

Title

Hop, Walk or Bound? Limb Proportions in Kangaroos and the Probable Locomotion of the extinct genus *Protemnodon*.

Journal

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Online Resource 1

Supplementary tables

Table S1 Specimens used in the analysis of macropodid limb proportions

Taxon	Spec. #	Tab. #	Family/Subfamily	Loc.	Common Name
<i>Hypsiprymnodon moschatus</i>	SAMA M11940	85	Hypsiprymnodontidae	Oq	Musky rat-kangaroo
<i>Aepyprymnus rufescens</i>	AMNH 65283	47	Potoroidae	S	Rufous rat-kangaroo
<i>Aepyprymnus rufescens</i>	QM J5579	48	Potoroidae	S	Rufous rat-kangaroo
<i>Aepyprymnus rufescens</i>	SAMA M9017	49	Potoroidae	S	Rufous rat-kangaroo
<i>Bettongia leseur</i>	AM M2132	50	Potoroidae	S	Boodie
<i>Bettongia leseur</i>	SAMA M2135	51	Potoroidae	S	Boodie
<i>Bettongia penicillata</i>	SAMA M18986	52	Potoroidae	S	Woylie
<i>Bettongia tropica</i>	AM M40067	53	Potoroidae	S	Northern bettong
† <i>Caloprymnus capestris</i>	NT 48959	54	Potoroidae		Desert rat-kangaroo

Taxon	Spec. #	Tab. #	Family/Subfamily	Loc.	Common Name
					(recently extinct)
<i>Potorous longipes</i>	NMV C32723	82	Potoroidae	Hq	Long-footed potoroo
<i>Potorous longipes</i>	NMV C12772	83	Potoroidae	Hq	Long-footed potoroo
<i>Potorous tridactylus</i>	AMNH 65297	84	Potoroidae	Hq	Long-nosed potoroo
<i>Lagostrophus fasciatus</i>	WAM M16285	42	Lagostrophinae	S	Banded hare-wallaby
<i>Lagostrophus fasciatus</i>	AM M6791	43	Lagostrophinae	S	Banded hare-wallaby
<i>Lagostrophus fasciatus</i>	WAM M4393	44	Lagostrophinae	S	Banded hare-wallaby
<i>Lagostrophus fasciatus</i>	AM M40303	45	Lagostrophinae	S	Banded hare-wallaby
<i>Lagostrophus fasciatus</i>	WAM M22911	46	Lagostrophinae	S	Banded hare-wallaby
<i>Dendrolagus bennettianus</i>	WAM M5530	67	Macropodinae	Hq, A	Bennett's tree-kangaroo
<i>Dendrolagus dorianus</i>	AM M9109	68	Macropodinae	Hq, A	Doria's tree-kangaroo
<i>Dendrolagus goodfellowi</i>	NMV C.25092	69	Macropodinae	Hq, A	Goodfellow's tree-kangaroo
<i>Dendrolagus inustus</i>	UMZC A12.72/1	70	Macropodinae	Hq, A	Grizzled tree-kangaroo
<i>Dendrolagus lumholtzi</i>	AMNH 65265	71	Macropodinae	Hq, A	Lumholtz's tree-kangaroo
<i>Dendrolagus lumholtzi</i>	SAMA M7206	72	Macropodinae	Hq, A	Lumholtz's tree-kangaroo
<i>Dendrolagus matschiei</i>	WAM M21013	73	Macropodinae	Hq, A	Matschie's tree-kangaroo
<i>Dendrolagus matschei</i>	QM J5287	74	Macropodinae	Hq, A	Matschie's tree-kangaroo
<i>Dorcopsis atrata</i>	AM M19461	77	Macropodinae	Hq	Black dorcopsis
<i>Dorcopsis luctuosa</i>	SAMA M15178	78	Macropodinae	Hq	Gray dorcopsis
<i>Dorcopsis muelleri</i>	AM M32341	79	Macropodinae	Hq	Brown dorcopsis
<i>Dorcopsis muelleri</i> (= <i>D. veterum</i>)	AMNH 22262	80	Macropodinae	Hq	Brown dorcopsis
<i>Dorcopsis</i> sp.	SAMA M12259	81	Macropodinae	Hq	Dorcopsis (New Guinea forest Wallaby)
<i>Lagorchestes conspicillatus</i>	WAM M7032	37	Macropodinae	S	Spectacled hare-wallaby
<i>Lagorchestes conspicillatus</i>	AMNH 197659	38	Macropodinae	S	Spectacled hare-wallaby
<i>Lagorchestes hirsutus</i>	SAM M3587	34	Macropodinae	S	Rufous hare-wallaby
<i>Lagorchestes hirsutus</i>	SAMA M3590	35	Macropodinae	S	Rufous hare-wallaby
<i>Lagorchestes hirsutus</i>	AM M40031	36	Macropodinae	S	Rufous hare-wallaby
<i>Macropus fuliginosus</i>	SAM M21497	1	Macropodinae	S	Western grey kangaroo
<i>Macropus fuliginosus</i>	SAMA M16578	2	Macropodinae	S	Western grey kangaroo

