

Available online at www.sciencedirect.com

SCIENCE @ DIRECT®



Journal of Human Evolution 47 (2004) 25–63

www.elsevier.com/locate/jhevol

A chronology for late prehistoric Madagascar

David A. Burney^{a,*}, Lida Pigott Burney^{a,b}, Laurie R. Godfrey^c,
William L. Jungers^d, Steven M. Goodman^e,
Henry T. Wright^f, A.J. Timothy Jull^g

^aDepartment of Biological Sciences, Fordham University, Bronx NY 10458, USA

^bLouis Calder Center Biological Field Station, Fordham University, P.O. Box 887, Armonk NY 10504, USA

^cDepartment of Anthropology, University of Massachusetts-Amherst, Amherst MA 01003, USA

^dDepartment of Anatomical Sciences, Stony Brook University, Stony Brook NY 11794, USA

^eField Museum of Natural History, 1400 S. Roosevelt Rd., Chicago, IL 60605, USA

^fMuseum of Anthropology, University of Michigan, Ann Arbor, MI 48109, USA

^gNSF Arizona AMS Facility, University of Arizona, Tucson AZ 85721, USA

Received 12 December 2003; accepted 24 May 2004

Abstract

A database has been assembled with 278 age determinations for Madagascar. Materials ¹⁴C dated include pretreated sediments and plant macrofossils from cores and excavations throughout the island, and bones, teeth, or eggshells of most of the extinct megafaunal taxa, including the giant lemurs, hippopotami, and ratites. Additional measurements come from uranium-series dates on speleothems and thermoluminescence dating of pottery.

Changes documented include late Pleistocene climatic events and, in the late Holocene, the apparently human-caused transformation of the environment. Multiple lines of evidence point to the earliest human presence at ca. 2300 ¹⁴C yr BP (350 cal yr BC). A decline in megafauna, inferred from a drastic decrease in spores of the coprophilous fungus *Sporormiella* spp. in sediments at 1720 ± 40 ¹⁴C yr BP (230–410 cal yr AD), is followed by large increases in charcoal particles in sediment cores, beginning in the SW part of the island, and spreading to other coasts and the interior over the next millennium. The record of human occupation is initially sparse, but shows large human populations throughout the island by the beginning of the Second Millennium AD.

Dating of the “subfossil” megafauna, including pygmy hippos, elephant birds, giant tortoises, and large lemurs, demonstrates that most if not all the extinct taxa were still present on the island when humans arrived. Many taxa overlapped chronologically with humans for a millennium or more. The extinct lemurs *Hadropithecus stenognathus*, *Pachylemur insignis*, *Mesopropithecus pithecoides*, and *Daubentonia robusta*, and the elephant birds *Aepyornis* spp. and *Mullerornis* spp., were still present near the end of the First Millennium AD. *Palaeopropithecus ingens*, *Megaladapis*

* Corresponding author: D.A. Burney, Department of Biological Sciences, Fordham University, Bronx NY 10458 USA, Tel.: 718.817.3674; Fax: 718.817.3645.

E-mail addresses: burney@fordham.edu (D.A. Burney), lburney@fordham.edu (L.P. Burney), lgodfrey@anthro.umass.edu (L.R. Godfrey), william.jungers@sunysb.edu (W.L. Jungers), sgoodman@fieldmuseum.org (S.M. Goodman), hwright@umich.edu (H.T. Wright), ajtjull@physics.arizona.edu (A.J.T. Jull).

edwardsi, and *Archaeolemur* sp. (cf. *edwardsi*) may have survived until the middle of the Second Millennium A.D. One specimen of *Hippopotamus* of unknown provenance dates to the period of European colonization.

© 2004 Elsevier Ltd. All rights reserved.

Keywords: Madagascar; lemur; extinction; dating; paleoecology; megafauna; ^{14}C ; human settlement

Introduction

Less than two thousand years separate our world from that of the extinct giant lemurs from Madagascar. This is one of the last great habitable landmasses to be colonized by humans and the only place on the planet in the late Quaternary to have a strepsirrhine-rich megafauna.

The sequence of natural and human events in late prehistoric Madagascar is also interesting from a global perspective because this is the last place on earth in which a diverse mammalian megafauna was extinguished prehistorically. The impact of human colonization on continents and most other large islands occurred much earlier. The relatively fresh record of paleoecological change in Madagascar deserves focused exploration through an intensive program of radiocarbon dating and other techniques for measuring time on relevant scales.

The age range of dates from individual sites varies markedly. The majority of fossil sites containing extinct megafauna that have been dated are late Holocene. A few open sites in the highlands and caves at widely scattered locations contain late Pleistocene fossils. Both cores and excavations have provided dates concerning the earliest evidence for humans and subsequent changes in the biota. A few regions of the island, notably portions of the humid eastern lowlands, are not well represented by prehistoric sites of any type. In the west and southwest of the island, on the other hand, two fortuitous sites, Belo-sur-Mer (Ankilibehandry Site) and Ambolisatra/Andolonomy, have yielded paleontological, archaeological, and paleoecological information in an integrated context with stratigraphic resolution of the key period of transformation since human arrival (Burney, 1999; Burney et al., 2003). Anjohibe Cave in the northwest and Ampasambazimba in the central highlands have also yielded a multiplicity of dated evidence, but their chronology for the late

Holocene is apparently less complete (see Burney, 1999).

It has been known for well over a century that Madagascar's biotic and human histories are quite distinct from those of other nearby lands, notably Africa. Madagascar is a biogeographic entity unlike any other on earth. It has many features of geology, soil, and climate that make it a sort of "Africa in miniature," yet its long isolation in the western Indian Ocean gives it an almost entirely independent time-track through the Cenozoic. In a land without native ruminants, canids, or anthropoids, Nature has forged a unique ecological and evolutionary configuration in which at least 17 species of extinct lemurs, all larger than indris and some as large as gorillas, shared a diverse floristic landscape with many species of smaller strepsirrhines, as well as the largest birds that ever lived, and a grazing system maintained by giant tortoises and three species of *Hippopotamus* (Godfrey and Jungers, 2002; also see articles in Goodman and Benstead, 2003).

What happened next was also unprecedented: Iron Age people found their way to Madagascar and settled in this strange new land, long after most of the habitable world except New Zealand, Hawaii, and a few other remote islands had been colonized by prehistoric humans. Almost nothing is known about how or why they came to Madagascar from distant parts of the Indian Ocean, how they lived in the beginning, or even how they blended with subsequent waves of colonists to become the uniquely Malagasy people (Dewar and Wright, 1993). We do not even know for sure whether the earliest visitors to the island were Asians or Africans.

In an effort to better understand the timing of these remarkable transformations, we report here new Accelerator Mass Spectrometry (AMS) ^{14}C dates for events and taxa, and present for the first time a compilation of all published and

unpublished absolute-age determinations for Madagascar known to us. It is hoped that, with careful attention to the limitations of each pretreatment protocol, material dated, and dating method, we may generate at least the broad outlines of the island's biotic history over the last few tens of millennia, focusing particularly on refining the chronometry of certain key events in the wake of the island's relatively recent invasion by our own species.

Methods

The chronological inferences presented here are drawn from a corpus of 278 dates from sites throughout the island (Figure 1; Appendix). These were determined on samples from caves and open paleontological sites, as well as additional dates on sediment cores for paleoecological studies, and dates on material from archaeological sites. Substances radiocarbon dated include bones, teeth, fecal pellets, and eggshells of vertebrates and pretreated sediments and plant macrofossils from cores. Also reported are 11 U-series determinations on speleothems and 16 thermoluminescence measurements on pottery. See individual citations and the "Comments" section in the Appendix for methods specific to individual dates.

A numerical rating system for dating reliability is adapted from Mead and Meltzer (1984), with modifications based on more recent information and the requirements of the present study. For instance, ratite eggshell is available in many sites in Madagascar, and is rated highly in our scheme (6 points) because experimental studies (Long et al., 1983) suggest that this is a dating material relatively free of carbon-reservoir and contamination problems. Bone collagen pretreatment issues, as discussed in Stafford et al. (1991) and Hedges and Van Klinken (1992), are reflected in our rating system. A high score (5) is awarded to dates based on collagen purified by alkali pretreatment or gelatinization, or inspected visually after acid pretreatment and confirmed to yield a large amount of pure white collagen. Bone collagen dates from material with poor collagen yield or humate discoloration received a low score (3). Whole-bone

dates and other bone dates from the early literature not specifying treatment received the minimum score (1). In addition, a scale factor has been included for assessing the age specificity of pretreated bulk sediment dates from cores. For details of the rating system, see Footnote 2 in the Appendix. In general, we mention in the text any caveats concerning the dating evidence presented for a particular event.

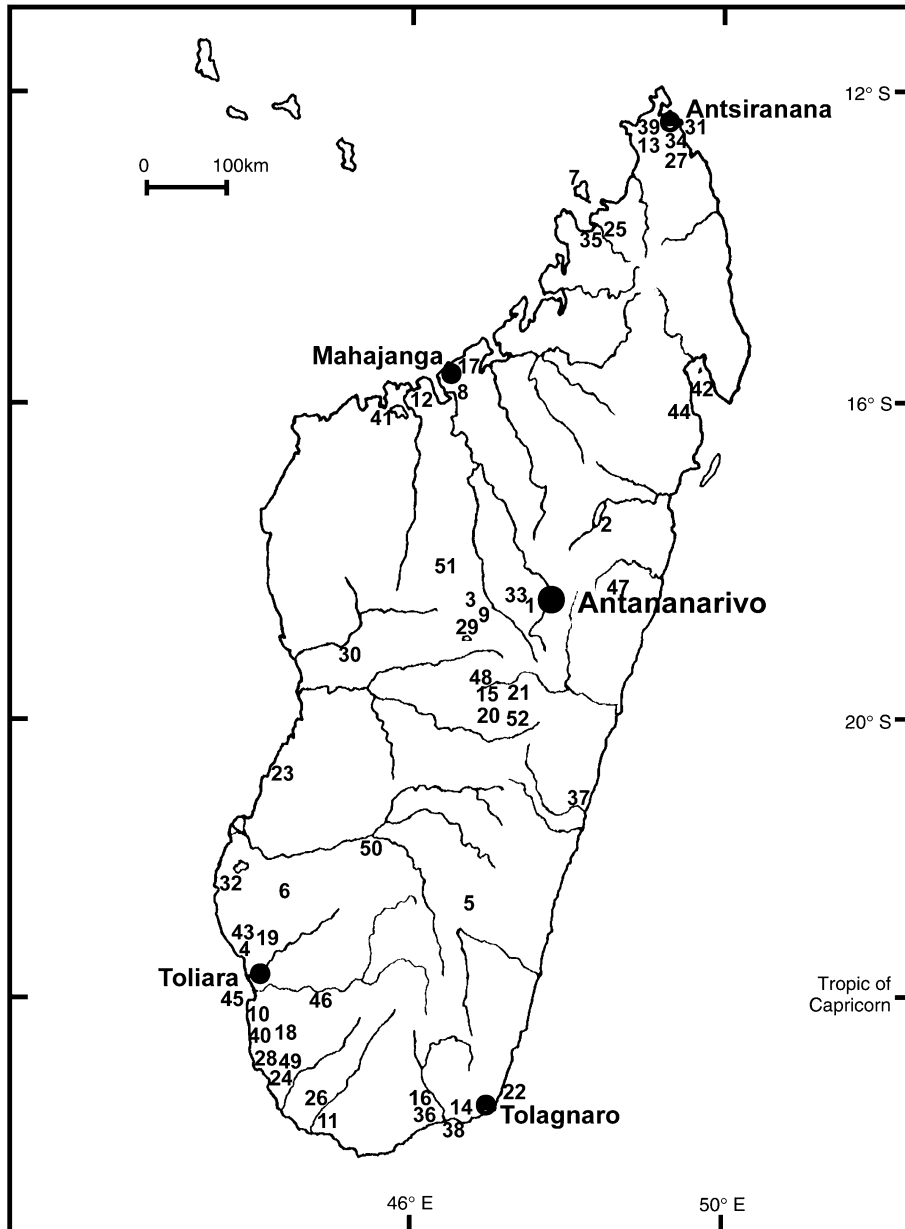
Radiocarbon dates have been calibrated using INTCAL98 (Stuiver et al., 1998). Some dates from the literature were originally reported with earlier calibration sets that differ slightly from the range given here. Dates are reported as conventional radiocarbon years (generally corrected for isotopic fractionation) $\pm 1\sigma$ (yr BP), followed by the calibrated range at 2σ (cal yr AD, BC, or BP). Many dates from the literature prior to the 1980s have probably not been corrected for isotopic fractionation, and some later papers do not indicate whether this has been done or not. However, since most dates are on material that generally gives a $\delta^{13}\text{C}$ close to the standard, correction of these dates would change them only very slightly.

Results and discussion

Climate and vegetation change before humans

Although Madagascar has undoubtedly experienced many profound shifts in climate and vegetation over the Cenozoic, details only begin to emerge in the dated records of the latest Pleistocene (Table 1). Some of the earliest dated evidence for climate and vegetation change in Madagascar comes from Lake Tritrivakely in the highlands (Burney, 1987a). Subsequent longer cores to 40 m from this crater lake extend beyond the range (ca. 40 kyr) of the radiocarbon method (Gasse et al., 1994; Gasse and Van Campo, 1998, 2001; Williamson et al., 1998). At this 1778 m ASL site, the crater's sediments record approximately 150 kyr of pollen and diatom evidence, based on comparison to isotopic variations in ice cores from Antarctica.

Evidence from this and other sites in the highlands (reviewed in Burney, 1996a; Burney, 1997a; Straka, 1996) shows that the typical full-glacial



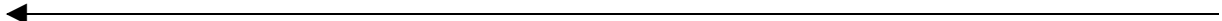


Figure 1. Location of dated sites in Madagascar. A few are omitted for which specific location is unknown.

KEY:

1. Imerina sites, including archaeological sites of Amboatany, Ambohidahy, Ambohinanjakana, Ambohitrikanjaka, Angavobe, Ankadivory, Fanongoavana, and coring site of Anosizato
2. Alaotra (paleoecological)
3. Ambohitratroandro (paleoecological)
4. Ambolisatra/Andolonomy (integrated)
5. Amboromena/Andonaham Pasipotsy (Andringitra) (paleoecological)
6. Ampanihy/Ampoza (paleontological)
7. Amparihibe (paleoecological)
8. Amparihingidro (paleontological)
9. Ampasambazimba (integrated)
10. Anakao (paleontological)
11. Anavoaha (paleontological)
12. Andavambatobe (archaeological)
13. Andrafiabe/Antsiroandoha, Ankarana (paleontological)
14. Andrahomana (paleontological/archaeological)
15. Andraikiba/Andraikibakely/Miangola (paleoecological)/Masinandraina (paleontological)
16. Andranosoa (archaeological)
17. Anjohibe/Anjohikely/Lavakasaka (integrated)
18. Ankazoabo (paleontological)
19. Ankilitelo (paleontological)
20. Antsetsindrano (archaeological)
21. Antsirabe (paleontological)
22. Baie des Galions (geological)
23. Belo-sur-Mer (integrated)
24. Bemafandry (paleontological)
25. Benavony (paleoecological)
26. Bevoha (paleontological)
27. Irodo (archaeological/paleontological)
28. Itampolo (paleontological/archaeological)
29. Itasy/Kavitaha (paleoecological)
30. Komango (paleoecological)
31. Lakaton'i Anja (archaeological)
32. Lamboharana (paleontological/archaeological)
33. Lohavohitra, Vonizonga (archaeological)
34. Mahery (paleontological)
35. Mahilaka (archaeological)
36. Manambovo River Mouth/Talaky (archaeological/paleontological)
37. Mananjary (paleontological)
38. Maroaloke (paleontological)
39. Matsabory Ampozalana (paleoecological)
40. Mitoho (paleontological)
41. Mitsinjo (paleoecological)
42. Nosy Mangabe (archaeological)
43. Ranobe (paleoecological)
44. Sandrakatsy (archaeological)
45. Sarodrano (archaeological)
46. Taolambiby (paleontological/archaeological)
47. Torotorofotsy (paleoecological)
48. Tritrivakely (paleoecological)
49. Tsiandroina (paleontological)
50. Tsirave (paleontological)
51. Tsiroanomandidy (paleoecological)
52. Vohimasina/Vohitrarivo (archaeological)

Table 1
Chronological highlights of late prehistoric Madagascar

Time	Event
> 40–20 kyr BP	Full glacial conditions, with domination of central highlands by ericoid bush. Mean temperatures $>4^{\circ}\text{C}$ colder than today. Maximum dryness recorded at LGM.
17,000 cal yr BP	Deglaciation marked by warming conditions, beginning with partial replacement of ericoid bush by savanna and woodland in highlands.
9800 cal yr BP	Holocene-type vegetation, probably a mosaic of wooded grassland and woodland, has replaced Pleistocene vegetation in the highlands.
ca. 5000 cal yr BP	Sea level reaches approximate present height.
ca. 4000 cal yr BP	Climatic desiccation in SW, continuing through rest of Holocene. Woodland vegetation on increase in central highlands due to higher effective moisture and lower temperatures.
2300 cal yr BP (350 cal yr BC)	First evidence for humans, in form of modified bones of extinct megafauna and pollen of introduced <i>Cannabis/Humulus</i> .
230–410 cal yr AD	Drastic decline of coprophilous <i>Sporormiella</i> fungus spores in sediments, due to reduced megafaunal densities. Abrupt increases in charcoal particles follow in SW sites, signaling increased human impact on the local landscape. Charcoal increase comes later in other regions, as humans spread up the west coast and into the interior.
780–1010 cal yr AD	Earliest indirect evidence for livestock proliferation, based on <i>Sporormiella</i> resurgence in NW.
ca. 1000–1400 cal yr AD	Charcoal particle evidence suggests deforestation was underway in the lowland rain forests. Islamized Indian Ocean traders active on coasts. Peak development of the entrepot of Mahilaka on the NW coast, followed by collapse. <i>Sporormiella</i> resurgence in highlands suggests pastoralism has reached this area.
1500 AD	Portuguese explorer Diogo Dias lands on N shore of Madagascar.

vegetation, down to 1000 m or less, was ericoid bushland with composites and grasses. The configuration was quite different from today, with much of the high interior dominated by vegetation that is now found primarily on isolated summits above 1900 m. At Last Glacial Maximum (LGM) around 20,000 years ago, lowland forest would probably have been restricted to refugia along the east coast and in the northwest of the island, with much of the high interior simply too dry and cold ($>4^{\circ}\text{C}$ lower mean annual temperature than today; Gasse and Van Campo, 1998). A much lower atmospheric CO_2 concentration could also have contributed to this vegetation pattern (Street-Perrot et al., 1997). In any case, the biogeographic implications of this major difference between Pleistocene glacial and Holocene interglacial Madagascar is profound, as montane species isolated in various high regions of the island today would have probably been prevalent over a much larger area, and many forest taxa may have been found only in a very restricted area of the more humid lowlands (Burney, 1996a; Goodman and Ganzhorn, 2004).

On the west coast, a few pollen spectra from the seasonally dry area around Anjohibe Cave

have been dated to as much as 40.1 kyr BP using uranium-series dating on speleothems containing microfossils (Burney et al., 1997). They show a *Medemia* palm savanna vegetation in this region north of Mahajanga quite similar to the vegetation at the site today, with only minor change through the LGM and into the Holocene. The late Pleistocene vegetation of Madagascar's arid SW is not known, as published pollen evidence for this region reaches back only five millennia (Burney, 1993a). However, the highly endemic taxonomic status of this region's flora would support the idea of long persistence of these ecosystems, although wetter episodes such as in the mid-Holocene and previous interglacials might have driven some of the xerophytic species into refugia periodically, promoting allopatric speciation (Burney, 1993a; Burney, 1996a).

