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Causes of the demise of a breeding population of *titi* on Mangaia, Cook Islands

DAVID G. MEDWAY
25a Norman Street, New Plymouth, New Zealand
dmedway@voyager.co.nz

Abstract A species of small procellariid known locally as *titi,* probably the black-winged petrel (*Pterodroma nigripennis*), nested into the historic period in burrows in the volcanic soil of the uplands of Mangaia in the southern Cook group. The demise of this *titi* as a breeding bird on Mangaia was probably caused by a combination of the detrimental effects of human harvesting and various introduced mammalian predators which were present on Mangaia after the arrival of missionaries in the early nineteenth century.

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INTRODUCTION

The island of Mangaia (21°55'S, 157°55'W) is the southernmost and 2nd largest (5180 ha) of the Cook Islands. It consists of 2 main concentric geological zones: a central volcanic cone with a maximum elevation of 169 m, and a ring of elevated coral limestone 1-2 km wide and 10-60 m a.s.l. known as the makatea. The geology of Mangaia has been dealt with by Marshall (1927) and Wood & Hay (1970), and the soils by Webb (1981). The native vegetation on the volcanic interior has been altered greatly through human interference, but the plant life of the makatea zone is still dominated by native species (Merlin 1991). No ornithological research was carried out on Mangaia until Holyoak spent a day there in 1973 (Holyoak 1974).

Mangaia was first sighted by Europeans on 29 March 1777 during Cook's 3rd voyage, but nobody from the ships landed (Beaglehole 1967). Recent investigations have shown that Mangaia may have been inhabited for much longer than was previously thought. Excavations in 1989 at the Tangatatau rock shelter, located on the inner cliff of the makatea, produced a stratified sequence of Polynesian artifacts and faunal remains ranging from about AD 1000-1100 to about AD 1500-1600 (Steadman & Kirch 1990). However, those authors contend that sediment cores from a lake a short distance away reveal clear signals of human presence on Mangaia beginning at about AD 350. Ellison (1994) considers that pollen analyses and charcoal concentrations indicate that humans were present on Mangaia as early as 550 BC. However, Anderson (1995) believes that, at present, the palynological and sedimentological evidence does not support the presence of human settlement on Mangaia at that early time. Nevertheless, there seems to be little doubt that Polynesians were permanently inhabiting Mangaia by at least 1000 years ago.

There is no way of knowing the size of the human population of Mangaia during any period of its prehistory. However, when the missionaries Williams and Barff (Barff 1830: 12) were at Mangaia in May 1830, they considered, from the number of people they saw and the account given to them by the native teachers, that the population of the island was about 2000. Williams (1837: 19) later thought the population was between 2000 and 3000. It does not appear to have varied much during subsequent decades because missionary W. Wyatt Gill (1894: 6) gave it as 2000 toward the end of the nineteenth century.

The *titi* of Mangaia

Steadman & Kirch (1990) found that, of the species of birds represented by bones recovered at the Tangatatau rock shelter, 9 were seabirds of which at least 3 had been extirpated on Mangaia. The identified procellariid bones represent only 3 species - Audubon's shearwater (*Puffinus*

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lherminieri), black-winged petrel (*Pterodroma nigripennis)*, and white-throated storm petrel (*Nesofregetta fuliginosa*). Kirch *et al.* (1992) indicated that the upper deposits at the site represented a phase of concentrated predation on nesting populations of seabirds. Steadman & Kirch (1990) found that seabirds, especially the black-winged petrel, account for a late increase in human exploitation of birds on Mangaia. They said that this situation differs from early sites in the Marquesas, Tonga, and Tikopia, where seabird as well as land-bird bones are abundant only - or mainly - in older cultural strata. Steadman (1997) considered a contributing factor on Mangaia may have been its precipitous, creviced limestone cliffs which provided an extensive, albeit narrow, band of relatively rat-free nesting habitat for seabirds.

