Helictite, (2019) 45**:** 39-50

A preliminary study of the use of hind limb skeletal elements to identify Australian rodent species (family Muridae) from Quaternary fossil cave deposits

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Abstract

The hind limb bones from small mammals are some of the more abundant elements found within cave fossil deposits and may be useful for species identification where craniodental elements are lacking. In this paper the usefulness of the hind limb elements (tibiofibula and femur) for species-level identification of eight native Australian rodents (family Muridae) from six South Australian genera is studied. A qualitative and quantitative methodology was adopted and observed differences assessed in hind limb bone morphology. Differences are reported between species on each of the two hind limb elements allowing identification of bones to species level. Identification keys are constructed using the most common identifiable features of limb elements. Identification of the femur could be made using measurements, while the tibiofibula required both quantitative measures and qualitative observed differences. Measures were taken using only digital vernier callipers and support one of the aims of the study: to be able to identify the limb bones to species level in the field without any specialised equipment. Results support that the observed and measured morphological differences between hind limb elements can be used to accurately identify the eight studied Australian murid rodents to a species level.

Key words: *mammal, rodent, Muridae, postcranial elements, Quaternary, caves.*

Introduction

Mammal fossil bone assemblages are found in caves worldwide and provide insight into the environment, flora and fauna of the past (see Barnosky and others 2004, Fernandez-Jalvo 1996, Jass and George 2010, Price and others 2019). The bones within these deposits can represent time scales of hundreds to thousands of years and preserve evidence of the animals surrounding the location, predator interactions and environmental conditions. Palaeoecological data gained from small body-sized mammals offer finer resolution than larger mammals due to their smaller home range and high sensitivity to environmental change (López Antoñanzas and Cuenca Bescós 2002). This allows elucidation of changes in species range, relative abundance and ecosystem stability over time (Macken and Reed 2014, Brace and others 2012). Small mammal remains are prevalent in cave deposits, where accumulating agents such as predatory birds may concentrate deep deposits of bones (Andrews 1990). In particular, rodent species are often the most numerous in Quaternary cave deposits due to their high diversity, abundance in the community surrounding caves and susceptibility to predation by avian threats such as owls (Andrews 1990).

For many years small mammals from Quaternary deposits were disregarded by researchers in favour of their larger relatives (Andrews 1990). In the last 30 years smaller mammals have had something of a resurgence in palaeontological research. Key sites such as Gran Dolina in Spain (Campaña Lozano and others 2017, Fernandez-Jalvo 1995, 1996, Fernandez-Jalvo and Andrews 1992, López Antoñanzas and Cuenca Bescós 2002), areas of North-West Europe (Brace and others 2012) and in Australia the Mt. Etna and Naracoorte regions (Cramb and others 2018, Hocknull and others 2007, Macken and Reed 2013, 2014) have yielded data from small mammal assemblages to increase understanding of the palaeoenvironment over the middle to late Pleistocene.

Palaeoecological reconstructions are based on the diversity and abundance of species preserved within a fossil deposit as a proxy for the original faunal community. Determining the preferred habitat and ecological niche of these species allows inferences regarding the environment present at the time their bones were deposited into the assemblage. The correct identification of species within the deposit is of paramount importance when drawing accurate conclusions about past environments and faunal interactions.

Species identification is typically based on cranial elements (teeth, skulls and jaws) found within a fossil assemblage (Ungar 2010, Thies and others 2012). This is because these elements possess unique diagnostic characters that are preserved well in fossil specimens. Thies and others (2012) noted that both the maxilla and mandible are required for genus level identification in rodents and that recovering pairs of jaws from a single individual in fossil sites is rare. Consequently, the more numerous postcranial elements of rodents could offer an alternative for species identification when sorting through bulk fossil material or completing field investigations of an *in situ* assemblage.

The diagnostic characters of Australian rodent dentitions have been documented by several authors (Crowther 2002, McDowell and Medlin 2009, Watts and Aslin 1981). However, the morphological differences in limb elements have not been presented. Matisoo-Smith and Allen (2001) reported femoral length differences within distinct geographical populations of *Rattus exulans* throughout island habitats of the Pacific. Differences in femoral length of almost 10 mm were reported across locations with the authors concluding that the current method of identification is difficult in the pacific rat. Limb bones of tupaiids (Mammalia, Scandentia) have been shown to have significant morphological differences within a genus related to the substrate in which it lives (Sargis 2002a, 2002b, 2002c). Koper (2014) concluded that morphological differences in the forelimbs of *Canis dirus* and *C. lupus* can be used to identify species when there is an absence of dental material. Veatch and others (2019) used limb bone measurements to assess body size classes in rodent fossil assemblages from Liang Bua Cave in Indonesia as a means to assess palaeoenvironmental and habitat change during the late Pleistocene.

This paper presents a preliminary investigation of a method for identifying some Australian rodent species (family Muridae) based on hind limb proportions and the viability of this technique for use in palaeontological and archaeological investigations. The aim of the study was to determine if species level identifications can be made from disarticulated rodent hind limb elements which are abundant in Quaternary cave deposits, offering an alternative to teeth if the latter are poorly represented in the assemblage.

