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A rich Pleistocene–Holocene avifaunal sequence from Te Waka #1: terrestrial fossil vertebrate faunas from inland Hawke's Bay, North Island, New Zealand. Part 2

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Abstract: The results of 13 m^2 of new excavations in the rockshelter called Te Waka #1, 900 m above sea level in inland Hawke's Bay, North Island, New Zealand, are presented. The site is shown to have an unparalleled continuous faunal record in sediments about 3 m deep that spans the period from the Kawakawa eruption 22 600 ^{14}C yrs BP to the present. Good temporal control is afforded by clear stratigraphy, three obvious tephras (Taupo Ignimbrite, one unidentified, Kawakawa Tephra (Oruanui Ignimbrite)), seven AMS radiocarbon ages, and one uranium-series age. Three frog species, a tuatara, five lizards, 42 birds, and three bats are represented in the 2490 identified bones from the combined faunas from W. H. Hartree's late 1950s and our 1999–2000 excavations. The fauna is interpreted as being mainly derived from the prey remains of *Falco novaeseelandiae*; it includes the first fossil records of *Garrodia nereis* and *Charadrius bicinctus* from the North Island. The presence in the fossil avifauna of species that live only in shrubland or forest indicates that such vegetation was present on Te Waka between 22 600 ^{14}C yrs BP and the Late Glacial Maximum (LGM, 18 000 ^{14}C yrs BP). *Pterodroma cookii* ceased to breed on Te Waka over the LGM. The absence of this species (which nests solely under forest), the lack of forest passerines, and the presence of species characteristic of open vegetation indicate a substantial loss of vegetation around the site at that time. The sedimentary and faunal record indicate that the area was reafforested about 14 000 ^{14}C yrs BP.

Keywords: Fossil avifauna, palaeoenvironment, climate change, Quaternary, Te Waka, Hawke's Bay, New Zealand.

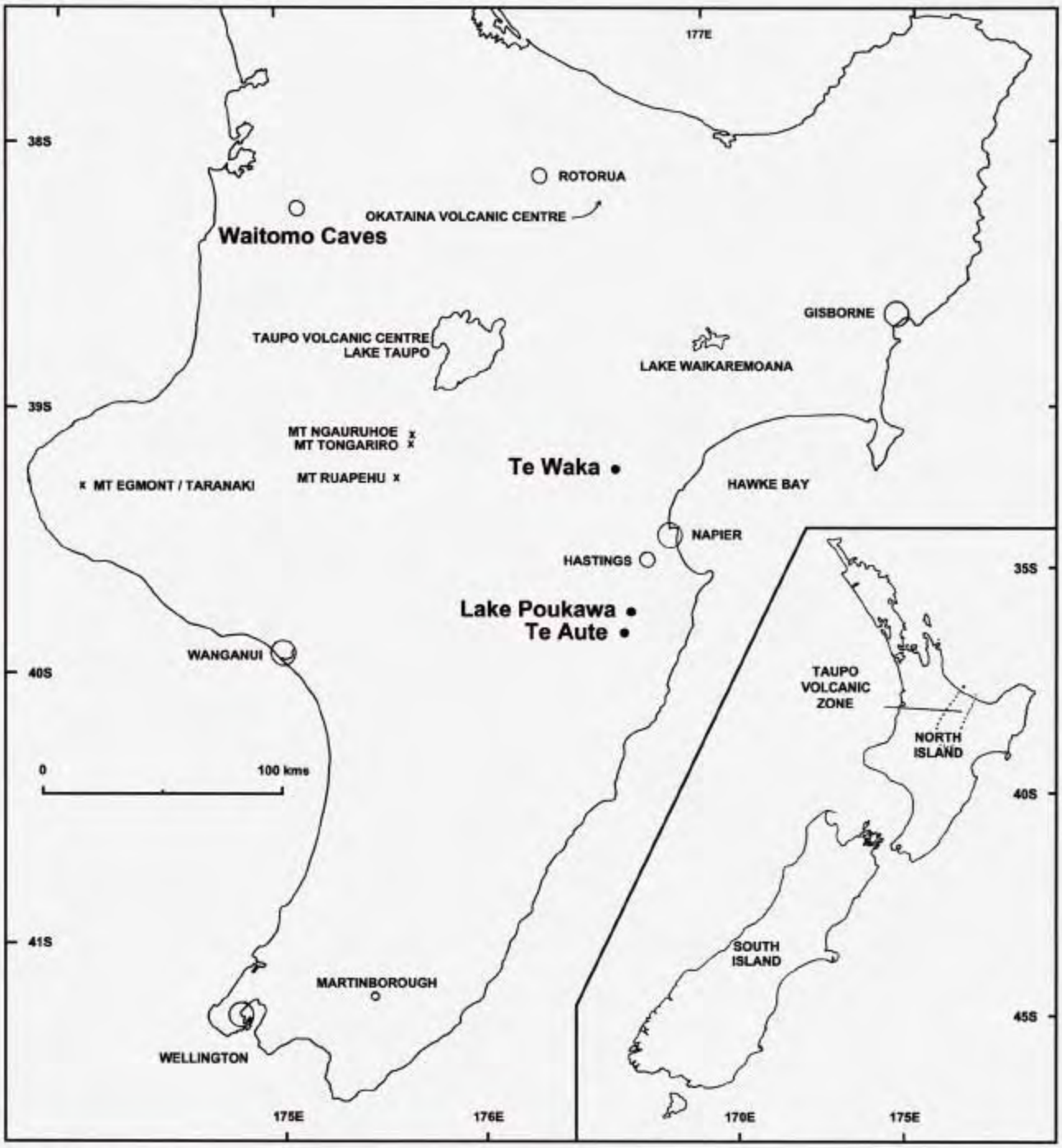

Fig 1. Map showing location of Te Waka #1 and various geographic features mentioned in the text.

Introduction

Mr W. H. (Bill) Hartree, jnr, farmed in the Puketitiri Valley in inland Hawke's Bay and was an enthusiastic excavator of rockshelter sites in the area. His collections during the period 1957 to 1961 are preserved in the Museum of New Zealand Te Papa Tongarewa, Canterbury Museum, and the Hawke's Bay Cultural Trust Museum in Napier. They formed the core of a regional analysis that primarily dealt with the Holocene fauna (Worthy & Holdaway 2000), the first in a planned series of papers on faunas of the inland Hawke's Bay region. Because of the species compositions in the deeper layers, the fauna in the site Te Waka #1 (Fossil Record Number [Geological Society of New Zealand] V20/f437) (Figs 1, 2) was identified by Worthy & Holdaway (2000) as having been accumulated from some time in the Pleistocene to the present.

Hartree located the site some time in 1957 and excavated it during several visits as follows: 28/6/58, 9/8/58, 2/4/59, 25/5/59, 11/7/59, 18/7/59 with R. J. Scarlett and others (W. H. Hartree's ms diary). The fauna from these excavations was summarised by Worthy & Holdaway (2000). Hartree's excavation notes, associated with the preserved specimens, indicate he excavated to a depth of 4 m (13 feet) in a trench on one side of the shelter. He encountered two tephra layers, which he identified with the bird bones as the Taupo and the Waimihia tephras.

The fossil sites in inland Hawke's Bay, especially in the Puketitiri – Te Pohue area (Fig 1), often include layers of tephra derived from eruptions from centres in the Taupo Volcanic Zone, some 70–80 km to the west. The main tephras encountered in fossil sites are the Taupo Ignimbrite (1850 ±10 yrs BP) and the Waimihia Tephra (Unit S of Wilson 1993, 3200 ^{14}C yrs BP) (Froggatt & Lowe 1990; Holdaway & Beavan 1999). Each forms distinct and, at times, thick layers, which provide good stratigraphical control for sites of Holocene age.

The fact that the species composition and the relative proportions of species within regional faunas varied considerably over time has been well documented by recent work in the South Island (Worthy 1994, 1998a, 1998b, 1999; Worthy & Holdaway 1993, 1994a, 1996a; Worthy & Mildenhall 1989). That such faunal changes over time also occurred in the North Island has been documented for the Hawke's Bay lowlands (Worthy 2000a) and Waitomo (Worthy & Swabey in press). The upland, inland site of Te Waka #1, as it has the recorded presence of tephras and deep stratigraphy, therefore afforded an excellent opportunity to extend this record further back in time in the North Island. Furthermore, the high frequency of small taxa found in the deposit, which is a result of the fauna having been accumulated primarily by a predator rather than there being mostly larger taxa as is normal in a cave pitfall or swamp, was believed to offer a unique insight into palaeofaunal composition of the region. Therefore, the site was re-excavated with the aim of obtaining adequate samples to describe the faunas from the various time periods represented and so map possible changes in the local fauna through time.

Methods

Excavation procedure

A metre grid was established over the site (Fig 3) with an origin at 4 cm below a bolt in the roof (860 mm above the floor at that point), on the northern side of the trench at the junction between squares B2 and B3. Bolts were drilled into the roof on the metre grid and weighted lines suspended from them to define the grid at floor level and below. A horizontal datum at –620 mm was established along the boundary of squares in rows B and C from an iron standard at the entrance side of square B1 to a bolt in the cave roof at the junction of squares C6 and C7 (Fig 4).

