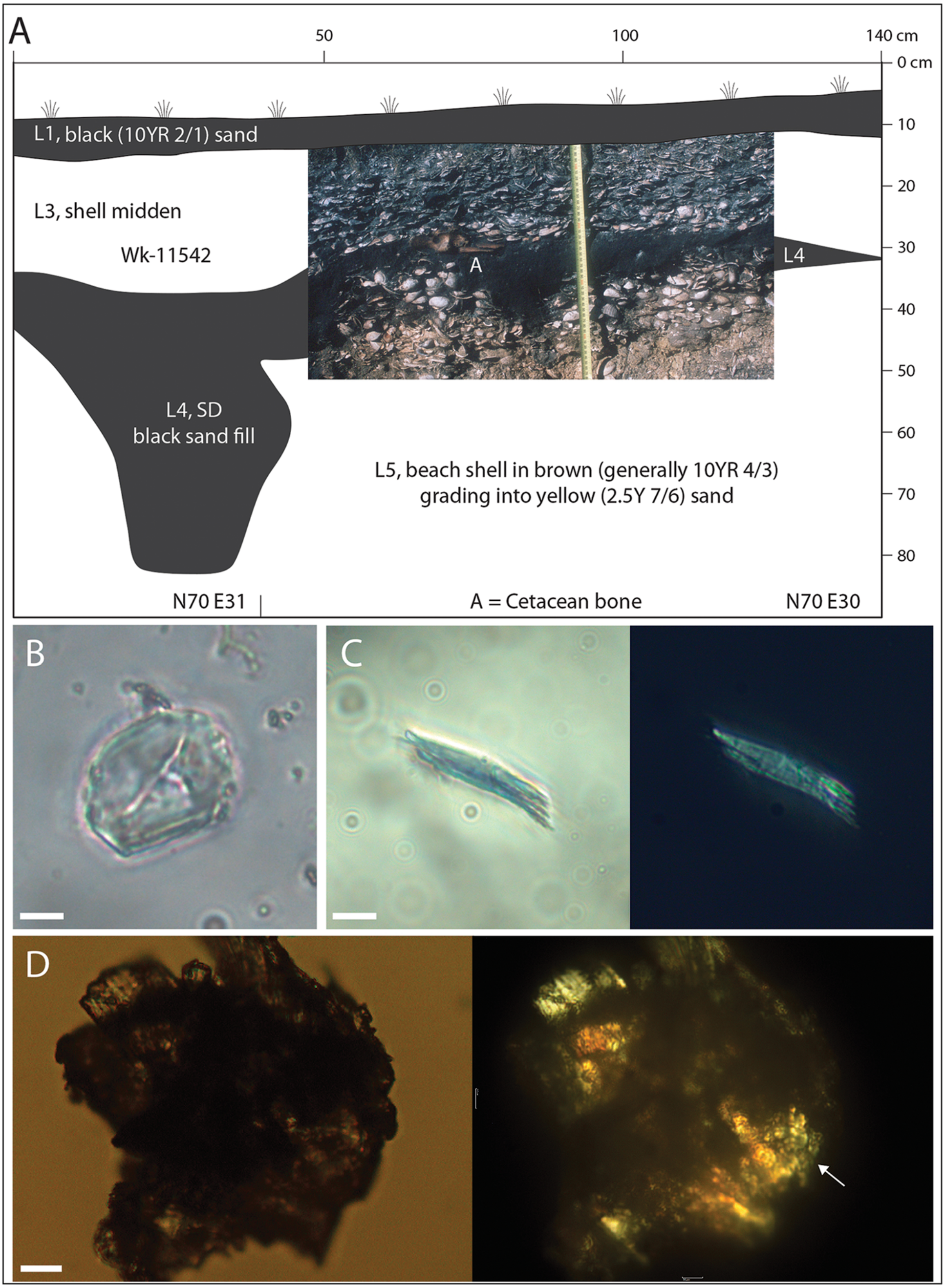

Figure 6. Deep, proposed taro planting pit with surface depression in L4 context, N70 E31: A) stratigraphic section and inset photograph for texture; B–D) photomicrographs from surface depression fill including B) large (35µm) faceted starch granule with central fissures cf. I. batatas, *scale, 10µm; C) bundles of needle-like structures 80µm long in brightfield (left) and polarised (right) light, cf. 'short thick'* C. esculenta *raphide bundles (see Figure S9A caption), scale 10µm; D) a granular aggregate (individually <7µm, e.g. by arrow) with dark tissue in brightfield (left) and polarisation (right) around projecting CaOx druses cf.* C. esculenta, *scale 20µm (photographs by Ian Barber & Rebecca Benham; figure by Les O'Neill).*