Throughout Madagascar, there is a variety of evidence suggesting that LGM desiccation was widespread. Lake Alaotra, a large shallow lake in humid eastern Madagascar, was almost certainly greatly reduced in area if not completely dry ca. 20 kyr BP (Reyes, 1993; Burney, 1997a). Lake Tritrivakely in the central highlands registers a

dry phase at this time, as does the bog known as Matsabory Ampozalana on the Mt. d'Ambre in the far north (Burney, 1987b).

At Tritrivakely, Ericaceae pollen drops from 86% at 16,900 cal yr BP to 39% at 16,500 cal yr BP (Gasse and Van Campo, 1998), signaling the onset of warming postglacial conditions. Romani et al. (2002) present evidence that glacial or periglacial conditions were present on the Andringitra Massif at LGM, and sedimentological changes prior to $11,580 \pm 145$ yr BP (14,030–13,150 cal yr BP) show that warming conditions had freed Lake Amboromena (2400 m elevation) from the ice by this time.

At Tritrivakely, a brief return to cooler conditions is noted at 16,000–15,100 cal yr BP (Gasse and Van Campo, 1998). Later at this site, pollen evidence shows the nearly complete replacement, by 9800 cal yr BP, of ericoid heath vegetation with pollen of plants typical of wooded grassland or a grassland/woodland mosaic (Burney, 1987a; Gasse and Van Campo, 1998).

Outside these palynological studies, remarkably little is known about the late Pleistocene biota, except for a few dates on extinct faunas from three sites. The density of data increases greatly for megafaunas and their environments in mid-Holocene times, probably owing to more favorable conditions for fossil site formation along the present coastline. Along the west coast, for instance, many lakes and swamps apparently formed only after postglacial sea level had approached its modern height, probably ca. five millennia ago. Whether sea level exceeded present heights at least briefly after this time is not known for certain (see Burney, 1993a).

In any case, wetter conditions than today prevailed along the semiarid SW coast in the mid-Holocene, with the expansion of dry forest at the expense of palm savanna and xerophytic communities. Evidence for desiccation appears after ca. 4,000 cal yr BP in this region. From this time until human arrival, the Andolonomy pollen record (Burney, 1993a) shows that palm savanna was expanding locally.

Meanwhile, in the central highlands, pollen evidence shows that cooler conditions had returned by 3500 cal yr BP, with higher effective moisture.

Pollen of tree genera such as *Celtis* rise at this time, perhaps as higher elevation savannas were being colonized by more trees, at least along watercourses (Burney, 1987a; Gasse and Van Campo, 1998).

Spores of the coprophilous fungus *Sporormiella*, a proxy for megafaunal density, were higher in the late Holocene (up to 15% of pollen sum + spores) in semiarid coastal savannas than in any other habitats for which the spore has been measured. In the woodland/grassland mosaic of the central highlands, spore-inferred megafaunal densities appear to have been moderate. In humid forests and montane habitats, the spore occurs only as a trace before humans (Burney et al., 2003). The spore occurrences may primarily reflect densities of hippos and other non-primate megafaunal taxa.

Whatever the ecological preferences of the extinct taxa, one fact is becoming increasingly clear from the growing corpus of dates: major climate and vegetation changes of the late Pleistocene and prehuman Holocene were survived by most, if not all, the known megafauna. Despite strong evidence for range shrinkage in the late Holocene for some lemurs with very limited distributions today (Vuillaume-Randriamanantena et al., 1985; Jungers et al., 1995; Simons et al., 1995; Godfrey et al., 1999), no prehuman disappearances, climate-driven or otherwise, have been detected in the record for these animals. Of the nine genera of extinct lemurs dated, only *Babakotia radofilai*, for which only one date has been obtained, is not securely dated to the human period. Although some sites in the SW show increasing desiccation, and perhaps local faunal declines, around two millennia ago (Mahé and Sourdat, 1972; Burney, 1993a; Goodman and Rakotozafy, 1997), pollen records show that even more severe climate change has occurred many times before on the island, with no discernible effect on megafaunal extinction patterns.

Human arrival and palynological signals

Many lines of evidence converge on the notion that humans first settled in Madagascar about two millennia ago: 1) first occurrence of human-modified bones of extinct animals, 2) first occurrence of pollen of introduced *Cannabis/Humulus*

(probably the former; see Merlin, 2003), 3) sudden large increases in microscopic charcoal particles above background values, and 4) an increase in ruderal pollen and other vegetational disturbance indicators. These key events have all been dated to within three centuries of 2000 ^{14}C yr BP. Studies of the Malagasy language also show a separation from its closest surviving linguistic relatives in the highlands of Borneo about two millennia ago (Dahl, 1951). Divergence could have begun before proto-Malagasy speakers departed from Indonesia, of course. If people had arrived many centuries earlier, they would have predated the advent of the Iron Age. No plausible evidence has been found for a stone-age culture on Madagascar (Dewar, 1984). This is merely a negative-evidence argument, but the persistence of stone artifacts in the archaeological record is much better than iron, yet no stone tools except sinkers and musket-flints have been found.

The very earliest date for a human presence, 2325 ± 43 yr BP (2366–2315 cal yr BP), comes from the SW interior site of Taolambiby. It is from a radius of the sloth lemur *Palaeopropithecus ingens* with cut marks that suggest flesh removal with a sharp object (Perez et al., 2003). This is approximately coeval with the earliest occurrence of *Cannabis/Humulus* pollen at Trivivakely in the central highlands, at an interpolated age of 2200 cal yr BP (Burney, 1987a; Gasse and Van Campo, 1998). A human-modified femur of extinct *Hippopotamus* from Ambolisatra on the SW coast yielded an age of 1970 ± 90 yr BP (60 BC–130 cal yr AD) (MacPhee and Burney, 1991). Thus, a conservative estimate for the earliest human presence on Madagascar is ca. 2300 cal yr BP (350 cal yr BC). This date is marked as a point of reference in Fig. 2 and subsequent figures.

In the Andolonomy core from the vicinity of the SW fossil site of Ambolisatra, a plant

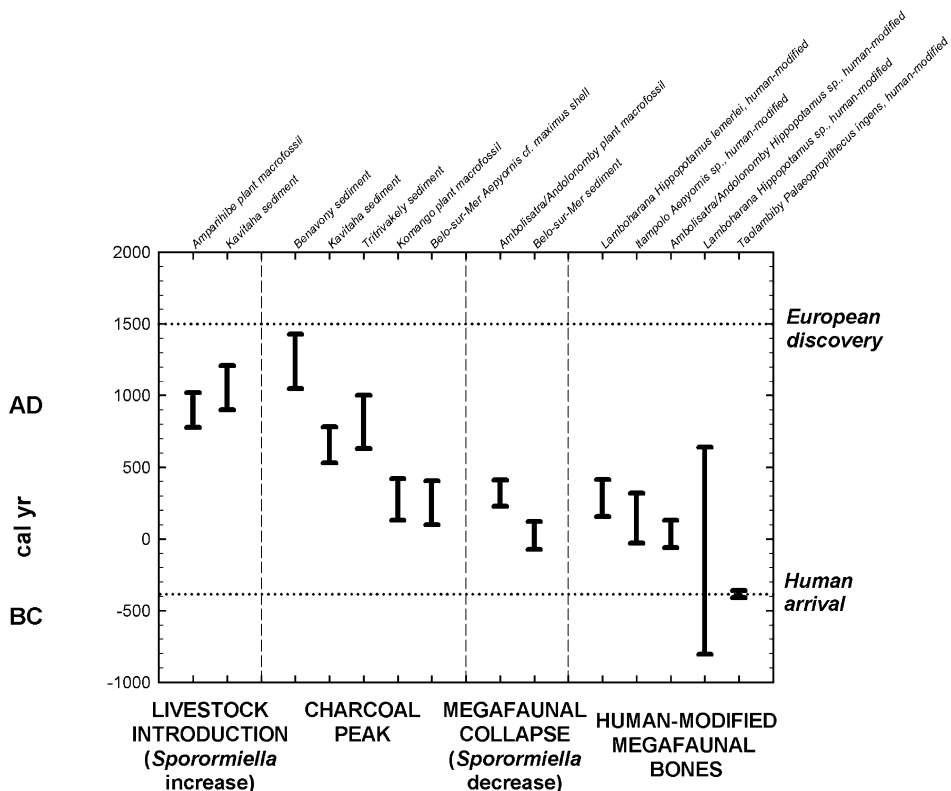


Figure 2. Radiocarbon dates for key events in the human prehistory of Madagascar, plotted as 2σ calibrated ranges.

macrofossil date on the layer of sediments showing the first marked decrease of *Sporormiella*, a proxy for the presence of megafauna (Burney et al., 2003), yielded 1720 ± 40 yr BP (230–410 cal yr AD). A similar spore decline, less securely dated, was noted at Belo-sur-Mer, another important megafaunal site, in sediments 10 cm above a layer dated 1990 ± 50 yr BP (100 cal yr BC–110 cal yr AD) on acid-treated organic bulk sediments.

It would appear that humans interacted with megafauna, although the evidence for this is scant, as it is in many other places experiencing comparable extinction events around the globe (Martin, 1984). If *Sporormiella* is indeed a reliable proxy for megafaunal density, then humans had a noticeable impact within a few centuries of arrival. However, the numerous taxa that yield much more recent terminal ages (see below) show that megafaunal decline and megafaunal extinction were not coeval, and in fact the two may be separated by at least one millennium for many taxa.

Although causes for the decline and extinction of the megafauna have long been debated (reviewed in Burney, 1999), fire has often been invoked as a major factor in the transformation of Madagascar's landscapes. Radiocarbon dating of sedimentary charcoal particles is problematic due to inherent-age and old-carbon reservoir effects (Burney et al., 2003). The stratigraphy of Ambolisatra/Andolonomby and Belo-sur-Mer, however, show that the *Sporormiella*-inferred decline of megafauna slightly predates the concomitant rise in microscopic charcoal particles. In both profiles, ca. 50 cm of sediment separates the two events, although they are apparently too close in time for good discrimination by ^{14}C measurement (Burney et al., 2003).

Fire incidence may have increased at these sites, and perhaps throughout Madagascar, due to the decline of such large herbivores as hippos, ratites, and tortoises. The loss of grazers and browsers could have resulted in excessive plant litter accumulation, leading to devastating fires. Before the advent of humans, adults of these taxa may have lacked predators other than perhaps the largest crocodiles (Brochu, 2000). Juveniles of these species and large lemurs may have also been vulnerable to the largest viverrids (Goodman et al., 2004), but the cow-sized adult hippos and half-ton

elephant birds would have been formidable prey. Consequently, their population densities may have reached high levels under favorable conditions of climate and vegetation, so that edible forage within reach may have cycled through the stomachs of megaherbivores too quickly for a large standing crop of plant litter to accumulate, thus imposing a limit on the flammability of the landscape under ordinary circumstances.

Dating of charcoal spikes, in which values increase at least one or two orders of magnitude above background, has permitted some inferences regarding the rate of transformation of the recently human-dominated landscape. This change in the fire ecology of the island shows several interesting patterns. First, it is time-transgressive, showing up nearly two millennia ago in the southwest, then spreading up the west coast to wetter climates, appearing in the central highlands about 1400 yr BP at Lake Kavitaha (Burney, 1987c) and within a century or two later at the higher Lake Tritrivakely site (Burney, 1987a). Charcoal increase does not appear at Benavony, a humid interior lowland site in the Sambirano rain forest of the northwest, until 710 ± 110 yr BP (1050–1430 cal yr AD). This conclusion is based on an acid–alkali treated bulk sediment date that may well be slightly too old, since some older carbon released by the fires may have been incorporated.

It is possible that Madagascar was first settled in the semi-arid southwest, and that over the next approximately seven centuries people gradually settled the other coasts and the central highlands. Humid forests of the low interior may have been the last areas settled (or at least burned), perhaps because of limitations posed by such human diseases as plague, malaria, or dysentery (Burney, 1999).

Another interesting pattern in the charcoal results is for charcoal to increase rapidly at the presumed time of the advent of local human activity, remain high for a few centuries, then gradually decline to moderate values. This may be a global trend on remote islands in the wake of human arrival, but it is not known certainly whether this trend is driven by ecological, microclimatic, or socioeconomic dynamics, or some combination (Burney et al., 1994; Burney, 1997b).

It is important to keep in mind that people did not *introduce* fire to Madagascar. Sediments of mesic sites of the center, north, and northwest contain large amounts of particulate carbon even tens of millennia before human arrival (Burney, 1987b; Matsumoto and Burney, 1994). The primary effect of humans on the pre-existing fire ecology was to further increase burning, at least for a while, and to spread fire to environments that are naturally too wet or too dry to support frequent fires before the arrival of humans. Very dry ecosystems often lack sufficient ground litter to support a natural fire ecology.

Population growth and ecological transformation

It is worrisome that there are no dated occupation sites during the first half millennium of significant indirect evidence for a human presence—including bones cut in an apparently fresh state; introduced pollen, disturbance indicators, and particulate charcoal in cores; and *Sporormiella* decline. It is typical of many lands, however, that indirect evidence for humans predates the earliest definite occupation sites, since a founding population may have considerable impact on the environment while their living sites are still few in number and difficult to detect archaeologically (see Burney et al., 1994).

The oldest direct evidence for occupation, probably temporary encampments for exploiting forest resources, comes from the Gorge d'Andavakoera on the north tip of the island (Dewar and Rakotoivololona, 1992; Dewar and Wright, 1993). A cave in this valley, Lakaton'i Anja, contained several levels of faunal materials mixed with pottery sherds. Upper levels include *sgraffiato* wares of the twelfth-fourteenth century. Below this level there are similar deposits lacking imported sherds. Two charcoal dates yielded 1680 ± 65 yr BP (230–530 cal yr AD) and 1300 ± 80 yr BP (620–900 cal yr AD).

Another possible early site, Sarodrano on the southwest coast, yielded a charcoal date of 1460 ± 90 yr BP (410–710 cal yr AD). Battistini and Vérin (1971) were not certain that the charcoal was derived from human activity and contemporaneous

with the pottery on the deflated surface. The charcoal could well have been from a natural brush fire. The site has since been destroyed by a cyclone.

Northeast Madagascar has yielded many occupation sites of the latest First Millennium and early Second Millennium (reviewed in Dewar and Wright, 1993). A stratified occupation site on the shelf island of Nosy Mangabe contained a layer with a date of 1250 ± 60 yr BP (660–990 cal yr AD) on charcoal associated with coarse ceramic and chlorite schist sherds and iron slag.

Within a few centuries of the beginning of the Second Millennium, evidence for human occupation is far more common in many parts of Madagascar. For example, in the small Gorge d'Andavakoera (Dewar and Rakotoivololona, 1992; Dewar and Wright, 1993), there are more than 40 sites of mostly twelfth-thirteenth century age, based on the occurrence of imported ceramics of a known age range. These sites contain few remains of domesticates, but many bones and shells of marine and terrestrial fauna. Among the primate and tortoise remains are a few bones of extinct species. These are “generally in a fragmentary state, but obvious cut and butchery marks are rare” (Dewar and Wright, 1993: 436).

Along the northeast coast in the vicinity of Irodo there are a number of sites that appear on the basis of imported pottery to range in age from slightly earlier than the twelfth to the fourteenth century, with possible smaller occupations a few centuries earlier (Vérin, 1975; Dewar, 1984). A few dates have been obtained, but all present interpretive problems (Dewar and Wright, 1993). A fragment of *Aepyornis* eggshell from one of these sites that dates to 1150 ± 90 yr BP (680–1030 cal yr AD) confirms that the bird survived until then, but it is not possible to determine whether its presence in the site was directly associated with human activity (Battistini and Vérin, 1966).

Settlements in the southernmost forests of the east coast are of similar age (Rakotoarisoa et al., 1993), as are sites such as Andranosoa, where pastoralists and foragers occupied a large area around the confluence of two rivers in the extreme south of the island, and the nearby coastal site of Talaky (reviewed in Dewar and Wright, 1993). At Andranosoa, which yielded dates as early as

920 ± 90 yr BP (1020–1210 cal yr AD) and as late as 730 ± 90 yr BP (1160–1410 cal yr AD), a pit contained large quantities of bones of sheep/goat and *Tenrec ecaudatus* and only a few cattle remains. A carapace fragment from an extinct giant tortoise and hippo teeth were excavated from an underlying terrace deposit nearby (Rasamuel, 1984).

Although dated evidence for earliest introduction of livestock to Madagascar is not available, indirect evidence in the form of a resurgence of *Sporormiella* probably can be used to assess cattle arrival in Madagascar, as it has in North America (Davis, 1987). At the Amparihibe crater lake on the shelf island of Nosy Be, a plant macrofossil date of 1130 ± 50 yr BP (779–1020 cal yr AD) on the *Sporormiella* increase in sediments is consistent with the settlement along this coast by Islamized Indian Ocean traders. A similar signal from Lake Kavitaha in the highlands at 960 ± 90 yr BP (900–1210 cal yr AD) suggests cattle may have spread to the people of the interior highlands within two centuries or less. Pollen data from sites throughout the island (reviewed in Burney, 1997a) show that, during this period around the beginning of the second millennium AD, woody vegetation was declining and grasslands were on the increase, most likely through human agency. Urban-scale human population aggregations were occurring in some areas by this time, notably at the walled city of Mahilaka on the northwest coast, which thrived between the eleventh and fourteenth centuries (Radimilahy, 1997). This city of several thousand people declined suddenly near the end of the fourteenth century for unknown reasons. It has been suggested that plague, malaria, dysentery, or other diseases that were rampant at this time in Eurasia and Africa might have limited human expansion in the more humid parts of Madagascar (Burney, 1999), although no direct evidence has been found to support this idea.

Evidence for very early settlements in the now heavily populated central highlands has proven elusive. Pollen and charcoal data (Burney, 1987c) point to local human impacts beginning in the late First Millennium. Definite settlement activity, with pollen of agriculturally associated ruderal plants

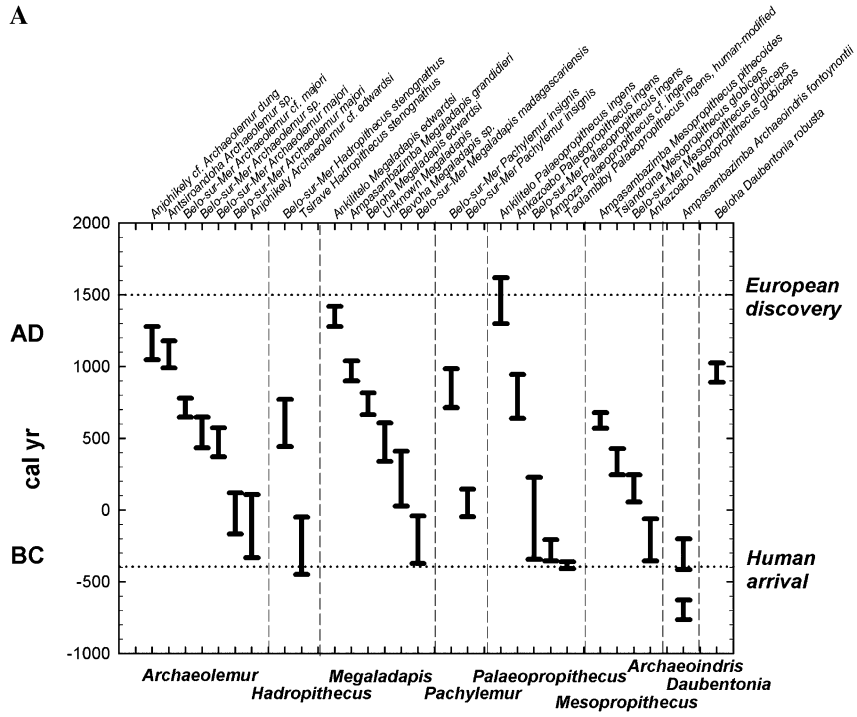
and increased charcoal in sediments, was underway by 960 ± 90 yr BP (900–1210 cal yr AD; Burney, 1987c). This is in good agreement with evidence from Fiekena ceramic assemblage sites such as Ankadivory. People with a different pottery style and other cultural distinctions from the coasts were well-established in the area by the thirteenth and fourteenth centuries, based on radiocarbon and thermoluminescence dates, and confirmed by some imported pottery, mostly of Far Eastern types (Wright et al., 1992; Rakotovolona, 1994).