Methods and Materials

Comparative skeletal material from seven extant and one extinct Australian rodent species (family Muridae) were examined from the sub-fossil and mammal collections of the South Australian Museum and the ornithology and mammalogy sections of Museum Victoria. The study species were chosen based on their presence in many south-eastern Australian Quaternary cave sites such as the Naracoorte Caves in South Australia. The species studied and number of specimens are reported in Table 1. The average live body weight of the study species was determined based on values in Watts and Aslin (1981), Van Dyck and Strahan (2008) and Menkhorst (2004). Tools used for measurements were a set of calibrated digital vernier callipers (150 mm TradeQuip™ part number #4001) modified by removal of a 7 mm notch from the back of the secondary jaws in order to fit the measuring surface between the tibiofibula fusion point. Hind limbs were chosen for this study as they are robust, numerous and easily identifiable within a cave fossil deposit.

Table 1. Rodent species examined for this study and number of specimens (N) measured for each.

Species	N
Leporillus conditor	15
Hydromys chrysogaster	12
Mastacomys fuscus	8
Notomys mitchelllii	6
*Pseudomys gouldii**	12
Pseudomys shortridgei	12
Rattus fuscipes	8
Rattus lutreolus	7

* extinct species

Rodents have a specialised tibia and fibula complex, hereafter referred to as a tibiofibula. This complex fuses shortly after birth (Moss 1977) and is useful in distinguishing rodents from other small mammals within a bone assemblage in the absence of cranial elements. A total of 16 measures adapted from Sargis (2002c) were taken for the femur and the tibiofibula as shown in Figures 1A and 1B.

Two measurements for each limb element were taken and averaged to minimise measurement error (see Blackwell and others (2006)). Fourteen indices were calculated (nine femur and five tibiofibula, reported in Table 2) and measure different ratios between osteological features in a single bone. These indices also allow comparison between different sizes of rodent limb bones and account for differences among adults and juveniles of a species. Mid-point measures for the medio-lateral and antero-posterior diaphysis width were taken at the point marked by half of the total limb bone length. Observed qualitative features of each limb element such as rolling of the tibial crest and completeness of tibiofibula fusion were also recorded.

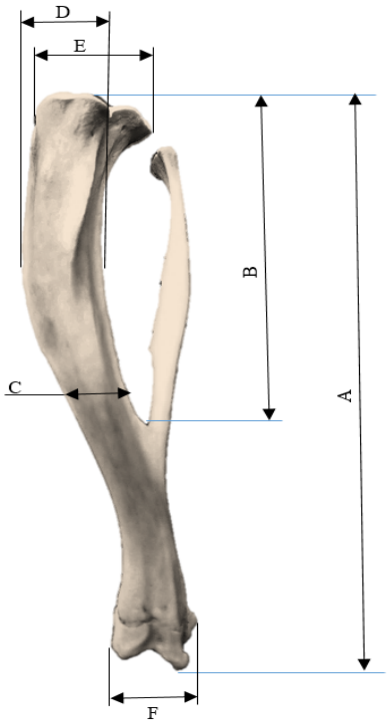


Figure 1A. Measurements taken from tibiofibula of Australian rodents (family Muridae);
A) total length, B) fusion point, C) Medio-lateral diaphysis width, D) diaphysis width at crest, E) proximal epicondyle width, F) distal epicondyle width. (Note. Antero-posterior diaphysis width was measured at the same point as medio-lateral diaphysis width as indicated in text.)

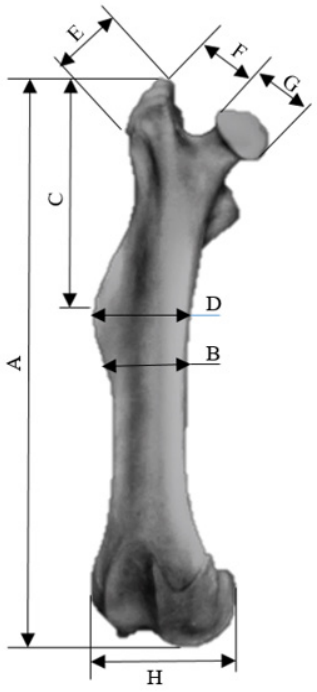


Figure 1B. Measurements taken from femur of Australian rodents (family Muridae) species in this study; A) total length, B) medio-lateral diaphysis width, C) third trochanter length, D) third trochanter width, E) length of greater trochanter, F) neck width, G) head width, H) distal epicondyle width. (Note. Antero-posterior diaphysis width was measured at the same point as medio-lateral diaphysis width as indicated in text.)

Table 2. Ratios and formulae calculated for limb bone measurements during this study

Description	Formula
Femoral diaphysis width index	(Femoral medio-lateral diaphysis width / Femoral total length) X 100
Femoral diaphysis thickness index	(Femoral antero-posterior diaphysis width / Femoral total length) X 100
Femoral third trochanter crest width index	(Femoral width of third trochanter crest / Femoral total length) X 100
Femoral third trochanter crest length index	(Femoral length of third trochanter / Femoral total length) X 100
Femoral third trochanter relative crest size index	([Femoral width of third trochanter - Femoral medio-lateral width] / Femoral total length) X 100
Femoral head length index	(Femoral largest head width / Femoral total length) X 100
Femoral head/neck ratio index	(Femoral largest head width / Femoral neck width) X 100
Femoral epicondyle/greater trochanter ratio index	(Femoral distal epicondyle width / Femoral length of greater trochanter) X 100
Femoral medio-lateral/epicondyle ratio index	(Femoral medio-lateral diaphysis width / Femoral distal epicondyle width) X 100
Tibiofibula diaphysis width index	(Tibiofibula medio-lateral diaphysis width / Tibiofibula total length) X 100
Tibiofibula diaphysis thickness index	(Tibiofibula antero-posterior width / Tibiofibula total length) X 100
Tibiofibula crest size index	(Tibiofibula diaphysis width at crest / Tibiofibula total length) X 100
Tibiofibula fusion point index	(Tibiofibula fusion point / Tibiofibula total length) X 100
Tibiofibula epicondyle ratio index	(Tibiofibula distal epicondyle width / Tibiofibula distal epicondyle width) X 100

