Dating the late prehistoric dispersal of Polynesians to New Zealand using the commensal Pacific rat

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The pristine island ecosystems of East Polynesia were among the last places on Earth settled by prehistoric people, and their colonization triggered a devastating transformation. Overhunting contributed to widespread faunal extinctions and the decline of marine megafauna, fires destroyed lowland forests, and the introduction of the omnivorous Pacific rat (*Rattus exulans*) led to a new wave of predation on the biota. East Polynesian islands preserve exceptionally detailed records of the initial prehistoric impacts on highly vulnerable ecosystems, but nearly all such studies are clouded by persistent controversies over the timing of initial human colonization, which has resulted in proposed settlement chronologies varying from ≈200 B.C. to 1000 A.D. or younger. Such differences underpin radically divergent interpretations of human dispersal from West Polynesia and of ecological and social transformation in East Polynesia and ultimately obfuscate the timing and patterns of this process. Using New Zealand as an example, we provide a reliable approach for accurately dating initial human colonization on Pacific islands by radiocarbon dating the arrival of the Pacific rat. Radiocarbon dates on distinctive rat-gnawed seeds and rat bones show that the Pacific rat was introduced to both main islands of New Zealand ≈1280 A.D., a millennium later than previously assumed. This matches with the earliest-dated archaeological sites, human-induced faunal extinctions, and deforestation, implying there was no long period of invisibility in either the archaeological or palaeoecological records.

archaeological visibility | colonization | East Polynesia | radiocarbon | *Rattus exulans*

The last major prehistoric human migration into a previously unoccupied region of the world was from the western archipelagos of Remote Oceania (Fiji, Tonga, and Samoa region) into the islands of East Polynesia (1). The devastating ecological consequences of human arrival are well documented on many East Polynesian islands and show striking similarities in terms of deforestation (2) and faunal extinctions or declines (3–7). However, the chronological sequence of the prehistoric colonization of East Polynesia remains controversial (1, 8–11), with one model suggesting dispersal from West Polynesia as early as 200 B.C. (1, 9, 10) after a pause of ≈500–1,000 years and another suggesting it began ≈800 A.D. after a delay of several thousand years (8, 12–16). These divergent chronologies and their related models of ecological and anthropological change result directly from various interpretations of conflicting radiocarbon dates on the earliest-dated archaeological sites, deforestation, Pacific rat introduction, and faunal extinctions from East Polynesia and have created many hotly debated ''long'' and ''short'' settlement chronologies (e.g., refs. 1, 8, 11, 14, 17, 18). These unresolved and contradictory age models currently hinder our understanding of the timing and processes of prehistoric human dispersal from West Polynesia (17) and rates of anthropogenic environmental change, faunal extinction, population growth, technological change, development of regionality in material culture and horticultural expansion on each island (18).

A new dating approach is required to help determine the actual chronological sequence and pattern of ecological and anthropological change on Polynesian islands. We illustrate this approach here using New Zealand, the southernmost archipelago of East Polynesia, because it provides an excellent case study where an unresolved polarized debate persists about the time of initial human colonization (18–22). We show how the earliest-dated evidence of the introduced commensal Pacific rat (*Rattus exulans*) can be used as a reliable proxy to pinpoint the time of initial human arrival by accelerator mass spectrometry (AMS) radiocarbon dating of Pacific rat bones found in extinct laughing owl (*Sceloglaux albifacies*) roost sites (20, 21) and distinctive rat-gnawed woody seed cases bearing the tell-tale incisor marks of seed predation found preserved in sediments (15, 22). Our method exploits the fact that the omnivorous rat was transported throughout the Pacific by prehistoric people and multiplied rapidly after its initial introduction. Consequently, introduction of rats to previously rat-free islands is unlikely to remain invisible in the palaeoecological record for any length of time.