The first European known to have visited Madagascar was Diogo Dias, a Portuguese explorer, in 1500 AD. History records that, over the next three centuries, Portuguese, Dutch, French, and English colonial ventures were attempted, and pirates used the many remote harbors as bases from which to launch their mischief (Brown, 1979). Some of these European colonists and adventurers, with their new technology, religions, and languages, were absorbed into the indigenous setting, contributing to the unique Malagasy cultural configuration of today. Population growth and land conversion have been particularly rapid since the mid-twentieth century (Green and Sussmann, 1990), with the result that many of the surviving biotic communities are under severe threat from human pressures.

Last of the megafauna

Intensified radiocarbon dating of apparent late occurrences of extinct giant lemurs, elephant birds, and hippos has brought into sharp focus the protracted nature of the subfossil extinctions. The “extinction window,” defined as the duration of the period from earliest human evidence to last occurrence of extinct megafauna, shows an overlap between humans and some of these lost creatures of up to two millennia. The extinct lemurs *Hadropithecus stenognathus*, *Pachylemur insignis*, *Mesopropithecus pithecoides*, and *Daubentonia robusta*, and the elephant birds *Aepyornis* and *Mullerornis*, were still present near the end of the First Millennium AD (Figure 3; Table 2). Dating suggests that *Archaeolemur* sp. (cf. *edwardsi*),

A



B

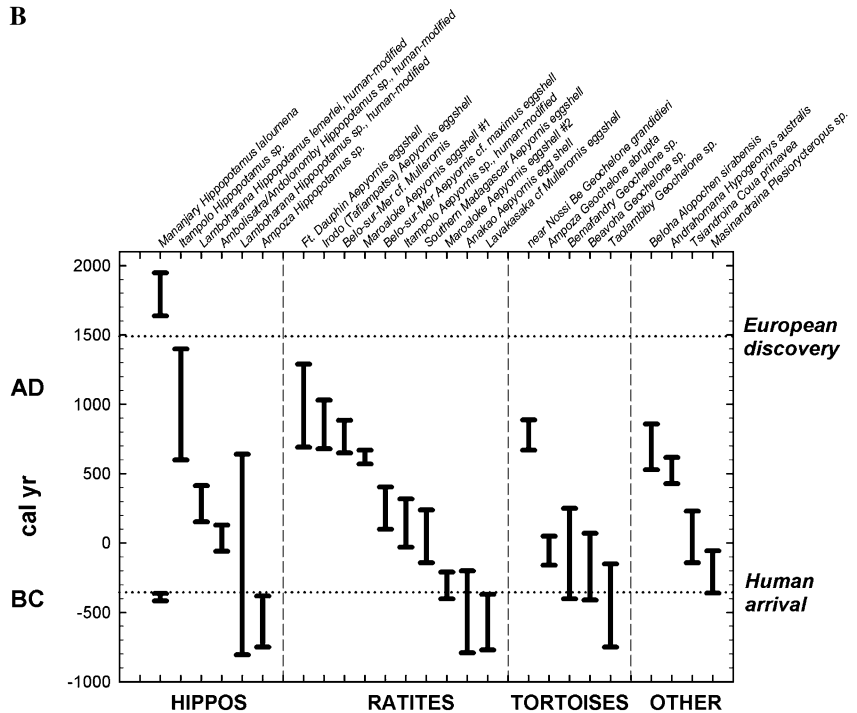


Figure 3. A. Dated late occurrences for eight genera of extinct lemurs, plotted as 2σ calibrated ranges. B. Dated late occurrences for extinct non-primate vertebrates, plotted as 2σ calibrated ranges.

Megaladapis edwardsi, and *Palaeopropithecus ingens* survived at least until 830 ± 60 yr BP (1040–1290 cal yr AD), 630 ± 50 yr BP (1280–1420 cal yr AD), and 510 ± 80 yr BP (1300–1620 cal yr AD), respectively.

It is therefore not surprising that the French colonial governor, Etienne de Flacourt (1661), reported eyewitness accounts of beasts in the remote interior that could have been giant lemurs, elephant birds, and hippopotami. Hippos in particular have cropped up in other colonial accounts from the eastern, central, and northwestern parts of the island as late as the nineteenth and early twentieth centuries (Godfrey, 1986; Burney and Ramilisonina, 1998). Dates on a large hippo skull of unknown provenance (an unlabeled specimen at the Université d'Antananarivo that may have been collected at the eastern site of Mananjary—or perhaps brought over from Africa) were as recent as 99 ± 36 yr BP and 213 ± 40 (combined calibrated range 1639–1950 cal yr AD). Ethnographic data collected in the Belo-sur-Mer region include putative eyewitness accounts of a hippolike animal as recently as 1976 (Burney and Ramilisonina, 1998).

Implications of chronological refinement for extinction models

The general outlines of human activity and biotic change are summarized in Figures 2 and 3, although many questions about cause and effect in Madagascar's transformation are left unanswered by the present state of chronometric analysis. The earliest humans on Madagascar saw the remarkable megafauna, and the coincidence of their temporal overlap is in itself strong circumstantial evidence for a human hand in the disappearances. This inference is rendered more compelling by the apparent lack of extinctions in the wake of documented major natural vegetation changes in the late Pleistocene and Holocene.

The argument over causes for the extinctions and rapid transformation of the island have generally centered around the *lack* of direct evidence for a human role (see Dewar, 1984). Human occupation sites from the earliest period are unknown, for

instance, and the extent of evidence for butchery has been slim, although this body of evidence continues to grow as more sites come to light (reviewed in Burney, 1999; also see Perez et al., 2003).

Burney (1999) advocated the use of a conceptual matrix approach to test the competing hypotheses for the extinctions. By tabulating all proposed hypotheses according to their expectations regarding the extinction rate, its geographic pattern, and the inferred processes involved, it is possible to evaluate chronometric data for consistency with the unique combination of predictions for each hypothesis. Direct evidence for the process by which the extinction occurred, which is regrettably scarce, may thus be augmented by looking at the landscape-level parameters of time and space as displayed by radiocarbon-dated occurrences.

Table 3 provides an updated version of this analysis of hypotheses. Although each of these has been proposed for Madagascar, the degree to which the expectations are articulated in the literature varies. All of these have likewise been proposed for other regions with late prehistoric megafaunal extinctions, notably North America (Burney and Robinson, in review).

Hypotheses H1, H3, and H5 each predict that the time period of overlap between humans and extinct megafauna at a given site with suitable stratigraphic and temporal resolution should be very short, probably a century or less (essentially the 95% confidence interval for AMS ^{14}C dates in this time-frame), because the entire extinction event should advance as a rapid wave ("Blitzkrieg," H3) or occur simultaneously throughout the island ("Great Fire," H1, and "Hypervirulent Disease," H5). Two other hypotheses ("Great Drought," H2, and "Synergy," H6) allow for a slower process (10^2 – 10^3 yr), with regional and mosaic patterns, respectively. Hypothesis H4 is not explicit as to how long the process of environmental degradation and postulated extinctions caused by cattle and other introduced herbivores should take at a given location or island-wide, but comparisons to historically recorded biological invasions on other islands (Atkinson, 1989; Burney, 1996b; Vitousek et al., 1996) would suggest that population build-up of feral herbivores would be moderately rapid (10^1 yr locally, 10^2 yr island-wide).

Table 2
¹⁴C dates for primates of Madagascar (see Appendix for sources and details)

Taxon	Age BP ± 1σ	Calibrated range at 2σ	Site	Comments
<i>Archaeoindris fontoynontii</i>	2291 ± 55	2362–2149 BP	Ampasambazimba	Gorilla-sized “sloth lemur.” Dates show that the largest of all extinct lemurs was extant when humans arrived.
<i>Archaeoindris fontoynontii</i> cf. <i>Archaeolemur</i>	2402 ± 45 830 ± 60	2711–2338 BP AD 1047–1280	Ampasambazimba Anjohikely	Latest dated occurrence of “monkey lemur” genus; from fecal pellet associated with juvenile skeleton.
<i>Archaeolemur</i> sp.	1020 ± 50	AD 990–1180	Antsiroandoha	
<i>Archaeolemur</i> cf. <i>majori</i>	1370 ± 40	AD 650–780	Belo-sur-Mer	
<i>Archaeolemur</i> sp.	1550 ± 50	AD 435–650	Belo-sur-Mer	
<i>Archaeolemur majori</i>	1650 ± 50	AD 370–575	Belo-sur-Mer	
<i>Archaeolemur majori</i>	2050 ± 60	BC 165–AD 120	Belo-sur-Mer	
<i>Archaeolemur</i> cf. <i>edwardsi</i>	2060 ± 70	BC 332–AD 110	Anjohikely	
<i>Archaeolemur</i> cf. <i>edwardsi</i>	7790 ± 70	8740–8410 BP	Anjohibe	
<i>Babakotia radofilai</i>	4400 ± 60	5290–4840 BP	Antsiroandoha	This medium-sized “sloth lemur” is the only extinct genus not yet dated to the human period.
<i>Daubentonia robusta</i>	1065 ± 40	AD 891–1027	Beloha	Date on the giant aye-aye shows its late survival.
<i>Hadropithecus stenognathus</i>	1413 ± 80	AD 444–772	Belo-sur-Mer	Latest dated occurrence for this “monkey lemur.”
<i>Hadropithecus stenognathus</i>	2194 ± 70	2344–1998 BP	Tsirave	
<i>Hadropithecus stenognathus</i>	6724 ± 54	7660–7490 BP	Andrahomana	
<i>Hapalemur simus</i>	4560 ± 70	5460–4980 BP	Andrafiabe	Date shows that the extant bamboo lemur had a range in the mid-Holocene that extended to the northernmost part of the island.
<i>Megaladapis edwardsi</i>	630 ± 50	AD 1280–1420	Ankilitelo	Latest dated occurrence for this large-bodied koala lemur.
<i>Megaladapis grandidieri</i>	1035 ± 50	AD 900–1040	Ampasambazimba	Presumably whole-bone radiometric date may not be reliable.
<i>Megaladapis edwardsi</i>	1277 ± 35	AD 666–816	Beloha	
<i>Megaladapis</i> sp.	1591 ± 60	AD 339–609	Site unknown	
<i>Megaladapis</i> sp.	1815 ± 60	AD 27–412	Bevoha	
<i>Megaladapis madagascariensis</i>	2140 ± 50	2320–1990 BP	Belo-sur-Mer	
<i>Megaladapis madagascariensis</i>	2713 ± 44	2870–2760 BP	Taolambiby	
<i>Megaladapis</i> sp.	4566 ± 35	5436–5059 BP	Andrahomana	
<i>Megaladapis grandidieri</i> / <i>madagascariensis</i>	12,760 ± 70	15,670–14,380 BP	Andrafiabe	
<i>Megaladapis grandidieri</i> / <i>madagascariensis</i> .	26,150 ± 400		Antsiroandoha	Oldest date for a lemur; poor collagen quality suggests this may be a minimum age.
<i>Mesopropithecus pithecoides</i>	1410 ± 40	AD 570–679	Ampasambazimba	Latest dated occurrence for this genus of “sloth lemurs,” smallest of the extinct lemur taxa.
<i>Mesopropithecus globiceps</i>	1694 ± 40	AD 245–429	Tsiandroina	
<i>Mesopropithecus globiceps</i>	1866 ± 45	AD 58–247	Belo-sur-Mer	
<i>Mesopropithecus globiceps</i>	2148 ± 35	BC 354–60	Ankazoabo	
<i>Pachylemur insignis</i>	1220 ± 50	AD 715–985	Belo-sur-Mer	Latest dated occurrence for this large relative of the ruffed lemur.

<i>Pachylemur insignis</i>	2000 ± 50	BC 45–AD 145	Belo-sur-Mer	
<i>Palaeopropithecus ingens</i>	510 ± 80	AD 1300–1620	Ankilitelo	Latest dated occurrence for this large, extremely suspensory “sloth lemur.” Calibrated range overlaps the period of European contact.
<i>Palaeopropithecus ingens.</i>	1269 ± 80	AD 640–946	Ankazoabo	
<i>Palaeopropithecus ingens</i>	2008 ± 90	2292–1729 BP	Belo-sur-Mer	
<i>Palaeopropithecus ingens</i>	2285 ± 40	2352–2157 BP	Ampoza	
<i>Palaeopropithecus ingens</i>	2325 ± 43	2366–2345 BP	Taolambiby	Cut marks on bone interpreted as evidence for butchery.
<i>Propithecus verreauxi</i>	Modern		Taolambiby	Extant sifaka with cut marks on bone interpreted as evidence for recent butchery. These marks are very similar to those described by Perez et al. (2003) for extinct lemurs at the same site.

Inferring processes, as opposed to rates and patterns, in the extinctions (see last column of Table 3) has required an indirect approach, taking care to avoid the logical trap of negative evidence. Hypotheses H1 through H5 each postulate a single cause that would presumably be sufficient to produce the rates and patterns observed. Detecting actual cause and effect in the fossil record, however, is challenging and prone to circular logic. Showing, for instance, that there is archaeological evidence for human hunting of the megafauna in no way proves that hunting caused the extinctions. Ironically, under a strict Blitzkrieg regime (Martin, 1984; also see Grayson, 1984), abundant evidence for overhunting would not be an expectation, as the extinction wave would pass any given point too rapidly to leave an extensive archaeological record of the event. Direct refutation is thus probably out of the question, although one must ask how much evidence for hunting would be necessary to show that overhunting was not a major factor (i.e., that hunting was sustainable).

If a rich site like Ankilibehandry (Belo-sur-Mer), which probably contains fossils from the entire period of the “extinction window” (Burney, 1999), also shows that some of the megafauna sustained hunting pressure and other human impacts for nearly a millennium, then Blitzkrieg and Hypervirulent Disease models have been refuted. Similar logic would suggest that

either a long coexistence between domesticated herbivores and native herbivores, or the disappearance of the natives before the appearance of introduced species in the fossil record, would refute H4, although Dewar (1984, 1997) and Burney (1993a,b, 1999) have suggested that biological invasions may be more important as a contributing cause rather than the exclusive cause in the decline of native species. Recent *Sporormiella* results (Burney et al., 2003), in combination with the large number of late-surviving megafaunal species documented here, suggest that, in fact, the major decline of native animals may have come well before livestock proliferated. Livestock do overlap with the persistent taxa that survived into the Second Millennium AD, such as *Megaladapis edwardsi*, *Palaeopropithecus ingens*, *Archaeolemur* sp. (cf. *edwardsi*), and *Daubentonia robusta* among the large lemurs, as well as the hippos and perhaps the ratites, so that competition between native and introduced herbivores, or more diffuse effects from the landscape modifications associated with pastoralism, may have played a role in finishing off some species.

Synergy (H6), like all combinatorial hypotheses, poses special problems for refutation, owing to the multifactorial nature of the inferred causes. However, the integrated site analysis approach has offered a partial solution. With subphreatic excavation and integrated site analysis (Burney, 1999; Burney and Robinson, in review), it has been

Table 3
Extinction hypotheses proposed for Madagascar

No.	Type	Source	Rate	Pattern	Process
H1	“Great Fire”	Humbert (1927)	Rapid	Simultaneous throughout	Landscape transformed by introduction of fire by humans; extinctions followed as a result of forest loss.
H2	“Great Drought”	Mahé and Sourdat (1972)	Slow	Southern region only	Climatic desiccation, extinctions due to spread of semiarid conditions.
H3	“Blitzkrieg”	Martin (1984)	Rapid	Wave across island	First-contact overkill of naïve fauna, beginning at coastal settlements and moving inland.
H4	“Biological Invasion”	Dewar (1984)	Moderately rapid	Multiple waves across island	Introduced herbivores disrupt natural vegetation and compete with native herbivores.
H5	“Hypervirulent Disease”	MacPhee and Marx (1997)	Very rapid	Panzootic disease pattern	Unknown pathogen(s) introduced by humans, spreading quickly; lethal to wide array of mammals, and possibly some birds and reptiles.
H6	“Synergy”	Burney (1999)	Very slow	Mosaic	Full array of human impacts played a role, but to differing extents in various regions; factors interacting to multiply effects; some amplification by background climate change.

to some extent possible to tease apart the evidence in the sediments for fire (H1), climate change (H2), overhunting (H3), and biological invasion (H4). If these “event horizons” specified by the unicausal hypotheses H1–H4 occurred at different times, as the radiocarbon evidence indicates, and all the extinctions correlate with a particular one, then synergy is unlikely to be important. If, on the other hand, as has been suggested here, these four events, or some combination of a subset, coincide temporally with disappearance of some megafaunal species, the case is strengthened (but, of course, not “proved”—see [Popper, 1969](#)) for a likely enhancement of the roles of individual factors through synergistic interaction. For instance, anthropogenic deforestation may make hunting less sustainable; biological invasions may involve introduced predators or herbivore competitors that exacerbate the effects of human hunting and/or deforestation.

No disease mechanism of the type specified by [MacPhee and Marx \(1997\)](#), lethally infecting a wide range of mammals, birds, and reptiles and transported by humans or their introduced commensals (H5), has been documented for Madagascar or any other part of the world.

Therefore it is difficult at this stage to specify what such an event would look like in the fossil record, except that one would predict by reference to known virulent diseases that an essentially instantaneous die-off would occur at first human contact. Instead, the radiocarbon evidence suggests that humans, and presumably any diseases they might have brought, overlapped with many of the extinct taxa for at least one, and in some cases nearly two, millennia. The rather sudden decline in megafaunal densities within a half millennium of human arrival, as inferred from the *Sporormiella* results, probably supports models that suggest rapid (but only partial) overkill by humans, followed by a protracted array of human impacts working against smaller surviving populations. To opt instead for a disease explanation requires that one must argue for an unknown disease or diseases having a different epidemiology from any known disease, knocking down the bulk of the population but somehow preventing rapid recovery of the immunized survivors to previous numbers.

There is considerable likelihood that the data presented here will not fully resolve the scientific

controversy over the cause of these extinctions. Building and carefully dating the large, precise, multiproxy data sets needed in order to address some of the questions surrounding the landscape transformations and extinctions is more likely to provide resolution, or at least clarification, than any conceivable alternative. A detailed mechanism for the Synergy Hypothesis was proposed in Burney et al., (2003). *Sporormiella* results, in combination with charcoal particle analysis and precision dating of both sediments and bones of extinct megafauna, suggest additional details concerning Madagascar at the brink of human transformation.