Fig 2. View of entrance in May 1959 showing Hartree excavating his 'entrance trench', photograph by J. C. Yaldwyn.

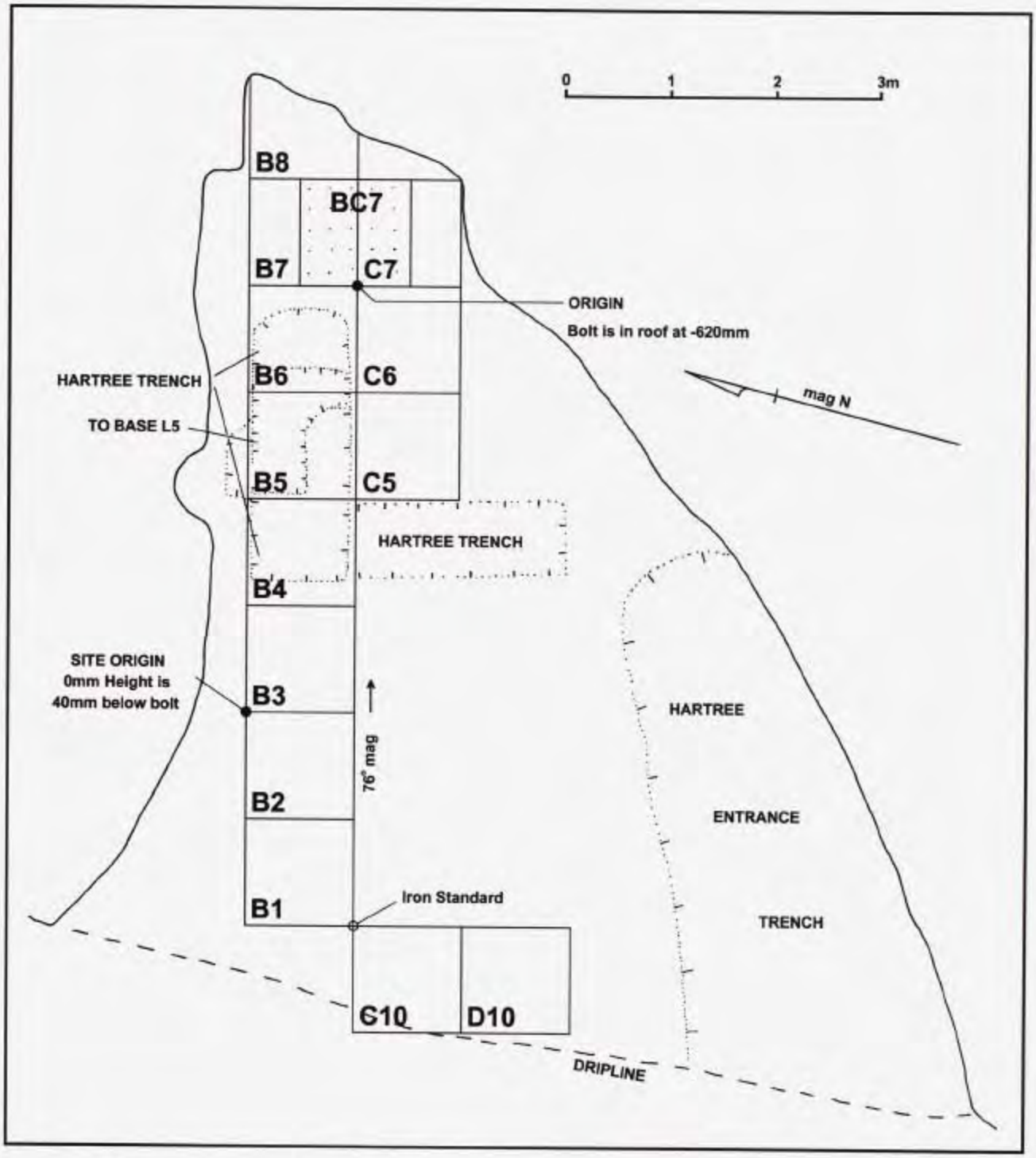

Fig 3. Plan of excavations in Te Waka #1. The 1999–2000 excavated squares are labelled B1–B8, C5–C7, C10, and D10. In part of squares B7–C7, the excavation was continued as square BC7 to the cave base. Three trenches made by Hartree were identified, of which 'Hartree Entrance Trench' was his main excavation. That which was encompassed by squares B4–B6 only penetrated the Taupo Ignimbrite in the smaller area labelled 'to base L5'. The original depth of the linking cross-wise trench is unknown, but it is unlikely to have penetrated the Taupo Ignimbrite. The 'Site Origin' for the excavation was taken as 40 mm below the bolt in the roof at B3, but a secondary origin in the roof at B7/C7 made a more practical point from which to run a string line to the iron standard in the southwest corner of B1.

The site was excavated in 1 m x 1 m squares by stratigraphic layer. Deeper layers were excavated in thinner units (spits). Larger bones were located with respect to the northwest corner of the square (eastings and southings) and their depths measured below the height datum. Depths were measured with a steel tape from a string line held level (as indicated by a spirit-bubble) between the square origin and a point above the bone. Plans of surface features at the interface between layers were drawn and profiles mapped for representative sections of the site. An extensive photographic record was kept of the excavations.

At all depths, but most especially in Layer 7, limestone slabs, some up to 2 m x 1 m x 0.5 m thick, were encountered. These were derived from slabs that had periodically spalled from the roof, following weathering that advanced preferentially along silty layers in the limestone. In squares C6 and C7, a buried layer of flowstone up to 40 cm thick and stalagmites up to 60 cm high (speleothems) were present. Rocks and flowstone were reduced to manageable units using sledgehammers and removed from the site. Otherwise, excavation was by trowel. All sediment was carried in buckets to the stream about 20 m away and wet-sieved through 6 and 2 mm meshes. Bones were hand-picked from the sieves. They were easily seen because the sediment was silty and generally washed cleanly though the mesh, leaving clean stones and bones behind. The exception was the sediments from Layers 2 and 5, which contained more clay. Washing the clay completely through fine mesh was very time-consuming, so in about half the squares the slurry retained on the fine mesh was collected and processed under laboratory conditions. After washing the clay out with a jet of water, the concentrate was dried and hand-picked for bones a few cubic centimetres at a time.

In all, 14 squares (B1–B8, C5–C8, C10, D10) were excavated to a depth of 2 m below the cave floor. A 1 m x 1 m excavation in square BC7 penetrated a further 1.5 m to reach the bedrock. In D10, a test pit was made from 2 to 2.5 m below ground level, where the Kawakawa Tephra (c. 26, 000 CAL yrs BP) was encountered and the excavation stopped.

Excavations were during the periods 10–16 December 1999, 2–9 April 2000, 9–18 October 2000, and 11–20 December 2000. Excavation design and control were by Worthy and Holdaway. All specimens were identified and catalogued into the fossil bird collection of the Museum of New Zealand Te Papa Tongarewa by Worthy.

Fig 4. Photograph of site in April 2000 viewed looking into cave along excavation trench squares B1–B8 with N. Field for scale.

In addition to the collection of fossil bones, samples were collected for micro-mollusc analysis and sent to F. Brook (Department of Conservation, Northland Conservancy) for separate analysis. A core was taken through Layers 4 and 5 for pollen analysis in square B7, but only badly corroded spores were present, with the tree fern types *Cyathea smithii* type and *Cyathea dealbata* type most strongly represented. Because of the strong corrosion only robust types can be expected, so a full analysis was not warranted (M. McGlone, Landcare Research, pers comm 11 Oct. 2001).

Radiocarbon dating

Bones were radiocarbon dated by the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand. The surfaces of all samples were ground with a Dremmel to remove surface coatings

and dirt. The remaining sample was then crushed and sieved to <450 µm, then demineralised in 0.5 M HCl while stirred at room temperature for 1 h to extract the collagen. The collagen was then gelatinised in 0.01 M HCl under N_2 at 90° C for a minimum of 16 h. The gelatin fraction was made into a graphite target and dated using accelerator mass spectrometry (AMS). Ages are reported as conventional radiocarbon ages (CRA), based on the Libby $T^1/_2$ of 5568 yrs, uncorrected for secular variation, in years before present (^{14}C yrs BP), where present is AD 1950. Calibrated dates in calendar years before present (CAL BP) were determined for the eggshell and petrel specimens using Winscal, which is based on 1998 atmospheric data and radiocarbon ages from Stuiver *et al.* (1998). The terrestrial calibration was done using CalPal, the Cologne Radiocarbon Calibration & Palaeoclimate package.