The first long-accepted colonization model for New Zealand was the ''orthodox'' archaeological model, which set the date for initial colonization to ≈800 A.D., several centuries before the earliest-dated archaeological sites. It assumed a small founding population (≈10–20 individuals) with a low population growth rate (<1%) that remained archaeologically invisible for several centuries (23, 24). Later, a ''short'' chronology was fitted to the orthodox model by a reassessment of all archaeological radiocarbon dates from New Zealand using strict criteria of acceptance (18), which put initial colonization in the 12th century A.D., a conclusion also supported by many dated deforestation records (19). The short model argued that the earliest archaeological sites represent those from the initial colonization phase (18). The most securely dated and oldest archaeological site in New Zealand (25) (Wairau Bar, South Island) containing the widest range and types of materials belonging to Archaic East Polynesian culture (25) dated from 1285 to 1300 A.D. (based on calibrated AMS dates on moa eggshell in human burial contexts) supports the short prehistory model, albeit a century later. Analyses of mtDNA variability within indigenous New Zealand Maori (26) are also more consistent with a larger founding population (≈100–200 individuals) arriving late, rather than a small founding population arriving earlier.

The short model is challenged by a "long" prehistory model that proposes initial human colonization began 0–500 A.D., at the same time as or soon after the earliest evidence for colonization in East Polynesia (27). This long model persists (28) despite increasingly younger settlement dates now emerging from East Polynesian islands (8, 11, 15, 16). The long model assumed a small founding population (<50 individuals) with slow growth rates (1% per year) that would have remained archaeologically invisible for >1,000 years until the 13th century A.D. There is no direct archaeological evidence to support this model, which assumes that any early settlements have long been destroyed (27). Instead, it relies on minor short-term forest disturbances (19) that occur well before deforestation began in the 13th century A.D. as evidence for initial human presence (27). However, these disturbances are common throughout the Holocene in many New Zealand pollen records and have more convincing natural explanations (19).

In 1996, the first series of AMS radiocarbon dates (hereafter "dates"), the oldest ≈200 B.C., were reported on bones of the introduced Pacific rat excavated from extinct laughing owl (*S. albifacies*) sites in New Zealand (20, 21). They were used to argue (20, 21) that the Pacific rat was introduced by an archaeologically invisible, transient human contact >1,100 years before the earliest-dated archaeological and palaeoecological evidence for human presence ≈1280 A.D. (19, 25). The dates were also used to propose circumstantially that there was an earlier wave of rat-induced faunal extinctions before permanent settlement (7, 20, 21). The rat dates have also been used as key evidence to support the long prehistory model (28, 29, 30). More controversially, because recent revisions of East Polynesian colonization now suggest later settlement at ≈800 A.D. (8, 11, 15), the rat bone dates imply a discovery of New Zealand from western Pacific archipelagos long before East Polynesia was even colonized. This then suggests that the current indigenous people of New Zealand (Maori and Morioriri) were neither of East Polynesian origin nor the first discoverers. However, this is inconsistent with analyses of New Zealand Pacific rat and Maori mtDNA (26, 31).

Subsequent dating of Pacific rat bones sampled from both laughing owl (32) and archaeological sites (33–35) failed to duplicate the early series of old rat bone dates (35–38). The most telling criticism of the original dates is that they fall into two distinct groups according to when the bones were processed in the same dating laboratory (22, 36, 37) (see Fig. 1). The early series of rat bone dates processed in 1995 and 1996 are all older than the oldest-dated archaeological evidence (≈1280 A.D.), but all bones dated after 1996 are younger (36, 37) (Fig. 1). Moreover, some rat bones from archaeological assemblages that were processed in 1995 and 1996 are significantly older than consistent dates on diverse materials from the same stratigraphic contexts (34, 35). Critics argued that this unusual bimodal distribution of ages according to when the bones were processed was due to inadequate pretreatment of small bones (33, 35–37). It has also been argued that some of the old 1995–1996 rat bone dates are older than their "true" age because of dietary uptake of carbon depleted in ^{14}C (e.g., refs. 39–40).

