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Prehistoric extinction of birds on Mangaia, Cook Islands, Polynesia

(Oceania/biogeography/archaeology/human impact)

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ABSTRACT **Mangaia (Cook Islands) consists of a weathered volcanic interior encircled by limestones known as the makatea. Excavations at Tangatatau Rockshelter (site MAN-44), located on the inner cliff of the makatea, produced a stratified sequence of Polynesian artifacts and faunal remains ranging from A.D. 1000–1100 to A.D. 1500–1600. Resident species of birds represented at MAN-44 include nine seabirds (at least three extirpated on Mangaia) and 12 land birds (eight extirpated or extinct). Seven of the extinct/extirpated land birds are confined to the site's four lowest stratigraphic zones, which represent the first 200–300 yr of human occupation at MAN-44. During this time, human exploitation of vertebrates switched from primarily native land birds to almost exclusively small reef fish, domesticates (chickens, pigs), and commensals (rats). Sediment cores from a lake 0.9 km from MAN-44 show clear palynological and stratigraphic signals of human presence on Mangaia, especially forest clearance of the volcanic interior, beginning at 1600 yr B.P. The rugged makatea must have provided a forest refuge for birds during the first 700 yr of human presence, after which Mangaians exploited the previously little used makatea because forest resources (trees, other plants, birds) had been depleted on the now badly eroded volcanic interior. MAN-44 is the oldest archaeological site known on Mangaia. Whether other species of birds were lost in the period of human activity that preceded occupation of MAN-44 remains to be seen.**

The modern avifaunas of Polynesia are so depleted by human activities that they no longer represent natural patterns of distribution that existed before human arrival (1, 2). Bones from archaeological and paleontological sites are the primary source of data on the natural distribution of Polynesian birds. Collaborative research by zoologists and archaeologists can, therefore, yield significant data on biogeography and extinction of birds, as well as on the changing habits of resource exploitation among prehistoric Polynesians (3, 4).

Bones from Mangaia (Fig. 1) revealed nine species of birds not known there previously (2, 5, 6). All of the bones were surface finds in limestone caves lacking stratified sedimentary deposits. Field research on Mangaia in 1989 resulted in the discovery and excavation of a large rockshelter site (MAN-44). The stratified and dated faunal sequence from MAN-44 now allows us to estimate the chronology of avian extinction and to learn more about the role of prehistoric humans in the extinction process.

Mangaia: Environment and Modern Avifauna

Most southerly of the Cook Islands, Mangaia (157° 55′ E, 21° 55′ S; land area 52 km^2) is part of the Austral Islands volcanic lineament (7, 8). There are two main concentric geological zones: a central volcanic cone (maximum elevation, 169 m) of highly weathered basalts, dating to 17–19 Myr (8, 9), and a ring of elevated reefal limestone surrounding the volcanic interior. This limestone, called the makatea, is 1–2 km wide and 10–60 m above sea level. Dated to ≈110 kiloyears or thousand years (kyr) (10), the makatea is considerably weathered, with an inner escarpment created by solution at the contact with the interior radial stream drainage of the volcanic cone (11).

The modern vegetation patterns on Mangaia correspond to the concentric geological structure. The volcanic interior is covered in a degraded, pyrophytic association dominated by the fern *Dicranopteris linearis*, with scattered scrub *Pandanus tectorius* and *Casuarina equisitifolia*. Pollen cores taken in 1989 (described below) indicate that this association is of human origin, dating from ≈1.6 kyr. The valley bottoms below the volcanic slopes are intensively cultivated today by indigenous methods of pond-field irrigation (12). Forest occurs on Mangaia today only on parts of the makatea and is dominated by the indigenous trees *Elaeocarpus tonganus*, *Hernandia moerenhoutiana*, *Pandanus tectorius*, *Guettarda speciosa*, *Ficus prolixa*, and *Pipturus argenteus*, and the introduced *Aleurites moluccana* (13). Other parts of the makatea are either disturbed by agriculture or habitation or lack forest because of a virtual absence of soil on the pinnacled creviced karst terrain.