Taxon	Spec. #	Tab. #	Family/Subfamily	Loc.	Common Name
<i>Macropus giganteus</i>	AMNH 35747	3	Macropodinae	S	Eastern grey kangaroo
<i>Macropus giganteus</i>	AMNH 35186	4	Macropodinae	S	Eastern grey kangaroo
<i>Macropus giganteus</i>	QM J11525	5	Macropodinae	S	Eastern grey kangaroo
<i>Macropus giganteus</i>	NMV C5532	6	Macropodinae	S	Eastern grey kangaroo
<i>Macropus †titan</i>	AMNH 18362	16	Macropodinae	S	Extinct
<i>Notamacropus agilis</i>	AMNH 35750	18	Macropodinae	S	Agile wallaby
<i>Notamacropus dorsalis</i>	NMV C6490	19	Macropodinae	S	Black-striped wallaby
<i>Notamacropus eugenii</i>	NMV C7908	20	Macropodinae	S	Tammar wallaby
<i>Notamacropus eugenii</i>	CMJ specimen	21	Macropodinae	S	Tammar wallaby
<i>Notamacropus parma</i>	SAMA M7192	17	Macropodinae	S	Parma wallaby
<i>Notamacropus parryi</i>	AMNH 65054	22	Macropodinae	S	Whiptail wallaby
<i>Onychogalea fraenata</i>	NMV C6400	39	Macropodinae	S	Bridled nail-tail wallaby
<i>Onychogalea fraenata</i>	SAMA M24347	40	Macropodinae	S	Bridled nail-tail wallaby
<i>Onychogalea unguifera</i>	WAM M11622	41	Macropodinae	S	Northern nail-tail wallaby
<i>Osphranter antilopinus</i>	AMNH 70449	7	Macropodinae	S	Antilopine kangaroo
<i>Osphranter robustus</i>	SAMA M3695	8	Macropodinae	S	Common wallaroo
<i>Osphranter robustus</i>	AMNH 65036	9	Macropodinae	S	Common wallaroo
<i>Osphranter robustus</i>	SAMA M13977	10	Macropodinae	S	Common wallaroo
<i>Osphranter rufus</i>	SAMA M6559	11	Macropodinae	S	Red kangaroo
<i>Osphranter rufus</i>	AMNH 200473	12	Macropodinae	S	Red kangaroo
<i>Osphranter rufus</i>	SAMA M2195	13	Macropodinae	S	Red kangaroo
<i>Osphranter rufus</i>	NHM 205	14	Macropodinae	S	Red kangaroo
<i>Osphranter rufus</i>	UMZC A12.21/3	15	Macropodinae	S	Red kangaroo
<i>Petrogale assimilis</i>	QM J4470	23	Macropodinae	S	Allied rock-wallaby
<i>Petrogale assimilis</i>	NHM 223	24	Macropodinae	S	Allied rock-wallaby
<i>Petrogale lateralis</i>	AM M24183	25	Macropodinae	S	Black-flanked rock-wallaby
<i>Petrogale herberti</i>	AMNH 65241	26	Macropodinae	S	Herbert's rock-wallaby
<i>Petrogale xanthropus</i>	AMNH 35642	27	Macropodinae	S	Yellow-footed rock-wallaby
<i>Petrogale xanthropus</i>	WAM M11469	27	Macropodinae	S	Yellow-footed rock-wallaby
<i>†Protemnodon anak</i>	NMV P229318	86	Macropodinae	Uk	Extinct
<i>†Protemnodon anak</i>	NMV P39105	87	Macropodinae	Uk	Extinct
<i>†Protemnodon anak</i>	NMV P39101	88	Macropodinae	Uk	Extinct
<i>†Protemnodon anak</i>	Composite	89	Macropodidae	Uk	Extinct
<i>†Protemnodon viator</i>	AMNH 145501	90	Macropodinae	Uk	Extinct
<i>Setonix brachyurus</i>	WAM M6792	75	Macropodinae	Hq	Quokka