The contentious early series of old rat bone dates (20, 21) is the only direct evidence in support of an early human presence in New Zealand. We now test this evidence by redating new rat bones from the original dated laughing owl sites using improved AMS radiocarbon ultrafiltration pretreatment methods [supporting information (SI) *Text*]. We also measure stable isotopes ($\delta ^{13}C$ and $\delta ^{15}N$) in the dated bones to test for potential dietary uptake of carbon depleted in ^{14}C (*SI Text*). Finally, we date rat-gnawed seed cases of native forest trees preserved in sediments (22) to independently test the veracity of the original (20, 21) and new rat bone dates.
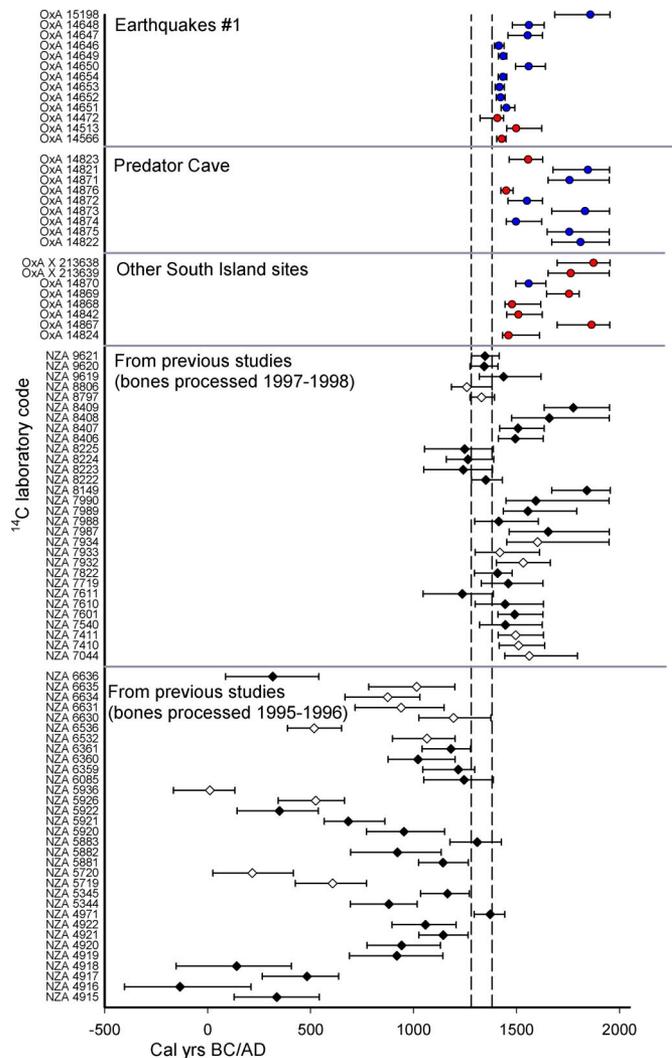

Fig. 1. Calibrated age ranges of rat bone dates from New Zealand. New calibrated age ranges of AMS dates on *R. exulans* from Earthquakes #1, Predator Cave, and seven other South Island laughing owl sites from which the original 1995–1996 rat bone dates were derived (20, 21). Blue circles, our reexcavations; red circles, museum collections (see Table S1 for stratigraphic and other details). *R. exulans* ages from previous studies (20, 21) also shown in their laboratory processing order (1995–1996 and 1997–1998) (40): open diamonds, archaeological sites (36); black diamonds, laughing owl sites (21), showing unusual bimodal distribution (36). Symbols, median age; bars, upper and lower limits of 2σ age range. Vertical dashed lines, 1σ age range of oldest archaeological site in New Zealand (1280–1382 A.D.) (25).