Data were entered in SPSS™ for Windows. A one-way ANOVA was performed for the measured limb element data to report standard deviations and mean within each raw measure and computed ratio. A Post-Hoc Tukey HSD comparison for each limb bone and limb bone measure was executed to create species-based groups based on significant differences for each hind limb bone measure. The significance value was set at 0.05 ($p < 0.05$). Keys for each element were constructed using significant differences within each limb element. The most common differences were used to allow the simplest identification to species level. Specimen details are reported in Appendix 1.

Results

Overall limb length

An increase in mean length of the femur and tibiofibula is generally consistent with an increase in the total average animal live weight (Figure 2A and Table 3). A notable exception is the tibiofibula and femur of *Notomys mitchellii* indicated at point 'A' in Figure 2A. Despite being one of the smaller species by live weight (avg. 52 grams), *N. mitchellii* has the third longest mean tibiofibula length at 36.5 mm. Figure 2B shows an image of the difference in size from *N. mitchellii* to *H. chrysogaster*.

The femur of *N. mitchellii* is longer than expected if a linear relationship existed between femur length and live animal weight. Notomys *mitchellii* has a live weight approximately the same as *Pseudomys gouldii* (52 g and 50 g respectively); however, the femur length of 25.8 mm is similar to that of heavier species *Rattus fuscipes* (27.1 mm, mean weight 125 g, $p = 0.991$), *Rattus lutreolus* (28.2 mm, 122 g, $p = 0.724$), *Mastacomys fuscus* at (30.1 mm, 122 g, $p = 0.084$) and slightly longer than *P. shortridgei* (24.79 mm, 70 g, $p = 0.996$). The other species of a similar live weight, *P. gouldii*, had a mean femur length of 18.6 mm, significantly shorter than *N. mitchellii* ($p < 0.001$).

Tibiofibula quantitative index measure

Measurements of the tibiofibula between species showed differences in diaphysis width index, diaphysis thickness index, tibiofibula crest size index and tibiofibula fusion point index (Table 3).

Diaphysis width index for *N. mitchellii* was significantly smaller (4.6) than all other species examined with *P. gouldii* (5.2, $p = 0.031$) and *M. fuscus* (5.3, $p = 0.003$) closest on the post-hoc Tukey HSD. The tibiofibula diaphysis thickness index was not significantly different from other species. The tibiofibula of *H. chrysogaster* shows a significantly higher diaphysis thickness index (9.0) than its closest comparator, *Leporillus conditor* (6.4, $p < 0.001$), but the diaphysis width index (6.5) is not significantly different from that of other large species (*L. conditor*, $p = 0.926$, *R. lutreolus*, $p = 0.103$). No other species showed significant differences in the diaphysis thickness index or diaphysis width index. Tibiofibula crest size index showed only one identifiable species, *H. chrysogaster*, with a significantly larger crest index at 12.1 ($p < 0.001$) than other species. No other species is directly identifiable. The tibiofibula fusion point for *N. mitchellii* was significantly closer to the proximal end of the tibiofibula than any other species at an index point of 44.6. The other seven species ranged from 49.9 (*M. fuscus, p* < 0.001) to 55.8 (*H. chrysogaster, p* < 0.001). *Rattus fuscipes* had a significantly different tibiofibula fusion point index from *R lutreolus* (51.1 and 55.8 respectively, $p < 0.001$).