Uranium-series dating

A speleothem (flowstone) sample was submitted to the Institute of Geological and Nuclear Sciences at Lower Hutt for uranium-series dating using alpha spectrometry. Counts of the uranium series isotopes ^{234}U, ^{238}U, ^{232}Th, and ^{230}Th were made. From the ratios ^{234}U/^{238}U and ^{230}Th/^{234}U, age was determined by assuming half-lives of ^{234}U at 245 000 years and ^{230}Th at 75 380 years.

Flowstone is difficult to date using uranium-series dating because authigenic ^{230}Th derived from surrounding sediments is often deposited with the secondary calcite. The commonly used test for this detrital contamination is to examine the ^{230}Th/^{232}Th ratio (Schwarcz 1980). If the activity ratio is greater than 20, it is assumed that the ^{230}Th in the sample is derived solely from in situ radiogenic decay and the uranium-series age is accurate. ^{230}Th/^{232}Th values between 5 and 20 should be treated with some caution as they may indicate the presence of authigenic ^{230}Th, but it may be assumed that the uranium-series age is close to the true age, although possibly older. ^{230}Th/^{232}Th ratios of less than 5 indicate samples with a high level of authigenic (detrital) ^{230}Th and that the uranium-series ages are likely to be inaccurate and the true ages significantly younger.

Tephra identification

Tephra samples were collected by THW and BVA for correlation and dating purposes. Tephra identification (especially Layer 11) required confirmation by ferromagnesian mineralogy and glass chemistry. Tephra samples were wet-sieved into >250, 250–125, 125–63, and <63 µm size fractions. For electron microprobe analysis, 50 mg of glass from the 250–125 µm fraction was separated using a Frantz Isodynamic Separator. Ferromagnesian minerals were examined using a polarising microscope. The major element compositions of glass shards were determined by using a JEOL JXA-733 electron microprobe housed at Victoria University of Wellington and a Cameca SX-50 wavelength dispersive microprobe housed at the University of Toronto (Table 1). The major element compositions of an internal glass standard (UA-5831) were routinely analysed to check and correct for machine drift.

Abbreviations and Terminology

Institutions: AU, Geology Department, University of Auckland, Auckland; CM, Canterbury Museum, Christchurch; WO, Waitomo Caves Museum, Waitomo Caves.

For bones in the following list, elements may be singular or plural: ad, adult; ant, anterior; cerv vert, cervical vertebrae; cmc, carpometacarpi; cor, coracoids; dent, side of mandible; fem, femora; fib, fibula; fur, furcula; frag/s, fragment/s; hum, humeri; innom, innominate (ilium and acetabular region of pelvis); juv, juvenile; mand, mandible; pal, palatines; pel, pelves; phal, phalanges; pmx, premaxilla; proc, process; pt, part; quad, quadrate; q-o-j, quadrateojugal; rad, radii; rami, articular end of mandible; scap, scapula; stern, sternum; thor vert, thoracic vertebrae; tmt, tarsometatarsi; tt, tibiotarsi. L left, R right; where p, s, or d precedes L or R, it refers to a proximal, shaft, or distal part respectively.

MNI is minimum number of individuals determined from the most frequently occurring element (maximum of left or right side only if relevant) in the sample.

Avian taxa reported here follow the taxonomy advocated by Holdaway *et al.* (2001) and Worthy *et al.* (in press) and thus differ from that of Turbott (1990), mainly by the recognition of some North Island taxa as full species, as they were originally described. *Euryanas finschi* is hereafter referred to *Chenonetta finschi* following Worthy & Olson (2002).

The Holocene is defined as beginning at 10 000 ^{14}C yrs BP, the time since the end of the most recent cold stage. The Otira Glaciation, the most recent New Zealand

glaciation, lasted from about 70 000 to 15 000 ^{14}C yrs BP. It is broadly equivalent to the Wisconsinan–Weichselian or Marine Oxygen Isotope stages 4-2. The Last Glacial Maximum (LGM) is taken as the period from c. 25 000 to 15 000 ^{14}C yrs BP, and the Late Glacial (Termination 1) is the period of rapid climatic and vegetational change from 15 000 to 10 000 ^{14}C yrs BP (eg, Newnham *et al.* 1999). These divisions better reflect the major episodes of vegetation history than does use of the term Aranuian (Suggate 1978), which covers all the time from 14 000 years to the present.

Fossil Site Parameters

Regional setting

Te Waka #1 (39° 14' 43"S, 176° 37' 52"E, NZMS 260 V20/234115) is a small cave at 900 m a.s.l. (Fig 1). The relationship of Te Waka #1 to other caves in the Puketitiri – Te Pohue area is given as Figure 2 in Worthy & Holdaway (2000). The cave is formed in the Te Waka Limestone of Mangapanian, mid–late Pliocene ages, that caps the Te Waka Range. The crest of the range peaks at 1021 m to the northeast and is remarkably flat, being formed by the surface of the Te Waka Limestone. The western side of the range has steep slopes, with cliffs in the limestone facies, whereas the gentle eastern slopes reflect the dip of the strata to the southeast. The Pacific Ocean, in Hawke Bay, is about 25 km distant and visible from Te Waka Range.

The cave entrance (Fig 2) opens to the west c. 8 m above the stream in a shallow valley c. 1 km southeast of, and 150 m below, the main ridge. The afternoon sun penetrates to the back of the cave. The entrance, as marked by the drip-line, is about 8 m wide, and the cave extends inward for a maximum of 8.5 m. Prior to excavations, the roof was about 3 m above ground level at the entrance and sloped down towards the rear of the cave, intersecting the floor at 7 m from the entrance.

Tephras in soil profiles

Formed vehicle tracks at many points across the hillsides near Te Waka #1 expose soil profiles and their contained tephras. The cuttings show an A horizon that contains a discontinuous tephra deposit (100–200 mm thick) comprising coarse (up to 150 mm) pieces of pumice derived from the Taupo Ignimbrite. About 200–300 mm lower in the profiles, the Waimihia Tephra (Unit S) is clearly visible as a layer of orange-brown lapilli (3–8 mm) about 100 mm thick. Being loose and unconsolidated, it is easily eroded to form a notch in the profile. In some profiles, a discontinuous, centimetre-thick, dark-grey coloured, water-flushed fine ash bed is about 200–300 mm below the Waimihia Tephra. The identification of this tephra is unknown, but its macroscopic features are most like tephras sourced from the Tongariro Volcanic Centre (Alloway pers observ).

Vegetation

The late Holocene vegetation on Te Waka is represented by a 300 ha remnant between 740–960 m a.s.l. It consists mainly of tall red beech (*Nothofagus fusca*) with scattered podocarps. Above about 820 m, Hall's totara (*Podocarpus halli*) is the main podocarp, but below this altitude, prior to them having been milled, rimu (*Dacrydium cupressinum*) and matai (*Prumnopitys taxifolia*) became increasingly common (Parsons 1997: 14-17). The main understorey trees are broadleaf (*Griselinia littoralis*), kamahi (*Weinmannia racemosa*), and kaikomako (*Pennantia corymbosa*). Common understorey shrubs include tree fuchsia (*Fuchsia excorticata*), putaputaweta (*Carpodetus serratus*), ongaonga (*Urtica ferox*), and horopito (*Pseudowintera colorata*). At the start of the twentieth century, the area above about 900 m was in grassland with matagouri (*Discaria toumatou*) bushes, daisies (*Celmisia* spp.), spaniards (*Aciphylla* spp.), and some associated kanuka (*Kunzea ericoides*) forest (Parsons 1997). While most of the vegetation destroyed by volcanic events such as the Taupo Eruption recovered within 100—200 years (Wilmshurst & McGlone 1996), the crests of high ridges (>800 m) exposed to the extremes of weather, such as Te Waka, probably either did not carry tall forest or had its re-establishment much delayed. The open vegetation recorded on Te Waka at the start of the twentieth century is probably typical of the open vegetation that occurred along the higher ridges throughout the Holocene, and areas of such vegetation were doubtless temporarily expanded by the destruction of forest during volcanic events.