Results and Discussion

Redating Rat Bones from Reexcavations and Museum Collections. We reexcavated the two key deposits that produced the oldest rat bone dates in New Zealand (20, 21): Predator Cave and Earthquakes #1 (Fig. 2; *SI Text* and Figs. S1–S6). Seventeen new rat bones recovered from the same and additional stratigraphic units as originally excavated were dated (Fig. 1; *SI Text* and Table S1) to test the reproducibility of the original series of rat bone dates (20, 21). At both sites, none of our new radiocarbon ages overlap at the calibrated 2σ range with the old series of rat bone dates from the same layers (Table S1) that were processed in 1995 and 1996, and all are younger than 1280 A.D. (Fig. 1). We also dated 13 rat bones selected from the same collections of bones originally excavated and now held in museum collections, representing seven of the 1995–1996 series of rat bone sampling sites (20, 21): Predator Cave,
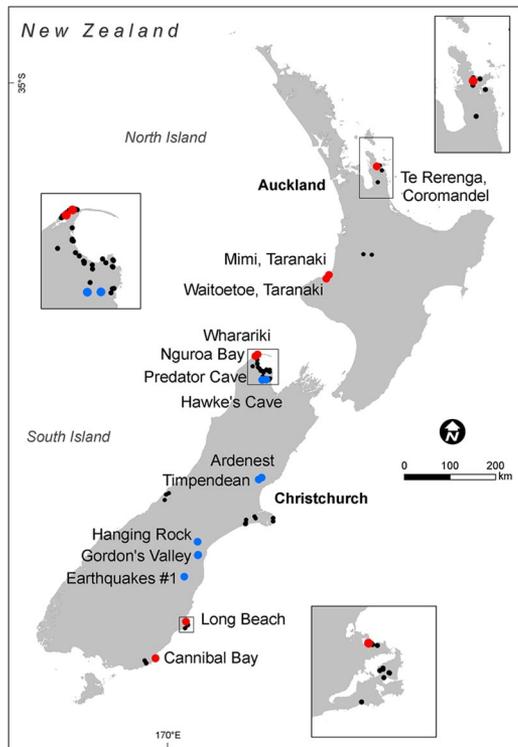
Fig. 2. Locations of laughing owl bone sites, seed deposits, and seed test pits in New Zealand. Symbols show location of redated laughing owl bone sites (20, 21) (blue), seed deposits (red) mentioned in text, and test pits (black) examined during the search for seed sites, but which did not contain preserved seeds.

Hawke's Cave, Earthquakes #1, Gordon's Valley (sites 2a, 4, and 7), Hanging Rock, Ardenest, and Timpendean (Fig. 2, Table S1). The calibrated ages of rat bones from these museum collections are also all younger than 1280 A.D. and overlap only with our reexcavated rat bone dates and with other rat bone dates processed in 1997 and 1998 (Fig. 1).

The stable isotope measurements on all our dated bones (reexcavated and museum collection) (Table S1) show a strong terrestrial vegetal signal, indicating a low probability of large reservoir offsets from their contemporary atmospheric ^{14}C levels. Thus, suggestions of dietary-related offsets (39, 40) are untenable as an explanation for the old rat bone dates processed in 1995–1996. Our redating of rat bones conclusively shows that explanation for the anachronously old series of rat bone dates (20, 21) lies most probably in laboratory pretreatment proce- dures at that time, which either failed to remove old carbon from the bones or added old carbon from some laboratory source (35, 41, 42).

Dating Pacific Rat and Human Arrival by Proxy Using Rat-Gnawed Seeds. The Pacific rat currently exerts high predation pressure on seeds (43) and has been implicated in the extinction of several prehistoric plants (13, 44). Seed cases are ideal for AMS radiocarbon dating, because they require less complex pretreat- ment than bone (22). Our earlier dates on 32 rat-gnawed seeds from the North Island (22) (Fig. 2) showed that none was older than 780 ± 70 yr before the present (BP) (Wk-8548), whereas 18 intact seeds from the same deposits (Fig. 3) dated back to 3,895 ± 45 yr BP (OxA-11737). Here, we present an additional 51 dates on seeds from the South Island (Fig. 3, Table S2). Of these, 29 seeds were from a deposit at Nguroa Bay (*SI Text*, Fig. 2), ≈50 km from Predator Cave, which produced the oldest rat bone dates (20, 21). The oldest rat-gnawed seed from Nguroa Bay was 702 ± 32 yr BP (Wk-17883), which is statistically the same as the oldest rat-gnawed seeds from sites in the North Island [$t = 1.0495$; χ^2 (0.5) = 5.99], giving a combined age for earliest rat presence in New Zealand of ≈700 yr BP (1290–1380 A.D. = 1σ range). The upper age limit for initial rat arrival can be further constrained by the age of the Kaharoa Tephra, a volcanic ash found in northeastern North Island, which has been wigglematch-dated to 1314 ± 12 A.D. (45), because rat-gnawed seeds have been found buried within this ash (22).