The resident (breeding) seabirds on Mangaia today are Audubon's shearwater (*Puffinus lherminieri*), red-tailed tropic bird (*Phaethon rubricauda*), white-tailed tropic bird (*Phaethon lepturus*), blue-gray noddy (*Procelsterna cerulea*), brown noddy (*Anous stolidus*), and common fairy tern (*Gygis alba*), of which only the last two occur in numbers >100. The five resident species of land or freshwater birds (for convenience, collectively called "land birds") are the Pacific reef heron (*Egretta sacra*), gray duck (*Anas superciliosa*), sooty crake (*Porzana tabuensis*), Mangaia kingfisher (*Halcyon mangaia*), and Cook Islands reed warbler (*Acrocephalus kerearako*). Current populations are <200 individuals for each of the first four species and 500–1000 individuals of the last species. The first three species are widespread in Oceania, whereas the last two are endemic to Mangaia at the species or subspecies level.

The MAN-44 Rockshelter Site

Site MAN-44 (local name: Tangatatau) covers 225 m^2 of habitable area at the base of the 25-m high makatea escarpment in Veitatei District (Fig. 1). We excavated a 1 × 5 m main trench through the central part of the shelter and a 1-m^2 test unit 20 m west of the main trench (Fig. 2). Our analyses herein are confined to the main trench.

The complex stratigraphy in the main trench comprises 36 discrete strata or features, extending to 1.5 m below surface (Fig. 2). We have combined these into 10 "analytic zones,"

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Abbreviation: kyr, 1000 yr.

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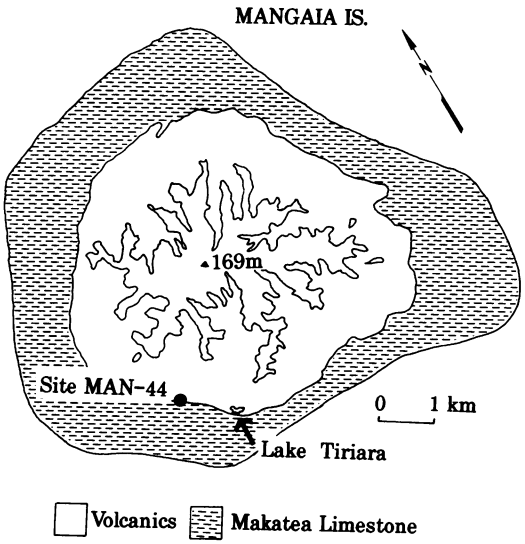

FIG. 1. Map of Mangaia island, showing the areas of volcanics and makatea limestone and the locations of Tangatatau Rockshelter (site MAN-44) and Lake Tiriara. The 100-m contour is depicted within the volcanic terrain.

defined on stratigraphic and artifactual criteria, independently of ^{14}C dates and faunal assemblages. The base (zone J) is a reddish-yellow silty clay derived primarily from weathered limestone; it lacks evidence of human use other than nonhuman bones. Zones I–G are gray-brown ashy midden deposits with much charcoal derived from Polynesian occupation. Zones F–B are a series of yellowish-red clay lenses intercalated with thin beds of shell midden, finely bedded charcoal and ash deposits, and oven or hearth features, representing intermittent periods of human use. The top of the section (zone A) is a reddish-brown ashy silt rich in charcoal and noncarbonized plant materials, with a few European-type artifacts.

Eleven ^{14}C dates from MAN-44 (Table 1) span the time interval of A.D. 1000–1100 to 1500–1600. MAN-44 is about the same age as the earliest sites elsewhere in the Cook Islands (17, 18). The artifact assemblage from MAN-44 indicates prehistoric Polynesian use as a habitation site throughout the period determined by the ^{14}C dates. Among