Stratigraphy of the fossil deposits

The stratigraphy of the site is illustrated by the north wall of squares B6–B8 (Figs 5, 6). The stratigraphy is clearer towards the rear of the cave, as soil mixing processes operating in the vegetated entrance zone and the absence of

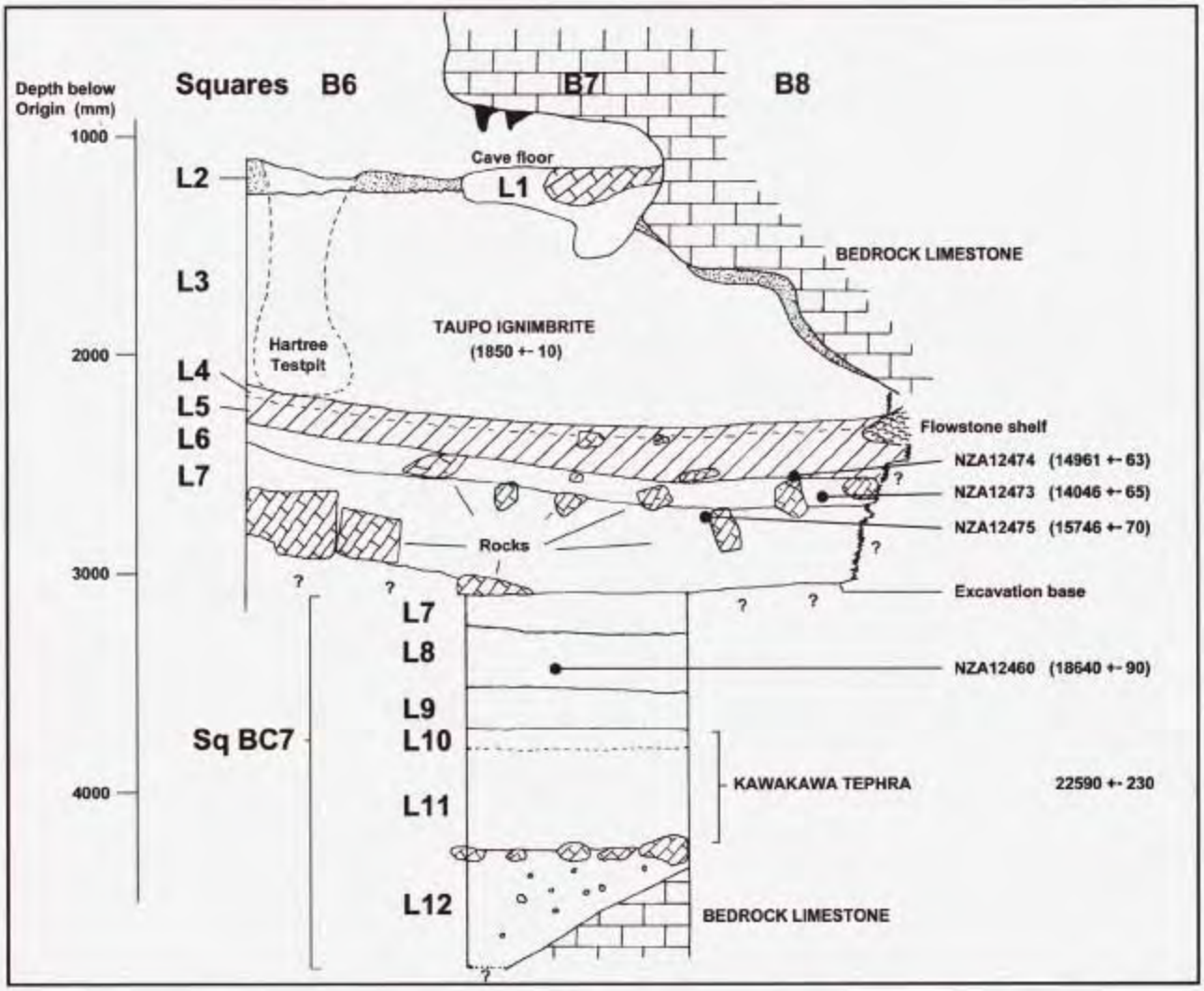

Fig 5. Stratigraphy of the deposits as shown by the section on the north wall of squares B6–B8 and square BC7. L1–L12 are the layers described in the text. Radiocarbon dates, shown after their identifying NZA numbers, are Conventional Radiocarbon Ages (^{14}C yrs BP). The ages of the two tephras are also given as comparable Conventional Radiocarbon Ages in ^{14}C yrs BP.

Fig 6. Photograph of north wall of section, squares B6–B8 on 18 October 2000. The set square is 300 x 200 mm.

Taupo Ignimbrite (Layer 3) near the entrance have resulted in Layer 2, Layer 4/5, and Layer 6 merging and having no clear boundaries. The stratigraphy is therefore described mainly from the B6–B8 section (Figs 5, 6), but with reference to the southern section in B1—B4 and C5–C7 (Fig 7). Hereafter, the alphanumerics B1, C5, etc can be taken as referring to the excavated squares.

Layer 1 was a friable, uncompacted, highly organic soil containing numerous goat (*Capra hircus*), rabbit (*Oryctolagus cuniculus*), and brush-tailed possum (*Trichosurus vulpecula*) bones. The sediment was derived mainly from decomposed goat droppings. It was thickest towards the back of the cave and had some admixture of Taupo Ignimbrite as a result of rabbit burrowing. Rabbit holes that had been excavated in only the upper parts of the Taupo Ignimbrite near the rear of the cave were infilled with this mixed material. The numerous mammal bones show that this layer was deposited after the area came under European influences in the late nineteenth century. Towards the centre and rear of the cave, fill derived from the Hartree excavations covered Layer 1 to a depth of up to 300 mm.

Layer 2 is a friable red-brown earth up to 150 mm deep that was compacted to a light red-brown loamy clay where humans and animals had access. It had a flat contact with the Taupo Ignimbrite, but its upper surface was uneven as a result of differential erosion by goat trampling or rabbit burrowing, and in places such activities had entirely removed it. At the rear of the cave, Layer 2 extended down as a wedge between the roof and the Taupo Ignimbrite, which had shrunk away from the roof/wall. The sediment contains small (10–20 mm) calcite clasts,

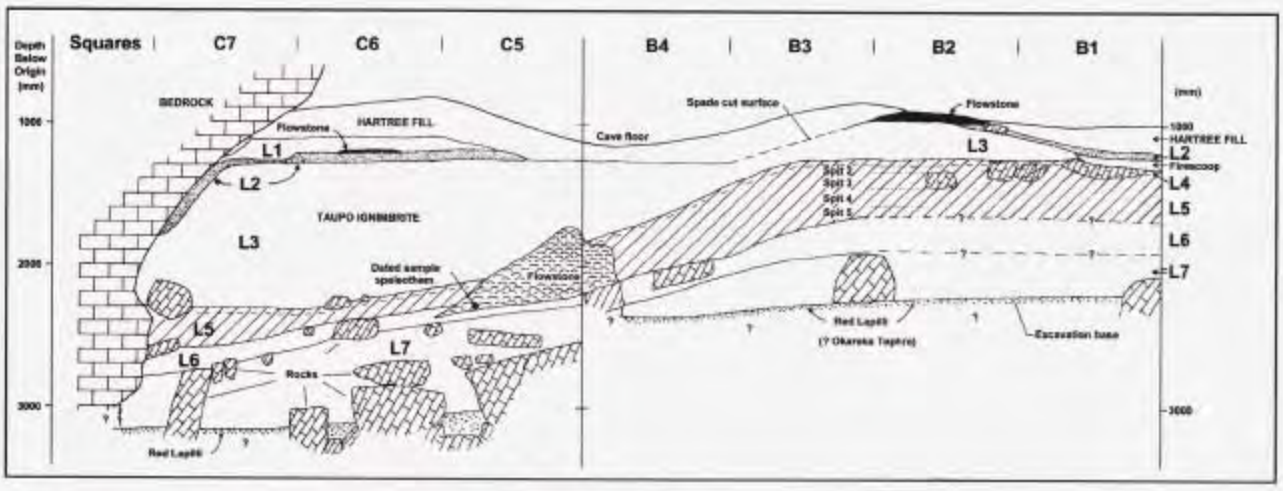

Fig 7. Stratigraphy of south wall compiled from squares B1–B4, C5–C7.

rare bones, and moa eggshell. Layer 2 is assumed to be a mixture of detritus from algae and bryophytes growing on the cave roof and the insoluble products of the weathering of the limestone itself. At scattered points over the cave floor, for example in C6 and B2, the boundary between Layer 2 and Layer 1 was separated by a thin sheet of flowstone, deposited below actively dripping stalactites.

Layer 3 is an unmistakable homogeneous layer of Taupo Ignimbrite. It forms a layer that reaches a maximum thickness of 1 m towards the back of the cave, where it filled a pre-existing hollow in the cave floor. In B2–B3, Layer 3 was up to 300 mm thick at the south wall, where it was capped with flowstone. The ignimbrite is whiter towards the top of the section and became greyer towards the base, where it had a greater moisture content. In the basal 100 mm of the ignimbrite, there are clasts of pumice up to 50 mm across, as well as carbonised twigs, leaves, and rare small branches. Occasionally, broken stalactites were found buried within the ignimbrite, for example one was lying horizontally in C6, 150 mm below the top of the ignimbrite. These must have fallen from the roof during the eruption. The Taupo Ignimbrite filled in the pre-existing cave hollows and so buried rocks lying on the previous silt floors in the cave rear. It also buried stalagmites up to 500 mm high in C5.

Layer 4 was defined arbitrarily as the first 30 mm of sediment below the Taupo Ignimbrite. It was a red-brown clay earth containing limestone blocks that were usually 50–150 mm in diameter and 20–50 mm thick, but occasionally up to 500 mm in diameter. The surface of Layer 4 represented the cave floor 1850 ^{14}C yrs BP, prior to the Taupo eruption. On that surface, scattered limestone rocks lay on a flat silt floor in B6–B8 and C6–C7. The cave floor over the area in C5 and B4–B3 rose 600–700 mm up a slope towards the entrance.