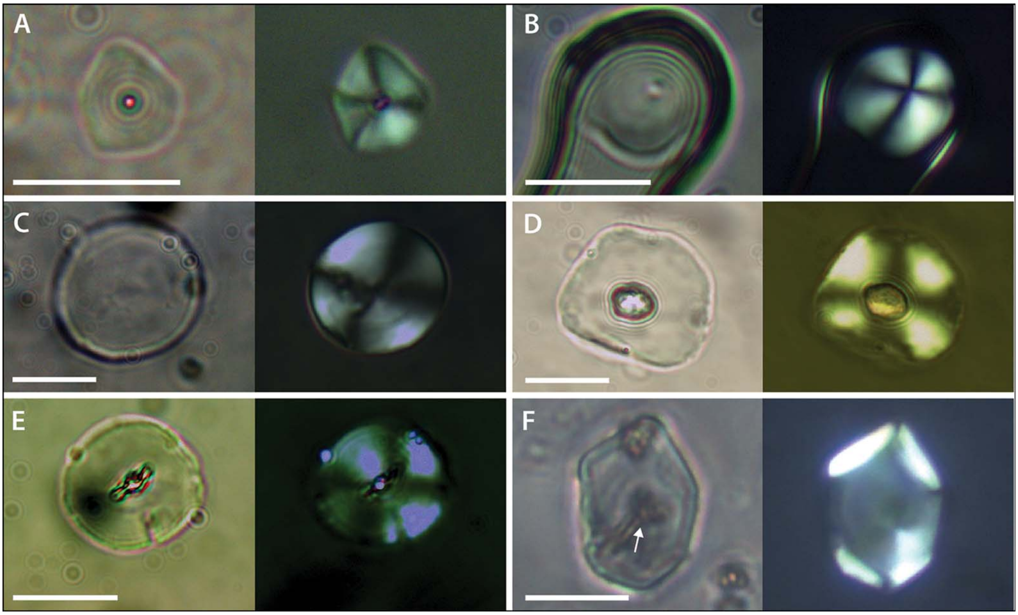

Figure 7. Photomicrographs (brightfield left, polarisation right) of polygonal, circular and cupule starch granules from M24/11 archaeological contexts cf. I. batatas. *Diagnostic features resolved (cf. reference specimens from Figure S5, Table S1) include small, round or ovate cavities at the hila (round in A, N21 E4, L4 channel fill; B, N21 E4–5, L4, SD2, with visual distortion in brightfield through bubble; faint ovate in C, SD2); a prominent circular to oval cavity at the hilum enclosed by marked central lamellae (D, in channel fill), and fissures from cavities at the hila (E, winged from prominent cavity; F, faint, by arrow, partly obscured extinction cross. Scales 10µm in each panel (photographs by Ian Barber & Rebecca Benham; figure by Les O'Neill & Chris Jennings).*

These forms resemble reference *C. esculenta* amyloplasts, and similar granules from northern Te-Ika-a-Māui *taro* soils (Figure 6; Horrocks *et al.* 2004: 155; Barber 2020; Prebble *et al.* 2020). There are comparable granular masses in L4 channel and SD2 fill, along with birefringent microcrystals that are bright and sometimes pleochroic (presenting variable colours) in polarisation (Figure S7; Barber 2024).