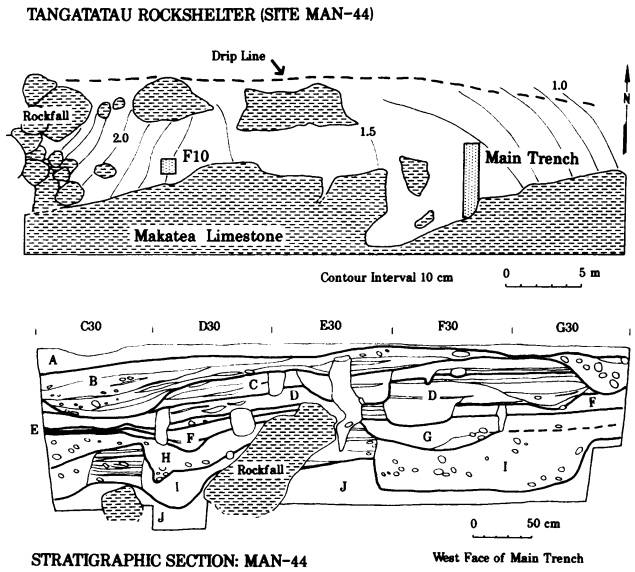

FIG. 2. Plan of site MAN-44 and stratigraphic section of the main trench, showing the analytic zones (A–J).

Table 1. Radiocarbon chronology of Tangatatau Rockshelter (MAN-44), Mangaia, Cook Islands

Lab no.	Analytic zone	Conventional age ± 1σ	Calendar date 1σ
Beta-32822	A	330 ± 80	A.D. 1446–1650
Beta-32823	C	450 ± 70	A.D. 1414–1480
Beta-32830	C	420 ± 70	A.D. 1425–1612
Beta-32821	E	200 ± 60*	A.D. 1647–1955*
Beta-32824	E	540 ± 80	A.D. 1311–1435
Beta-32825	G	900 ± 70	A.D. 1024–1216
Beta-32818	H	490 ± 50*	A.D. 1409–1440*
Beta-32817	I	230 ± 160*	A.D. 1450–1955*
Beta-32827	I	700 ± 80	A.D. 1259–1387
Beta-32816	J	550 ± 120	A.D. 1280–1440
Beta-32826	J	980 ± 70	A.D. 988–1155

All determinations are on wood charcoal, adjusted for $^{13}C/^{12}C$ ratios (14). The calendar dates are also calibrated for secular effects (15) and have probability estimates (16).
*Dates are later than expected on stratigraphic grounds; charcoal may be intrusive from higher in the section.

the significant artifacts are one-piece fishhooks of pearl shell and *Turbo* shell, adzes and adz flakes of basalt, coral and echinoid-spine abraders, and tattooing needles. The large numbers of basalt and chert cores and flakes are derived, in part, from the manufacture of adzes.

The Vertebrate Faunal Sequence at MAN-44

The vertebrate assemblage includes many bones with burns, cut marks, or breakage patterns indicative of butchering. Virtually all of the bones represent human food items. Like other islands in East Polynesia, Mangaia lacks indigenous predatory birds or mammals that might concentrate bones in caves or rockshelters. Fish make up 90.4% of the entire bone assemblage (Table 2), being >88% in all analytic zones except the oldest (zone J, where native land birds are common) and youngest (zones A and B, where rats and native seabirds are common). Nearly all of the fish bones are of small reef species, such as scarids, labrids, and acanthurids. Reptiles (sea turtles, lizards) are a minor component throughout the sequence.

Bones of the fruit bat *Pteropus tonganus* are most common in zones I and J (Table 2). This suggests that a previously little exploited population of fruit bats was available to the first occupants of MAN-44. On Mangaia today, fruit bats are restricted to a few roosts deep in the makatea forest. The Polynesian or Pacific rat (*Rattus exulans*) occurs commonly in all zones except J. These rats have become established on all islands colonized by Polynesians (19). Prehistoric Mangaians regularly ate rats (20, 21). The few human bones from MAN-44 occurred only late in the sequence, perhaps reflecting the overpopulation, warfare, human sacrifice, and cannibalism that characterized Mangaia's late prehistory (20, 22). No remains of domesticated animals occurred in zone J. Bones of pigs and chickens are most frequent in the middle zones. The absence of pig bones in zones A and B corroborates their reported absence on Mangaia in the late 18th century (20, 21). Dog bones were not recovered at MAN-44.