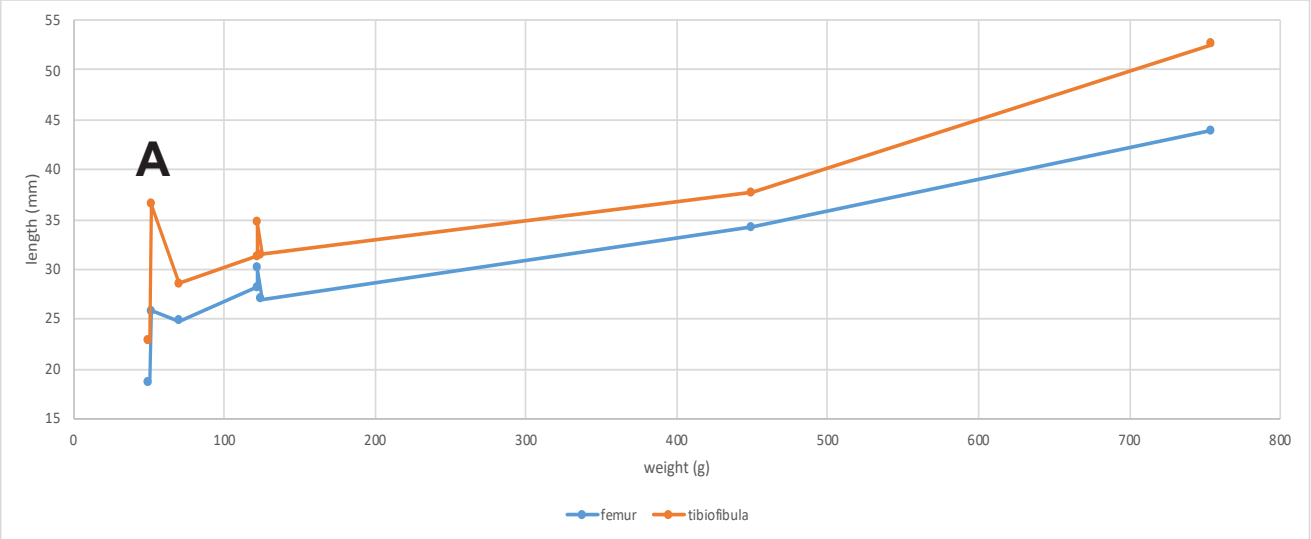


Figure 2A. Average live weight vs. average hind limb length of measured Australian murid rodents selected in this study. Sizes for species are reported in Table 3.

Figure 2B. Tibiofibulae and femora of selected species present in this study. From left to right: *N. mitchellii, P. shortridgei* (femur only), *R. lutreolus, R. fuscipes, L. conditor, H. chrysogaster.* Scale bar = 10 mm.

Tibiofibula qualitative measures

Three qualitative differences were also observed in the tibiofibula. *Hydromys chrysogaster* showed a flattening of the proximal side of the medio-lateral face of the tibial crest. This flattening occurred between the proximal epiphysis and the tibiofibula mid-point and is represented in Figure 3A. *Mastacomys fuscus* showed a pronounced 'rolling' of the tibial crest (Figure 3B). This 'rolling' occurred on the posterior of the proximal end of the tibial crest and curved from the lateral towards the medial side of the bone. *Leporillus conditor* showed an observable difference in the fusion of the tibia and fibula (Figure 3C). The fusion point index is not significantly different from other species at 54.4 (e.g. *H. chrysogaster,* $p = 0.935$) but there is a separation of the fusion of the two bones towards the distal end. No other species showed this trait and all had more complete fusion.

Femur quantitative index measures

Femur diaphysis width index showed identifiable differences in two species at the lower and upper end of the results. *Notomys mitchellii* showed the smallest value at 7.3, significantly smaller than all other species including *P. gouldii* (9.7, $p < 0.001$) which is similar in live weight. *Hydromys chrysogaster* was significantly larger than all other species with a result almost twice as large as *N. mitchellii* at 14.4 and significantly larger than *L. conditor* (11.6, $p < 0.001$). Diaphysis thickness index showed no species with significant differences from all other species. *Leporillus conditor* (9.2) and *H. chrysogaster* (9.4) were significantly larger than all other species observed, although the difference between these species was not significant ($p = 0.929$). Third trochanter crest width index allowed two species to be identified. *N. mitchellii* was significantly smaller than all other species at 11.6 ($p < 0.001$) and *H. chrysogaster* was significantly larger than all other species at 17.1 ($p < 0.001$). All other species showed no significant differences among them. Third trochanter crest length index showed two species were significantly different: *Leporillus conditor* (38.2, $p = 0.002$) and *Hydromys chrysogaster* (45.7, $p < 0.001$).

Femur head/neck index showed that only one species, *L. conditor,* was significantly different from all other species at an index of 177.8, *R. lutreolus* was the closest with an index of 153.1 but remained significantly different ($p = 0.020$). Femur medio-lateral diaphysis/epicondyle width index showed that only *N. mitchellii* had a significantly different measurement index from all other species at 47.9 ($p < 0.001$).

Table 3. Average computed hind limb ratios and measurements from eight Australian rodent species (family Muridae).

		FEMUR									
Species	live weight (g)	Femur total length (mm)	Diaphysis width index	Diaphysis thickness index	Third trochanter crest width index	Third trochanter crest length index	Relative third trochanter size index	Femur Head Length index	Femur Head Neck Index	Femur epicondyle/ greater trochanter index	Femur mediolateral/ epicondyle index
H. chrysogaster	755	43.9	14.4*	9.4	17.1*	45.7*	2.7	12.0	127.4	195.1	56.6
L. conditor	450	34.2	11.6	9.2	14.8	38.2*	3.2	11.4	177.8*	149.1	57.3
R. fuscipes	125	27.1	10.7	8.3	14.4	34.9	3.7	9.7	140.1	179.7	60.9
M. fuscus	122	30.1	10.3	7.7	14.7	35.1	4.4	10.0	152.9	169.5	57.5
R. lutreolus	122	28.2	10.1	8.2	14.5	35.4	4.4	10.0	153.1	169.8	54.2
P. shortridgei	70	24.8	9.1	7.4	13.3	32.7	4.2	9.2	151.8	148.0	55.6
N. mitchellii	52	25.8	7.3*	7.0	11.6*	28.6	4.2	8.5	128.3	136.3	47.9*

		TIBIOFIBULA					
Species	live weight (g)	Tibiofibula total length (mm)	Tibiofibula diaphysis width index	Tibiofibula diaphysis thickness index	Tibiofibula crest size index	Tibiofibula fusion point index	Tibiofibula epicondyle index
H. chrysogaster	755	52.6	6.5	9.0*	12.1*	53.5	79.7
L. conditor	450	37.7	6.3	6.4	9.7	54.4	67.7
R. fuscipes	125	31.5	5.7	5.8	8.3	51.1	81.6
M. fuscus	122	34.7	5.3	5.9	6.4	49.9	72.9
R. lutreolus	122	31.3	6.1	6.1	9.1	55.8	75.2
P. shortridgei	70	28.6	5.4	6.0	8.4	52.1	85.6
N. mitchellii	52	36.5	4.6*	6.0	7.2	44.6*	77.8
P. gouldii	50	22.8	5.2	5.5	7.7	55.5	63.9