What is novel in these data sets is evidence suggesting that the late prehistoric extinctions in Madagascar were not a single, brief event with a simple uncausal explanation, but rather a more complex and drawn-out process in which human-perturbed systems underwent a series of drastic phase transitions. By combining the dated evidence from paleontology, archaeology, and palynology, it is reasonable to hypothesize that: 1) the megafauna was probably concentrated in wooded savannas, a plant community type rare in Madagascar today; 2) the large mammal biomass decreased sharply within a few centuries of first evidence for humans in the locality; 3) immediately following this ecological collapse, a new fire regime emerged that was likely a response to plant biomass buildup following decline of the grazer-browser regime; 4) the vegetation was transformed to less productive systems (depauperate steppe grasslands and closed forest) with feedbacks to the local climate system and the simpler, reorganized biota. These ideas are consistent with changes documented for other areas, and help explain the extent of the great transformations observed for Madagascar (for details see Burney, 1999; Burney et al., 2003).

Whatever the specific reconstruction of megafaunal paleoenvironments, the dating evidence presented is also consistent with the hypothesis that the extinction event here, as perhaps elsewhere, is not a single event but a stepwise cascade of extinctions, as the synergistic combination of human impacts and nonlinear natural responses creates a mosaic of environmental change, population

fragmentation, and local extirpation. The late occurrences of some of the taxa documented are also consistent with the notion that the “extinction window” is unfortunately not yet closed. Today in Madagascar, the same negative synergies of resource overutilization, fire-mediated vegetation change, and biological invasion continue to swirl about, pulling smaller lemur species and a host of other organisms into the extinction vortex.

Acknowledgements

This research was supported by NSF BCS-0129185 (to DAB, LRG, and WLJ), BCS-0237388 (to LRG), and EAR-0115488 (to AJTJ), and conducted under collaborative agreements with the Département de Paléontologie et d'Anthropologie Biologique, Université d'Antananarivo, and the Académie Malgache. For dates first reported here, we thank the curators and caretakers of the following collections from which dating samples were collected: Laboratoire de Paléontologie des Vertébrés, Université d'Antananarivo (UA; Armand Rasoamiamanana, Gisèle Randria); Académie Malgache, Parc Tsimbazaza, Antananarivo, Madagascar (AM; C. Rabenoro, L. Rakotozafy); Natural History, Oxford, United Kingdom (OX-UM; Thomas Kemp, Malgosia Nowak-Kemp); the Swedish Museum of Natural History (S. Steunes); and the University of Massachusetts Anthropological Primate and Comparative Collection. Alan Walker donated specimens for dating, and Anne Yoder provided unpublished dates. Nancy Beavan of the Rafter Radiocarbon Laboratory (New Zealand) supplied advice on pretreatment protocols and interpretation of results. Darden Hood of Beta Analytic, Inc. (Miami, FL, USA) assisted with calibration of many older dates. Paul S. Martin gave useful advice on dating priorities and interpretations. Mirya Ramarolahy, Lydia Raharivony, Ramilisonina, Toussaint Rakotondrazafy, and Natalie Vasey assisted with collecting and subsampling materials for dating.

Appendix

Catalog of age determinations for Madagascar

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Alaotra Large lake	sediment/ radiometric (4x)	5190 \pm 110 BP	BP 6250–5670	61–70 cm ALO-2A + 2B	β -45005	–16.30	17°25' S, 48°30' E 752 m	Acid/alkali/ acid	Reyes, 1993	3 + 2
Alaotra Large lake	sediment/ radiometric	6830 \pm 110 BP	BP 7860–7480	91–105 cm ALO-3C, 3D,3E	β -45854	–18.10	17°25' S, 48°30' E 752 m	Acid/alkali/acid	Reyes, 1993	3 + 2
Alaotra Large lake	sediment/ radiometric (4x)	29,690 \pm 510 BP		191–200 cm ALO-4A	β -31514	–17.90	17°25' S, 48°30' E 752 m	Acid/alkali/acid	Reyes, 1993	3 + 2
Ambila-Lemaitso	sediment/ radiometric	not given	AD 1030–1260	100–150 cm	KI-3398				Straka, 2001	3? + 1
Ambinanibe, Anosy	wood/ radiometric	700 \pm 100 BP	AD 1160–1420	Sondage 1, Layer 4	LY-3911		25°04' S, 46°57' E 5m		Rakotoarisoa et al., 1993	5 + 2
Amboatany, Imerina Archaeological	potsherd/TL	1670 \pm 65 AD		Operation D, Layer 4c	DurTL-50-11(a) AS		18°46' S, 47°32' E		Wright et al., 1992	TL
Amboatany, Imerina Archaeological	potsherd/TL	1480 \pm 100 AD		Operation D, Layer 4c	DurTL-50-11(b) AS		18°46' S, 47°32' E		Wright et al., 1992	TL
Ambohidahy, Imerina Archaeological	potsherd/TL	1520 \pm 100 AD		Sondage 1, Layer 2	DurTL-77-6 AS		18°46' S 47°31' E		Wright et al., 1992	TL
Ambohidahy, Imerina Archaeological	potsherd/TL	1500 \pm 100 AD		Sondage 1, Layer 2	DurTL-77-3 AS		18°46' S 47°31' E		Wright et al., 1992	TL
Ambohidahy, Imerina Archaeological	potsherd/TL	1420 \pm 110 AD		Sondage 1, Layer 2	DurTL-77-5 AS		18°46' S 47°31' E		Wright et al., 1992	TL
Ambohidahy, Imerina Archaeological	potsherd/TL	1100 \pm 190 AD		Sondage 1, Layer 2	DurTL-77-4 AS		18°46' S 47°31' E	Exceptionally early for human occupation on the central highlands	Wright et al., 1992	TL
Ambohinanajakana, Imerina Archaeological	potsherd/TL	1780 \pm 50 AD		Operation C, Layers 9-10	DurTL-77-2 AS		18°44' S 47°35' E		Wright et al., 1992	TL
Ambohinanajakana, Imerina Archaeological	potsherd/TL	1720 \pm 50 AD		Operation C, Layers 9-10	DurTL-77-1 AS		18°44' S 47°35' E		Wright et al., 1992	TL
Ambohinanajakana, Imerina Archaeological	potsherd/TL	1650 \pm 70 AD		Operation C, Layer 2b	DurTL-50-14 AS		18°44' S, 47°35' E		Wright et al., 1992	TL
Ambohinanajakana, Imerina Archaeological	charcoal/ radiometric	221 \pm 61 BP	AD 1520–1950	Operation C, Layer 7	SMU-1522		18°44' S, 47°35' E		Wright et al., 1992	6 + 2
Ambohitratoandro Wetland	sediment/ radiometric	3720 \pm 50 BP	BP 4230–3910	160 cm AMB-160	β -28591	–21.50	18°54' S, 46°39' E	Acid/alkali/acid	Burney, 1997a,b	3 + 2
Ambohitrikanjaka, Imerina Archaeological	charcoal/ radiometric	380 \pm 90 BP	AD 1410–1670	Site 1, Excavation 2 Layer 3	Gif-5154		18°51' S, 47°38' E		Wright et al., 1992	6 + 2

Ambolisatra/Andolonomy Shallow pond	plant macrofossil/AMS	1720 ± 40 BP	AD 230–410	150 cm ALB-150	β-167657	–26.10	23°04' S, 43°45' E? 2m	<i>Sporormiella</i> decline (megafaunal collapse) Acid/alkali/acid	Burney et al., 2003	5 + 3
Ambolisatra/Andolonomy Shallow pond	sediment/radiometric (4x)	1890 ± 90 BP	BC 60–AD 350	90–100 cm ALB-1A,B	β-24345	–24.10	23°04' S, 43°45' E 2m	Acid/alkali/acid	Burney, 1993a	3 + 2
Ambolisatra/Andolonomy Shallow pond	<i>Hippopotamus</i> femur (human-modified)/AMS	1970 ± 50 BP	BC 60–AD 130	MNIP MAD 1711	AA-2895		23°03' S, 43°45' E?	Human-modified megafaunal bone	MacPhee and Burney, 1991	5 + 3
Ambolisatra/Andolonomy Shallow pond	bone/radiometric (4x)	2915 ± 170 BP	BP 3470–2740	1.8 m AND-87-2A,2B	β-23149	–24.50	23°04' S, 43°45' E 2m		Burney, 1993a	5 + 3
Ambolisatra/Andolonomy Shallow pond	sediment/radiometric	4920 ± 90 BP	BP 5900–5470	306–326 cm ALB-2A,B,C,D (6-25)	β-24469	–26.50	23°04' S, 43°45' E 2m	Acid/alkali/acid	Burney, 1993a	3 + 2
Ambolisatra/Andolonomy Shallow pond	bone/radiometric	4965 ± 70 BP	BP 5900–5590	2.6 m AND-87-1	β-23148	–24.60	23°04' S, 43°45' E 2m		Burney, 1993a	5 + 3
Amboromena Etched depression lake	sediment	11,580 ± 145 BP	BP 14030–13150	165 cm					Romani et al., 2002	3 + 3
Amboulitsate Paleolake/Wetland	<i>Geochelone abrupta</i> bony carapace/radiometric	750 ± 370 BP	AD 580–1960	Muséum National d'histoire Naturelle (Paléontologie), Paris. 1884-30	BM-2125	–20.90	23°04' S, 43°45' E 2m	Late occurrence of extinct taxon Collagen extraction	Burleigh and Arnold, 1986	5 + 3
Ampamalora	<i>Aepyornis</i> eggshell (9 pieces collectively dated) radiometric	1970 ± 90 BP	BC 190–AD 240		not given		not given	Late occurrence of extinct taxon	Marden, 1967 (p.487) Sauer, 1972 (p.12)	6 + 2
Ampangandiria, Astimo Archaeological	potsherds/TL	1490 ± 55 AD		Feature 1, Sounding I			20°45' S, 44°02' E		This paper	TL
Ampanihy	unidentifiable bone fragments not given	2430 ± 100 BP	BP 2760–2190		Hela-3854		22°19.8' S, 44°42.7' E 660m		Jernvall et al., 2003	5? + 2
Amparihibe Deep crater lake	plant macrofossil/AMS	1130 ± 50 BP	AD 780–1010	156 cm AHB-156	β-67392 ETH-11460	–21.10	13°18' S, 48°13' E	<i>Sporormiella</i> increase (livestock) Acid/alkali/acid	Burney, 1999	5 + 3
Amparihibe Deep crater lake	sediment/AMS	1660 ± 90 BP	AD 150–600	275 cm AHB-3:10-11	β-62509 CAMS-6424		13°18' S, 48°13' E	Acid/alkali/acid	This paper	3 + 3
Amparihibe Deep crater lake	sediment/AMS	1780 ± 70 BP	AD 80–410	193 cm AHB-2:15-16	β-62508 CAMS-6423		13°18' S, 48°13' E	Acid/alkali/acid Date rejected old carbon contamination	This paper	3 + 3
Amparihibe Deep crater lake	sediment/AMS	1820 ± 60 BP	AD 70–370	338 cm AHB-4-74	β-55059 CAMS-3542		13°18' S, 48°13' E	Acid/alkali/acid	This paper	3 + 3
Amparihingidro	wood/radiometric	2850 ± 200 BP	BP 3460–2470	220 cm	Gif-?				Mahé and Sourdat, 1972	3 + 2

(continued on next page)

Appendix (continued)

Site name and site type	Material/ dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Ampasambazimba (Itasy) Paleolake/Wetland	<i>Archaeoindris fontoyrontii</i> crown of upper left p4/AMS	2291 \pm 55 BP	BP 2362–2149	AM 6239 (type specimen) DB -03-1	NZA-18519 R-28331/1	-23.50	18°54' S, 46°44' E 1200m	Collagen extraction with gelatinisation	This paper	5 + 3
Ampasambazimba Paleolake/Wetland	<i>Megaladapis grandidieri</i> tibia/ radiometric	1035 \pm 50 BP	AD 900–1040	not recorded BM M 9927	Pta-739		18°54' S, 46°44' E 1200 m		Tattersall, 1973	1? + 3
Ampasambazimba Paleolake/Wetland	<i>Mesopropithecus pithecooides</i> proximal left femur/AMS	1410 \pm 40 BP	AD 570–679	MP12, UA3926 DB-03-8	NZA-18523 R-28331/6	-22.09	18°54' S, 46°44' E 1200m	Collagen extraction with alkali	This paper	5 + 3
Ampasambazimba Paleolake/Wetland	<i>Archaeoindris fontoyrontii</i> proximal end of femur/AMS	2402 \pm 45 BP	BP 2711–2338	AI ₄ DB-03-4	NZA-18520 R-28331/3	-23.40	18°54' S, 46°44' E 1200m	Collagen extraction with alkali	This paper	5 + 3
Ampasambazimba Paleolake/Wetland	wood	4725 \pm 180 BP	BP 5890–4870	unit 1, trench B ca 1m	GX-9989		18°54' S, 46°44' E 1200m		MacPhee et al., 1985	5 + 2
Ampasambazimba Paleolake/Wetland	wood	7540 \pm 200 BP	BP 8760–7960	unit 1,trench G ca 1.8m	GX-9836		18°54' S, 46°44' E 1200m		MacPhee et al., 1985	5 + 2
Ampasambazimba Paleolake/Wetland	wood	8245 \pm 215 BP	BP 9580–8580	unit 1, trench G, ca 2.9m	GX-9835		18°54' S, 46°44' E 1200m		MacPhee et al., 1985	5 + 2
Ampasambazimba Paleolake/Wetland	<i>Alopochen sirabensis</i> Bone fragments/AMS	22,550 \pm 170 BP		UA-360	β -63116		18°54' S, 46°44' E 1200m		Goodman, 1999	5 + 3
Ampoza Wetland/ floodplain	<i>Hypogeomys antimena</i>	1350 \pm 60 BP	AD 620–770		β -72676		22°19' S, 44°44' E 570m		Goodman and Rakotondravony, 1996	5 + 3
Ampoza Wetland/ floodplain	unidentifiable bone fragments not given	1705 \pm 55 BP	AD 225–435	65 cm	Hela-157		22°18.9'S, 44°42.3'E 570m		Jernvall et al., 2003	5? + 2
Ampoza Wetland/ floodplain	unidentifiable bone fragments not given	1810 \pm 60 BP	AD 70–380	110 cm	Hela-156		22°18.9'S, 44°42.3'E 570m		Jernvall et al., 2003	5? + 2
Ampoza Wetland/ floodplain	unidentifiable bone fragments not given	1850 \pm 55 BP	AD 550–325	top	Hela-158		22°18.9'S, 44°42.3'E 570m		Jernvall et al., 2003	5? + 2
Ampoza Wetland/ floodplain	Bones	1910 \pm 120 BP	BC 190–AD 400		GaK-2309		22°19' S, 44°44' E	Goodman says this is giant tortoise	Mahé and Sourdat, 1972	1? + 3?

Ampoza Wetland/ floodplain	<i>Geochelone abrupta</i> (cf. <i>gigantea</i>) humerus/ radiometric	2035 ± 35 BP	BC 160—AD 50	B.M.N.H. (P) R5890	BM-1628	−27.30	22°19' S, 44°44' E 570 m	Late occurrence of extinct taxon Collagen extraction	Burleigh and Arnold, 1986	5? + 3
Ampoza Wetland/floodplain	<i>Palaeopropithecus</i> cf. <i>ingens</i> /AMS	2285 ± 40 BP	BP 2350— 2160	AMO-2	NZA-16997 R-28139/8	−20.60	22°19' S, 44°44' E 570m	Late occurrence of extinct taxon Collagen extrac- tion with gelatini- sation	This paper	5 + 3
Ampoza Wetland/floodplain	<i>Hippopotamus</i> / AMS	2370 ± 50 BP	BP 2700— 2330		GrA-11626		22°19' S, 44°44' E 570m	Late occurrence of extinct taxon	This paper	5 + 3
Ampoza Wetland/floodplain	<i>Hippopotamus</i> <i>lernerlei</i> pelvis AMS	2517 ± 40 BP	BP 2747— 2372	AMO-1	NZA-16996 R-28139/7	−21.57	22°19' S, 44°44' E 570m	Collagen extrac- tion with gelatini- sation	This paper	5 + 3
Ampoza Wetland/floodplain	<i>Hippopotamus</i> / AMS	2760 ± 60 BP	BP 2980—2760		Pta-7728		22°19' S, 44°44' E 570m		This paper	5 + 3
Anakao, south of Tulear Coastal dunes	<i>Aepyornis</i> eggshell	2375 ± 100 BP	BP 2740—2150		QC-971		23°39' S, 43°39' E	Late occurrence of extinct taxon	Dewar, 1984 (p. 582)	6 + 3
Anakao, south of Tulear Coastal dunes	<i>Aepyornis</i> eggshell	2775 ± 95 BP	BP 3160—2740		QC-970		23°39' S, 43°39' E		Dewar, 1984 (p. 582)	6 + 3
Anakao, south of Tulear Coastal dunes	<i>Aepyornis</i> eggshell	3960 ± 150 BP	BP 4840—3980		QC-972		23°39' S, 43°39' E		Dewar, 1984 (p. 582)	6 + 3
Anavoaha Coastal dunes	wood/radiometric	1954 ± 110 BP	BC 200—AD 3- 30	77 cm	GaK-1654				Mahé and Sourdat, 1972	5 + 2
Andavambatobe Cave	charcoal/ radiometric	580 ± 100 BP	AD 1260— 1480	Sq 1, layer 8 77 cmbd HFJ-92-10 170 cm	β-55092	363.0- 1125.7 (L)	42 cm. In Wright et al., 1996	Wright et al., 1996		6 + 2
Andonaham Pasipotasy Small glacial cirque	sediment	7060 ± 110 BP	BP 8050— 7670				19°04' S, 46°17' E 2120 m		Romani et al., 2002	3 + 3
Andrafiabe Cave	<i>Hapalemur simus</i> / AMS	4560 ± 70 BP	BP 5460—4980		β-62841 CAMS-6775				Simons et al., 1995	5 + 3
Andrafiabe Cave	<i>Megaladapis</i> /AMS	12,760 ± 70 BP	BP 15670— 14380		β-61703 CAMS-6394				Simons et al., 1995	5 + 3
Andrahomana Cave	<i>Hypogeomys</i> <i>australis</i> /AMS	4440 ± 60 BP	BP 5640— 4420		β-73370		25°11'55" S, 46°37' * 59"E 10m		Goodman and Rakotonravony, 1996	5 + 3
Andrahomana Cave	<i>Hadropithecus</i> <i>stenognathus</i> humeral fragment/ AMS	6724 ± 54 BP	BP 7660— 7490	not given BJ-HS-1	AA-45963 T-16044A	−9.10	25°11'55" S, 46°37' * 59"E 10m		This paper	5 + 3
Andrahomana Cave	<i>Hypogeomys</i> <i>australis</i> tooth/ AMS	1536 ± 35 BP	AD 428—618	AHA-I, Sq C,D 1,2 layer 1 AHA-03-01	NZA-18996 R-28421/1	−20.00	25°11'55" S, 46°37' * 59"E 10m	Collagen extrac- tion with gelatini- sation	This paper	5 + 3

(continued on next page)

Appendix (continued)