Some clear trends are evident in the bird-bone assemblage (Table 3). The absolute and relative number of bones from native birds (i.e., all species except chickens) is high in zones I and J, low in the middle zones, and high again in zones B and C. The species composition is different, however, between the early zones and the late zones. Native landbirds dominate zones I and J, whereas seabirds, especially *Pterodroma nigripennis*, account for the late (zones B and C) increase in exploitation of birds. This situation differs from early sites in the Marquesas, Tonga, and Tikopia, where

Table 2. Vertebrate faunal summary by analytic zones (A–J), main trench (squares C30–G30), Tangatatau Rockshelter (MAN-44), Mangaia, Cook Islands

	A	B	C	D	E	F	G	H	I	J	Total
Fish	51	667	973	937	2464	1206	875	735	1379	80	9367
Reptiles											
Sea turtle	1			1							2
Lizard		1					1		3		5
Birds											
All native species	7	27	22	4	7	1	9	13	49	47	186
Gallus gallus (chicken)	1		2	3	13	3	6		3		31
Mammals											
Pteropus tonganus (fruit bat)							1	2	15	13	31
Rattus exulans (Pacific rat)	19	125	83	50	39	14	61	34	40	1	466
Sus scrofa (pig)			3	10	13	2	1	1	1		31
Delphinidae sp. (porpoise)							1				1
Homo sapiens (human)	1	1									2
Unidentifiable bird	5	27	20	10	23	4	11	13	36	52	201
Unidentifiable mammal		2		2	4	2	1				11
Unidentifiable bone (not fish)		5	3		12	2		4	11		37
Totals											
All species	85	855	1106	1017	2575	1234	967	803	1535	191	10,366
All nonfish	34	188	133	80	111	28	92	67	158	113	1,004
Nonfish, %	40.0	22.0	12.0	7.9	4.3	2.3	9.5	8.4	10.3	59.2	9.6
Fish, %	60.0	78.0	88.0	92.1	95.7	97.7	90.5	91.6	89.6	41.9	90.4

seabird as well as land-bird bones are abundant only or mainly in older cultural strata (2–4, 23).

Except for *Ptilinopus rarotongensis*, which still lives on Rarotonga and Atiu, each of the eight extinct or extirpated species of land birds is confined to zones G–J. Based on absolute numbers of bones, predation on native land birds was most intense in zones I and J and tapers to practically nil by zone G. Based on relative abundance of bones (% of all vertebrates, Table 3), predation on native land birds was extremely intense only in zone J. Most species survive into zones I, H, or G, but only in greatly reduced numbers.

Extinction of Birds

While they may be less affected than land birds by moderate levels of forest clearing, most seabirds are vulnerable to nest predation by rats. Although the precipitous, creviced makatea cliff has provided relatively rat-free nesting grounds for many seabirds, at least three species (*Pterodroma nigripennis*, *Nesofregetta fuliginosa*, and *Gygis microrhyncha*) have been extirpated. The eight species of extinct or extirpated land birds from MAN-44 consist of rails, pigeons, doves, and parrots. Direct predation and forest clearance account for their loss on Mangaia and elsewhere in Polynesia (2). Both of Mangaia's extinct rails were flightless. Obligatory foraging and nesting on the ground undoubtedly facilitated their predation by humans and rats (6). Pigeons, doves, and parrots are forest birds favored as food by Polynesians, who hunted them historically with snares, slings, bird lime, and by hand. Most of these birds forage in middle or upper levels of the forest, although the two species of ground doves presumably foraged on or near the forest floor. Parrots and, to some extent, pigeons and doves were sought for brightly colored feathers as well as for food.

Of the five species of land birds from MAN-44 that survive on Mangaia (Table 3), the duck, crake, and migrant plover do not inhabit forests, while the kingfisher and warbler occur in forest patches of varying size, disturbance, and maturity. Their lack of dependency upon large tracts of undisturbed forest partly explains why the kingfisher and warbler have survived on Mangaia. In addition, these two species are not prized as food by modern (and presumably the prehistoric) Mangaians, who would prefer to take seabirds, shorebirds, ducks, or fruit bats.

The fauna of MAN-44 can be interpreted stratigraphically, chronologically, and culturally. Zone J is naturally deposited sediment underlying the lowest unequivocal cultural strata (zone I). Bones probably were deposited within zone J through bioturbation by Polynesians during formation of zone I. The scarcity or absence of bones of fish, chickens, pigs, and rats in zone J would suggest that the very first people to inhabit the site found and preferred a variety of tame birds abundantly available in the makatea forests. Obtaining these birds, which had evolved in the absence of mammalian predators, may have resembled our concept of gathering more than hunting (2, 3).