W. Wyatt Gill (1880: 7-12; 1894: 24-31) recorded the Mangaian legend of Uriitepitokura and Temoaakaui who apparently lived on Mangaia in the late prehistoric period. Those persons purportedly lived for some 4 years in exile in the makatea of the Tavaenga district, during which time they never once ventured into the interior of the island. Gill recorded that:

> "Amongst the rocks of that part of the island there was at that time abundance of beautiful birds ... several sorts of sea-roving birds, who incubate in the stones and hollow trees of that part of the island ...The bird most easily caught by Uriitepitokura and Temoaakaui was the *titi* (so called from its cry). In the month of December it leaves its burrowings in the red mountain soil, and comes to the rocks near the sea to fatten its young on small fish. By day it hides in holes, and sleeps. The hunter has only to call at the entrance to the dark cave, in a plaintive tone, *E titi e*, when the foolish bird, imagining it to be the voice of its mate, comes out of its secure hiding-place, and, dazzled by the unwelcome light, allows itself to be caught by the hand. In size and colour it closely resembles the dove, but the breast is of a light yellow ."

When writing about the language of the South Sea islanders generally, W. Wyatt Gill (1876a: 33-34) said that:

> "In many of these islands there is a pretty bird named from its cry Titi. Its flesh is regarded by the natives as a delicacy. The Titi burrows its nest in the mountain side. During the period of incubation it is easily caught by the hand, or by plaintively imitating its cry. Accordingly, in the Tahitian dialect, a slave or conquered person is called a Titi, because the conquered took refuge in the mountains, where they were easily captured and slain."

Further details of the nesting of the *titi* were given by W. Wyatt Gill (1876a: 135-136) when he considered the reminiscences of native preachers. He referred in his account to Mamae, a native pastor and evangelist on Mangaia, who died in 1889 (W. Wyatt Gill 1876a: 114–116):

> "*The "Titi" bird.* - A small sea-bird, named from its note, the *titi*, at the beginning of the dry season seeks the land for the purpose of incubation. The beak and feet of this bird are so strong that it burrows a hole for itself in the red clay of the mountain-side. These holes sometimes extend a yard, frequently intersecting each other. At a safe distance the narrow gallery is enlarged into a round chamber, where the eggs are laid and hatched. The same hole is used for more than one season. When the young are sufficiently strong they are led by the parent birds to the rocks near the sea, where they are nourished with fish until able to roam the ocean on their own account.
>
> "Referring to the period when the *titi* occupies the rocks and caves near the shore, Mamae said:
>
> " "We are all familiar with the *titi.* By day it loves to hide in dark holes and caverns; but if any one approaches its hiding-place and plaintively calls 'E titi e! E manu e!' (O titi! O bird!), it will at once indicate its exact hiding-place by answering, 'Titi, titi.' Only repeat your call two or three times, and it will come out of its dark hole, and, its eyes being dazzled by the light of day, it is easily caught by the hand." "

These various accounts as recorded by W. Wyatt Gill confirm that at least 1 species of small procellariid known locally as *titi* nested on Mangaia into the historic period. However, no known procellariid lays its egg in 1 place and takes its young elsewhere on land for part of the period in which it is being raised. Therefore, it would appear that the accounts of the *titi* as recorded by W. Wyatt Gill actually confuse at least 2 different species of procellariid, 1 that nested in burrows in the volcanic soil of the uplands, and another that nested in the makatea. Indeed, Christian (1920) in his list of Mangaia birds gives *titi* as the name of a bird living in the rocks and crags which was much relished for food, whereas Steadman (1985) records that Mangaians told him the *titi* is a seabird which formerly nested in large numbers in burrows in the soft soil of Mangaia's volcanic uplands. These separate accounts of W. Wyatt Gill, Christian, and Steadman, based as they are on information given to each of them by different people at various times over the course of more than a century, together may confirm the former presence of at least 2 distinct procellariid species having the same name - *titi* - but nesting in different habitats on Mangaia.

Bones referable to a few individuals of Audubon's shearwater were found in 2 of the most recent analytic zones of the Tangatatau site (Steadman & Kirch 1990; Steadman 1997). In April 1984, Steadman (1985) was shown a fledgling belonging to the *Puffinus lherminieri/ assimilis* group which had been collected from a crevice in the inner cliff of the makatea.