Site name and site type	Material/ dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Andrahomana Cave	<i>Megaladapis</i> sp. infant femur/AMS	4566 \pm 35 BP	BP 5436– 5059	AHA-03-7	NZA-18997 R-28421/7	–20.10	25°11'55" S, 46°37'59" E	Old spoil NE of AHA-G Collagen extraction with gelatinisation	This paper	5 + 3
Andraikiba Deep crater lake	sediment/ radiometric	1200 \pm 70 BP	AD 670–990	76–90 cm ck depth AND-2A,B,C	β -23486	–24.50	19°53' S, 46°57' E 1520 m	Acid	This paper	3 + 2
Andraikiba Deep crater lake	sediment/ radiometric (2x)	2310 \pm 100 BP	BP 2720–2100	327–341 cm AND-4 A,B,C	β -22837	–25.90	19°52' S, 46°57' E 1520 m	Acid	Burney, 1988	3 + 2
Andraikiba Deep crater lake	sediment/ radiometric	2320 \pm 70 BP	BP 2690–2150	219–233 cm AND 3,A,B,C	β -23487	–25.90	19°52' S, 46°57' E 1520 m	Acid	This paper	3 + 2
Andraikibakely Pond	sediment/ radiometric (extended)	6990 \pm 130 BP	BP 8030–7590	ca. 110 cm AKK-2A,B	β -67393	–20.60	19°52' S, 46°58' E 1520m		This paper	3 + 2
Andrakibaikely Pond	sediment/ radiometric	27,970 \pm 540 BP		ca. 381–390 cm AKK-4	β -31513	–18.30	19°52' S, 46°58' E 1520m		This paper	3 + 2
Andrakibaikely Pond	sediment/ radiometric	31,400 \pm 630 BP		786–822 cm AKK-9 II A,B,C,D	β -14852	–21.33	19°52' S, 46°58' E 1520m		This paper	3 + 2
Andranosoa Archaeological	charcoal/ radiometric	220 \pm 70 BP	AD 1500–1950	iron-smelting feature south end of site	β -8094		24°46' S, 45°35' E 240m		Emphoux, 1981	6 + 2
Andranosoa Archaeological	charcoal/ radiometric	730 \pm 90 BP	AD 1160–1410	undesignated pit	Gif-4570		24°46' S, 45°23' E 240m	Early archaeological site	Emphoux, 1979 cited in Dewar, 1984 (p. 582)	6 + 2
Andranosoa Archaeological	charcoal/ radiometric	920 \pm 90 BP	AD 970–1280	“fosse d’odore”	Gif-4571		24°46' S, 45°23' E 240m	Early archaeological site	Emphoux, 1979 cited in Dewar, 1984 (p. 582)	6 + 2
Andranosoa Archaeological	potsherd/TL	950 \pm 210 AD		pit 1.02 mbs	DurTL-75 4AS		24°46' S, 45°35' E 240m		Emphoux unpublished	TL
Angavobe, Imerina Archaeological	charcoal/ radiometric	330 \pm 80 BP	AD 1430–1800	Sondage II, Pocket I	GaK-1058		18°55' S, 47°44' E 1780m		Wright et al., 1992	6 + 2
Anjohibe Cave	<i>Eidolon dupreanum</i> postcranial bones/ AMS	330 \pm 70 BP	AD 1430–1800	surface (19-8)	β -56770 CAMS-4255		15°32.55' S, 46°53.17' E 100 m		Burney et al., 1997	5 + 3
Anjohibe Cave	speleothem/ U-series	371 \pm 50 BP		28–38 mm from top MA2			15°32.55' S, 46°53.17' E 100 m		Brook et al., 1999 U	
Anjohibe Cave	speleothem/ U-series	1122 \pm 43 BP		84–90 mm from top MA2			15°32.55' S, 46°53.17' E 100 m		Brook et al., 1999 U	

Anjohibe Cave	speleothem/ U-series	3412 ± 14 BP		base MA 1			15°32.55' S, 46°53.17' E 100 m	Brook et al., 1999	U
Anjohibe Cave	<i>Hippopotamus</i> cf. <i>lemerlei</i> rib/AMS	3730 ± 70 BP	BP 4280–3880	Sq E3, level 2 (19-5) HFJ-92- 11	β-55093 CAMS- 3562		15°32.55' S, 46°53.17' E 100 m	Burney et al., 1997	5 + 3
Anjohibe Cave	speleothem/ U-series	<4.0 kyr BP		0-3 cm ANJ-92-3			15°32.55' S, 46°53.17' E 100 m	Burney et al., 1997	U
Anjohibe Cave	<i>Hippopotamus</i> cf. <i>lemerlei</i> mandible/ AMS	5300 ± 60 BP	BP 6270–5920	surface (19-8) HFJ-93-2-B	β-64961 CAMS- 8648	–31.80	15°32.55' S, 46°53.17' E 100 m	Burney et al., 1997	5 + 3
Anjohibe Cave	speleothem/ U-series	6.52 ± 2.64 kyr BP		0–2 cm ANJ- 92-2			15°32.55' S, 46°53.17' E 100 m	Outermost layer of collapsed column Burney et al., 1997	U
Anjohibe Cave	sediment/AMS	7040 ± 70 BP	BP 7970– 7700	100 cm ANJ- AM-2-100	β-60947 CAMS- 5645		15°32.55' S, 46°53.17' E 100 m	Burney et al., 1997	3 + 3
Anjohibe Cave	sediment/AMS	7080 ± 80 BP	BP 8020– 7720	248–252 cm ANJ-AM-2-250	β-58395 CAMS- 4628		15°32.55' S, 46°53.17' E 100 m	Burney et al., 1997	3 + 3
Anjohibe Cave	speleothem/ U-series	7340 ± 46 BP		base MA2-6			15°32.55' S, 46°53.17' E 100 m	Brook et al., 1999	U
Anjohibe Cave	<i>Archaeolemur</i> cf. <i>edwardsi</i> pelvis/ AMS	7790 ± 70 BP	BP 8740– 8410	surface (19-8) HFJ-93-1-A	β-64960 CAMS- 8647	–27.50	15°32.55' S, 46°53.17' E 100 m	Collagen extrac- tion with alkali Burney et al., 1997	5 + 3
Anjohibe Cave	speleothem/ U-series	22.88 ± 4.48 kyr BP		0–2 cm ANJ-92-4			15°32.55' S, 46°53.17' E 100 m	Burney et al., 1997	U
Anjohibe Cave	speleothem/ U-series	37.55 ± 4.67 kyr BP		ANJ-92-5			15°32.55' S, 46°53.17' E 100 m	Date rejected due to ratio Burney et al., 1997	U
Anjohibe Cave	speleothem/ U-series	40.11 ± 7.21 kyr BP		100 cm ANJ-92-2			15°32.55' S, 46°53.17' E 100 m	Center of col- lapsed column Burney et al., 1997	U
Anjohibe Cave	speleothem/ U-series	69.6 ± 7.3 kyr BP		NCC-1 #3			15°32.55' S, 46°53.17' E 100 m	Directly below bone breccia in collapsed-cave deposit This paper	U
Anjohibe Cave	speleothem/ U-series	86.8 ± 7.8 kyr BP		NCC-1 #4			15°32.55' S, 46°53.17' E 100 m	Laminated sta- lagmite on floor of collapsed- cave feature This paper	U
Anjohikely Cave	cf. <i>Archaeolemur</i> dung/AMS	830 ± 60 BP	AD 1040– 1290	site 1-1 HFJ-92-13A	β-55060 CAMS-3543		15°33' S, 46°53' E	Late occurrence of extinct taxon Acid washes Burney et al., 1997	5 + 3
Anjohikely Cave	<i>Archaeolemur</i> cf. <i>edwardsi</i> small pieces of bone/ AMS	2060 ± 70 BP	BC 350–AD 80	site 31-1 HFJ-92-16	β-55095 CAMS -3709		15°33' S, 46°53' E	Late occurrence of extinct taxon Collagen extrac- tion with alkali Burney et al., 1997	5 + 3

(continued on next page)

Appendix (continued)

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Ankadivory, Imerina Archaeological	charcoal/radiometric	523 \pm 80 BP	AD 1290–1500	Sq. P 108/bV-Pit 3	β -23989		18°46' S 47°34' E		Wright et al., 1992	6 + 2
Ankadivory, Imerina Archaeological	charcoal/radiometric	810 \pm 100 BP	AD 1020–1390	Sq. E 116/O, Layer XVI	SMU-2632		18°46' S 47°34' E	Early archaeological site	Wright et al., 1992	6 + 2
Ankadivory, Imerina Archaeological	charcoal/radiometric	810 \pm 185 BP	AD 880–1440	Sq. E 116/O, Layer VII	SMU-2077		18°46' S 47°34' E	Early archaeological site	Wright et al., 1992	6 + 2
Ankadivory, Imerina Archaeological	charcoal/radiometric	880 \pm 50 BP	AD 1030–1260	Sq. P 108/b-Pit 10	SMU-2361		18°46' S 47°34' E	Early archaeological site	Wright et al., 1992	6 + 2
Ankadivory, Imerina Archaeological	pottery/TL	1295 \pm 140 AD		Sq E 116/O, Layer VII	DurTL 97-3AS		18°46' S 47°34' E	Early archaeological site	Wright et al., 1992	TL
Ankazoabo Cave	<i>Palaeopropithecus</i> pr-emolar/AMS	1269 \pm 80 BP	AD 640–946	AM 6184 #11	NZA-10059 R-24649/1	–19.00	24°33' S, 43°56' E	Late occurrence of extinct taxon Collagen extraction with gelatinisation	This paper	5 + 3
Ankazoabo Cave	<i>Mesopropithecus globiceps</i> tooth/AMS	2148 \pm 35 BP	BC 354–60	AM 6531, UA 4853 DB -03-5	NZA-18998 R-28421/9	–15.80	24°33' S, 43°56' E	Univ. of Antananarivo collection Collagen extraction with gelatinisation	This paper	5 + 3
Ankazoaraka	sediment/radiometric	not given	BP 3364–3049	260–280 cm	KI-3223		9 m	In Straka, 2001 this date is given as BC 1400 to 1040 yr	Straka, 1993	3? + 2
Ankazomiranga	sediment/radiometric	not given	AD 1520–1670	10–20 cm	KI-3854		290 kms of Tana 1330 m		Straka, 2001	3? + 2
Ankazomiranga	sediment/radiometric	not given	BP 3479–3259	20–30 cm	KI-3854		290 kms of Tana 1330 m		Straka, 2001	3? + 2
Ankazomiranga	sediment/radiometric	12,200 \pm 90 BP	BP 15,340–13,840	120–140 cm	KI-3455		290 kms of Tana 1330 m		Straka, 2001	3? + 2
Ankazomiranga	sediment/radiometric	19,450 \pm 280 BP		160–180 cm	KI-3854.17		290 kms of Tana 1330 m		Straka, 2001	3? + 2
Ankazomiranga	sediment/radiometric	28,850 \pm 720 BP		180–200 cm	KI-3854.19		290 kms of Tana 1330 m		Straka, 2001	3? + 2
Ankilitelo Cave	<i>Palaeopropithecus in-gens</i> AMS	510 \pm 80 BP	AD 1300–1620	not given	β -		22°54.819'S, 43°52.610'E	Late occurrence of extinct taxon Collagen extraction with alkali	Simons, 1997	5 + 3
Ankilitelo Cave	<i>Megaladapis edwardsi</i> AMS	630 \pm 50 BP	AD 1280–1420	not given	β -		22°54.819'S, 43°52.610'E	Late occurrence of extinct taxon Collagen extraction with alkali	Simons, 1997	5 + 3

Anosizato Wetland	sediment/ radiometric	9020 ± 120 BP	BP 10430– 9760	1.45 m AZ-47	β-28592	–21.20	18° 55' S, 47° 30' E		Rafamantanantsoa, 3 + 2 1991
Antsetsindrano, Vakinankaratra Archaeological	charcoal/ radiometric	250 ± 60 BP	AD 1490– 1950	Shelter 7, Pit 2 Layer IIIC 0.20–0.30m	β-14168		20° 07' S, 47° 00' E	1260 m	Wright et al., 6 + 2 1992
Antsetsindrano, Vakinankaratra Archaeological	charcoal/ radiometric	430 ± 60 BP	AD 1410– 1630	Shelter 2, Pit 3 Layer IIIC 0.66–0.73m	β-14169		20° 07' S, 47° 00' E	2100m	Wright et al., 6 + 2 1992
Antsetsindrano, Vakinankaratra Archaeological	charcoal/ radiometric	360 ± 60 BP	AD 1430– 1660	Shelter 7, Pit 2 Feature 3 0.32–0.39 m	β-14167		20° 07' S, 47° 00' E	2100m	Wright et al., 6 + 2 1992
Antsirabe Paleolake/Wetland	<i>Numida meleagris</i> bone	90 ± 60 BP	AD 1660– > 1960	UA-322	β-63120		19° 52' S, 47° 02' E		Goodman, 1999 5 + 3
Antsirabe Paleolake/Wetland	<i>Alopothen sirabensis</i> bone/AMS	17,100 ± 100 BP	BP 20,910– 19,820	UA-119	β-63118		19° 52' S, 47° 02' E		Goodman, 1999 5 + 3
Antsirabe Paleolake/Wetland	<i>Centroranis majori</i> bone/AMS	17,370 ± 90 BP	BP 21200– 20150	UA-214	β-63119		19° 52' S, 47° 02' E		Goodman, 1999 5 + 3
Antsirabe Paleolake/Wetland	<i>Alopothen sirabensis</i> bone/AMS	19,250 ± 110 BP	BP 23470– 22240	UA-142	β-63117		19° 52' S, 47° 02' E		Goodman, 1999 5 + 3
Antsiroandoha Cave	<i>Archaeolemur</i> sp. fibula/AMS	1020 ± 50 BP	AD 910– 1150		β-60797 CAMS- 5484		12° 54' S, 49° 05' E	Late occurrence of extinct taxon Collagen extraction with alkali	Simons et al., 1995 5 + 3
Antsiroandoha Cave	<i>Babakotia radofilai</i> /AMS bone	4400 ± 60 BP	BP 5290– 4840		β-60798 CAMS- 5485			Collagen extraction with alkali	Simons et al., 1995 5 + 3
Antsiroandoha Cave	<i>Megaladapis</i> sp./AMS	26,150 ± 400 BP			β-30982 ETH-52- 55			poor collagen yield Collagen extraction with alkali	Simons et al., 1995 1 + 3
Baie des Galions Wave-cut notch	shell/radiometric	2250 ± 420 BP	BC 900–AD 1010	1–1.4 m asl	GaK-277		25° 30' S, 46° 30' E	collected by Battistini	Kigoshi et al., 1964 2 + 2
Bassin de Bealanana	sediment/ radiometric	not given	BP 2779– 2739	230–250 cm	KI-3612		18° 5' S, 47° 20' E	1500m	Straka, 2001 3? + 2
Behavoha Coastal dunes	<i>Geochelone</i> carapace/ radiometric	2160 ± 110 BP	BC 410– AD 70		GaK-1658			Late occurrence of extinct taxon	Mahé and Sourdat, 1972 1? + 3
Beloha	<i>Daubentonia robusta</i> left humerus/ AMS	1065 ± 40 BP	AD 891– 1027	UA 3890, Dr5 (1932) DB-03- 11	NZA-18524 R-28331/7	–16.30	20° 08' S, 47° 01' E	Collagen extraction with alkali	This paper 5 + 3
Beloha	<i>Alopothen sirabensis</i> /AMS	1380 ± 90 BP	AD 530– 860		β-63675		20° 08' S, 47° 01' E	Late occurrence of extinct taxon	Goodman and Rakotozafy, 1997 5 + 3
Beloha	<i>Megaladapis edwardsi</i> tooth/ AMS	1277 ± 35 BP	AD 666– 816	UA 4595, AM 6565 DB-03-21	NZA-18999 R-28421/10	–20.40	20° 08' S, 47° 01' E	University of Antananarivo collection Collagen extraction with gelatinisation	This paper 5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	palm leaf base/ radiometric	190 ± 80 BP	AD 1515– 1950	Sq. 3, 60–70 m	c-β-103347 BSM-95-8	–26.60	20° 44' S, 44° 01' E	Acid/alkali/acid	This paper 5 + 1

(continued on next page)

Appendix (continued)

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Pachylemur insignis</i> ulna/AMS	1220 \pm 50 BP	AD 680–960	Sqs. 3–5 100+ cm BSM-95-5	β -90098	–20.60	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	cf. <i>Mullerornis</i> right tibiotarsus/AMS	1280 \pm 60 BP	AD 650–890	Sq. 3, 50–70 cm BSM-95-10	β -103349	–24.90	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Archaeolemur</i> cf. <i>majori</i> jaw/AMS	1370 \pm 40 BP	AD 620–700	Sq. 5, Level 3 BSM-95-2	β -90095	–19.90	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Hadropithecus stenognathus</i> AMS	1413 \pm 80 BP	AD 444–772	1934 C. Lambertton BSM-00-1 AM 6083	NZA-12582 R-26341/1	–8.40	20°44' S, 44°01' E	Late occurrence of extinct taxon Collagen extraction with alkali	This paper	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Archaeolemur</i> sp. Fibula/AMS	1550 \pm 50 BP	AD 410–620	Sq.4, Level 2 BSM-95-3	β -90096	–20.50	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with gelatinisation	Burney, 1999	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Archaeolemur majori</i> jaw/AMS	1650 \pm 50 BP	AD 260–530	Sq. 5, Level 1 BSM-95-1	β -90094	–19.90	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Aepyornis</i> cf. <i>maximus</i> eggshell/radiometric (extended)	1830 \pm 60 BP	AD 60–350	Sq. 5, level 3 4 5 cm BSM-95-6	β -90099	–17.30	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon. Charcoal increase, probably anthropogenic Acid etching	Burney, 1999	6 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Mesopropithecus globiceps</i> left femoral shaft/AMS	1866 \pm 45 BP	AD 58–247	MP22, UA3932 (1934) DB-03-7	NZA-18522 R-28331/5	–20.30	20°44' S, 44°01' E 2m	Collagen extraction with alkali	This paper	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	sediment at base of bone layer/AMS	1990 \pm 50 BP	BC 100–AD 110	Sq. 5, 105 cm BSM-95-9	β -103348	–28.00	20°44' S, 44°01' E 2m	10 cm below Sporormiella decline (megafaunal collapse) Acid washes	Burney, 1999	3 + 2
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Pachylemur insignis</i> ulna/AMS	2000 \pm 50 BP	BC 110–AD 100	Sqs. 3-5 100+ cm BSM-95-4	β -90097	–20.20	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3

Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Palaeopropithecus ingens</i> /bone AMS	2008 ± 90 BP	BP 2292–1729	1934 C. Lambertton BSM-0-0-2 UA 1042	NZA-12583 R- 26341/2	–21.00	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	This paper	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Archaeolemur majori</i> mandible/AMS	2050 ± 60 BP	BC 200–AD 70	Sq.1, Layer 1 BSM-1-1	β-76612 CAMS-16368	–18.30	20°44' S, 44°01' E	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3
Belo-sur-Mer Ankilibehandry Interdunal swale	<i>Megaladapis madagascariensis</i> talus/AMS	2140 ± 50 BP	BP 2320–1990	Sq.3, 105+ cm BSM-95-7	β-102567	–22.40	20°44' S, 44°01' E 2m	Late occurrence of extinct taxon Collagen extraction with alkali	Burney, 1999	5 + 3
Bemafandry Coastal dunes	wood adjacent to dated <i>Geochelone carapace</i> /AMS	1980 ± 90 BP	BC 190–AD 230	98 cm	GaK-1656		24°59' S, 44°07' E		Mahé and Sourdat, 1972	5 + 2
Bemafandry Coastal dunes	<i>Geochelone carapace</i> /radiometric	2060 ± 150 BP	BC 400–AD 250		GaK-1655		not given	Late occurrence of extinct taxon	Mahé and Sourdat, 1972	1? + 3
Benavony Wetland	sediment/radiometric (4x)	710 ± 110 BP	AD 1050–1430	197–201 cm Ben-2-3A,B	β-81218	–28.80	13°42' 48" S, 48°28' 53" E	Charcoal increase, probably anthropogenic	Burney, 1999	3 + 3
Benavony Wetland	sediment/AMS	2980 ± 50 BP	BP 3330–2980	383–387 cm Ben-2-5A	β-103532	–26.90	13°42' 48" S, 48°28' 53" E	Acid/alkali/acid Acid washes	This paper	3 + 3
Benavony Wetland	sediment/radiometric	3790 ± 50 BP	BP 4350–3990	828–837 cm BEN-2-9A,B	β-77549	–30.10	13°42' 48" S, 48°28' 53" E	Acid washes	This paper	3 + 2
Beropitika Archaeological	charcoal/radiometric	750 ± 90 BP	AD 1050–1400		Gif-4496		24°37' S, 45°35' E 360m	Early archaeological site	Emphoux, 1979 cited in Dewar, 1984 (p. 582)	6 + 2
Bevoha	<i>Megaladapis</i> tooth/AMS	1815 ± 60 BP	AD 27–412	AM 6479 #6	NZA-10060 R -2- 4649/2	–20.20	23°04' S, 43°45' E? 2m	Late occurrence of extinct taxon Collagen extraction with gelatinisation	This paper	5 + 3
Fanongoavana, Imerina Archaeological	charcoal/radiometric	410 ± 100 BP	AD 1320–1660	Unit 15030, EL.1624.05	LY-3161		19°03' S, 47°51' E		Wright et al., 1992	6 + 2
Fanongoavana, Imerina Archaeological	charcoal/radiometric	450 ± 120 BP	AD 1290–1660	Unit 600-16600 EL. 1625.15	LY-3162		19°03' S, 47°51' E		Wright et al., 1992	6 + 2
Fanongoavana, Imerina Archaeological	charcoal/radiometric	450 ± 100 BP	AD 1300–1650	Unit 1000-15.0-00 Sq. E5m	Gif-547		19°03' S, 47°51' E		Wright et al., 1992	6 + 2
Forest of Ambohitantely	sediment/radiometric	not given	BP 2479–2329	230–250 cm	KI-3454		18°5' S, 47°20' E 1500m		Straka, 2001	3? + 2
Ft. Dauphin, 50 km WSW	<i>Aepyornis</i> eggshell/radiometric	1000 ± 150 BP	AD 690–1290	unknown	UCLA-1893	–14.40	21°01' S, 47°E	Late occurrence of extinct taxon	Berger et al., 1975	6 + 3
Ifanja	sediment/radiometric	not given	AD 1270–1430	260–280 cm	KI- 3221.95		49°10' E, 18°50' S		Straka, 2001	3? + 2
Ifanja	sediment/radiometric	not given	BC 370–40	500–520 cm	KI-3221.51		S of Sanganoro		Straka, 2001	3? + 2

(continued on next page)

Appendix (continued)

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Irodo (Antanimenabe) Archaeological	charcoal/radiometric	980 \pm 100 BP	AD 880–1260		GaK-350b		12°38' S, 49°31' E	Early archaeological site	Battistini and V�erin, 1967	6 + 2
Irodo (Antanimenabe) Archaeological	charcoal/radiometric	1200 \pm 40 BP	AD 710–960		GaK-380		12°38' S, 49°31' E	Early archaeological site	Battistini and V�erin, 1967	6 + 2
Irodo (Tafiampatsa) dune	<i>Aepyornis eggshell</i> /radiometric	1150 \pm 90 BP	AD 680–1030		GaK-		12°38' S, 49°31' E	Early archaeological site	Mah�e and Sourdat, 1972 (p. 305)	6 + 3
Irodo (Tafiantirbeka) Archaeological	Gastropod shell/radiometric	1090 \pm 90 BP	AD 720–1160		GaK-692		12°38' S, 49°31' E	Early archaeological site	Battistini and V�erin, 1967	2 + 2
Itampolo Interdunal swale	<i>Hippopotamus</i> sp./radiometric	980 \pm 200 BP	AD 660–1400	15 cm	GaK-1506		24°41' S, 43°57' E	Late occurrence of extinct taxon	Mah�e and Sourdat, 1972	1 + 3
Itampolo Interdunal swale	<i>Aepyornis tibiota-rsus</i> (human-modified)	1880 \pm 70 BP	BC 30–AD 320	1-A HFJ-92-12	β -67659			Human-modified megafaunal bone Collagen extraction with alkali	Burney, 1999	5 + 2
Itampolo Interdunal swale	wood/radiometric	2290 \pm 90 BP	BP 2700–2100	120 cm	GaK-1652		24°41' S, 43°57' E		Mah�e and Sourdat, 1972	5 + 2
Itasy Large lake	sediment/radiometric	2260 \pm 60 BP	BP 2360–2130	400–420 cm	KI-3160		19S, 46.3° E		Straka, 1993	3? + 2
Itasy Large lake	sediment/radiometric	8165 \pm 90 BP	BP 9410–8800	900–930 cm	GRO-2804		not given		DeWaard and Straka, 1961	3? + 2
Kavitaha Lava-barrier lake	sediment/radiometric	670 \pm 80 BP	AD 1220–1420	151–160 cm VI A,B	β -14856	–18.28	19°02' S, 46°47' E		Burney, 1987c	3 + 2
Kavitaha Lava-barrier lake	sediment/radiometric	710 \pm 100 BP	AD 1160–1420	10 cm I (KAV-IA,B)	β -11729	–19.31	19°02' S, 46°47' E	Date rejected due to old carbon contamination	Burney, 1987c	3 + 1
Kavitaha Lava-barrier lake	sediment/radiometric	960 \pm 90 BP	AD 900–1260	220 cm (centered) KAV-2A	β -15528	–25.00	19°02' S, 46°47' E	<i>Sporormiella</i> increase (livestock). Acid washes	Burney, 1987c	3 + 3
Kavitaha Lava-barrier lake	sediment/radiometric	1400 \pm 80 BP	AD 530–780	291–295 cm V (KAV-3), VA	β -14855	–23.51	19°02' S, 46°47' E	Charcoal increase, probably anthropogenic	Burney, 1987c	3 + 3
Kavitaha Lava-barrier lake	sediment/radiometric	1490 \pm 60 BP	AD 430–660	341–350 cm II-A,B (KAV-3, 101-110)	β -11730	–22.63	19°02' S, 46°47' E		Burney, 1987c	3 + 2
Komango Lake	macrofossil/AMS	1750 \pm 60 BP	AD 130–420	KOM-8 (48 cm) KOM-8	β -68068 CAMS-10245	–27.90	19°9' 4"S, 44°48' 30" E	Charcoal increase, probably anthropogenic	Burney, 1999	5 + 3
Komango Lake	sediment/AMS	3390 \pm 50 BP	BP 3720–3480	KOM-9 (41-46 cm) KOM-9A	β -103350	–28.10	19°9' 40'S, 44°48' 30"E	Acid washes	This paper	3 + 3
Lakaton'i Anja Archaeological Rockshelter	charcoal/radiometric	1300 \pm 80 BP	AD 620–900		β -18424		Not given		Dewar and Wrig-ht, 1993 (p.429)	6 + 2
Lakaton'i Anja Archaeological, Rockshelter	charcoal/AMS	1680 \pm 65 BP	AD 230–530		β -29946 ETH-5408		Not given	Early archaeological site	Dewar and Wrig-ht, 1993 (p.429)	6 + 2

Lamboharana Shallow pond	Bones presumably megafaunal/radiometric	1220 ± 80 BP	AD 660–990	40 cm	GaK-2310		22°11' S, 43°16' E		Mahé and Sourdat, 1972	1? + 2
Lamboharana Shallow pond	<i>Hippopotamus lemerlei</i> femur (human-modified)/AMS	1740 ± 50 BP	AD 155–415	MNIP MAD 1709	TO-1437		22°11' S, 43°16' E	Human-modified megafaunal bone	MacPhee and Burney, 1991	5 + 3
Lamboharana Shallow pond	<i>Hippopotamus</i> femur (human-modified)/AMS	2020 ± 300 BP	BC 805–AD 640	MNIP MAD 1710	TO-1438		22°11' S, 43°16' E	Human-modified megafaunal bone	MacPhee and Burney, 1991	5 + 3
Lamboharana Shallow pond	bone/radiometric	2350 ± 120 BP	BP 2740–2100	60 cm	GaK-2307		22°11' S, 43°16' E		Mahé and Sourdat, 1972	1? + 2
Lamboharana Shallow pond	<i>Hippopotamus</i> femur (human-modified)/AMS	3495 ± 55 BP		MNIP MAD 1710	AA-2894		22°11' S, 43°16' E	Date rejected; sample redated to 2020 BP ± 300	MacPhee and Burney, 1991	5 + 1
Lavakasaka Cave	cf. <i>Mullerornis</i> eggshell/AMS	2380 ± 70 BP	BP 2720–2320	sondage 1, layer 1 HFJ-92-15	β-55094 CAMS-3547		15°34' S, 46°51' E	Late occurrence of extinct taxon	Burney et al., 1997	6 + 3
Lohavohitra, Vonizonga Archaeological	charcoal/radiometric	90 ± 30 BP	AD 1680–1950	Zone 1, Location 03 Stratigraphic Unit 25	SMU-2075		19°38' S, 47°17' E		Wright et al., 1992	6 + 2
Lohavohitra, Vonizonga Archaeological	charcoal/radiometric	> 100 BP		Sondage I, Level 7	LY-3749		19°38' S, 47°17' E		Wright et al., 1992	6 + 2
Lohavohitra, Vonizonga Archaeological	charcoal/radiometric	230 ± 60 BP	AD 1510–1950	Zone 1, Location 03 Stratigraphic Unit 29	Gif-7470		19°38' S, 47°17' E		Wright et al., 1992	6 + 2
Lohavohitra, Vonizonga Archaeological	charcoal/radiometric	260 ± 60 BP	AD 1480–1950	Zone 1, Location 01 Stratigraphic Unit 16	Gif-7471		19°38' S, 47°17' E		Wright et al., 1992	6 + 2
Lohavohitra, Vonizonga Archaeological	charcoal/radiometric	270 ± 45 BP	AD 1510–1670	Sondage I, Layer 4	SMU-1520		19°38' S, 47°17' E		Wright et al., 1992	6 + 2
Mahery Shallow crater lake	sediment/radiometric	2950 ± 70 BP	BP 3340–2890	MAH-0 (11-30 cm)	β-23488	–35.50	12°26' S, 49°14' E		Burney, 1988	3 + 2
Mahery Shallow crater lake	sediment/radiometric	3680 ± 70BP	BP 4230–3840	MAH-0A,B (61-70 cm)	β-22618	–32.40	12°26' S, 49°14' E		This paper	3 + 2
Mahery Shallow crater lake	sediment/radiometric	4620 ± 90 BP	BP 5580–5040	MAH-2 (21-50 cm)	β-24614	–17.70	12°26' S, 49°14' E		Burney, 1988	3 + 1
Mahilaka Archaeological	<i>Oryza</i> /AMS	830 ± 70 BP	AD 1030–1290	I - - 3	ST-12097		13°45' S, 48°19' E	Early archaeological site (rice)	Radimilahy, 1997	5 + 3
Mahilaka Archaeological	charcoal/radiometric	890 ± 45 BP	AD 1025–1250	VIII-A-6	Ua- 3802		13°45' S, 48°19' E		Radimilahy, 1998	6 + 2
Mahilaka Archaeological	charcoal/radiometric	910 ± 75 BP	AD 995–1270	II-P-3-4	Ua- 3804		13°45' S, 48°19' E		Radimilahy, 1998	6 + 2
Mahilaka Archaeological	charcoal/radiometric	930 ± 90 BP	AD 965–1275	VI-N-4	Ua -3803		13°45' S, 48°19' E		Radimilahy, 1998	6 + 2
Mahilaka Archaeological	charcoal/radiometric	1030 ± 65 BP	AD 885–1160	X-LT-6	Ua -3805		13°45' S, 48°19' E		Radimilahy, 1998	6 + 2

(continued on next page)

Appendix (continued)

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Mahilaka Archaeological	charcoal/radiometric	1120 \pm 160 BP	AD 630–1250	I - - 3	St-12098		13°45' S, 48°19' E		Radimilahy, 1998	6 + 2
Mahilaka Archaeological	charcoal/radiometric	1175 \pm 70 BP	AD 685–1005	VII-G-4	Ua-3806		13°45' S, 48°19' E 5m		Radimilahy, 1998	6 + 2
Maliavola Archaeological		1140 \pm 80 BP	AD 690–1030				24°59' S, 46°54' E 15m		Rakotoarisoa and Radimilahy, 2003	6 + 2
Maliavola, Anosy Archaeological	potsherd/TL	1475 \pm 100 AD		Operation I, Feature I	DurTL-77-8AS		24°59' S, 46°54' E 15m	Same context as SMU 2078	Rakotoarisoa et al., 1993	TL
Maliavola, Anosy Archaeological	charcoal/radiometric	1144 \pm 29 BP	AD 810–980	Operation I, Feature I	SMU-2078		24°59' S, 46°54' E 15m	Same context as DurTL 77 - 8AS	Rakotoarisoa et al., 1993	6 + 2
Manambovo River mouth Sandstone terrace	<i>Aepyornis</i> shell and pottery/radiometric	840 \pm 80 BP	AD 1020–1290		no given		25°28' S, 45°42' E	Early archaeological site	Battistini, Vérin and Raison, 1963	6 + 2
Mananjary Flood plain	<i>Hippopotamus laloumena</i> AMS	99 \pm 36 BP	AD 1670–1950	not given DB-HA-1	AA-45965 T-160-46A	-8.00	21°14' S, 48°20' E	Collagen extraction with gelatinisation	This paper	5 + 3
Mananjary Flood plain	<i>Hippopotamus laloumena</i> AMS	213 \pm 40 BP	AD 1639–1945	DB-HA-1 (2)	NZA-16993 R- 28139/1	-8.69	21°14' S, 48°20' E	Collagen extraction with gelatinisation	This paper	5 + 3
Mananjary Flood plain	<i>Hippopotamus laloumena</i> AMS	2327 \pm 40 BP	BP 2364–2212	DB-03-20	NZA-18525 R -28331/10a	-17.20	21°14' S, 48°20' E	Collagen extraction with gelatinisation	This paper	5 + 3
Marais d'Ifanja Swamp/Lake	sediment/radiometric	4200 \pm 80 BP	BP 4870–4520	780–800 cm	GRO-2197		not given	Near Itasy	DeWaard and Straka, 1961	3? + 2
Maranakely	sediment radiometric	> 41,400 BP		360–370 cm	KI-3576.25		not given		Straka, 2001	3? + 2
Maroaloke Coastal dunes	charcoal/not given	915 \pm 45 BP	AD 1020–1210		OxA-5638		25°12' S, 46°12' E	Early archaeological site	Parker Pearson et al., 1995	6 + 2
Maroaloke Coastal dunes	<i>Aepyornis</i> eggshell/not given	1415 \pm 40 BP	AD 570–670		OxA-5078		25°12' S, 46°12' E	Late occurrence of extinct taxon	Parker Pearson et al., 1995	6 + 3
Maroaloke Coastal dunes	<i>Aepyornis</i> eggshell/not given	2285 \pm 40 BP	BP 2350–2160		OxA-5077		25°12' S, 46°12' E	Late occurrence of extinct taxon	Parker Pearson et al., 1995	6 + 3
Masinandriana Large Wetland	<i>Plesiorycteropus</i> pelvic fragment/AMS	2154 \pm 40 BP	BP 2309–2006	MAS-2	NZA-16994 R-28139/3	-18.69		Late occurrence of extinct taxon. Did not produce sufficient gelatin for CN analysis. Collagen extraction with gelatinisation.	This paper	5 + 3
Masinandriana Large Wetland	<i>Aepyornis</i> sp. Tibiotarsus/AMS	4496 \pm 40 BP	BP 5307–4974	MAS-5	NZA-16995 R-28139/6	-13.99		Collagen extraction with gelatinisation	This paper	5 + 3

Matsabory Ampozalana Wetland	sediment/radiometric	18,860 ± 240 BP	BP 23310–21500	36–40 cm MA-P-1	β-17531	–28.52	12°31' S, 49°11' E	Acid washes	Burney, 1987b	3 + 3
Matsabory Ampozalana Wetland	sediment/radiometric	19,680 ± 240 BP		MAP-3 (26-30)	β-17532	–27.52	12°31' S, 49°11' E	Acid washes	Burney, 1987b	3 + 3
Matsabory Ampozalana Wetland	sediment/radiometric	35,090 ± 800BP		MAP-4 (31-70 cm) MAP-4,A,B,C,D,E, F,G,H	β-16809	–26.32	12°31' S, 49°11' E	Acid washes	Burney, 1987b	3 + 2
Matsabory Ampozalana Wetland	sediment/radiometric	35,750 ± 1360 BP		MAP-5 III (M-AP-5) IIIA, II-IB,IIIC,IIID	β-14853	–25.89	12°31' S, 49°11' E	Acid washes	Burney, 1987b	3 + 2
Miangola Crater bog	sediment/radiometric	30,580 ± 590 BP		MIA-2A (25.5-30 cm) MIA-2A	β-22348	–24.50	19°52' S, 46°59' E	Acid washes	This paper	3 + 3
Miangola Crater bog	sediment/radiometric	32,710 ± 820 BP		MIA-9 (51-70 cm) I (MIA-9) IA,IB	β-14851	–24.92	19°52' S, 46°59' E	Acid washes	Burney, 1987b	3 + 2
Mitoho Cave	Elephant bird eggshell/radiometric	4030 ± 70 BP	BP 4810–4300	surface	β-16442	–13.25	24°03' S, 43°46' E	Acid etched	MacPhee, 1986	6 + 3
Mitsinjo Flood plain lake	sediment/radiometric	470 ± 90 BP	AD 1300–1640	198–212 cm MIT-3A,B	β-50275	–24.80	16°02' S, 45°51' E	Acid washes	Matsumoto and Burney, 1994	3 + 2
Mitsinjo Flood plain lake	sediment/radiometric	530 ± 80 BP	AD 1290–1490	90–110 cm MIT-2A	β-48177	–27.40	16°02' S, 45°51' E	Acid washes	Matsumoto and Burney, 1994	3 + 2
Mitsinjo Flood plain lake	sediment/radiometric (4x)	890 ± 80 BP	AD 1000–1280	264–268 cm MIT-3.5A (3:81-85)	β-51797	–29.40	16°02' S, 45°51' E	Acid washes	Matsumoto and Burney, 1994	3 + 3
Mitsinjo Flood plain lake	wood, sediment radiometric (4x)	2400 ± 90	BP 2740–2180	390–420 cm MIT-6W,A,B,C (6:41-70)	β-51799	–27.30	16°02' S, 45°51' E	Acid washes	Matsumoto and Burney, 1994	3 + 2
Mitsinjo Flood plain lake	sediment/radiometric (4x)	3160 ± 210 BP	BP 3870–2840	323–349 cm MIT-5A,B,C,D (5:1-27)	β-52365	–26.70	16°02' S, 45°51' E	Rejected due to old carbon contamination	Matsumoto and Burney, 1994	3 + 1
Mitsinjo Flood plain lake	sediment/radiometric	3420 ± 120 BP	BP 3980–3390	480–500 cm MIT-7A	β-48178	–23.50	16°02' S, 45°51' E	Acid washes	Matsumoto and Burney, 1994	3 + 2
Nosy Mangabe Archaeological	pottery/TL	AD 950 ± 160			Dur91TL-15-2ASQi		15°30' S, 49°46' E	Early archaeological site	Dewar and Wrig-ht, 1993 (p.439)	TL
Nosy Mangabe Archaeological	charcoal/radiometric	1250 ± 60 BP	AD 660–990		SMU-2501		15°30' S, 49°46' E	Early archaeological site	Dewar and Wrig-ht, 1993 (p. 429)	6 + 2
Ranobe Pond	sediment/radiometric	600 ± 70 BP	AD 1280–1440	51–70cm RAN-0-A,B,C,D	β-24423	–26.30	23°01' S, 43°37' E	Acid washes	This paper	3 + 2