Layer 5 was defined as the remainder of the red-brown clay-loams below the Taupo Ignimbrite. In B7–B8, the combined Layers 4 and 5 was 250 mm thick. In C5, stalagmites up to 250 mm diameter and 500 mm high had been deposited within, and protruded above, combined Layers 4 and 5, beneath large stalactites. These stalagmites were formed at the same time as the red-brown clay-loams of Layer 5 were deposited. On the limestone wall, speleothem deposition was contemporaneous with the build-up of silt on the floor, which resulted in an upwardly widening wedge of flowstone. The sediment of Layer 5 was thinnest on the former slopes in the mid-reaches of the cave. For example, in C6 it was only 160 mm thick. Towards the entrance, over B1–B3, the combined Layers 4 and 5 were up to 400 mm thick, but these layers graded into Layer 6 without clear boundaries so that the combined Layers 4–6 were together about 700 mm thick. At the back of the cave, higher moisture levels facilitated weathering, which resulted in the sediments of Layers 4 and 5 being wetter and containing a higher clay fraction. Towards the entrance, the better-drained sediments were more friable, though still a red-brown clay. In areas near the cave wall in B1–B3, the sediment was greyer and soil voids contained white 'fungus'-like growths, reflecting alternate wetting and drying, and the deposition of calcite by percolating water from the wall. Throughout Layer 5 were small limestone clasts. Fossil bones and moa eggshell fragments were rare towards the cave entrance; the greatest concentrations were in the former hollow at the rear of the cave. Some 600 g of moa eggshell was recovered from B8 alone.

A tephra in Layer 5 was not visible during excavation or in the sections, but was identified during wet-sieving of sediment from 50 to 100 mm below the Taupo Ignimbrite (Layer 3). It appeared as reddish-brown lapilli up to 10 mm in diameter. The lapilli are consistent in colour, size, and stratigraphic position with the Waimihia Tephra (Unit S) in other sites in the Puketitiri – Te Waka area, and are assumed to represent it in this site.

In B6–B8, Layer 6 was marked by an abrupt change from the red-brown clay-rich sediment of Layer 5 to a very friable, grey, rubbly layer with c. 50% by volume of small (mainly 10–40 mm diameter) limestone clasts with rounded edges. The layer was 80–120 mm thick and rich in land snails and bones. The layer is interpreted as being the result of a hiatus in deposition of fine sediments, during which drips from the roof concentrated and rounded the small limestone clasts and land snails were concentrated on the cave floor. As mentioned above, Layer 6 was not clearly differentiated from Layer 5 near the entrance.

Layer 7 was a grey silty sand that was soft to the touch, as it lacked the small rough limestone clasts common in Layers 5 and 6. It lacked any clay component and washed through sieves easily. It also was homogeneous and lacked laminations that might have reflected variable water flows during deposition. However, this sand had been deposited around large boulders derived from a roof collapse. In B6–B8 and C6–C7, Layer 7 was 500–600 mm

deep. We designated a thin concentration of reddish lapilli (2–5 mm diameter) as the lower boundary of Layer 7. Small amounts of similar lapilli were found floating on sieves from the sediment in B7 at all levels below 200 mm under Layer 5, but an obvious concentration, visible during excavation as smudged red-orange specks in a trowelled surface, was present 400–550 mm below the Taupo Ignimbrite. We terminated our excavation at this level in B1–B8 and C5–C7. The sandy sediment was interpreted as having been washed into the site by periodic sheet-flows of water, presumably during periods of heavy rain. The bones were all lying horizontally and, while none was articulated, occasional groups of bones obviously came from part of a single individual, implying a low energy depositional environment.

Layers below Layer 8 were examined only in BC7 and D10.

Layer 8 was marked by an increase in proportion of grit from small limestone clasts and an absence of the red lapilli. Layer 7 graded into it. In BC7 and in the south wall of C6, the upper boundary of Layer 8 was 600–700 mm below Layer 5. As seen in BC7 (Fig 3), Layer 8 was 250 mm thick. The base of the layer seemed to be the lower limit of petrel bones. No land snails were found in Layer 8: they were obvious in the layers above as they floated from the sediment during sieving.

Layer 9 was a 180 mm layer of grey, gritty sediment, lacking any pumice. A disarticulated parakeet skeleton from this layer provided perhaps the oldest bones found in our excavations.

Layer 10 was coarse, grey, gritty pumice sediment, with white vesicular clasts up to 20 mm in diameter. It commenced 1.1 m below Layer 5 and was 100 mm thick.

Layer 11 was a layer of compacted grey-white pumice sand 500 mm thick, whose laminar structure indicates that it was a secondary deposit. The interface between Layer 11 and Layer 10 was flat. Layers 10 and 11 are the secondarily deposited components of the Kawakawa Tephra (see section below). Layer 11 overlaid a cave floor formed on Layer 12 sediments and enclosed the prominent limestone rocks of that layer.

The top of the Kawakawa Tephra was found on the east side of D10 at a depth of –3740 mm below site datum, which was only 10 mm higher than in BC7 (upper surface at –3730 mm). However, 500 mm towards the west side of D10 (ie, towards the entrance) the upper surface of the tephra was 250 mm higher, which suggests that the tephra layer sloped down into the cave to a flat floor from D10 to the cave rear at that time.

Layer 12 was stream-laid sediment of coarse sand and grit with limestone clasts, and contained pebbles reworked from the Te Waka Limestone. In BC7, this layer was up to 500 mm deep, but its base was the sloping surface of bedrock of the cave floor. Layer 12 was barren.

Ages of the deposits

^{14}C AMS ages

Seven radiocarbon ages were obtained from material (6 bones, 1 eggshell) excavated from Te Waka #1 (Appendix 1). The ^{14}C ages were generally stratigraphically consistent both with each other and with the age of the tephras (Fig 5). The exception was NZA12474 (14 961 ± 65 ^{14}C yrs BP; 17 619–17 103 CAL BP), which came from the boundary between Layers 5 and 6. Because the age is determined from a bone of a species common in Layer 6, it is assumed that the bone came from Layer 6 and may have been brought higher in the sequence by the nesting activity of moa in the site. This is probable as Layer 6 is only about 100 mm thick and probably represents about 2000 years of deposition. The age from a piece of moa eggshell from within Layer 6 (14 046 ± 65 ^{14}C yrs BP, 17 092–16 601 CAL BP; NZA 12473) suggests that the maximum age for the base of Layer 5 is not older than c. 14 000 ^{14}C yrs BP.

Three dates were obtained on bones of *Chenonetta (=Euryanas) finschi* collected by Hartree. The stratigraphic data recorded with the Hartree specimens cannot be directly related to that shown in Figures 5 or 7 as there is considerable variation of layer depth both into and across the cave and we do not know where Hartree's depth origin was in relation to ours. The bones were chosen at random from the collection, using such data as was available, to increase the likelihood that all came from strata below the equivalent of our Layer 7 and so to date the deeper parts of Hartree's excavation. The purpose was to determine whether his excavation had the same temporal range as ours. The dates ranged from 17 499 to 20 450 ^{14}C yrs BP (20 779 ± 441 to 23 914 ± 284 CAL BP), which supported the conclusion that the layers he sampled were contemporary with our Layers 8 to 10.

The collagen yields, N and C contents, and C:N ratio for the bones (Appendix 1) are well within the acceptable

range for AMS ages of bones without enhanced treatment protocols (Holdaway & Beavan 1999). The ancillary isotopic data also support the reliability of the AMS ages. The $\delta^{13}C$ values for the three samples of bone from mottled petrels (*Pterodroma inexpectata*) are, at -15.1 to -15.7, similar to that of -16.1 for a bone of the same species from the late Holocene of North Canterbury (NZA6967; CRA 1115 ± 70 ^{14}C years BP) (RNH, unpubl. data). These values are in the usual range for marine birds (Schoeninger & DeNiro 1984). For the Finsch's duck, the values are as would be expected for a vegetarian bird foraging on C3 plants in an open environment. For example, they are comparable to the $\delta^{13}C$ of 22.1 measured on a bone (from Bohemia Cave) of the same species that foraged above the tree line on Mt Owen (NZA12766, 1262 ± 45 ^{14}C years BP). Finsch's duck was neither an aquatic nor a riparian grazer, unlike most *Anas* species. However, individual Finsch's ducks from sites within former areas of forest, such as that from Cave F1c near Waitomo Caves (NZA12768, 2024 ± 50 ^{14}C years BP; $\delta^{13}C$ = -27.2; RNH unpubl. data), exhibit a depleted level of $\delta^{13}C$ that is consistent with the bird having fed on vegetation growing beneath a dense canopy (Lajtha & Marshall 1994).

Reported values of $\delta^{13}C$ for moa eggshell are mostly between –9.2 and –15.4 (Higham 1994; Holdaway & Beavan 1999), although a piece of shell from dunes in Northland yielded a markedly enriched value of –4.2, which was attributed to one of several possible sources of error (Higham 1994). The eggshell $\delta^{13}C$ from Te Waka, with a value of –8.4, was at the enriched end of the range, but markedly less so than the obvious outlier in the present data.