In three seed deposits (*SI Text*) with no rat-gnawed seeds, intact and bird-cracked seeds were also dated (Fig. 3; Table S2). Collectively, these dates, along with our body of dates on seeds (Fig. 3), strongly suggest that rats were not present in the coastal forests of New Zealand during the first millennium A.D. This is
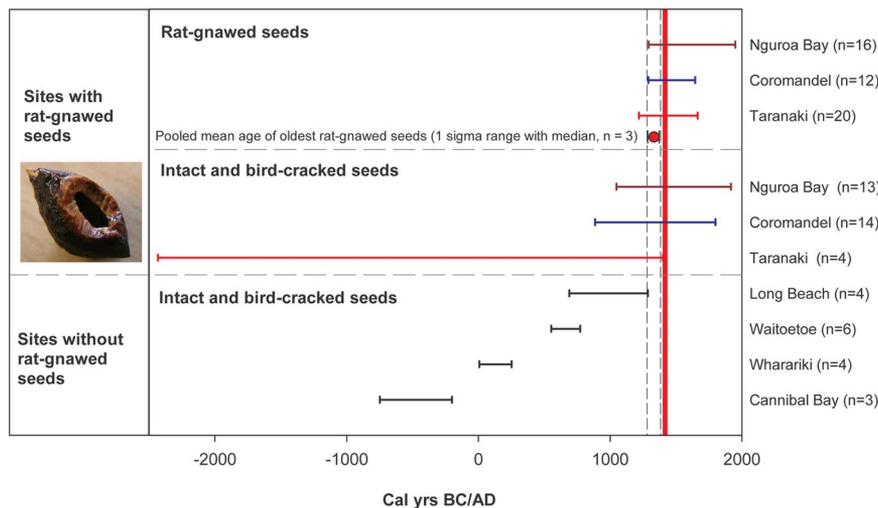

Fig. 3. Calibrated age ranges of seeds, earliest archaeological evidence, and our oldest rat bones from New Zealand. Horizontal bars represent 1σ calibrated age ranges for seeds (from the oldest to the youngest seed dates) at South Island (this study) and North Island sites (22), including sites with rat-gnawed seeds present and sites with only intact or bird-cracked seeds present. Red circle is the pooled mean age of oldest rat-gnawed seeds from three sites (1σ range with median). Vertical dashed lines represent the 1σ calibrated age range of the oldest archaeological evidence from New Zealand (1280–1382 A.D.) (25). Vertical red bar is the 1σ calibrated age range of our oldest rat bone (OxA 14472), and *n*, number of dates within each range limit (see Table S2 for details). (*Inset*) Typical rat-gnawed endocarp (*Elaeocarpus dentatus*) showing distinctive incisor bite marks (length 8 mm).

supported by radiocarbon dated rat-gnawed land snail shells (*Placostylus* spp.) from northern New Zealand, which also show distinctive signs of rat predation began no earlier than ≈750 yrs BP (46).

The close agreement of the oldest dates on rat-gnawed seeds from widespread natural sites, with those from the oldest dated archaeological site (25) suggests that the Pacific rat dispersed rapidly after its initial introduction. With abundant food and few avian predators, rat populations would have irrupted and spread rapidly throughout New Zealand, perhaps within <≈80 years, which is the time it took the Norway rat (*Rattus norvegicus*) to become widespread in both islands of New Zealand after its introduction by Europeans in the late eighteenth century A.D. (47).