These birefringent L4 microcrystals resemble CaOx raphides and druses (needle-like and larger group formations of crystals, respectively) from *C. esculenta* corms and northern Te-Ika-a-Māui *taro* soils (Figures 6C–D & S8; OSM Methods). CaOx crystals do occur in other plant families and native Aotearoa Araceae, including duckweeds (*Lemna* sp.) with starch granules less than 10µm (albeit not in tiny-granule masses). Context and association therefore become more determinative at M24/11. Of note, a smaller granule aggregate encloses druses from fill of the deep N70 E31 pit, while microcrystals are incorporated within tiny-granule masses in channel and contiguous SD2 fills. Epidermal fragments cf. *C. esculenta* leaf in these L4 samples strengthen the interpretation of *taro* presence (Figures 6D, S7A–C & S8B–C; OSM Methods).

One granule group from SD2 includes large elongate, flattened ovoid shapes, individually >30µm, with no facets and highly eccentric extinction crosses. Collectively these features characterise larger starch granules of greater yam/*uwhi* (*D. alata*) that present individually and in aggregate (Figure 9, Table S2; cf. Allen & Ussher 2013: fig. 10c–d; see also OSM

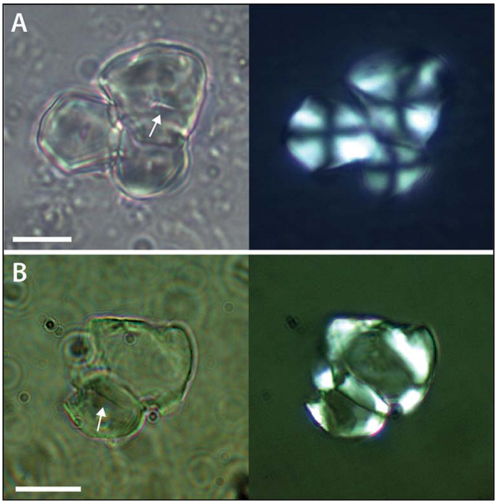

Figure 8. Photomicrographs (brightfield left, polarisation right) of grouped to semi-compound starch granules cf. I. batatas *(e.g. Barber & Higham 2021: fig. 6D–F) from archaeological planting pits with arrows pointing to fissures from hila: A) N41 E15, lower L2; and B) N21 E4–5, SD2, L4, scales at slightly different magnification each 10µm (photographs by Ian Barber & Rebecca Benham; figure by Les O'Neill & Chris Jennings).*

Methods). Large-granule lab contaminants with eccentric hila are uncommon and typically singular (Type III in Crowther *et al.* 2014), while Dioscoreaceae are not native to Aotearoa (see OSM Methods). Accordingly, this group is attributed as likely *D. alata*, representing the pre-modern world's southernmost credible *Dioscorea* cultivation datum (40°S, previously 38°S at Anaura Bay, eastern Te-Ika-a-Māui; Leach 1984: 64–66, 68). It is plausible that *uwhi* were composted (if not planted) in the contiguous channel and subsequently incorporated into the shallow SD2 as detritus, along with *C. esculenta*.

Radiocarbon analysis

Carbonised branches and twigs containing intact vascular structures and without fungal hyphae—indicating that they were fresh when burnt—were radiocarbon dated using accelerator mass spectrometry (AMS) (Figure S9). Three single dating entities were selected from a primary concentration of well-preserved twigs in the L4 channel fill. Wood was also dated from an intact surface of discarded charcoal and cooking stone materials capping the L4 channel. These capping samples were short-life outer sections of a carbonised