In the absence of other evidence, the MAN-44 faunal sequence might suggest that zone J represents the human colonization of Mangaia. This, however, does not seem to be the case. J. R. Flenley extracted three sediment cores in 1989 from Lake Tiriara, 0.9 km from MAN-44. Eight ^{14}C dates show that these cores represent 6.8 kyr of sediment influx. The pollen spectra (24), stratigraphy (25), and ^{14}C chronology reveal clear signals of human arrival on Mangaia at 1.6 kyr B.P., which is ≈600–700 yr before the earliest occupation of MAN-44. These signals are major increases in relative and absolute pollen or spore counts of coconut (*Cocos nucifera*), ferns, grasses, and sedges, with coeval decreases in pollen of indigenous forest trees, including the loss of *Weinmannia* (Cunoniaceae) and *Coprosma* (Rubiaceae). These changes were accompanied by decreases in the organic component of the sediment and increases in extractable Fe, resulting from exposure and erosion of the laterized volcanic slopes. Thus MAN-44, at the edge of the makatea, was first occupied only after the forests of Mangaia's interior had been cleared and the volcanic soils eroded.

Two future considerations, however, might reduce the apparent 600- to 700-year gap between the initial human impact at MAN-44 and Lake Tiriara. (*i*) ^{14}C dates on bones from zone J might prove older than the dates on charcoal. (*ii*) Inwash of soil carbon into Lake Tiriara may have resulted in ^{14}C dates that are too old, as has occurred on Easter Island (26).

For now, we hypothesize that the makatea forests experienced relatively little human impact during Mangaia's first centuries of human occupation. Several factors may be involved in the greater human impact on the volcanic interior versus the makatea. (*i*) The initial human population of

Table 3. Summary of birds by analytic zones (A–J), main trench (squares C30–G30), Tangatatau Rockshelter (MAN-44), Mangaia, Cook Islands

	Zones										
	A	B	C	D	E	F	G	H	I	J	Total
Seabirds											
Puffinus lherminieri (Audubon's shearwater)		1	2								3
*Pterodroma nigripennis** (black-winged petrel)	3	17	14	2	1						37
Procellariidae sp. (petrel/shearwater)					1						1
*Nesofregetta fuliginosa** (Polynesian storm petrel)	1				1						2
Phaethon lepturus (white-tailed tropic bird)		1	1				1		1	1	5
Fregata ariel (lesser frigate bird)		2	3	2							7
Anous stolidus (brown noddy)	1		2			1					4
Procelsterna cerulea (blue-gray noddy)									1		1
Gygis alba (common fairy tern)					1			1	3	1	6
*Gygis microrhyncha** (lesser fairy tern)									1		1
Landbirds											
Anas superciliosa (gray duck)	1	5			3						9
Pluvialis dominica (M) (lesser golden plover)									1		1
Gallus gallus (I) (chicken)	1		2	3	13	3	6		3		31
Gallirallus ripleyi† (Ripley's rail)							2	3	7	6	18
Porzana tabuensis (sooty crake)							1				1
Porzana rua† (Mangaian crake)								2	13	11	26
*Gallicolumba erythroptera** (Society Island ground dove)									4	3	7
Gallicolumba nui† (giant ground dove)										1	1
*Ptilinopus rarotongensis** (Cook Islands fruit dove)		1							1	1	3
*Ducula galeata** (Nuku Hiva pigeon)							1		1	2	4
*Vini kuhlii** (Rimatara lorikeet)							2	3	5	10	20
Vini vidivici† (conquered lorikeet)							2	3	5	9	19
Vini kuhlii/vidivici† (Rimatara/conquered lorikeet)								1	4	2	7
Halcyon mangaia (Mangaia kingfisher)	1										1
Acrocephalus kerearako (Mangaia reed warbler)									2		2
Totals											
All species	8	27	24	7	20	4	15	13	52	47	217
All native species	7	27	22	4	7	1	9	13	49	47	186
Seabirds	5	21	22	4	4	1	1	1	6	2	67
Native land birds	2	6			3		8	12	43	45	119
Extinct/extirpated land birds		1					7	12	40	45	105
Extinct/extirpated land birds, % of all vertebrates		0.1					0.7	1.5	2.5	24	
Extinct/extirpated land birds, % of all nonfish		0.5					8	18	24	41	
Extinct/extirpated land birds, % of all birds		4					47	86	77	98	

I, introduced species; M, migrant species.
*Extant species extirpated on Mangaia.
†Extinct species.