(continued on next page)

Appendix (continued)

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Ranobe Pond	sediment/radiometric	1300 \pm 80 BP	AD 620–900	RAN-2:81-100 cm RAN-2A,B	β -22619	–27.40	23°01' S, 43°37' E 10 m		This paper	3 + 2
Ranobe Pond	sediment/radiometric	1360 \pm 80 BP	AD 550–860	RAN-2:21-40 RAN-1A,B	β -23489	–26.60	23°01' S, 43°37' E 10 m		Burney, 1997a,b	3 + 2
Sandrakatsy East Archaeological	charcoal/radiometric	1140 \pm 60 BP	AD 770–1010	Operation D, Layer 3	SMU-2076		16°09' S, 49°46' E	Early archaeological site	Wright and Fanony, 1992	6 + 2
Sandrakatsy East Archaeological	charcoal/radiometric	1240 \pm 50 BP	AD 670–900	Operation D, Layer 3	SMU-2359		16°09' S, 49°46' E	Early archaeological site	Wright and Fanony, 1992	6 + 2
Sandrakatsy West Archaeological	charcoal/radiometric	970 \pm 60 BP	AD 980–1200	Operation E, Layer 2	SMU-2502		16°09' S, 49°46' E	Early archaeological site	Wright and Fanony, 1992	6 + 2
Sarodrano Archaeological	charcoal/radiometric	160 \pm ? BP		Site 1	GaK-926		23°30' S, 43°44' E	B and V believe that the modern-looking ceramics and glass bead suggest the layer mixed with older natural charcoal. No # given for \pm	Battistini and Vé- rin, 1971 (p.58)	6 + 1
Sarodrano Archaeological	charcoal/radiometric	210 \pm 80 BP	AD 1490–1950	Site 2	GaK-927		23°30' S, 43°44' E		Battistini and Vé- rin, 1971 (p.58)	6 + 1
Sarodrano Archaeological	charcoal/radiometric	535 \pm 80 BP	AD 1290–1480	Site 1	GaK-1057		23°30' S, 43°44' E		Battistini and Vé- rin, 1971 (p. 58)	6 + 1
Sarodrano Archaeological	charcoal/radiometric	1460 \pm 90 BP	AD 410–710	Site 2	GaK-928		23°30' S, 43°44' E	Early archaeological site?	Battistini and Vé- rin, 1971 (p.60)	6 + 1
Southern Madagascar	<i>Aepyornis eggshell</i> /radiometric	2930 \pm 85 BP	BP 3340–2860		not given		19° ' S, 47° ' E		Marden, 1967. (p.487)	6 + 3
SW Madagascar near Nossi Bé	<i>Geochelone grandis</i> carapace radiometric	1250 \pm 50 BP	AD 670–890	B.M.N.H. (Z) 1984.1282	BM-1399	–13.90	not given	Late occurrence of extinct taxon	Burleigh and Arnold, 1986	5? + 3
Talaky Archaeological, Sandstone bench	charcoal/radiometric	840 \pm 80 BP	AD 1020–1290	Sq. C4 and C5 of 2nd site in B zone 20 cmts not given	GaK-276		25°27' S, 45°43' E 3m	Early archaeological site	Battistini and Vé- rin, 1967	6 + 2
Taolambiby seepage deposit	<i>Propithecus verreauxi</i> humerus (cut marks)/AMS	modern		not given AW-T-66-1	AA-45962		23°40' S, 44°25' E		This paper	5 + 3
Taolambiby seepage deposit	Tortoise bone/radiometric	2290 \pm 90 BP	BP 2700–2100	1.90 m	GaK-1651		23°40' S, 44°25' E	Late occurrence of extinct taxon	Mahé and Sour- dat, 1972	1? + 3
Taolambiby seepage deposit	<i>Palaeopropithecus ingens</i> radius (cut marks)/AMS	2325 \pm 43 BP	BP 2366–2315	not given OX-UM 14346j	AA-45960 T16041A	–20.20	23°40' S, 44°25' E	Human-modified megafaunal bone; Collagen extraction with gelatinisation	This paper	5 + 3

Taolambiby seepage deposit	<i>Megaladaois grand- idieri/madagascar- iensis</i> 2nd molar, lower jaw/AMS	2713 ± 44 BP	BP 2870– 2760	not given OX- UM 5105	AA-45961 T-16042	–18.90	23°40' S, 44°25' E	This paper	5 + 3
Torotorofotsy Paleolake/ Wetland	wood/radiometric	9390 ± 100 BP	BP 11070– 10270	2.1m TTF-2.1	β-28590	–29.50	18°55' S, 48°26' E 956m	Rakotondrazafy, 1992	5 + 2
Torotorofotsy Paleolake/ Wetland	sediment/ radiometric	35,000 + 2500/ - 1900 BP		200–220 cm	KI-3222		18°55' S, 48°26' E 956m	Straka, 1993	3? + 2
Tritrivakely Crater lake	plant macrofossil/ AMS	modern		15 cm LT1	H-616		19°47' S, 46°55' E	Gasse et al., 1994	5 + 3
Tritrivakely Crater lake	sediment/ radiometric	1240 ± 100 BP	AD 630– 1000	41–45cm TRI-1A	β-15884	–26.51	19°47' S, 46°55' E 1778 m	Charcoal in- crease, probably anthropogenic Burney, 1987a	3 + 3
Tritrivakely Crater lake	plant macrofossil/ AMS	2840 ± 60 BP	BP 3140– 2790	140 cm LT2/5	H-667	–26.00	19°47' S, 46°55' E 1778m	Gasse et al., 1994 (p. 1517)	5 + 3
Tritrivakely Crater lake	sediment/ radiometric	3810 ± 70 BP	BP 4420– 3980	151–155 cm T- RI-2A (61-65)	β-15885	–22.65	19°47' S, 46°55' E 1778 m	Burney, 1987a	3 + 3
Tritrivakely Crater lake	plant macrofossil/ AMS	4340 ± 90 BP	BP 5290– 4650	305 cm LT4	H-618	–24.80	19°47' S, 46°55' E 1778 m	Gasse et al., 1994 (p. 1517)	5 + 3
Tritrivakely Crater lake	sediment/ radiometric	5730 ± 70 BP	BP 6670– 6390	246–255 cm TRI-3A,B (56-65)	β-16807	–24.31	19°47' S, 46°55' E 1778 m	Burney, 1987a	3 + 2
Tritrivakely Crater lake	plant macrofossil/ AMS	5840 ± 80 BP	BP 6800– 6450	300 cm T-II/ 300 cm			19°47' S, 46°55' E 1778 m	Williamson et al., 1998	5 + 3
Tritrivakely Crater lake	plant macrofossil/ AMS	6290 ± 110 BP	BP 7430– 6900	340 cm LT4/5	H-669	–22.80	19°47' S, 46°55' E 1778 m	Gasse et al., 1994 (p. 1517)	5 + 3
Tritrivakely Crater lake	plant macrofossil/ AMS	8460 ± 130 BP	BP 9690– 9130	350 cm LT4 (40)	H-711	–21.11	19°47' S, 46°55' E 1778 m	Gasse et al., 1994 (p. 1517)	5 + 3
Tritrivakely Crater lake	sediment/ radiometric	8490 ± 100 BP	BP 9600– 9290	326–335 cm TRI-4A,B (36- 45)	β-16808	–23.75	19°47' S, 46°55' E 1778 m	Burney, 1987a	3 + 2
Tritrivakely Crater lake	plant macrofossil/ AMS	9920 ± 90 BP	BP 11650– 11180	350 cm T-II/350 cm			19°47' S, 46°55' E 1778 m	Williamson et al., 1998	5 + 3
Tritrivakely Crater lake	sediment/ radiometric	10,470 ± 110 BP	BP 12910– 11910	473–490 cm IV (TRI-5) IVA, IVB (83-100)	β-14854	–18.31	19°47' S, 46°55' E 1778 m	Burney, 1987a	3 + 2
Tritrivakely Crater lake	plant macrofossil/ AMS	12,750 ± 170 BP	BP 15930– 14220	379 cm LT4 (69)	H-712	–18.83	19°47' S, 46°55' E 1778m	Gasse et al., 1994	5 + 3

(continued on next page)

Appendix (continued)

Site name and site type	Material/dating method	Age $\pm 1\sigma$	Calibrated range at 2σ	Provenience or Accession # Sample I.D.	Lab nr	$\delta^{13}\text{C}$	Lat./long. Elevation	Comments	Source	Rating
Tritrivakely Crater lake	plant macrofossil/AMS	13,740 \pm 130 BP	BP 17030–15980	411 cm T-II/ 411 cm			19°47' S, 46°55' E 1778m		Williamson et al., 1998	5 + 3
Tritrivakely Crater lake	plant macrofossil/AMS	15,070 \pm 170 BP	BP 18700–17390	412 cm LT5 (19)	H-710	–18.06	19°47' S, 46°55' E 1778 m		Gasse et al., 1994 (p. 1517)	5 + 3
Tritrivakely Crater lake	charcoal/AMS	18,550 \pm 210 BP	BP 22870–21220	450 cm T-II/ 450 cm			19°47' S, 46°55' E 1778 m		Williamson et al., 1998	6 + 2
Tritrivakely Crater lake	plant macrofossil/AMS	19,210 \pm 180 BP	BP 23590–22030	463 cm LT5/8	H-670	–16.70	19°47' S, 46°55' E 1778 m		Gasse et al., 1994	5 + 3
Tritrivakely Crater lake	charcoal/AMS	22,700 \pm 290 BP		552 cm T-II/ 552 cm			19°47' S, 46°55' E 1778m		Williamson et al., 1998	6 + 2
Tritrivakely Crater lake	sediment/AMS	24,010 \pm 330 BP		550 cm LT6	H-624	–19.90	19°47' S, 46°55' E 1778 m		Gasse et al., 1994	3 + 3
Tritrivakely Crater lake	sediment/AMS	28,290 \pm 500 BP		732 cm LT8	H-650	–21.90	19°47' S, 46°55' E 1778 m	Gasse believes the sediment dates may be slightly biased by contamination by organic detritus	Gasse et al., 1994	3 + 3
Tritrivakely Crater lake	sediment/AMS	34,630 \pm 990 BP		904 cm LT10	H-626	–10.40	19°47' S, 46°55' E 1778m		Gasse et al., 1994	3 + 3
Tritrivakely Crater lake	sediment/AMS	34,720 \pm 980 BP		1165 cm LT14	H-619	–24.50	19°47' S, 46°55' E 1778m		Gasse et al., 1994	3 + 3
Tritrivakely Crater lake	plant macrofossil/AMS	36,200 \pm 120 BP		1300 cm LT16	H-617	–25.70	19°47' S, 46°55' E 1778 m		Gasse et al., 1994	5 + 3
Tritrivakely Crater lake	sediment/AMS	43,100 \pm 2700 BP		1034 cm LT12	H-628	–21.00	19°47' S, 46°55' E 1778 m	Date rejected	Gasse et al., 1994	3 + 2
Tsiandroina	<i>Mesopropithecus globiceps</i> right distal humerus/AMS	1694 \pm 40 BP	AD 245–429	MP13 DB- 03-6	NZA-18521 R-28331/4	–19.30		Late occurrence of extinct taxon; Collagen extraction with gelatinisation	This paper	5 + 3
Tsiandroina Wetland	<i>Coua primavea</i> bone/AMS	1980 \pm 60 BP	BC 110–AD 130		β -63676			Late occurrence of extinct taxon	Goodman and Rakotozafy, 1997	5 + 3
Tsiandrora Archaeological	charcoal/radiometric	950 \pm 80 BP	AD 960–1260	Sondage I, Level 10-12	LY 3912		25°03' S, 46°54' E 12m		Rakotoarisoa, 1993	6? + 2

Tsirave	<i>Hadropithecus stenognathus</i> tooth/ AMS	2194 ± 70 BP	BP 2344–1998	not given BJ-HS-2	NZA-15672 R-26931/1	–13.22	21°50' S, 45°7' E	Late occurrence of extinct taxon Collagen extraction with gelatinisation	This paper	5 + 3
Tsiroanomandidy Wetland	sediment/ radiometric	1160 ± 110 BP	AD 660–1040	2.2–2.3 m KZ-26	β-28593	–27.30	18°45' S, 46°3' E	This is same as Kizato	Rafamantanantsoa, 1991	3 + 2
Tulear (Belande) Coastal dunes unknown	<i>Aepyornis</i> eggshell/ radiometric	5210 ± 140 BP	BP 6290–5640		not given				Sauer, 1972	6 + 3
	<i>Megaladapis</i> tooth/ AMS	1591 ± 60 BP	AD 339–609	AM 6527 #5	NZA-10102 R-24649/3	–20.40		Late occurrence of extinct taxon Collagen extraction with gelatinisation	This paper	5 + 3
Vinaninony Wetland	sediment/ radiometric	11,100 ± 150 BP	BP 13,750–12,660	200–220 cm	KI-3220.21		19.5° S, 47.2° E 1875 m		Straka, 1993	3? + 2
Vinaninony Wetland	sediment/ radiometric	> 27,000 BP		600–620 cm	KI-3220.61		19.5° S, 47.2° E 1875 m	In Straka, 2001 this date is given as 27,000 BP	Straka, 1993	3? + 2
Vohimasina, Vakin'ankaratra Archaeological	charcoal/ radiometric	480 ± 50 BP	AD 1400–1480	Sondage 3, Layer V	SMU-1519		20°08' S, 47°01' E		Wright et al., 1992	6 + 2
Vohimasina, Vakin'ankaratra Archaeological	charcoal/ radiometric	710 ± 60 BP	AD 1220–1400	Sondage 1, Layer VI	SMU-2630		20°08' S, 47°01' E	Early archaeological site	Wright et al., 1992	6 + 2
Vohimasina, Vakin'ankaratra Archaeological	potsherd/TL	1410 ± 115 AD		Sondage 1, Layer VI	DurTL-50-13 AS		20°08' S, 47°01' E		Wright et al., 1992	TL
Vohimasina, Vakin'ankaratra Archaeological	potsherd/TL	1515 ± 95 AD		Sondage 3, Layer V	DurTL-50-9 AS		20°08' S, 47°01' E		Wright et al., 1992	TL
Vohitrarivo, Vakin'ankaratra Archaeological	charcoal/ radiometric	290 ± 80 BP	AD 1440–1950	not given	β-24479		20°05' S, 47°05' E		Wright et al., 1992	6 + 2

Refer notes to the appendix for key to abbreviations for dating laboratories.

Refer notes to appendix for rating system.

Notes to the appendix

Key to abbreviations for dating laboratories:

Abbreviation	Laboratory	Location
AA	NSF-Arizona AMS Facility	USA
BM	British Museum	England
β	Beta Analytic	USA
CAMS	Center for Accelerator Mass Spectrometry	USA
Dur	Durham University	England
ETH	ETH/AMS Facility	Switzerland
GaK	Gakushuin University	Japan
Gif	Gif sur Yvette	France
GrA	Groningen AMS	The Netherlands
GRO*	Groningen	The Netherlands
GX	Geochron Laboratories	USA
H	LHGI, Orsay	France
Hela	Helsinki	Finland

(continued on next page)

Abbreviation	Laboratory	Location
KI	Kiel	Germany
LY	University of Lyon	France
NZA	New Zealand	New Zealand
OxA	Oxford Radiocarbon Accelerator Unit	England
Pta	Pretoria	South Africa
QC*	Queens College	USA
R	Rafter	New Zealand
SMU*	Southern Methodist Univ.	USA
ST*	Stockholm	Sweden
T	Trondheim	Norway
TO	IsoTrace	Canada
Ua	Uppsala AMS	Sweden
UCLA	University of California Los Angeles	USA

*Indicates laboratories that are closed or operating under a different code designation

Rating system: For each ^{14}C determination, a score was assigned to provide a rough guide for assessing the reliability of the date based on the simple system proposed by Mead and Meltzer (1984) with modifications based on suggestions in Long et al. (1983); Stafford et al. (1991); and Hedges and Van Klinken (1992). Ratings are based on adding together a score from each section.

Section I. Material dated	Score
Faunal	
Eggshell	6
Collagen	5
Fecal pellet	5
Pretreated bone with poor collagen yield	3
Whole bone	1
Other organic material	
Charcoal	6
Plant macrofossil (wood, seeds)	5
Peat, organic mud, soil	3
Shell (freshwater/terrestrial/marine)	2
Section II. Strength of association with event of interest	
Strong (includes pretreated sediments spanning < 5 cm)	3
Unknown or medium (includes pretreated sediments 5-20 cm)	2
Weak (includes sediments > 20 cm)	1

Dates scoring a total of 8-9 are likely to be the most reliable; 5-7, may have less certainty, depending on context; 2-4, generally unreliable. Question marks indicate insufficient information was available to determine score.