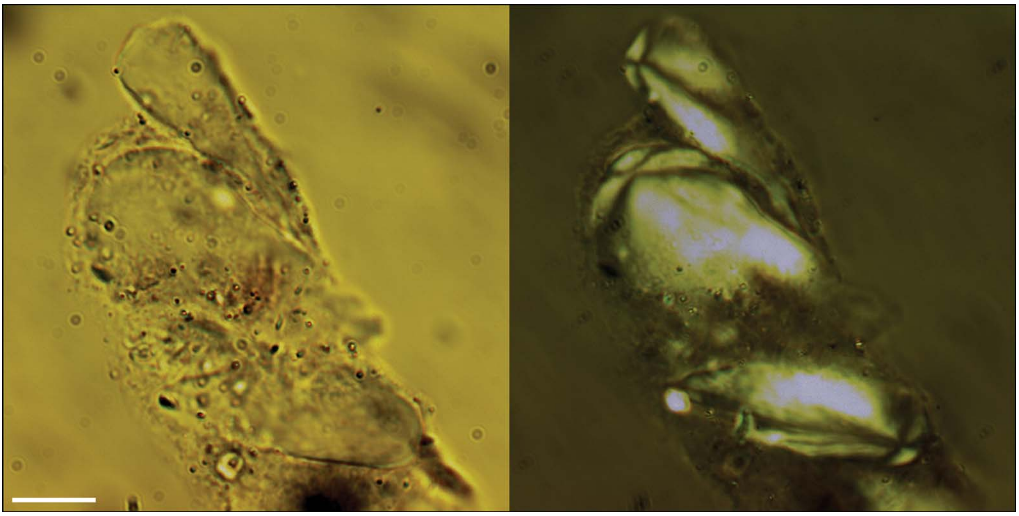

Figure 9. Photomicrograph (brightfield left, polarisation right) of grouped SD2 starch granules presenting flattened, ovate shapes with highly eccentric crosses cf. D. alata. *Scale 10µm (photographs by Ian Barber; figure by Les O'Neill).*