* significant difference $p < 0.05$

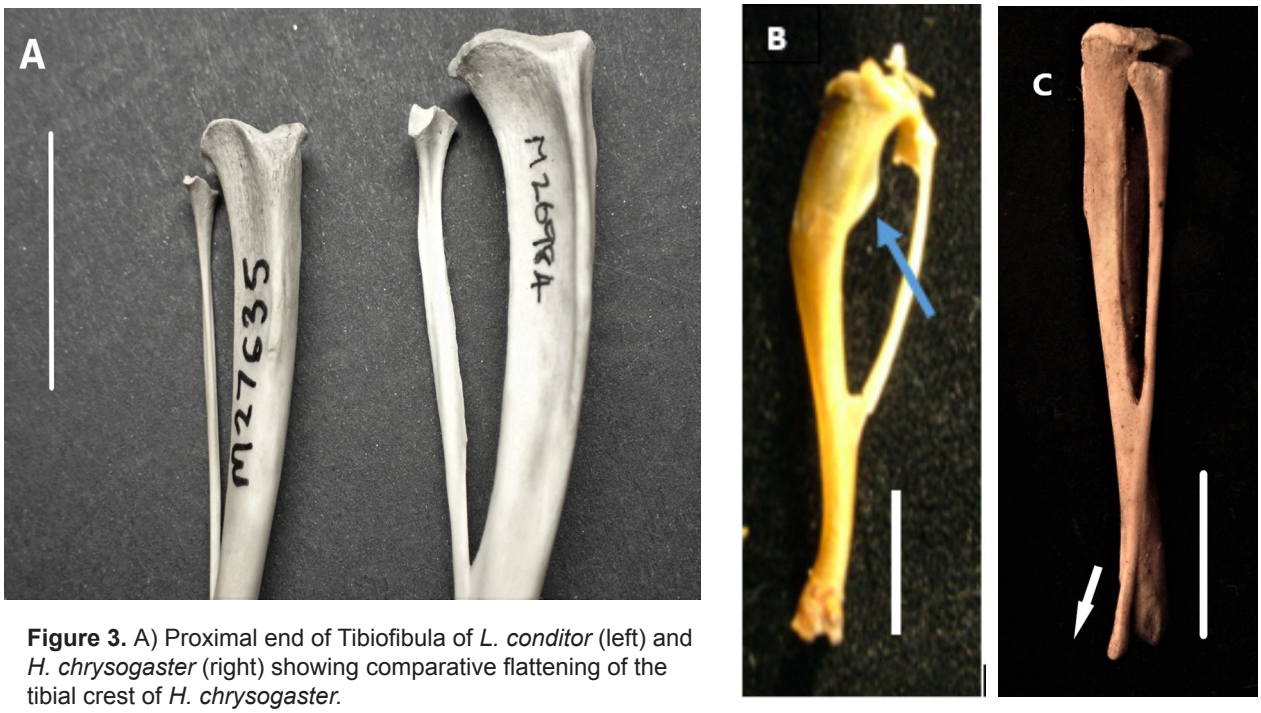


Figure 3. A) Proximal end of Tibiofibula of *L. conditor* (left) and *H. chrysogaster* (right) showing comparative flattening of the tibial crest of *H. chrysogaster.*

B) Tibiofibula of *M. fuscus* showing rolling of the tibial crest (indicated by arrow),

C) Tibiofibula from *Leporillus conditor* showing the 'Fusion Separation' described in the text (indicated by arrow). Scale bar = 10 mm.

Identification keys

The tibiofibula key is shown in Figure 4. In this key qualitative osteological features of separation in tibiofibula fusion (see Figure 3C) and rolling of the tibial crest (Figure 3B) identify *L. conditor* and *M. fuscus* respectively. Total tibiofibula length differentiates *H. chrysogaster* (< 45.5 mm), *P. shortridgei* (24.5 to 30 mm) and *P. gouldii* (< 24.5 mm). The tibiofibula fusion point is able to identify the remaining three species. *N. mitchellii* has a fusion point less than 47, *R. fuscipes* has a fusion point between 47 and 53.5 and *R. lutreolus* has a fusion point greater than 53.5. These values are based greater than one standard deviation from the mean of total length and tibiofibula fusion point to eliminate error through crossover of standard deviations.

The femur identification key is shown in Figure 5. Total femur length was able to identify *P. gouldii* with a length less than 21 mm. The remaining seven species were then divided into the larger species above 30 mm, *H. chrysogaster* (mean = 43.9 mm), *L. conditor* (mean = 34.3 mm) and *M. fuscus* (mean = 30.1 mm), and other species *R. fuscipes* (mean = 27.1 mm), *R. lutreolus* (mean = 28.2 mm), *P. shortridgei* (mean = 24.8 mm) and *N. mitchellii* (mean = 25.8 mm). *Hydromys chrysogaster* has a femur length above 30 mm with a diaphysis width index greater than 13.3, both *L. conditor* and *M. fuscus* have a total length above 30 mm and a diaphysis width index smaller than 13.3. Third trochanter crest length index was able to separate *L. conditor* (above 36.5) and *M. fuscus* (below 36.5). In species with a total femur length between 21 mm and 30 mm, diaphysis width index was able to identify *N. mitchellii* (< 8.2) from *P. shortridgei*, *R. fuscipes* and *R. lutreolus*. *Pseudomys shortridgei* has a third trochanter crest width index less than 13.8 while *R. lutreolus* and *R. fuscipes* have a value above 13.8. *Rattus lutreolus* and *R. fuscipes* showed a significant difference ($p = 0.007$) on medio-lateral epicondyle index with *R. lutreolus* less than 57.5 and *R. fuscipes* greater than 57.5.