The level of enrichment in ^{15}N ($\delta^{15}N$) for the three bones of *P. inexpectata* was consistent with that for bone protein of carnivores at the top of the marine food chain (Schoeninger & DeNiro 1984). Mottled petrels eat mainly lantern fish, with some crustacea and squid (Heather & Robertson 1996). The values for the three bones of different geological age were also extremely similar. The $\delta^{15}N$ for the three Finsch's duck bones is typical for bones from areas with relatively high rainfall, such as near Waitomo Caves (eg, NZA12768, 2024 ± 50 ^{14}C years BP; $\delta^{15}N$ = 3.9; RNH unpubl. data).

There is nothing in these isotopic data to indicate that the obtained radiocarbon ages would be affected in any way, and there is no source of ancient carbon in the system to be incorporated in the food chain as was shown to occur in, for example, Lake Taupo (Beavan-Athfield *et al.* 2001).

Speleothem age

A single uranium-series age (GNS R25433) was obtained from a speleothem in Te Waka #1; the sample was taken from the base of a stalagmite in C5 on its southern profile. The stalagmite was deposited coevally with Layer 5, resulting in its base being surrounded by the sediments of that layer. It was then completely buried by the Taupo Ignimbrite. It yielded an age of 29 600 CAL yrs BP (+1400, -1500 yrs) (Table 1). However, the very low activity ($^{230}Th/^{232}Th$) ratio (1.92) for this sample indicates the measured age is older than the true age (see Methods, and Schwarcz 1980) and so this age is discounted.

Table 1. Uranium-series results for the analysis of a calcite speleothem (GNS R25433) from the base of Layer 5, Te Waka #1 (see text regarding $^{230}Th/^{232}Th$ ratio).

	Bq/kg	SD
^{238}U	0.692	0.015
^{235}U	0.03187	0.00068
^{234}U	0.750	0.016
$^{234}U/^{238}U$	1.083	0.026
^{232}Th	0.0934	0.0047
^{230}Th	0.1790	0.0065
$^{230}Th/^{232}Th$	1.92	0.11
$^{230}Th/^{234}U$	0.239	0.010
AGE	29.6 ka	+ 1.4 , - 1.5 ka

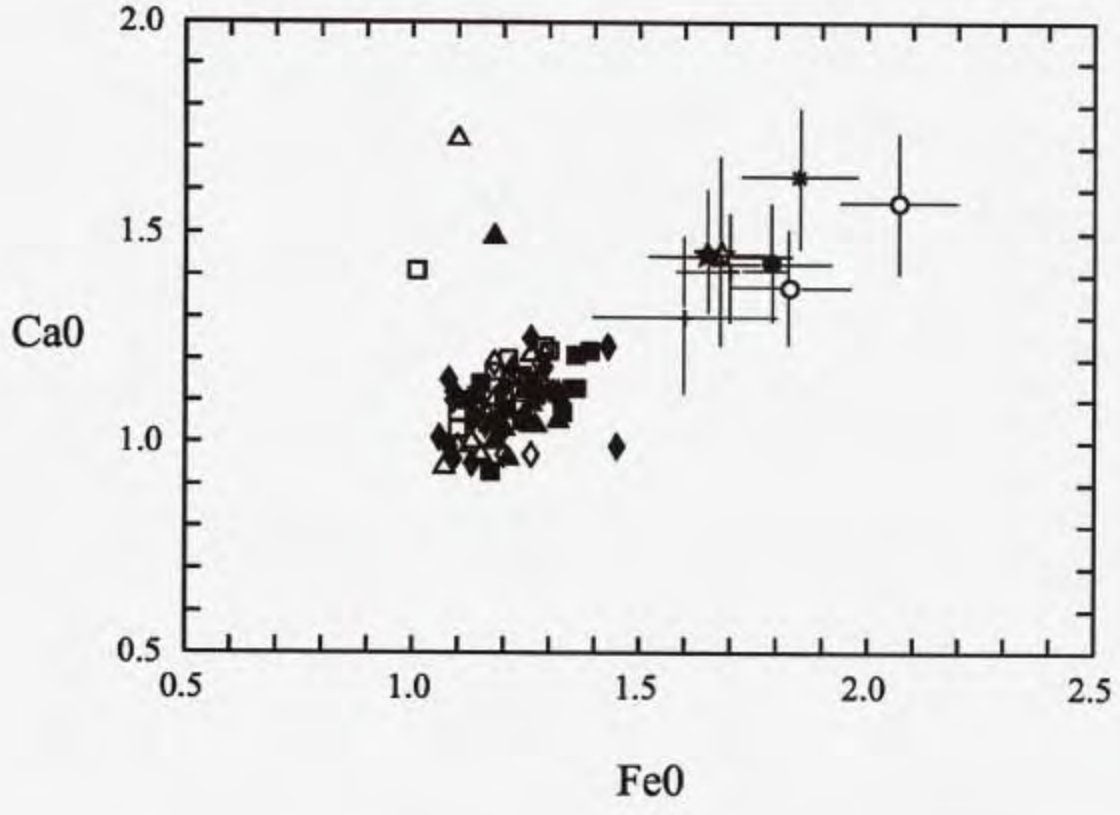

Fig 8. FeO versus CaO for glass shards (determined by EMP) of Kawakawa Tephra correlatives and younger distal tephras similarly derived from the Taupo Volcanic Centre.

Tephrochronology

Widespread distal tephras can provide key stratigraphic marker horizons for defining the temporal relationships of cover-bed sequences at sites where the stratigraphies and ages are not well known. Three macroscopic rhyolitic tephras were observed at the excavation site – though only the lowest tephra was geochemically analysed to verify its identity. The two uppermost tephras at an adjacent site have previously been identified as Taupo Ignimbrite and Waimihia Tephra (Unit S) (Holdaway & Beavan 1999). Both were erupted from the Taupo Volcanic Centre (Wilson 1993) and have been extensively recorded in near surface cover-bed successions throughout Hawke's Bay and adjacent regions. These tephras have conventional radiocarbon ages of 1850 ± 10 (n = 41) and 3230 ± 20 yrs BP (n = 17), respectively (Lowe *et al.* 1999).

The lowermost tephra, Layer 11, is here correlated with Kawakawa Tephra (Oruanui Ignimbrite) on the basis of stratigraphic position and associated radiocarbon chronology, mineralogy, and major element composition of glass shards. The most voluminous and widespread late Pleistocene silicic tephra, Kawakawa Tephra was erupted from the Taupo Volcanic Centre at approximately 26 500 calibrated years ago (Vucetich & Howorth 1976; Wilson *et al.* 1988; Froggatt & Lowe 1990; Pillans *et al.* 1993; Wilson 2001). This tephra has proven to be extremely useful in regional studies because it defines an isochronous horizon for correlation and age control of early LGM deposits, geomorphic surfaces, and associated soils. It is found extensively within North Island cover-bed successions (eg, Auckland, Sandiford *et al.* 2001; East Cape, Vucetich & Pullar 1969; Taranaki–Wanganui, Alloway *et al.* 1995, Pillans *et al.* 1993; Wairarapa, Palmer 1982), as well as South Island successions (eg, Canterbury, Kohn 1979, Nicol *et al.* 1994; West Coast, Campbell 1986, Mew *et al.* 1986, Almond 1996) and offshore marine environment (eg, Pillans & Wright 1992, Carter *et al.* 1995).

Mineralogically, Layer 11 is typically composed of vesicular and chunky glass shards (70–90%) with subordinate plagioclase and quartz (<10–15%). Layer 11 is also characterised by the presence of hornblende and hypersthene with subordinate augite and rare Fe-Ti oxides. The major element compositions of glass shards of Layer 11 were determined by electron microprobe (EMP) analysis (Table 2). Major element composition of glass shards from Layer 11 (AT-429) supports a Taupo Volcanic Centre origin and are indistinguishable from Kawakawa Tephra correlatives analysed from the Ruapehu District (AT-369 & AT-472), Taranaki (RSES-50819), and Auckland isthmus (AT-83 & AT-445). Despite Layer 11 being a secondarily reworked deposit, EMP analysis indicates that the glass constituents are homogeneous, as indicated by the generally low standard deviations (Table 2). Kawakawa Tephra and its correlatives can also be clearly distinguished from other distal tephras derived from the Taupo Volcanic Centre (Fig 8).

Summary of depositional history

The Te Waka #1 cave was undercut below harder limestone by the erosion of softer, more muddy limestone, initially along the intersection of two major joints. Subsequent roof collapse and stream erosion of the limestone slabs led to the formation of the cave before 22 590 ^{14}C yrs BP (26 500 CAL BP). Stream sediments (Layer 12) formed the lower layer in the cave 4.25 m below site datum (which was on the cave roof at the present entrance). The Kawakawa Tephra was erupted about 26 500 CAL BP (Froggatt & Lowe 1990), and the associated ignimbrite (Oruanui Ignimbrite) was deposited in the stream catchment and redeposited into the cave shortly after to form Layers 10 and 11 to a total thickness of 600 mm. The slope of the tephra surface down into the cave at the entrance suggests the cave had already been abandoned by the stream by that time and a debris pile had already formed at the entrance, on to which the tephra was deposited. From this time on no stream entered the cave.