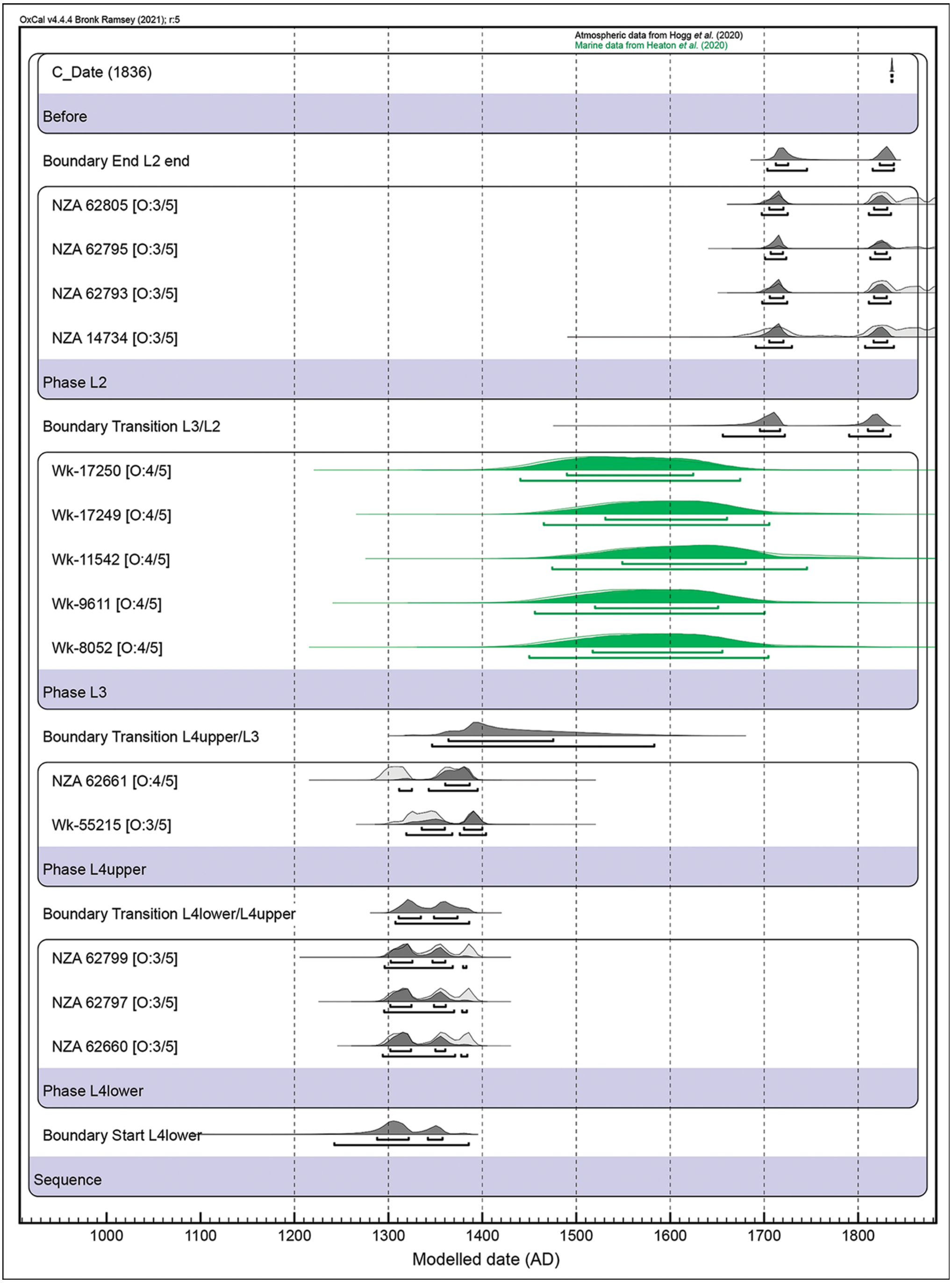

Figure 10. Bayesian radiocarbon model for M24/11 phases calibrated by SHCal20 (Hogg et al. *2020) and Marine20 (Heaton* et al. *2020) with local marine ΔR -166 ± 25 and outlier analysis (O: prior probability 0.05 or 5%) in OxCal v. 4.4 (Bronk Ramsey 2009 with data and references in Tables S3–S5). Posterior distributions in darker histogram fill are grey for atmospheric and green for marine above 68.3% and 95.4% ranges (figure formatted by Les O'Neill).*

Table 1. Calibrations for atmospheric Conventional Radiocarbon Ages (CRA), L4, with Bayesian radiocarbon model outputs in OxCal v. 4.4.

Phase: taxon, part *Boundary start & transition within L4*	Lab#	CRA	Cal AD 68.3% probability, unmodelled/modelled	Cal AD 95.4% probability, unmodelled/modelled
L4 channel cap:				
*Gl,** outer stem	NZA 62661	700 ± 20	1296–1384/1360–1387	1288–1390/1311–1395
*Mu,** outer stem	Wk-55215	651 ± 21	1320–1395/1335–1400	1304–1401/1318–1404
Boundary transition			1310–1375†	1310–1390†
L4 channel fill:				
Angiosperm, twig	NZA 62799	673 ± 19	1304–1391/1302–1360	1296–1395/1296–1383
Myrtaceae, twig	NZA 62797	679 ± 20	1300–1390/1301–1361	1295–1394/1295–1383
Angiosperm, twig	NZA 62660	684 ± 20	1300–1388/1302–1360	1293–1393/1294–1385
Boundary start L4			1285–1360†	1245-1390†

**Gl = Griselinia lucida; Mu = Metrosideros umbellata.*

†Rounded to 5 in OxCal v.4.4.

SHCal20 after Bronk Ramsey 2009; Hogg *et al.* 2020; see also Table S3.

puka (*Griselinia lucida*) branch and a southern *rātā* (*Metrosideros umbellata*) branchlet. These outer stem samples were processed at different radiocarbon laboratories as NZA 62661 and Wk-55215, respectively (Figures 4, S2 & S9C–D). Three angiosperm twigs were also dated from L2, where a previous AMS age had been derived (Figure S3).

These nine atmospheric AMS determinations are analysed around five standard L3 marine ages in a four-phase Bayesian model. Calibration curves Marine20 (with a local marine offset) and SHCal20 are applied with outlier analysis in OxCal v.4.4 (Bronk Ramsey 2009 for Heaton *et al.* 2020 and Hogg *et al.* 2020, respectively; also OSM Methods, Tables S3–S5). A historical *terminus ante quem* of 1836 mitigates the effect of multimodal L2 distributions across the wiggly post-1600 atmospheric curve (Figure 10, Tables S3 & S5).

All prior and posterior L4 distributions including capping ages from different laboratories fall within the interval AD 1285–1405 at 95.4% probability (rounded to five, as below). No outliers are identified beyond 0.05, or 5% (Figure 10). Lower modelled L4 distributions for NZA 66620, 62797 and 62799 span 1290–1385 at 95.4% probability and 1300–1365 at 68.2% probability (Table 1). This secure fourteenth-century chronology covers granules cf. *I. batatas* from channel fill and the contiguous pit SD2 with its mixed crop remains (Figure 4). For radiocarbon ages above L4, highest posterior density intervals begin around the mid-fifteenth century from the L3 midden, and from the end of the seventeenth century for L2 soil (Figure 10, Table S3).