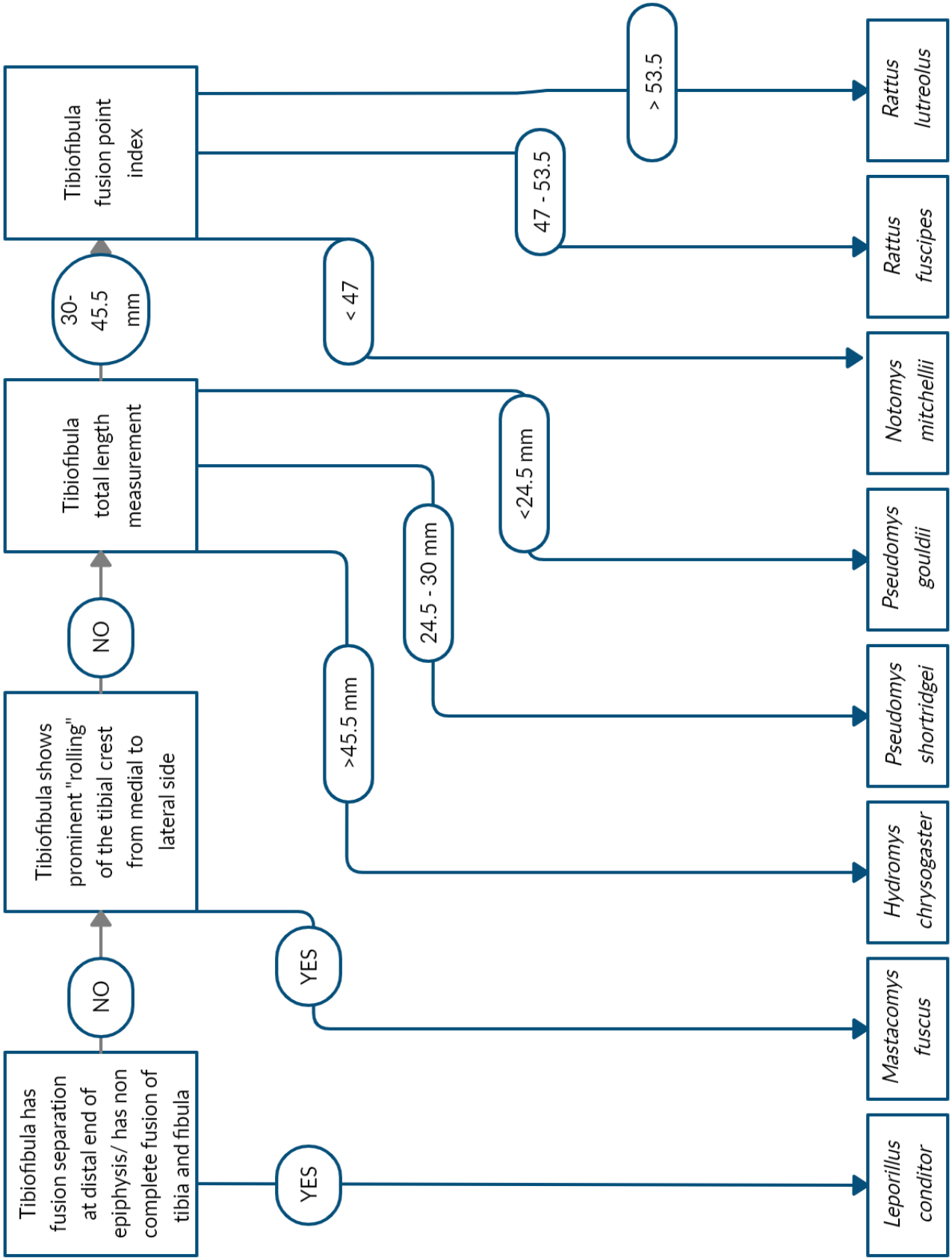
Discussion

The increase in total length of hind limbs (femur and tibiofibula) in relation to the average live weight of the species studied here represented an almost linear relationship for all species except *N. mitchellii* (Figure 2A). *N. mitchellii* had a longer tibiofibula and femur than its relatively low live weight (52 g) would suggest. The longer length of the tibiofibula also altered the tibiofibula diaphysis width index and gave a physical appearance of a more gracile and less robust tibiofibula than other species, as seen in Figure 2B. The elongated nature of the tibiofibula and the femur (to a lesser extent) of *N. mitchellii* are likely related to the form of locomotion that give rise to the common name for the various species of *Notomys*, the 'hopping mice'. The difference in tibiofibula and femoral length of *N. mitchellii* and *P. gouldii* (species of a similar weight), suggests that *P. gouldii* can be assigned an accurate identification based on having a significantly smaller total length of both elements (tibiofibula < 24.5 mm, femur < 21 mm). The total length of the hind limb elements of *H. chrysogaster* is of sufficient size to identify the tibiofibula with a length over 45.5 mm; however, the femur length above 30 mm needed to be combined with a diaphysis width above 13.3 to ensure accurate identification.