Layers 8 and 9 were relatively gritty sands, which were probably deposited by sheet-flows of water flowing downslope from the entrance during rainstorms. The closely associated, though disarticulated, remains of a single parakeet skeleton indicate that flow energies were not great in Layer 9. A date of 18 640 ^{14}C yrs BP (NZA12460; 21 940–21 246 CAL BP) on a bone about 280 mm above the Kawakawa Tephra indicates a relatively slow period of deposition, or that perhaps dripping water was sufficient to erode fine sediment from the cave. From the layout of the cave, it is apparent that water flowed towards the back of the cave and then along the south-eastern wall towards the entrance (Fig 2). Deposition of Layer 8 ended at the same time as an unidentified eruption deposited fine red lapilli in the catchment. This tephra is stratigraphically consistent with

its being the Okareka Tephra, erupted about 18 000–19 000 ^{14}C yrs BP from the Okataina Volcanic Centre (Froggatt & Lowe 1990; Sandiford *et al.* 2001). The tephra was washed into the cave, presumably from the area about the entrance or off the overlying hillside, to form the thin layer visible in our excavation. In Hartree's excavation in the south-eastern (downhill and downstream) part of the site, the layer was 100–150 mm thick, as is shown in J. C. Yaldwyn's photographs taken in 1959 (Fig 9), when it was mistaken for the Waimihia Tephra.

After that, until about 16 000 ^{14}C yrs BP, as shown by NZA12475 (18 550-17 982 CAL BP), fine sands (Layer 7) were deposited, accumulating to a depth of about 600 mm in about 2000 years. There was a major roof collapse in the cave at some point in this period; at least two rock layers, about 1 m thick in total, spalled from much of the cave roof. The sands of Layer 7 were worked around these blocks by intermittent, low-energy sheetflows of water. The pile of rocks was particularly attractive to avian predators, which used the site as a roost or feeding station and left many bones to accumulate in the sands. Some moa nested in the cave at this time as well.

From about 18 000 to about 16 800 CAL BP, as shown by NZA12473, the deposition of fine sands ceased and dripping water from the roof created a lag deposit of small limestone clasts and concentrated bones, eggshell, and land snails in the 100 mm thickness of Layer 6.

About 14 046 ^{14}C yrs BP, as shown by NZA12473 (17 092-16 601 CAL BP), a further change in the hydrology of the catchment was marked by the onset of speleothem deposition and the contemporaneous deposition of red-brown clay-rich sediments. Deposition of similar clayey sediments on cave floors without water transport has been the norm in most lowland caves in humid sites in New Zealand throughout the Holocene (THW pers. observ). It is assumed that the result of higher temperatures and greater availability of water caused increased weathering of the cave walls and roof, providing a steady 'rain' of the non-soluble weathering products. The combination of higher temperatures and increased water availability, and the simultaneous establishment of dense shrubland or forest vegetation on the land above Te Waka #1 (as the onset of forest growth nearby at that time (McGlone 1988; Newnham *et al.* 1999) shows is likely), would have facilitated the biogenic supersaturation of groundwaters with the CO_2 necessary for speleothem growth.

Fig 9. Photograph of stratigraphy in Hartree's entrance trench taken in 1959 by John Yaldwyn. It is interpreted following the stratigraphy observed in Figures 5–7, as follows: the thin upper layer is Layer 2; a thick layer of Taupo Ignimbrite (Layer 3); the middle series of light, slightly darker, and light bands are Layers 4 and 5 and 6 in the drier form seen nearer the entrance. These are followed by a layer of grey sands (Layer 7). The next layer is a lens of reddish lapilli, which Hartree erroneously referred to the 'Waimihia Tephra' and which is possibly the Okareka Tephra. It is the thicker, downslope accumulation of the unidentified tephra we found in the base of Layer 7. Below that are more sands of Layers 7 and 8.

Table 2. Mean major element composition of glass shards from Layer 11, Te Waka and Kawakawa Tephra correlatives

		SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Cl	H_2O	n
AT-429*[1]	Layer 11, Te Waka	77.74	0.14	12.56	1.20	0.12	1.14	4.08	2.92	0.19	5.68	11
		(0.51)	(0.04)	(0.35)	(0.04)	(0.01)	(0.19)	(0.16)	(0.14)	(0.02)	(0.07)	
AT-472*[1]	Karioi,	77.99	0.12	12.49	1.25	0.12	1.10	3.80	2.92	0.19	7.15	13
	Ruapehu District	(0.31)	(0.04)	(0.22)	(0.05)	(0.01)	(0.13)	(0.12)	(0.10)	(0.02)	(0.58)	
	(S20/242918)											
AT-445*[1]	Pukaki Core-2	77.68	0.15	12.41	1.19	0.14	1.17	3.90	3.21	0.15	4.85	15
	Auckland	(0.38)	(0.04)	(0.30)	(0.08)	(0.01)	(0.10)	(0.20)	(0.23)	(0.02)	(1.25)	
	(R11/715674)											
AT-83*[1]	Mt Richmond,	78.08	0.12	12.29	1.26	0.11	1.11	3.77	3.13	0.14	7.95	11
	Auckland	(0.27)	(0.07)	(0.10)	(0.10)	(0.02)	(0.07)	(0.22)	(0.15)	(0.02)	(0.55)	
	(R11/742729)											
50819[‡2]	Inglewood, Taranaki	79.35	0.12	12.40	1.19	0.12	1.07	2.47	3.08	0.18	7.14	15
	(Q19/147267)	(0.30)	(0.03)	(0.12)	(0.11)	(0.01)	(0.09)	(0.37)	(0.10)	(0.02)	(0.98)	
Waipara	Omihi Stream,	77.55	0.15	12.65	1.20	0.15	1.08	3.87	3.12	0.23	6.10	19
Site-A[‡3]	North Canterbury	(0.43)	(0.05)	(0.26)	(0.13)	(0.03)	(0.09)	(0.19)	(0.17)	(0.03)	(1.04)	
	(N34/915943)											
50334-40*[2]	Whangamata Road	79.01	0.13	12.15	1.15	0.12	1.05	3.31	3.07	—	5.65	74
	Type Section	(0.38)	(0.03)	(0.30)	(0.10)	(0.02)	(0.19)	(0.21)	(0.25)		(1.62)	
	(T17/619830)											

Note: ‡Analyses made using a JEOL JXA-733 electron microprobe housed at Victoria University of Wellington. A beam current of 80nA and a 20 μm beam diameter were used for all analyses. * Analyses made using a Cameca SX-50 wavelength dispersive microprobe operating at 15 keV accelerating voltage and housed at University of Toronto. Beam current of 15 nA and a 10-20 mm beam diameter were used for all analyses. All elements calculated on a water-free basis, with H_2O by difference from 100%. All Fe expressed as FeO. Mean and ± 1 SD (in parentheses) based on *n* analyses. [1]Analyst – B. V. Alloway, [2]Analyst – P.C. Froggatt, [3]Analyst – D. Manning.

Throughout the Holocene, autochthonous deposition was slow; only 250 mm was deposited in the period 14 000 to 1850 ^{14}C yrs BP, and this included some reworked Waimihia Tephra in its upper part. Then, at 1850 ^{14}C yrs BP (c. AD 200, 1750 CAL BP) the rear parts of the cave received a primary deposit of at least 1 m of Taupo Ignimbrite. This tephra arrived with sufficient violence to knock stalactites from the roof and carry branches into the cave, and it was hot enough to have carbonised all leaves and branches. The environment surrounding the cave must have been severely impacted. However, in a relatively short time, moa were back in the area and nesting in the cave. Only 100 mm of sediment was deposited on top of the Taupo Ignimbrite before European influences began in the 1870s.

Site taphonomy

Taphonomic processes are the processes by which the fossils in a site are accumulated and preserved. The identification of these processes is essential to an understanding of the composition of the fossil fauna and its relationships to the living faunas from which it was drawn. Several different taphonomic processes operated in Te Waka #1 sequentially and simultaneously.

The site was used by moa for shelter and nesting, which provided a primary source of fossils in the form of eggshell fragments and bones from the rare random death of individuals sheltering in the cave. Moa eggshell was abundant in all non-tephra post-Kawakawa levels and, judging by the presence of two classes of thickness, represented at least two species of moa. Some moa died in the site, including individuals of *Euryapteryx curtus* and *E. geranoides* in the Pleistocene levels, and *Anomalopteryx didiformis* and *Dinornis struthoides* in the Holocene levels. The nesting and other activities of these large birds resulted in much trampling and disturbance of the sediments and associated damage to bones on the surface at the time. Bones that lay on the surface for any length of time in the humid Holocene became weathered and were also often coated in calcite speleothems, as were, for example, those of an *Aptornis* that died in the early Holocene. The inward slope of the cave floor and the trampling of moa resulted in most bones accumulating against the wall, where overhangs gave them some protection.