Mangaia probably was small (<50 persons) and would have required a significant, although unknown, time to build up to >1000 persons. [The population at European contact was 2000–3000 persons (22).] (*ii*) Following the pattern seen virtually throughout Polynesia (27), the initial inhabitants of Mangaia probably lived along the coast, where access to marine resources was greatest. (*iii*) Most soils on the makatea are poorly suited for agriculture, so the early Mangaians probably wasted little time in using the richer, deeper soils of the volcanic interior for shifting cultivation of root crops, such as taro, yams, and sweet potatoes. This may have warranted the establishment of settlements in the volcanic interior, which was connected to the coast by well developed trails across an otherwise little-used makatea.

If MAN-44 represented the first human arrival on Mangaia, then a "blitzkreig"-type of extinction/extirpation (28) for Mangaian land birds would be suggested by the great relative abundance of land-bird bones in zone J, which tapers off to near-total depletion during zone G. However, the evidence from MAN-44 and the Lake Tiriara sediment cores suggests that depletion of Mangaia's land birds involved two primary phases of human impact: (*i*) the destruction of forests in the volcanic interior beginning at 1600 yr B.P. and (*ii*) the intensification of hunting and habitation in and at the edge of the makatea, beginning at 850–950 yr B.P. Because the indigenous forest still growing on the rugged makatea probably has existed through most of prehistory, predation by humans and rats may have been more important than forest clearing in the second phase of land-bird depletion on Mangaia. This may be the case on other Polynesian islands dominated by makatea limestone, such as Henderson Island (29), where forest clearance for agriculture was impractical, and predation alone might account for prehistoric losses of birds.

Mangaia's complex geology prevented the prehistoric forest clearance from being as complete and socioeconomically devastating as, for example, on Easter Island (26, 27), where no indigenous land bird has ever been recorded. The loss of species on Mangaia included at least 62% (8 of 13) of the land birds and at least 33% (3 of 9) of the seabirds present at human arrival. The situation is actually worse than one might deduce solely from the presence or absence of species because some of the birds still alive on Mangaia, such as Audubon's shearwater and blue-gray noddy, are in great danger of extirpation.

Our Mangaian research reinforces the need for intensive interdisciplinary approaches to studying the archaeology, paleoecology, and biogeography of Polynesia. On small is-

lands, human impact on forests and native birds may have been relatively swift and absolute, as attested, perhaps, by the current lack of land birds on most Polynesian atolls. Rugged terrain, such as the makatea on Mangaia or the steep, knife-edge mountains of Marquesas or Hawaii, would have slowed the destruction of forests and birds. Analyses of the chronology and severity of extinction should consider that patterns of settlement and resource exploitation often change through time and may not be distributed uniformly over an island.

From a broad biogeographic perspective, the prehistoric land-bird fauna of Mangaia was similar to that of other East Polynesian islands in having one or two species each of *Porzana*, *Gallirallus*, *Ducula*, *Ptilinopus*, *Gallicolumba*, *Vini*, *Halcyon*, and *Acrocephalus*. Genera of East Polynesian land birds not found in the relatively rich prehistoric bone record of Mangaia include *Ardeola* (= *Butorides*), *Dendrocygna*, *Porphyrio*, *Prosobonia*, *Macropygia*, *Cyanoramphus*, *Collocalia*, *Hirundo*, *Pomarea*, *Myiagra*, and *Aplonis*. To learn which of these "missing" genera once occurred on Mangaia awaits the discovery of bird bones from the first centuries of human occupation, a crucial interval of time sampled thus far only in sediment cores.

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