Quantitatively, the total tibiofibula length could be used to identify three species in the absence of any qualitative measures (rolling of the tibial crest and incomplete fusion of the tibia and fibula) as noted in the text. *Hydromys chysogaster* had a tibiofibula length over 45.5 mm, *P. shortridgei* had a length between 24.5 mm and 30 mm and *P. gouldii*, the smallest studied species at 50 g live weight, was identifiable if the value for the tibiofibula total length was less than 24.5 mm. Diaphysis thickness index was a useful measure for confirming the difference between *H. chrysogaster* and other species although was not included in the identification key. Instead, total length was included as this measure does not require any calculations. The tibiofibula fusion point was significantly different for only *N. mitchellii* compared to all other species; however, there was a significant difference between *R. lutreolus* and *R. fuscipes*. This was the only differentiating factor between the *Rattus* species and is included as an identifying measure within the key.

Qualitative identifying features on the tibiofibula included rolling of the tibial crest in *M. fuscus*, flattening of the tibial crest in *H. chrysogaster* and distal separation of fusion in *L. conditor*. These observations were pronounced enough to identify species based on their presence but only two are recorded in the key. The flattening of the tibial crest in *H. chrysogaster* was not included in the identification key as the total length of the bones was a more measurable difference between the eight species, as shown in Figure 2B. The separation of fusion present in the distal tibiofibula of *L. conditor* was observed in all specimens, this was rarely the case for other species. The rolling of the tibial crest was useful in identifying *M. fuscus* from other species with similar tibiofibula total lengths such as *R. fuscipes* or *R. lutreolus* and was included in the key as the identifying characteristic for *M. fuscus* tibiofibula.

Figure 4.
Key for identification of rodent tibiofibula elements measured in this study using a combination of total measurements (as indicated by millimetres after number), indices (values) and qualitative observations (yes/no).



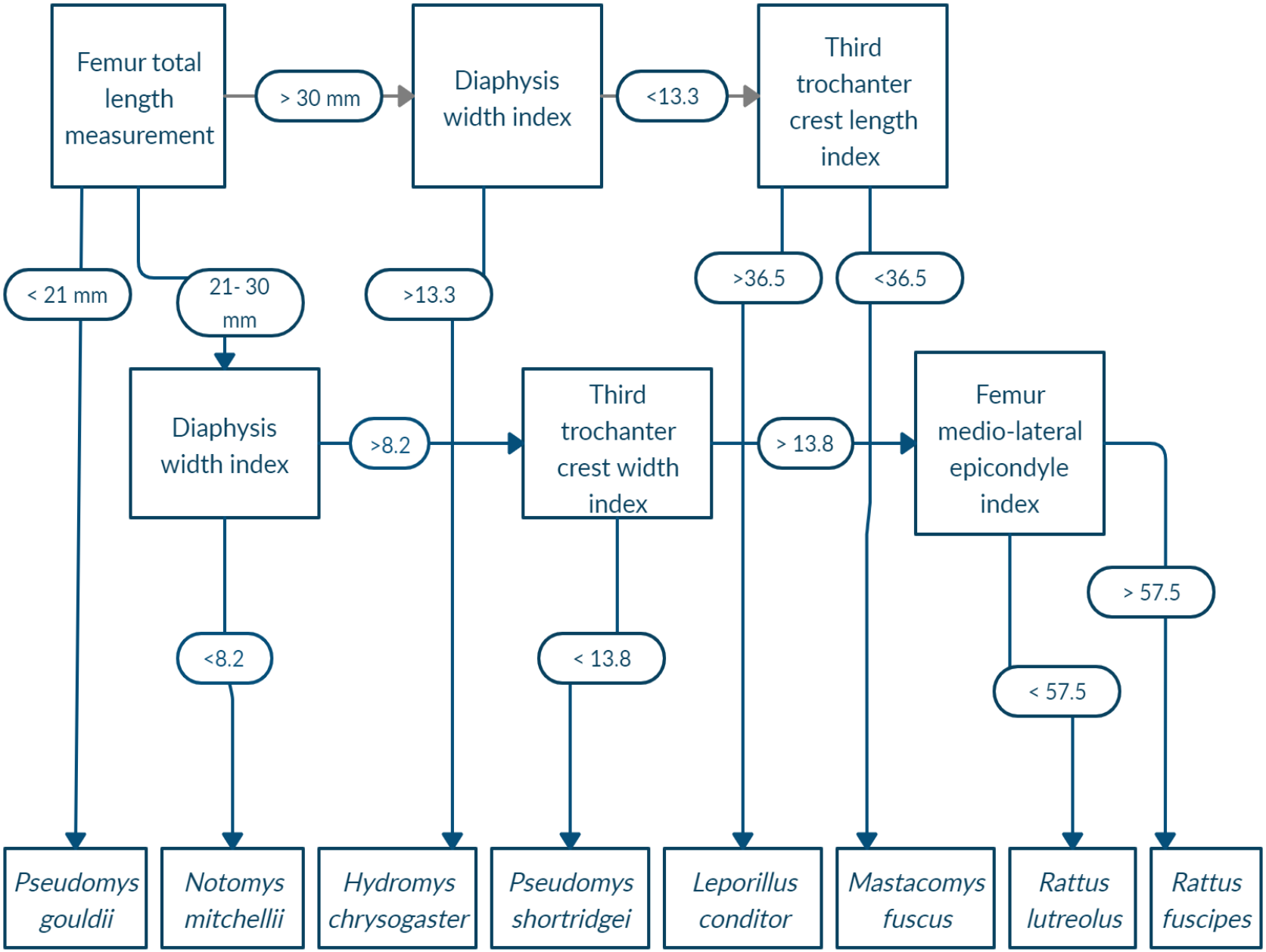


Figure 5.
Key for identification of rodent femur elements measured in this study using a combination of total measurements (as indicated by millimetres after number) and indices (values).