Audubon's shearwater breeds on tropical islands, raised coral atolls, and rocky islets. It nests in burrows in soft soil or in cavities in rocky sites, including coralline

limestone, inland and coastal cliffs, and boulder falls (Marchant & Higgins 1990). The makatea of Mangaia would seem to provide ideal nesting habitat. There is a breeding population of Audubon's shearwaters, estimated at 3000-5000 pairs, on volcanic Reunion Island (Bretagnolle *et al.* 2000) which is at the same latitude in the tropical Indian Ocean as Mangaia is in the tropical Pacific. Although Audubon's shearwaters seem to breed all year round on Reunion, they appear to be mainly summer breeders on that island. Most fledgling recoveries reported in the literature were between December and April, with the bulk of fledging between December and February (Bretagnolle *et al.* 2000). This coincides with the time of year recorded by W. Wyatt Gill when the young of the *titi* on Mangaia were sufficiently strong to be led by their parents from their burrows in the red mountain soil to the rocks near the sea. The *titi* that W. Wyatt Gill recorded were to be found from December onwards occupying the rocks and caves near the shore of Mangaia may therefore have been young Audubon's shearwaters. This view is supported by Steadman's (1985) record of a fledgling of the *Puffinus lherminieri/assimilis* group in the makatea in April.

W. Wyatt Gill (1880: 28) gave the dry season on Mangaia as being from July to December which agrees with the dry season given by Webb (1981). The *titi* which Gill said sought the land at the beginning of the dry season on Mangaia for the purpose of incubation may have been Audubon's shearwater. The presence of young Audubon's shearwaters in the makatea of Mangaia from about December would fit in with the return of the first breeding birds of the species to the nesting grounds on the island from about July.

Mangaians who saw the fledgling of the *Puffinus lherminieri/assimilis* group shown to Steadman in 1984 called it *rakoa* (Steadman 1985). The different name given this bird does not necessarily mean it was a different species to the one that nested in the makatea called *titi* by earlier Mangaian informants of W. Wyatt Gill and Christian. Their different informants, at different times, could have known the same species by different names. Even today, the New Zealand pigeon (*Hemiphaga novaeseelandiae*) is known by the various Maori names of *kukupa* in the northern North Island, *kereru* elsewhere on the main islands, and *parea* on the Chatham Islands (Heather & Robertson 2000).

The specific identity of the *titi* which nested into the historic period in the Mangaia makatea will probably never be known with certainty. Nevertheless, available evidence suggests that it was Audubon's shearwater.

There can be no reasonable doubt that a small procellariid known locally as *titi* also nested into the historic period in burrows in the volcanic soil of the uplands of Mangaia. Steadman (1985) was advised by Mangaians that this *titi* was similar, or identical, to the New Zealand 'muttonbird'. Steadman initially considered that the Mangaian bird was likely to be a species of *Puffinus*, perhaps the wedge-tailed shearwater (*Puffinus pacificus*), or the Christmas shearwater (*Puffinus nativitatis*). However, no bones or other evidence confirming the presence of either taxon on Mangaia at any time have apparently ever been found. Later, Steadman (1997) thought this *titi* was probably an undetermined species of shearwater (*Puffinus* sp.) that may no longer exist on the island. However, the Polynesian name *titi* is not restricted to members of the genus *Puffinus*. For instance, on Rapa it is the black-winged petrel (Holyoake & Thibault 1984), and in earlier times it was the Maori name for the similar Cook's petrel (*Pterodroma cookii*). Furthermore, Cook's petrels were among the New Zealand 'muttonbirds' formerly collected in large numbers by Maori for food (Oliver 1955).

The black-winged petrel was by far the most abundant seabird represented by bones found at the Tangatatau site in 1989. Evidence from archaeological sites on two widely-separated islands in the South Pacific - Mangaia (Steadman & Kirch 1990) and Henderson (Wragg 1995) - indicates that, over recent centuries, the breeding range of this species has contracted significantly, no doubt as a result of human-induced habitat alteration, human exploitation, and mammalian predation. However, the black-winged petrel now appears to be making something of a comeback, by either re-occupying former breeding grounds, or expanding its former breeding range as appears to be the case, e.g., at Norfolk Island (Holdaway & Anderson in press), in northern New Zealand (Pierce & Parrish 1993), and at the Chatham Islands (Tennyson 1991).