Discussion

This study contributes the first credible evidence of pre-AD 1400 *I. batatas* on Te Waipounamu (cf. Anderson & Petchey 2020: 362–64) and the southernmost identification of *D. alata* in pre-contact Oceania. Moreover, the modelled L4 transition at M24/11 (AD 1310–1390; Figure 10) closely brackets the dates for the earliest, secure archaeological chronology in Aotearoa—the *moa*-hunting era Wairau Bar site (1320–1360; cf. Table 1 and Jacomb *et al.* 2014). The proximity of silcrete rock and regular local whale strandings help explain the appeal of early M24/11 settlement (Anderson *et al.* 2014: 81; Barber 2024). We infer that Te Tau Ihu *moa*-hunting and multi-cultigen (including *I. batatas*) cultivation were probably contemporary.

These results illustrate the more complete picture that combined archaeological and microbotanical analyses provide (cf. Barber & Higham 2021). Archaeological excavation and radiocarbon dating identified shallow, dry fourteenth-century planting pits that are indicative of *kūmara* cultivation. The deep pit in N70 E31, with its concave surface, is also suggestive of semiaquatic *taro* cultivation. The dominance of palynomorphs cf. *I. batatas* in the shallow pits and cf. *C. esculenta* in deeper N70 E31 is consistent. And microbotany alone has identified likely *D. alata* in SD2 from possible compost applications.

What should one make of this early multi-crop evidence? If the M24/11 channel is considered a likely crop detritus catchment, then there are fewer than 10 palynomorphs cf. *C. esculenta* compared with tens of granules of cf. *I batatas* in each analysed sample from channel fill. Moreover, fewer than 10 granules of cf. *D. alata* are present in any sample. This dominance of *I. batatas* from the outset of channel use resonates with the "relative frequency" of sweet potato starch on fourteenth-century tools from the homeland-region

Marquesan Anaho site (Allen & Ussher 2013: 2811). *Kūmara* are also prominent in Māori accounts of crop introductions from Hawaiki, homeland of tradition and mythic abode of *atua* (deities) and the dead (cf. Figure 1; Anderson *et al.* 2014: 60–62, 67). In one stream of lore, original if not autochthonous non-agricultural inhabitants are so impressed by *kūmara* introduced from a Hawaiki visitor that they send *waka* (canoes) for new roots. The visitor's core name is frequently Rongo (southern var. Roko), the ancient Polynesian *atua* of agriculture, and of *kūmara* for Māori (Barber 2012b; Anderson & Petchey 2020: 354–56; Barber & Higham 2021: 13–15).

Given the advantages of the hardy, fast-growing *I. batatas* in areas of marginal agricultural productivity, contemporaneous attempts at *uwhi* and *taro* cultivation at M24/11 might seem curious. One possibility is that the site was a social production experiment to replicate high-value, multi-crop 'Hawaiki' settings (Leach 1984: 54–56). Here one might compare founding Wairau Bar settlers who assiduously reproduced high status homeland artefacts in local materials (Anderson *et al.* 2014: 37, 78). But with the American new outperforming the Asia-Pacific old, *uwhi* and perhaps even *taro* disappeared from pre-contact Te Waipounamu (cf. Leach 1984: 105–6). Māori *kūmara* planting rituals continued, imposing potent *tapu* (supernatural separation) on cultivation fields (Barber 2012b). *Tapu*-removing activities, people and cooked food were strictly prohibited, perhaps explaining why raw beach mollusc rather than cooked midden mulch was applied to *māra* at M24/11 (e.g. Figures 4 & 5; Barber 2013: 49–50). In our new chronology this ritual preference has fourteenth-century roots.