Conclusions

AMS radiocarbon dates on 30 Pacific rat bones and >100 woody seed cases are consistent in showing that the Pacific rat was widespread in New Zealand by ≈1280 A.D. The dates provide no evidence for the presence of rats at any time during the preceding millennium, as suggested by previous dating of rat bones (20, 21). Our findings, based on several lines of evidence, indicate that the Pacific rat was introduced by the first human colonists from central East Polynesia to both main islands of New Zealand *ca.*1280 A.D. This age has several important implications. First, rat predation on the New Zealand biota only began after ≈1280 A.D., which is a much shorter period than previously implied by an early-rat-arrival model (7, 21). This makes the risk to currently declining populations of rat-sensitive species more pressing, because they could be diminishing faster than previously assumed. Second, prehistoric human colonization of New Zealand did not involve a protracted delay between discovery and subsequent colonization, an idea implicit in the early-rat arrival and long prehistory model (21). The first people arriving in New Zealand from tropical East Polynesia initiated an immediate and rapid biotic transformation that is easily detectable and consistently dated across a range of records. There is now excellent agreement between the ages of the earliest archaeological sites (25) and the earliest-dated evidence for widespread deforestation (19), massive megafaunal extinc-tions (4, 7), the decline of marine mammal populations (48), and rat predation on seeds (22) and invertebrates (6, 46).

Our conclusions allow us to reject not only the original series of rat bone dates but also the orthodox and long prehistory models of colonization in New Zealand, which both assume early settlement and long periods of archaeological invisibility. Our results generally agree with, but shorten by about one century, the short prehistory model and lend support to the probability that the earliest dated archaeological sites (e.g., ref. 25) represent those from the initial colonization phase (18, 25, 49).

Although our oldest-dated rat-gnawed seeds are in close agreement with the oldest dated archaeological sites from New Zealand, they are older than our oldest-dated rat bones (Fig. 3), suggesting that rat-gnawed seeds provide a more sensitive and reliable method of detecting initial rat presence than dating rat bones directly. Plant taxa with woody seed cases large enough to preserve rat bite marks (>5 mm) are common in Pacific island floras, which makes AMS radiocarbon dating of rat-gnawed seeds a relatively simple and robust way of resolving similar colonization debates elsewhere in the Pacific where rats have been introduced prehistorically.

Materials and Methods

All material was dated using AMS radiocarbon dating. All AMS determina-tions were on extracts of ultrafiltered bone gelatin (41). All seeds were pretreated using an acid-base-acid sequence and bleaching to yield holocel-lulose (50). All AMS radiocarbon dates given in years BP are conventional radiocarbon ages with standard error, where BP is before present, and present is 1950, following standard reporting procedures. Radiocarbon calibrations and pooled means were calculated by using the software CALIB v5.0.1 (51) using the Southern Hemisphere Calibration dataset SHCal04 (52). Details of seed and bone excavations, stratigraphic contexts, and radiocarbon dates are described fully in *SI Text*.