Black-winged petrels breed in the southwest Pacific, mostly on subtropical and tropical islands and islets. They nest in summer in dense colonies in burrows up to 1 m long, in rock crevices on vegetated coastal slopes or in rugged terrain inland, or under scrubs, tussocks or grassy mats. Black-winged petrels arrive at their Kermadec breeding grounds from mid October, eggs are laid in late December and the first half of January, and young fledge in late April and May. Black-winged petrels undertake a pre-laying exodus during December (Marchant & Higgins 1990). It may have been the departure of Mangaian *titi* on a pre-laying exodus in December which gave the impression, as recorded by W. Wyatt Gill, that those birds left their burrowings in the red mountain soil at that time.

The specific identity of the *titi* which nested into the historic period in burrows on the volcanic hills of Mangaia will probably never be known with certainty. Nevertheless, available evidence suggests that it was the black-winged petrel which appears to be the only extant procellariid which has the characteristics attributed to it. The Tangatatau record confirms that the black-winged petrel must have nested in some numbers on Mangaia in the past, but it is not known to nest there now. This paper is primarily concerned with the factors which might have contributed to the demise of this *titi* as a breeding bird on Mangaia.

Polynesian rat (*Rattus exulans*)
Missionary William Gill (1871: 80) believed that the people of Mangaia "in their heathenism" knew no animal larger than a rat. W. Wyatt Gill (1876a: 316-317; 1880: 84) said that rats were very plentiful before cats were introduced, and were the only quadruped on the island. Williams (1837: 246-247) also observed that rats were the only animals on Mangaia until he visited it. He noted that the Polynesian rat was a common and relished item of food of the Mangaians, who had no difficulty in catching them in great numbers.

The Polynesian rat was still present on Mangaia in 1992 (Rowe 1993; Rowe & Empson 1996). It has probably been on the island since human habitation first began. Steadman & Kirch (1990), Steadman (1997), and Kirch (1997) indicated its continuous presence from the earliest analytic zone of the Tangatatau sequence. It is not known what effect over time the introduction of that species of rat to Mangaia might have had on the breeding viability of any populations of procellariids which nested there. Nevertheless, it now appears that predation by the Polynesian rat is almost certainly detrimental in the long-term to the breeding viability of those populations of most species of small and medium-sized procellariid which nest on islands where that rat is present (e.g., Brooke 1995; Booth *et al.* 1996; Holdaway 1999). Indeed, a survey of the literature suggests that the Polynesian rat is perhaps the most underestimated factor in the extinctions that have befallen islands throughout the Pacific (Holdaway 1999).

European rats (*Rattus rattus* and *R. norvegicus*)
W. Wyatt Gill (1876a: 316) noted that in 1852 a solitary male Norway rat (*R. norvegicus*) made it to shore at Mangaia from the wreck of an American whaler. It would be surprising if this 1 rat was the only individual of the species which did so, but the Norway rat apparently did not become established on Mangaia. Only specimens of the ship rat (*R. rattus*) were available from the island in 1963 for examination by Alicata & McCarthy (1964). Rowe (1993), and Rowe & Empson (1996), recorded the ship rat, the Polynesian rat, and the house mouse (*Mus musculus*) on the island in 1992.

The ship rat is known to be detrimental to the breeding success of procellariids. For example, Tomkins (1985) found that ship rats were responsible for most losses of eggs and chicks at colonies of the dark- rumped petrel (*Pterodroma phaeopygia*) on 4 islands in the Galapagos. Rats investigated all holes and cracks in a colony, and if a sound egg was unattended, or a chick was too small to defend itself successfully, they ate it. Harris (1970) observed that on Santa Cruz, eggs of this petrel were eaten by ship rats if they were not protected by adults.