Femoral qualitative measures were not observed. Identification of the femur to species level is based on the measured indices and total limb length. *Pseudomys gouldii* had the smallest total length of femur, significantly different from all other species (18.59, $p < 0.001$) and this was used as the first identifiable species measure. Femora with a longer total length than *P. gouldii* were then grouped into those species above 30 mm (*H. chrysogaster*, *L. conditor* and *M. fuscus*) and those between 21 mm and 30 mm (*N. mitchelli, P. shortridgei, R. fuscipes* and *R. lutreolus*). In the group of smaller total length of femur, *N. mitchellii* had a significantly smaller diaphysis width index (<8.2, $p < 0.001$) compared to all other species in the group and therefore this measure was used for positive identification. The third trochanter crest width index allowed identification of *P. shortridgei* if it was below 13.8 and the diaphysis width index was greater than 8.2. The two *Rattus* species had a third trochanter crest width index above 13.8 and a diaphysis width index above 8.2. The femur medio-lateral epicondyle index showed a significant difference between *R. lutreolus* and *R. fuscipes* ($p = 0.007$). *Rattus lutreolus* had a femur medio-lateral diaphysis width index below 57.5 and *R. fuscipes* had a value above 57.5. A femur total length above 30 mm and a diaphysis width index greater than 13.3 identified *H. chrysogaster*. Third trochanter crest length index was able to identify *M. fuscus* (values less than 36.5) and *L. conditor* (values above 36.5) when combined with a total femur length of above 30 mm and a diaphysis width index of less than 13.3.

The keys provided in this paper offer a means of identification for the rodent hind limbs that are present within fossil bone assemblages and are primarily to be used on single, disarticulated elements. The femoral identification is based solely on the quantitative measurements and computed indices, whereas the tibiofibula, an unusual complex with fused limb elements, combined with observed qualitative features, enables one to differentiate two of the eight species.

This study is limited by the small species diversity for each of the six Australian rodent genera chosen, that is four genera have only a single species in them (*Hydromys, Mastacomys, Leporillus* and *Notomys*) and further investigation into the differences within a single genus may yield useful identification measures. More replications of chosen species from different geographical regions may add greater certainty to the results.

Conclusion

This research aimed to investigate morphological differences within Australian rodent hind limbs (family Muridae) in order that researchers and interested parties (e.g. cavers) could make field-based decisions on the rodent fossils found within many cave sites. Results indicate that osteological differences observed are not linked in a linear relationship to the live weight of the animal. Significant differences were observed between all species studied allowing identification of each of the hind limb elements to species level. Rodents that exhibit habitual differences such as hopping (*N. mitchelli*) or swimming (*H. chrysogaster*) showed the greatest number of significant differences in hind limb proportions from all other species. Femoral identification was based solely on quantitative measures and indices; whereas tibiofibula identification was based on a mix of quantitative and qualitative measures. The preliminary results from this study appear to support the combination of total measurements, computed indices and morphological difference for species level identification of Australian murid rodent hind limb elements in Quaternary fossil deposits.

Acknowledgements

This research was completed in part as an Honours project undertaken at the Flinders University of South Australia. EP would like to acknowledge David Stemmer and Graham Medlin from the South Australian Museum for access to comparative samples and advice during my research, Rory O'Brien for the loan of rodent skeletal material from the Victorian Museum's collection and the guidance and support of my supervisors Dr Liz Reed and Dr Ken Sanderson. Thanks are also given to the editor and reviewers whose suggestions have greatly improved this manuscript. This research has no financial support to acknowledge.

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Appendix 1. Specimen registration details for eight Australian murid rodents examined for this study

Leporillus conditor	M21372	M21396	83SF6-1	83SF6-2	83SF6-7	83SF6-8
	83SF6-3	83SF6-4	83SF6-5	83SF6-6	83SF6-9	83SF6-10
	83SF6-11					
Hydromys chrysogaster	M22268	M8287	M3533	M1639	C29746	C29798
	M1638	M1637	M20174	M17788	C20283	C29684
Mastacomys fuscus	C11656	C25989	C11508	C25086	C15026	C22529
	C15674	C15033				
Notomys mitchellii	C15021	C2866	C11357	C10301	C16236	C11333
Pseudomys shortridgei	C21598	C19923	C22111	C21599	C9648	C16049
	C22125	C16050	C19925	C27069	C22113	C22134
Pseudomys gouldii	CHG.11.12.1.p	CHG.11.13.1.p	CHG.11.15.1.p	CHG.11.17.1.p	ARD.1.33.1.p	ARD.1.215.1p
	CHG.11.24.1.p	ARD.1.3.1.p	ARD.1.9.1.p	ARD.1.40.1.p	ARD.1.215.2p	CHG.3.21.1.p
Rattus lutreolus	C12748	C26004	C25794	C8701	C10164	C20129
	C26622	C10163				
Rattus fuscipes	M10399	M19815	M10398	M10396	M10401	M10397
	M10400					

HELICTITE

END OF VOLUME 45