References

- Atkinson, I., 1989. Introduced animals and extinctions. In: Western, D., Pearl, M. (Eds.), *Conservation for the Twenty-first Century*. Oxford University Press, New York, pp. 54–69.
- Battistini, R., Vérin, P., 1966. Les datations à Madagascar par la méthode du RC-14. *C.R. Semaine Géologique, Antananarivo*.
- Battistini, R., Vérin, P., 1967. Ecologic changes in protohistoric Madagascar. In: Martin, P.S., Wright Jr., H.E. (Eds.), *Pleistocene Extinctions*. Yale University Press, New Haven, pp. 407–424.
- Battistini, R., Vérin, P., 1971. Témoignages archéologiques sur la cote vezo de l'embouchure de l'onilahy à la baie des assassins. *Taloha* 4, 51–63.
- Battistini, R., Vérin, P., Raison, R., 1963. Le site archéologique de Talaky: cadre géographique. *Annales Malgaches, Faculté des Lettres et Sciences Humaine, Antananarivo* 1, 112–153.
- Berger, R., Ducote, K., Robinson, K., Walter, H., 1975. Radiocarbon date for the largest extinct bird. *Nature* 258, 709.
- Brochu, C.A., 2000. Phylogenetic relationships and divergence timing of *Crocodylus* based on morphology and the fossil record. *Copeia* 2000, 657–673.
- Brook, G.A., Raftar, M.A., Railsback, L.B., Sheen, S.-W., Lundberg, J., 1999. A high-resolution proxy record of rainfall and ENSO since AD 1550 from layering in stalagmites from Anjohibe Cave, Madagascar. *The Holocene* 9, 695–705.
- Brown, M., 1979. *Madagascar Rediscovered*. Archon, Hamden, CT.
- Burleigh, R., Arnold, E.N., 1986. Age and dietary differences of recently extinct Indian Ocean tortoises (*Geochelone s. lat.*) revealed by carbon isotope analysis. *Proc. R. Soc. Lond. B* 227, 137–144.
- Burney, D.A., 1987a. Pre-settlement vegetation changes at Lake Tritrivakely, Madagascar. *Palaeoecology of Africa* 18, 357–381.
- Burney, D.A., 1987b. Late Quaternary stratigraphic charcoal records from Madagascar. *Quat. Res.* 28, 274–280.
- Burney, D.A., 1987c. Late Holocene vegetational change in central Madagascar. *Quat. Res.* 28, 130–143.
- Burney, D.A., 1988. Modern pollen spectra from Madagascar. *Paleogeogr., Paleoclimatol., Paleoecol.* 66, 63–75.
- Burney, D.A., 1993a. Late Holocene environmental changes in arid southwestern Madagascar. *Quat. Res.* 40, 98–106.
- Burney, D.A., 1993b. Recent animal extinctions: recipes for disaster. *Am. Sci.* 81, 530–541.
- Burney, D.A., 1996a. Climate change and fire ecology as factors in the Quaternary biogeography of Madagascar. In: Lourenço, W.R. (Ed.), *Biogéographie de Madagascar*. Editions de l'ORSTOM, Paris, pp. 49–58.
- Burney, D.A., 1996b. Historical perspectives on human-assisted biological invasions. *Evol. Anthropol.* 4, 216–221.
- Burney, D.A., 1997a. Theories and facts regarding Holocene environmental change before and after human colonization. In: Goodman, S.M., Patterson, B.D. (Eds.), *Natural Change and Human Impacts in Madagascar*. Smithsonian Press, Washington, DC, pp. 142–168.
- Burney, D.A., 1997b. Tropical islands as paleoecological laboratories: gauging the consequences of human arrival. *Human Ecology* 25, 437–457.
- Burney, D.A., 1999. Rates, patterns, and processes of landscape transformation and extinction in Madagascar. In: MacPhee, R.D.E. (Ed.), *Extinction in Near Time*. Kluwer/Plenum, New York, pp. 145–164.
- Burney, D.A., Ramilisonina, 1998. The kilopilopitsofy, kidoky, and bokyboky: accounts of strange animals from Belo-sur-Mer, Madagascar, and the megafaunal “extinction window.” *Am. Anthropol.* 100, 957–966.
- Burney, D.A., Robinson, G.S., in review. Excavating and interpreting flooded megafaunal sites.
- Burney, D.A., Burney, L.P., MacPhee, R.D.E., 1994. Holocene charcoal stratigraphy from Laguna Tortuguero, Puerto Rico, and the timing of human arrival on the island. *J. Archaeol. Sci.* 21, 273–281.
- Burney, D.A., James, H.F., Grady, F.V., Rafamantanantsoa, J.-G., Ramilisonina, Wright, H.T., Cowart, J.B., 1997. Environmental change, extinction, and human activity: evidence from caves in NW Madagascar. *J. Biogeogr.* 24, 755–767.
- Burney, D.A., Robinson, G.S., Burney, L.P., 2003. *Sporormiella* and the late Holocene extinctions in Madagascar. *Proc. Natl. Acad. Sci. USA* 100, 10800–10805.
- Dahl, O., 1951. *Malgache et Maanyan*. Egede Instituttet, Oslo.
- Davis, O.K., 1987. Spores of the dung fungus *Sporormiella*: increased abundance in historic sediments and before Pleistocene megafaunal extinction. *Quat. Res.* 28, 290–294.
- de Flacourt, E., 1661. *Histoire de la grand isle de Madagascar*. Paris.
- DeWaard, H., Straka, H., 1961. C¹⁴-datierung zweier torfproben aus Madagaskar. *Naturwissenschaften* 48, 45.
- Dewar, R., 1984. Extinctions in Madagascar: the loss of the subfossil fauna. In: Martin, P.S., Klein, R.G. (Eds.), *Quaternary Extinctions: A Prehistoric Revolution*. University of Arizona Press, Tucson, pp. 574–593.
- Dewar, R.E., 1997. Were people responsible for the extinction of Madagascar's subfossils, and how will we ever know? In: Goodman, S.M., Patterson, B.D. (Eds.), *Natural Change and Human Impact in Madagascar*. Smithsonian Press, Washington, DC, pp. 364–377.
- Dewar, R.E., Rakotovololona, S., 1992. La chasse aux subfossiles: les preuves de XI^{ème} siècle au XIII^{ème} siècle. *Taloha* 11, 4–15.
- Dewar, R.E., Wright, H.T., 1993. The culture history of Madagascar. *J. World Prehist.* 7, 417–466.
- Emphoux, J.-P., 1979. Archéologie de Androy. Colloque d'Histoire Malgache, Tulear. Mimeo (cited in Dewar, 1984).
- Emphoux, J.-P., 1981. Archéologie de l'Androy: deux sites importants—Andranosoa et le manda de Ramananga. *Omalysy Anio* 13–14, 89–87.
- Gasse, F., Cortijo, E., Disnar, J.-R., Ferry, L., Gibert, E., Kissel, C., Laffoun-Defarge, F., Lallier-Vergès, E., Miskovsky, J.-C., Ratsimbazafy, B., Ranaivo, F., Robison,

- L., Tucholka, P., Saos, J.-L., Siffedine, A., Taieb, M., VanCampo, E., Williamson, D., 1994. A 36 ka environmental record in the southern tropics: Lake Tritrivakely (Madagascar). *C.R. Acad. Sci. Paris* 318, 1513–1519.
- Gasse, F., Van Campo, E., 1998. A 40,000-yr pollen and diatom record from Lake Tritrivakely, Madagascar, in the southern tropics. *Quat. Res.* 46, 299–311.
- Gasse, F., Van Campo, E., 2001. Late Quaternary environmental changes from a pollen and diatom record in the southern tropics (Lake Tritrivakely, Madagascar). *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 167, 287–308.
- Godfrey, L.R., 1986. The tale of the Tsy-aomby-aomby. *The Sciences* 1986, 49–51.
- Godfrey, L.R., Jungers, W.L., 2002. Quaternary fossil lemurs. In: Hartwig, W.C. (Ed.), *The Primate Fossil Record*. Cambridge University Press, Cambridge, pp. 97–121.
- Godfrey, L.R., Jungers, W.L., Simons, E.L., Chatrath, P.S., Rakotosamimanana, B., 1999. Past and present distributions of lemurs in Madagascar. In: Rakotosamimanana, B., Rasamimanana, H., Ganzhorn, J., Goodman, S. (Eds.), *New Directions in Lemur Studies*. Kluwer Academic/Plenum, New York, pp. 19–53.
- Goodman, S.M., 1999. Holocene bird subfossils from the sites of Ampasambazimba, Antsirabe and Ampoza, Madagascar: changes in the avifauna of south central Madagascar over the past few millennia. In: Adams, N.J., Slotow, R.H. (Eds.), *Proceedings of the 22nd International Ornithological Congress*. BirdLife South Africa, Johannesburg, pp. 3071–3083.
- Goodman, S.M., Rakotondravony, D., 1996. The Holocene distribution of *Hypogeomys* (Rodentia: Muridae: Nesomyinae) on Madagascar. In: Lourenço, W.R. (Ed.), *Biogéographie de Madagascar*. Editions de l'ORSTOM, Paris, pp. 283–293.
- Goodman, S.M., Rakotozafy, L.M.A., 1997. Subfossil birds from coastal sites in western and southwestern Madagascar: a paleoenvironmental reconstruction. In: Goodman, S.M., Patterson, B. (Eds.), *Natural Change and Human Impacts in Madagascar*. Smithsonian Institution Press, Washington, DC, pp. 142–168.
- Goodman, S.M., Benstead, J. (Eds.), *The Natural History of Madagascar*. University of Chicago Press, Chicago, pp. 142–168.
- Goodman, S.M., Ganzhorn, J.U., 2004. Altitudinal ranges of lemurs in the humid forests of Madagascar: the role of geological history in modeling community composition. *Int. J. Primatol.* 25, 331–350.
- Goodman, S.M., Rasoalarison, R.M., Ganzhorn, J.U., 2004. On the specific identification of subfossil *Cryptoprocta* (Mammalia, Carnivora) from Madagascar. *Zoosystema* 26, 129–143.
- Grayson, D.K., 1984. Explaining Pleistocene extinctions: thoughts on the structure of a debate. In: Martin, P.S., Klein, R.G. (Eds.), *Quaternary Extinctions: A Prehistoric Revolution*. University of Arizona Press, Tucson, pp. 354–403.
- Green, G.M., Sussmann, R.W., 1990. Deforestation history of the eastern rain forests of Madagascar from satellite imagery. *Science* 248, 212–215.
- Hedges, R.E.M., Van Klinken, G.J., 1992. A review of current approaches in the pretreatment of bone for radiocarbon dating by AMS. *Radiocarbon* 34, 279–291.
- Humbert, H., 1927. Destruction d'une flore insulaire par le feu. *Memoires de l'Académie Malgache* 5, 1–80.
- Jernvall, J., Wright, P.C., Ravoay, F.L., Simons, E.L., 2003. Report on the finding of subfossils at Ampoza and Ampanihy in southwestern Madagascar. *Lemur News* 8, 21–23.
- Jungers, W.L., Godfrey, L.R., Simons, E.L., Chatrath, P.S., 1995. Subfossil *Indri indri* from the Ankarana Massif of northern Madagascar. *Am. J. Phys. Anthropol.* 97, 357–366.
- Kigoshi, K., Lin, D.-H., Endo, K., 1964. Gakushuin natural radiocarbon measurements III. *Radiocarbon* 6, 197–207.
- Long, A., Hendershott, S., Martin, P., 1983. Radiocarbon dating of fossil eggshell. *Radiocarbon* 25, 533–540.
- MacPhee, R.D.E., 1986. Environment, extinction, and Holocene vertebrate localities in southern Madagascar. *National Geographic Research* 2, 441–455.
- MacPhee, R.D.E., Burney, D.A., 1991. Dating of modified femora of extinct dwarf *Hippopotamus* from southern Madagascar: implications for constraining human colonization and vertebrate extinction events. *J. Archaeol. Sci.* 18, 695–706.
- MacPhee, R.D.E., Marx, P.A., 1997. The 40,000-year plague: humans, hypervirulent diseases, and first-contact extinctions. In: Goodman, S.M., Patterson, B.D. (Eds.), *Natural Change and Human Impacts in Madagascar*. Smithsonian Press, Washington, DC, pp. 169–217.
- MacPhee, R.D.E., Burney, D.A., Wells, N.A., 1985. Early Holocene chronology and environment of Ambasambazimba, a Malagasy subfossil lemur site. *Int. J. Primatol.* 6, 463–489.
- Mahé, J., Sourdat, M., 1972. Sur l'extinction des vertébrés subfossiles et l'aridification du climat dans le Sud-Ouest de Madagascar. *Bull. Soc. Geol. Fr.* 14, 295–309.
- Marden, L., 1967. Madagascar, island at the end of the Earth. *Nat. Geogr.* 132, 443–487.
- Martin, P.S., 1984. Prehistoric overkill: the global model. In: Martin, P.S., Klein, R.G. (Eds.), *Quaternary Extinctions: A Prehistoric Revolution*. University of Arizona Press, Tucson, pp. 354–403.
- Matsumoto, K., Burney, D.A., 1994. Late Holocene environmental changes at Lake Mitsinjo, northwestern Madagascar. *The Holocene* 4, 16–24.
- Mead, J.I., Meltzer, D.J., 1984. North American Late Quaternary extinctions and the radiocarbon record. In: Martin, P.S., Klein, R.G. (Eds.), *Quaternary Extinctions: A Prehistoric Revolution*. University of Arizona Press, Tucson, pp. 440–450.
- Merlin, M.D., 2003. Archaeological evidence for the tradition of psychoactive plant use in the Old World. *Economic Botany* 57, 295–323.
- Parker Pearson, M., Godden, K., Ramilisonina, R., Retsihisatse, S., Schwenninger, J.-L., Smith, H., 1995. The Central Androy Survey. Third Report. Department of Archaeology and

- Prehistory, University of Sheffield, and Institut de Civilisations, Musée d'Art et d'Archéologie, Antananarivo.
- Perez, V.R., Burney, D.A., Godfrey, L.R., Nowak-Kemp, M., 2003. Butchered sloth lemurs. *Evol. Anthropol.* 12, 260.
- Popper, K., 1969. *Conjectures and Refutations*. Routledge and Kegan Paul, London.
- Radimilahy, C., 1997. Mahilaka, an eleventh- to fourteenth-century Islamic port: the first impact of urbanism in Madagascar. In: Goodman, S.M., Patterson, B.D. (Eds.), *Natural Change and Human Impacts in Madagascar*. Smithsonian Press, Washington, DC, pp. 342–363.
- Radimilahy, C., 1998. Mahilaka: archaeological studies of an early port in northwestern Madagascar. *Studies in African Archaeology* No. 15. Societas Archeologica Uppsaliensis and Department of Archaeology and Ancient History, Uppsala.
- Rafamantanantsoa, J.-G., 1991. Contribution à l'étude micropaléontologique (spores-pollen-diatomées) de quatre tourbières des Hautes Terres de Madagascar: Valorisation énergétique, paléocologie, dynamique des environnements. Thèse de Doctorat de 3ème Cycle, Université d'Antananarivo.
- Rakotondrazafy, T., 1992. Dynamique des environnements Quaternaires du Madagascar par l'étude sédimentologique, l'analyse palynologique et la diatomologie de quelques bassins lacustres. Thèse de Doctorat de 3ème Cycle, Université d'Antananarivo.
- Rakotoarisoa, J.A., 1993. Le site Mokala dans la région dite Mozambique du sud-est de Madagascar. In: *Project Working Papers*. Musée d'Art et d'Archéologie, Antananarivo, pp. 132–156 (cited in Dewar and Wright, 1993).
- Rakotoarisoa, J.A., Wright, H.T., Huertebize, G., Vérin, P., 1993. The evolution of settlement systems in the Efafo River Valley, Anosy: a preliminary report on archaeological reconnaissances of 1983–1986. *Indo-Pacific Prehistory Association Bulletin* 12, 2–20.
- Rakotovololona, H.S., 1994. Ankadivory: Témoin d'une culture de l'Imerina Ancien. *Taloha* XII, 7–24.
- Rasamuel, D., 1984. In: *Alimentation et techniques anciennes dans le Sud Malgache à travers une fosse à ordures du XI^{ème} siècle*, 4. Tsiokantimo – Etudes de l'Océan Indien, Paris, pp. 81–109.
- Reyes, N.E., 1993. The modern diatom spectra of Madagascar and diatom-inferred late Quaternary climatic changes in north-eastern and central Madagascar. Ph.D. dissertation, Fordham University.
- Romani, J.R.V., Mosquera, D.F., Campos, M.L., 2002. A 12,000 yr BP record from Andringitra Massif, (southern Madagascar): post-glacial environmental evolution from geomorphological and sedimentary evidence. *Quaternary International* 93–94, 45–51.
- Sauer, E.G.F., 1972. Ratite eggshells and phylogenetic questions. *Bonner Zoologische Beiträge* 23, 3–48.
- Simons, E.L., 1997. Lemurs: old and new. In: Goodman, S.M., Patterson, B.D. (Eds.), *Natural Change and Human Impacts in Madagascar*. Smithsonian Press, Washington, DC, pp. 142–168.
- Simons, E.L., Burney, D.A., Chatrath, P.S., Godfrey, L.R., Jungers, W.L., Rakotosamimanana, B., 1995. AMS ¹⁴C dates for extinct lemurs from caves in the Ankarana Massif, northern Madagascar. *Quat. Res.* 43, 249–254.
- Stafford Jr., T.W., Hare, P.E., Currie, L., Jull, A.J.T., Donahue, D.J., 1991. Accelerator radiocarbon dating at the molecular level. *J. Archaeol. Sci.* 18, 35–72.
- Straka, H., 1993. Beiträge zur Kenntnis der vegetationsgeschichte von Madagaskar (vorläufige Mitteilung) Festschrift Zoller. *Dissertationes Botanicae* 196, 439–449.
- Straka, H., 1996. Histoire de la végétation de Madagascar oriental dans les derniers 100 millénaires. In: Lourenço, W.R. (Ed.), *Biogéographie de Madagascar*. Editions de l'ORSTOM, Paris, pp. 49–58.
- Straka, H., 2001. *Palynologia madagassica et mascarenica* III. Sur l'histoire tardiquaternaire de la végétation de la partie orientale de Madagascar et des Mascareignes. *J. Bot. Soc. Bot. Fr.* 13, 47–88.
- Street-Perrot, F.A., Huang, Y., Perrot, R.A., Eglington, G., Barker, P., Ben Khelifa, L., Harkness, D.D., Olago, D.O., 1997. Impact of lower atmospheric CO₂ on tropical mountain ecosystems. *Science* 278, 1422–1426.
- Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, F.G., Plicht, J.v.d., Spurk, M., 1998. *INTCAL98 ¹⁴C Radiocarbon* 40, 1041–1083.
- Tattersall, I., 1973. A note on the age of the subfossil site of Ampasambazimba, Miarinarivo Province, Malagasy Republic. *Am. Mus. Novit.* 2520, 1–6.
- Vérin, P., 1975. *Les Échelles Anciennes du Commerce sur les Côtes Nord de Madagascar*. Service de Reproduction des Thèses, Lille.
- Vitousek, P.M., D'Antonio, C.M., Loope, L.L., Westbrooks, R., 1996. Biological invasions as global environmental change. *Am. Sci.* 84, 468–478.
- Vuillaume-Randriamanantena, M., Godfrey, L.R., Sutherland, M.R., 1985. Revision of *Hapalemur* (*Prohapalemur*) *gallieni* (Standing 1905). *Folia Primatol* 45, 89–116.
- Williamson, D., Jelinowska, A., Kissel, C., Tucholka, P., Gibert, E., Gasse, F., Massault, M., Taieb, M., Van Campo, Wieckowski, K., 1998. Mineral-magnetic proxies of erosion/oxidation cycles in tropical maar-lake sediments (Lake Tritrivakely, Madagascar): paleoenvironmental implications. *Earth and Planetary Science Letters* 155, 205–219.
- Wright, H.T., Fanony, F., 1992. L' évolution des systèmes d'occupation des sols dans la vallée de la rivière Mananara au Nord-est de Madagascar, Allibert, C. (trans.). *Taloha* 11, 16–64.
- Wright, H.T., Andrianalvoarivony, R., Bailiff, I., Burney, D., Haas, H., Raharijaona, V., Rakotovololona, S., Rasamuel, D., Dewar, R., 1992. Datation absolue de sites archéologiques du centre de Madagascar: présentation des déterminations. *Taloha* 11, 121–146.
- Wright, H.T., Vérin, P., Ramilisonina, Burney, D., Burney, L.P., Matsumoto, K., 1996. The evolution of settlement systems in the Bay of Boeny and the Mahavavy River valley, north-western Madagascar. *Azania* 32, 37–73.