Dogs (*Canis familiaris*)
Dog bones were not recovered at the Tangatatau site (Steadman & Kirch 1990). W. Wyatt Gill (1876a: 318) said that the dog was unknown in the Hervey group (the former name for the Cook Islands) until 1 was obtained from Cook's *Resolution* in 1777. This was the dog given to the natives at Atiu on 3 April 1777 in exchange for a hog (Beaglehole 1967). Atiu is about 185 km north of Mangaia. A century later, W. Wyatt Gill (1876a: 318) was able to say that the islands of the Hervey group were overrun with 'curs'.

Dogs are known to predate nesting procellariids. Harris (1970) considered that even tame dogs can inflict heavy losses on nesting dark- rumped petrels. Tomkins (1985) suspected that dogs, probably from nearby farms, were relatively infrequent visitors to the colonies of that petrel on Santa Cruz. Nevertheless, in 1978 and 1979 in 1 sub-colony, dogs dug up a large percentage of burrows in which eggs had been laid and killed many adults. They dug mostly adult petrels out of burrows and killed them, but they also caught adults walking to or from their burrows, or while courting on the surface.

Cats (*Felis catus*)
William Gill (1856: II: 164-166) recorded that 2 cats had been introduced to Mangaia in 1842. He was informed that cats very soon plagued the island. They lived in the hills and bush, increased rapidly, were ferocious, and destroyed nearly all the poultry. Gill said that cats were very plentiful on Mangaia, presumably when he was there in 1845.

W. Wyatt Gill (1880: 84, 162) recorded that Polynesian rats had been very plentiful on Mangaia before cats were introduced, and that guns and wild cats had effectively reduced the numerous birds on the island, some species having become entirely extinct. Feral cats were still present in 1992 (Rowe 1993; Rowe & Empson 1996).

Cats have been a major factor in the reduction or extermination of breeding populations of small and medium-sized procellariids. For example, cats on Raoul Island fed to a large extent on black-winged petrels and wedge-tailed shearwaters as they came ashore to nest, and cats undoubtedly played a major role in exterminating the island's vast Kermadec petrel (*Pterodroma neglecta*) breeding population (Merton 1970). Cats on Little Barrier Island preyed heavily on adult and young Cook's petrels, and predation by them was the main cause of breeding failure of black petrels (*Procellaria parkinsoni*) on the island (Imber 1973, 1987). Cats on Herekopare Island fed mainly on petrels, and a vast population of diving petrels (*Pelecanoides urinatrix*) which bred on that island was probably exterminated by them (Fitzgerald & Veitch 1985).

Pigs (*Sus scrofa*)
Only a few pig bones were found in the earliest analytic zones of the Tangatatau sequence. They were most frequent in the middle zones, but absent in the most recent zones which appear to date from about AD 1400-1600 (Steadman & Kirch 1990; Steadman 1997). Kirch (1997) noted that pigs appear to have increased in

importance as a food item for humans during the middle part of the Tangatatau sequence, and that their later disappearance from the record accorded with ethnohistoric evidence that pigs were not present on Mangaia at the time of first European contact with the island.

It is not known why pigs died out on Mangaia (see Kirch (1997) for a possible cause), but they had probably been absent for some time, perhaps centuries, before the arrival of Europeans. Their absence at that time is confirmed by the missionaries William Gill (1871: 80), W. Wyatt Gill (1880: 84), and John Williams (1837: 246) who separately recorded that the Polynesian rat was, variously, either the largest animal, or the only quadruped, or the only animal, on Mangaia at the time of the missionaries' first contact with the island. More specifically, W. Wyatt Gill (1876a: 15) also observed that

> "It is a singular circumstance that whilst pigs were found on Atiu and Rarotonga at the time of their discovery, on the neighbouring islands of Aitutaki and Mangaia the largest quadruped existing at that time was the rat. Yet at Mangaia there was a rocky district known as "Pig-sty" (*pa puaka*); another rugged spot was called "Grunting-pig" (*puaka ngunguru*), showing that at one time they had at least a tradition of pigs."

W. Wyatt Gill (1880: Introductory remarks) recorded that, during his long residence on Mangaia, he had enjoyed great facilities for studying the natives themselves and their traditions. He has provided an invaluable and comprehensive record of Mangaian traditions covering a few hundred years before the advent of the missionaries. Many of those traditions undoubtedly, as Gill said, relate veritable history. It is of particular significance in the present context that pigs do not appear to be mentioned in any of them. It is reasonable to assume that someone would have referred to those animals had they been present during the time period involved. Therefore, the ethnological evidence supports the archaeological evidence from the Tangatatau site in this regard.