1. Kirch PV (2000) *On the Road of the Winds: An Archaeological History of the Pacific Islands Before European Contact* (University of California Press, Berkeley).
2. Rolett B, Diamond D (2004) Environmental predictors of pre-European deforestation on Pacific islands. *Nature* 431:443–446.
3. Steadman DW (2006) *Extinction and Biogeography of Tropical Pacific Birds* (University of Chicago Press, Chicago).
4. Holdaway RN, Jacob C (2000) Rapid extinction of the moas (Aves: Dinornithiformes): Model, test, and implications. *Science* 287:2250–2254.
5. Anderson A (2002) Faunal collapse, landscape change and settlement history in Re-mote Oceania. *World Archaeol* 33:375–390.
6. Tennyson A, Martinson P (2006) *Extinct Birds of New Zealand* (Te Papa Press, Well-ington, New Zealand).
7. Worthy TH, Holdaway RN (2002) *The Lost World of the Moa, Prehistoric Life of New Zealand* (Canterbury Univ Press, Christchurch, New Zealand).
8. Anderson AJ (2003) Initial human dispersal in remote Oceania: pattern and explana-tion. *Cahiers Archaeol Nouvelle Caledonie* 15:71–84.
9. Kirch PV (1996) Late Holocene human-induced modifications to a central Polynesian island ecosystem. *Proc Natl Acad Sci USA* 93:5296–5300.
10. Kirch PV, Green RC (2001) *Hawaiki, Ancestral Polynesia: An essay in historical anthro-pology* (Cambridge Univ Press, Cambridge, UK).
11. Kirch PV, Khan JG (2007) Advances in Polynesian Prehistory: A review and assessment of the past decade (1993–2004). *J Archaeolog Res* 15:191–238.
12. Kennett D, Anderson A, Prebble M, Conte E, Southon J (2006) Prehistoric human impacts on Rapa, French Polynesia. *Antiquity* 80:1–15.
13. Athens JS, Tuggle HD, Ward JV, Welch DJ (2002) Avifaunal extinctions, vegetation change, and Polynesian impacts in prehistoric Hawai'i. *Archaeol Oceania* 37:57–78.
14. Spriggs M, Anderson A (1993) Late colonization of East Polynesia. *Antiquity* 67:200–217.
15. Hunt TJ, Lipo CP (2006) Late colonisation of Easter Island. *Science* 311:1603–1606.
16. Anderson A, Sinoto Y (2002) New radiocarbon ages of colonization sites in East Polynesia. *Asian Persp* 41:242–257.
17. Kirch PV, Ellison J (1994) Palaeoenvironmental evidence for human colonization of remote Oceanic Islands. *Antiquity* 68:310–321.
18. Anderson AJ (1991) The chronology of colonization in New Zealand. *Antiquity* 65:767–795.
19. McGlone MS, Wilmshurst JM (1999) Dating initial Maori environmental impact in New Zealand. *Q Int* 59:5–16.
20. Holdaway RN (1996) Arrival of rats in New Zealand. *Nature* 384:225–226.
21. Holdaway RN (1999) A spatio-temporal model for the invasion of the New Zealand archipelago by the Pacific rat *Rattus exulans. J Roy Soc NZ* 29:91–105.
22. Wilmshurst JM, Higham TFG (2004) Using rat-gnawed seeds to independently date the arrival of rats and humans to New Zealand. *Holocene* 14:801–806.
23. Green RC (1975) in *Biogeography and ecology in New Zealand*, ed Kuschel G (Junk, The Hague, The Netherlands), pp 591–641.
24. Davidson J (1984) *The Prehistory of New Zealand* (Longman Paul, Auckland, New Zealand).
25. Higham TFG, Anderson AJ, Jacomb C (1999) Dating the first New Zealanders: The chronology of Wairau Bar. *Antiquity* 73:420–427.
26. Murray-McIntosh RP, Scrimshaw BJ, Hatfield PJ, Penny D (1998) Testing migration patterns and estimating founding population size in Polynesia by using human mtDNA sequences. *Proc Natl Acad Sci USA* 95:9047–9052.
27. Sutton DG (1987) A paradigmatic shift in Polynesian prehistory: implications for New Zealand *NZ J Archaeol* 9:135–155.
28. Sutton DG, et al. (2008) The timing of the human discovery and colonization of New Zealand. *Q Int*, in press.
29. Empson L, Flenley J, Sheppard P (2002) A dated pollen record of vegetation change on Mayor Island (Tuhua) throughout the last 3000 years. *Global Planet Change* 33:329–337.
30. Worthy TH (1999) What was on the menu- avian extinction in New Zealand. *NZ J Archaeol* 19:125–160.
31. Matisoo-Smith E, et al. (1998) Patterns of prehistoric human mobility in Polynesia indicated by mtDNA from the Pacific rat. *Proc Natl Acad Sci USA* 95:15145–15150.