In examining change over time, the more frequent cold and wet conditions affecting late Holocene Aotearoa (*c.* AD 1500–1900) need to be considered. These conditions correspond approximately to the global 'Little Ice Age' climate convergence (Lorrey & Bostock 2017: 117). After AD 1600, Aotearoa was influenced further by "harsh" winds during one of the "strongest periods of westerly flow" for 4000 years (Lorrey *et al.* 2008: 71). Such adverse conditions may have affected marginal cultivation outputs and influenced the abandonment of extensive *kūmara* fields at Palliser Bay, south-eastern Te-Ika-a-Māui (Leach 1984: 35–43, 61–63; Barber & Higham 2021). But if so, microclimate M24/11 *kūmara* and, perhaps, limited *hue* (*L. siceraria*) cultivation persisted after 1650 (Barber 2024). Hundreds of starch granules cf. *I. batatas* are identified in a lower L2 planting pit below mounded beach shells. Extensive, stabilising eighteenth-century shelly surfaces may have been spread above pits to counter increasing wind effects (Figures 5A, 10, S4 & S5B–C; Barber 2013).

Coastal southern *kūmara* agronomy during the Little Ice Age likely relied on the crop's tolerance of impoverished sandy soils that enabled cultivation in warm, if less fertile, dune settings. Moreover, the low, spreading, wind-resistant canopy and fast-setting roots of *I. batatas* would facilitate greater storm resilience than plants with larger, exposed leaves such as *C. esculenta* (Yen 1974: 70–72; Iese *et al.* 2018: tab. 1; Gatto *et al.* 2021). Repeated re-introduction may have improved *kūmara* stock further. One nineteenth-century authority from the post-1600 Te Waipounamu *iwi* (tribe) Ngāi Tahu recalled that later *waka* introduced "better kinds" of *kūmara* (Barber & Higham 2021: 14). Original southern varieties have not survived, unfortunately (Leach 1984: 103–04), but archaeological evidence of leeward, eastern Te Waipounamu *kūmara* field systems and stores indicates some success (Barber 2004: 177–78, 185–86; Barber & Higham 2021). Ngāi Tahu traditions also acknowledge *kūmara* food and social production values, naming the crop in accounts of reciprocal ceremonial feasts (*kaihaukai*). In one history, *kūmara* were stored against an eighteenth-century east coast *pā* siege, just 12km north of Pūrākaunui's fifteenth-century *rua kūmara* (Barber & Higham 2021: 2, 13–15, 16, S1 Text 10–13). *Kūmara* persistence through changing southern seasons and climate underscores Kirch's (2017: 238) observation that sweet potato came "preadapted" to Aotearoa.

This research may even have applied uses. Today, sweet potato is the world's fifth most important comestible crop (Heider *et al.* 2021: 64). But adverse impacts of climate and other environmental changes, including cyclones, drought and desertification, have affected twenty-first century production. In response, new agronomies focused on natural *I. batatas* hardiness seek to maintain, if not improve on, the geophyte's naturally high nutritional value (Heider *et al.* 2021; Rosero *et al.* 2022). The ancient knowledge (*ngā mātauranga o mua hei* in Māori) and archaeology of marginal Oceanic *I. batatas* persistence might encourage if not inform these modern food security developments.

Conclusion

Dating of early cultivation and composting contexts containing proposed *I. batatas* palynomorphs in Te Tau Ihu points to a pre-1300 presence of sweet potato in the Polynesian homeland. From that Hawaiki, a pre-adapted *I. batatas* resilience, bequeathed by continental evolution, may have helped motivate early migrants to cross cooler waters for southern Polynesian isles (Barber 2012a). Certainly, the presence of shallow planting pits and large numbers of starch granules suggest that fast-growing *I. batatas* was the primary fourteenth-century crop at the temperate-climate M24/11 site. A colonising experimental strategy that prioritised hardy *kūmara* over *taro* and *uwhi* is indicated. In time, wider amplification of that strategy would support social and subsistence *kūmara* production in selected areas of Te Waipounamu (Barber 2010; Barber & Higham 2021). This ancient southern Oceanic agronomy underscores the modern food security value of sweet potato.

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Online supplementary materials (OSM)

To view supplementary material for this article, please visit https://doi.org/10.15184/aqy.2024.143 and select the supplementary materials tab.

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