The missionaries Williams and Bourne landed 2 pigs at Mangaia on 13 July 1823. Williams (1837: 80) recorded that pigs were animals the inhabitants had never seen before. When he visited Mangaia in June 1830, Williams (1837: 241-248) recommended that the inhabitants take great care of the pigs and goats which had been brought to the island so that they would quickly gain an abundant supply of meat far superior to Polynesian rats. During that visit, enough pigs were roasted whole to serve at a feast for 400-500 persons. A large feast on Mangaia in 1841 included pigs (William Gill 1871: 70), and 1000 pigs were killed and eaten during the annual May festivities in 1852 (W. Wyatt Gill 1876b: 135). Apparently, the number of pigs on the island was considerably reduced, at least for a time, by cyclones in 1866, 1867 and 1869 (W. Wyatt Gill 1876b: 135; 1894: 341). Domestic pigs, both free-ranging and tethered, were present on Mangaia in 1992 (Rowe 1993; Rowe & Empson 1996).

Pigs and petrels

Pigs are detrimental to nesting procellariids. Rhodes (in Straubel 1954) found abundant nesting procellariids at Macauley Island in the Kermadec group when he visited it on 20 December 1836. His boats returned from the island with various items, including 2 pigs which could not be eaten because of their fishy flavour. Rhodes attributed the taste to the pigs subsisting on the flesh of aquatic birds. On 1 November 1795, King (1788–1799: 305) stated that no opportunity was lost in getting male pigs from Phillip Island (near Norfolk Island) where large numbers of procellariids nested at the time, but their flesh was tainted by the birds and other things they fed on. The pigs were fed on maize for at least 4 months before being killed.

Harris (1970) considered that pigs were probably the greatest threat to the dark-rumped petrel on Santa Cruz because they ate both adults and young and destroyed burrows. Pigs were introduced onto Santa Cruz about 1927, and by 1935 were abundant in many areas. At that time the settlers relied heavily on pigs for meat, but during the petrel breeding season the fat of the pigs was so tainted by the smell and taste of petrels as to be almost unusable (Harris 1970). Coulter (1984) recorded that in 1982 a pig which had been feeding almost exclusively on dark-rumped petrels was shot on Floreana Island, also in the Galapagos. Shortly before they were eradicated from Lord Howe Island in 1981, analyses of the contents of pig stomachs revealed that they were eating Providence petrel (*Pterodroma solandri*) chicks in some areas (Hutton 1991). Feral cats and pigs continue to kill large numbers of antarctic prions (*Pachyptila desolata*) on Auckland Island (Taylor 2000). Pigs were purposely released on New Island in the Falklands to root out incubating and young thin-billed prions (*Pachyptila belcheri*), and evidence of the losses caused by them was to be found over much of the island (Strange 1980).

Moors & Atkinson (1984) considered that evidence for pigs causing declines in particular seabird populations is largely circumstantial. However, breeding populations of procellariids can increase spectacularly after pigs are eradicated, as is well illustrated by the recovery of Buller's shearwaters *(Puffinus bulleri)* on Aorangi Island in the Poor Knights group off north-eastern New Zealand (Harper 1983).

Petrels, pigs, and people on Mangaia

The black-winged petrel can be a successful coloniser, particularly in the absence of mammalian predators and feral ungulates. For example, the numbers breeding on Macauley Island apparently increased significantly after goats were eradicated in 1966. An estimated 2-3 million pairs now nest on the island (Taylor 2000). The black-winged petrel was first seen at Great Island of the Three