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32. Holdaway RN, Roberts RG, Beavan-Athfield NR, Olley JM, Worthy TH (2002) Optical dating of quartz sediments and accelerator mass spectrometry ^{14}C dating of bone gelatin and moa eggshell: a comparison of age estimates for non-archaeological deposits in New Zealand. *J Roy Soc NZ* 32:463–505.

33. Higham TFG, Anderson A, Bronk Ramsey C, Tompkins C (2005) Diet-derived variations in radiocarbon and stable isotopes: A case study from Shag River mouth, New Zealand. *Radiocarbon* 47:367–375.

34. Smith IWG, Anderson AJ (1998) Radiocarbon dates from archaeological rat bones: the Pleasant River case. *Archaeol Oceania* 33:88–91.

35. Anderson AJ (1996) Was *Rattus exulans* in New Zealand 2000 years ago? AMS radiocarbon ages from Shag River Mouth. *Archaeol Oceania* 31:178–184.

36. Anderson AJ (2000) Differential reliability of ^{14}C AMS ages of *Rattus exulans* bone gelatin in South Pacific prehistory. *J Roy Soc NZ* 30:243–261.

37. Anderson AJ (2002) in *Environmental Histories of New Zealand,* eds Pawson E, Brooking T (Oxford Univ Press, Oxford, UK), pp 19–34.

38. Anderson AJ, Higham TFG (2004) The age of rat introduction in New Zealand: Further evidence from Earthquakes #1, North Otago. *NZ J Archaeol* 24:135–147.

39. Beavan NR, Sparks RJ (1998) Factors influencing ^{14}C ages of the Pacific Rat *Rattus exulans. Radiocarbon* 40:601–613.

40. Beavan-Athfield N (2006) Comment on ''Diet-derived variations in radiocarbon and stable Isotopes: A case study from Shag River mouth, New Zealand.'' *Radiocarbon* 48:117–121.

41. Bronk Ramsey C, Higham TFG, Bowles A, Hedges R (2004) Improvements to the pretreatment of bone at Oxford. *Radiocarbon* 46:155–163.

42. Hedges REM (2000) Appraisal of radiocarbon dating of kiore bones (Pacific rat *Rattus exulans*) in New Zealand. *J Roy Soc NZ* 30:385–398.

43. Campbell DJ, Atkinson IAE (2002) Depression of tree recruitment by the Pacific rat (*Rattus exulans* Peale) on New Zealand's northern offshore islands. *Biol Conserv* 107:19–35.

44. Hunt TJ (2007) Rethinking Easter Island's ecological catastrophe. *J Archaeol Sci* 34:485–502.

45. Hogg AG, *et al.* (2003) A wiggle-match date for the Polynesian settlement of New Zealand. *Antiquity* 77:116–125.

46. Brook FJ (2000) Prehistoric predation of the landsnail *Placostylus ambagiosus* Suter (Stylommatophora: Bulimulidae), and evidence for the timing of establishment of rats in northernmost New Zealand. *J Roy Soc NZ* 30:227–241.

47. Innes JG (2005) in *The Handbook of New Zealand Mammals,* ed King CM (Oxford Univ Press, Oxford, UK), pp 174–187.

48. Smith IWG (1989) in *Saying So Doesn't Make It So*, ed Sutton DG, New Zealand Archaeological Association Monograph 17 (New Zealand Archaeological Association, Dunedin, New Zealand), pp 76–108.

49. Higham TFG, Hogg AG (1997) Evidence for late Polynesian colonization of New Zealand; University of Waikato radiocarbon measurements. *Radiocarbon* 39:149–192.

50. Tornqvist TE, de Jong AFM, Oosterbaan WA, van der Borg K (1992) Accurate dating of organic deposits by AMS ^{14}C measurements of macrofossils. *Radiocarbon* 34:566.

51. Stuiver MP, Reimer PJ (1993) Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35:215–230.

52. McCormac FG, *et al.* (2004) SHCal04 Southern Hemisphere calibration, 0–11.0 cal kyr BP. *Radiocarbon* 46:1087–1092.

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