The second, and most important, source of fossils was the activity of predatory birds. The abundance of bones with greenstick fractures and digestion features is evidence of dismemberment, if not actual killing, of prey, and ingestion of their bones (Andrews 1990). In New Zealand, the only predators were birds, with the laughing owl (*Sceloglaux albifacies*) responsible for most deposits (Worthy & Holdaway 1994b, 1996b; Worthy 1997, 2001). The New Zealand falcon (*Falco novaeseelandiae*) and Eyles's harrier (*Circus eylesi*) also accumulated several deposits (Worthy 1997; Worthy & Holdaway 2002).

The identity of the predator is indicated by a combination of the species composition of the fauna and the representation of, and damage to, the skeletal elements. Falcons primarily hunt diurnal prey. Smaller taxa such as quail and parakeet are their favoured prey size, though pigeons are also taken occasionally. Falcon prey remains usually consist of very digested bones, with few complete elements. Similarly, the faunas attributed to Eyles's harrier from Hukanui 7A (Worthy & Holdaway 2002) include mainly diurnal species, but the bones found in the deposits are mostly the distal wing and leg elements and part of the sternum, the parts of the body that were not ingested. A few very heavily digested bone fragments were also present. The large harrier took mainly larger species; pigeons (*Hemiphaga novaeseelandiae*) and kokako (*Callaeas wilsoni*) were very common in its diet. In contrast, the laughing owl took mainly nocturnal prey, usually weighing 100–200 g. Among the diurnal species that were taken, parakeets and similar-sized birds were common, but larger species, including pigeons, young kiwi, and weka, were taken occasionally. The bone remains in laughing owl accumulations often show some digestion features, but few elements are heavily digested and most elements are represented, some of which are complete. The actual damage observed depends on the prey species and the relative robustness of its bones (Worthy & Holdaway 1994b, 1996b; Holdaway & Worthy 1996).

Element survival in prey species

As the mottled petrel (*Pterodroma inexpectata*) was one of the main prey species at Te Waka #1, we compared the survival patterns of its elements there with those of petrels in Hermits Cave (West Coast, South Island), where the predators were laughing owls (Worthy & Holdaway 1994b), and with those observed at falcon feeding stations in the Auckland Islands (Table 3). The petrel remains at Te Waka #1 were dominated by pectoral girdle (coracoid, sternum,

Table 3. Element representation for *Pterodroma inexpectata* from the 1999–2000 excavations at Te Waka #1 compared to similar data from *Pachyptila turtur* from Hermits Cave (Worthy & Holdaway 1994b) and *Pachyptila* spp. from falcon roosts on Auckland Islands (Worthy & Hyde, unpubl. data). The elements listed from Te Waka #1 were derived from all squares and levels below Layer 5 and represent a minimum of 19 individuals, as determined from ulnae. The analysed sample of 305 bones is less than the total sample of 346 bones as shafts and other fragments were not counted. The column headed %E shows the proportion that N represents for the minimum number of individuals (MNI) represented by the sample (assuming that bilateral elements number potentially 2xMNI and that an individual has 18 presacral vertebrae and 15 phalanges in a foot, including the metatarsal). Where elements have (pt) appended, it means either whole or incomplete bones were included.

Element	N, Te Waka	% E MNI=19 Te Waka	N, Hermits	%E MNI=28 Hermits	N, Akd Is.	%E MNI=8 Akd Is.
Crania (pt)	2	10.5	7	25.0	0	0
Sterna (pt)	13	68.4	13	46.4	3	37.5
Pelvis synsacra (pt)	1	5.3	8	28.6	0	0
Mandible rami	5	13.2	2	3.6	0	0
Premaxillae	7	36.8	2	7.1	0	0
Furculae (pt)	9	47.4	11	39.3	2	25.0
Vertebrae (presacral)	17	5.0	230	45.6	11	7.6
Coracoids (pt)	28	73.7	450	89.3	6	37.5
Scapulae (pt)	18	47.4	28	50.0	4	25.0
Humeri	20	52.6	8	14.3	13	81.2
Humeri proximal	3	7.9	8	14.3	0	0
Humeri distal	3	7.9	5	8.9	0	0
Ulnae	19	50.0	35	62.5	14	87.5
Ulnae proximal	3	7.9	10	17.8	0	0
Ulnae distal	10	26.3	5	8.9	0	0
Radii	14	36.8	9	16.1	14	87.5
Radii proximal	9	23.7	44	78.6	0	0
Radii distal	12	31.6	42	75.0	1	6.2
Carpometacarpi (pt)	28	73.7	27	48.2	12	75.0
Manual phalanges 1.1, 2.1, 2.2	28	24.6	95	56.5	33	68.3
Femora	1	2.6	17	30.3	1	6.2
Femora proximal	4	10.5	7	12.5	3	18.7
Femora distal	1	2.6	10	17.8	2	12.5
Tibiotarsi	2	5.3	8	14.3	0	0
Tibiotarsi proximal	2	5.3	22	39.3	2	12.5
Tibiotarsi distal	6	15.8	12	21.4	2	12.5
Tarsometatarsi	10	26.3	23	41.1	3	18.7
Tarsometatarsi proximal	2	5.3	10	17.8	0	0
Tarsometatarsi distal	2	5.3	10	17.8	1	6.2
Pedal phalanges	26	4.6		NA	19	7.9
	305		1158		146	

Table 4. List of vertebrates known as fossils from Te Waka #1, derived from identification of 2093 bones excavated in 1999–2000 and those of Hartree's excavations listed in Worthy & Holdaway (2000).

Layer	2	2	4&5	4&5	6	6	7	7	8	8	9&10	9&10	Hartree
Species	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	X/y
Anomalopteryx didiformis			32	1									3/1
Euryapteryx curtus							9	1					4/1
Euryapteryx geranoides													1/1
Pachyornis mappini													1/1
Indet emeid sp.			3				2				1	1	
Dinornis struthoides			12	1									
Apteryx mantelli			6	1	2	1	10	2			1	1	12/1
Apteryx owenii							2	1					
Apteryx sp.							4	1					
Pterodroma inexpectata	4	2	18	3	98	8	346	19	4	2	7	1	266/27
Pterodroma cookii							1	1					256/16
Garrodia nereis							2	1					
Cnemiornis gracilis													31/1
Chenonetta finschi					7	2	8	1					54/3
Falco novaeseelandiae													
Coturnix novaezelandiae	10	1	1	1	2	1	9	1					5/2
Aptornis otidiformis			64	1									
Fulica prisca									2	1			
Gallirallus australis	9	1	6	1	2	1	1	1					10/2
Capellirallus karamu			2	1									
Gallinula hodgenorum													11/3
Charadrius bicinctus							2	1					
Coenocorypha barrierensis			2	1			11	1			2	1	1/1
Hemiphaga novaeseelandiae			14	3									14/1
Strigops habroptilus			9	1	4	1							5/1
Nestor meridionalis			9	1	2	1							6/2
Cyanoramphus spp.	28	3	84	6	17	3	32	2	16	1			36/8
Ninox novaeseelandiae	12	1											
Aegotheles novaezealandiae	1	1	40	3	3	1	4	1					20/5
Acanthisitta chloris	3	1	62	5	4	2	11	3					2/2
Xenicus spp.	1	1	33	4	7	2	9	2					9/4
Pachyplichas jagmi			6	2	4	1	6	2					1/1
Traversia lyalli													1/1
Anthus novaeseelandiae			3	1	2	1	14	2					6/3
Mohoua albicilla	5	2	46	3	1	1	1	1					4/1
Petroica longipes	2	1	141	9	5	2	12	2					57/5
Petroica toitoi	19	1	3	2									3/2
Notiomystis cincta			1	1									1/1
Anthornis melanura	30	2	6	2	1	1							
Prosthemadera novaeseelandiae	8	1											1/1
Callaeas wilsoni	3	1	10	3	2	1							32/2
Philesturnus rufusater	3	1	4	2									6/1
Turnagra tanagra	1	1											17/3
Heteralocha acutirostris			1	1									
Totals	139	21	618	60	163	30	496	46	22	4	11	4	
Chalinolobus tuberculatus			1	1									
Mystacina robusta			11	1	3	1	2	1					
Mystacina tuberculata			5	2									3/1
Rattus exulans	353		4										
Gecko 2 spp	1		68		4		12						
Skink 2 small spp	7		101		4		40		3		4		
Cyclodina alani			3	1									
Leiopelma hochstetteri			2	1									
Leiopelma hamiltoni			2	1									
Leiopelma markhami	3	1	5	1									
Leiopelma hamiltoni/hochstetteri			6										
Sphenodon sp.													4/1
Total vertebrates	503	22	826	68	174	31	550	47	25	4	15	4	
Total bones 1999-2000	2093												