Kings group in northern New Zealand in 1945 (Turbott & Buddle 1948); goats were eradicated from that island in 1946 (Turbott 1948); the first evidence of breeding on the island was found in 1951 (Turbott 1951); and by 1976 the Three Kings group had become an important breeding station for the species (Bartle, in Jenkins & Cheshire 1982). An estimated 800-1000 pairs were breeding on Motuopao Island in Northland in February 1990 (Pierce & Parrish 1993) after Polynesian rats had been eradicated from that island in 1989 (Parrish & Anderson 1999). The black-winged petrel has also recently colonised Portland Island in Hawke Bay (Eagle 1980). Further south, black-winged petrels were first noticed on Mangere Island in the Chatham group in the early 1970s, by which time the island was free of introduced mammals (Bell 1974). Breeding on the island was confirmed in 1987, but the ability of black-winged petrels to prosper there appears to be limited by predation by skuas and by interference with their burrows by other petrel species (Tennyson 1991). Elsewhere in the south-west Pacific, breeding was first confirmed on Lord Howe Island in 1971, but at that time their colonisation of the island was being limited by severe predation by owls and cats (Recher & Clark 1974). The subsequent removal of feral cats from Lord Howe has allowed the black-winged petrel to increase in numbers and to extend the area in which it nests (Hutton 1991). It was first confirmed nesting on Phillip Island in 1968 (Schodde *et al.* 1983), but its attempts to establish on nearby Norfolk Island apparently continue to be thwarted by cats (Hermes *et al.* 1986). According to Rinke *et al.* (1992), breeding black-winged petrels have recently been discovered on Rarotonga.

The absence of bones of black-winged petrels from the earliest analytic zones of the Tangatatau site may indicate that the species did not nest on that, or any, part of Mangaia during that period, or that it nested there but in such low numbers that any human use of it as a food item is not reflected in the Tangatatau record, or that it was not a significant human food item at that time. Whichever is true, by far the majority of bones identified as being of the black-winged petrel were found in 2 of the most recent zones which appear to date from about AD 1400-1600 (Steadman & Kirch 1990; Steadman 1997). The appearance in the archaeological record of a significant number of bones referable to the black-winged petrel at almost exactly the time pigs disappeared from the same record may not be a coincidence.

Together, pigs and people on Mangaia may have been primarily responsible prehistorically for causing the black-winged petrel to become absent or rare as a breeding species on the island. The demise of the pig on Mangaia may have allowed the petrels to re-establish a breeding population on the island, or a remnant breeding population to increase. Polynesian rats may not have prevented such a recovery, because the same rats have not prevented the black-winged petrel from increasing on Macauley Island. In the absence of any other significant predator, a moderate human population on Mangaia may not have prevented an increase in the number of black-winged petrels breeding on the island.

It is quite possible that the loss of pigs resulted in the human use, or increased use, of the black-winged petrel for food. Such a change may be reflected by the appearance, and subsequent increase in the number, of black-winged petrel bones in the Tangatatau record after pig bones ceased to be deposited. However, human use may have been more than offset by a contemporaneous increase in the number of petrels that resulted from the absence of predation by pigs. Human predation of black-winged petrels may have declined after pigs were re-introduced by the missionaries in the nineteenth century, but it is probable that those same pigs soon became one of several new threats to the breeding viability of procellariids on the island.

CONCLUSIONS

There is no direct evidence of the factor or factors that eliminated the *titi* as a breeding species on the volcanic uplands of Mangaia. Many burrows may have been destroyed by periodic erosion like that in 1854 (W. Wyatt Gill 1894: 49). Such episodes must have been frequent and regular since prehistoric Polynesians first denuded the volcanic hills of their vegetation. Indeed, much of the volcanic soil of the central uplands of Mangaia has eroded away because of centuries of deforestation (Crombie & Steadman 1986). More importantly, the flesh of this *titi* was regarded as a delicacy by the Mangaians (W. Wyatt Gill 1876a: 33-34). Nevertheless, harvesting by humans was probably not the only factor which eliminated the *titi* as a breeding species on Mangaia. Its demise was most likely caused by a combination of the detrimental effects of human harvesting and various introduced mammalian predators which were present on Mangaia after the arrival of missionaries in the early nineteenth century. Such a conclusion is reasonable given the known effects of human harvesting and introduced mammalian predators on nesting procellariids elsewhere. The evidence presented here indicates that a combination of those factors would have been more than capable of eliminating the *titi* as a breeding species on the volcanic uplands of Mangaia within the time frame involved.

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