Taxon	Spec. #	Tab. #	Family/Subfamily	Loc.	Common Name
<i>Setonix brachyurus</i>	NMV C23029	76	Macropodinae	Hq	Quokka
<i>Thylogale billardieri</i>	NHM 49.6.20.3	31	Macropodinae	S	Tasmanian pademelon
<i>Thylogale stigmatica</i>	AMNH 65153	29	Macropodinae	S	Red-legged pademelon
<i>Thylogale thetis</i>	AM M51512	30	Macropodinae	S	Red-necked pademelon
<i>Wallabia bicolor</i>	AMNH 65722	32	Macropodinae	S	Swamp wallaby
<i>Wallabia bicolor</i>	SAMA M11364	33	Macropodinae	S	Swamp wallaby
† <i>Procoptodon gilli</i>	SAMA composite (P18323, UN)	56	†Sthenurinae	Bs	Extinct
† <i>Procoptodon goliah</i>	UMCP 45475*	55	†Sthenurinae	Bs	Extinct
† <i>Simosthenurus</i> <i>occidentalis</i>	SAMA P20820	57	†Sthenurinae	Bs	Extinct
† <i>Simosthenurus</i> <i>occidentalis</i>	SAMA P17476	58	†Sthenurinae	Bs	Extinct
† <i>Sthenurus andersoni</i>	SAMA P13673	59	†Sthenurinae	Bs	Extinct
† <i>Sthenurus maddocki</i>	SAMA P17529	60	†Sthenurinae	Bs	Extinct
† <i>Sthenurus stirlingi</i>	AMNH 140809	61	†Sthenurinae	Bs	Extinct
† <i>Sthenurus stirlingi</i>	AMNH 117496	62	†Sthenurinae	Bs	Extinct
† <i>Sthenurus stirlingi</i>	AMNH 117497	63	†Sthenurinae	Bs	Extinct
† <i>Sthenurus stirlingi</i>	SAMA P22533	64	†Sthenurinae	Bs	Extinct
† <i>Sthenurus tindalei</i>	AMNH 117499	65	†Sthenurinae	Bs	Extinct
† <i>Sthenurus tindalei</i>	AMNH 117493	66	†Sthenurinae	Bs	Extinct

Bold face indicates complete individuals used in the PCA. Tab. # refers to the specimens listed in Supplementary Table 4). *Data from Tedford 1967. Uk = unknown, UN = unnumbered, † = extinct (*Caloprymnus campestris* is recently extinct. Key to abbreviations of locomotor mode (Loc.): A = arboreal, Bs = bipedal strider (sthenurine), Hq = habitual quadruped, Oq = obligate quadruped, S = Saltator. Key to museum acronyms: AM: Australian Museum (Sydney, NSW, Australia); AMNH = American Museum of Natural History (New York, USA); CMJ = personal collection of Christine Janis (specimen of natural bone from Skulls Unlimited, USA); NHMUK = Natural History Museum, London (UK); NT = Museums and Art Galleries of the Northern Territories (Alice Springs, NT, Australia); QM = Queensland Museum fossil collection (Brisbane, QLD, Australia); SAMA = South Australian Museum (Adelaide, SA, Australia); UCMP = University of California Museum of Paleontology (Berkeley, USA); UCMZ = University of

Cambridge Museum of Zoology, Cambridge, UK; WAM = Western Australian Museum (Perth, WA, Australia).

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Online Resource 2

Phylogenetic Analysis of Principal Components Analysis

To take phylogenetic effects into account a phylogenetic PCA (pPCA) was applied in RStudio (RStudio Team 2015) using the molecular node-calibrated phylogeny of Cascini *et al.* (2019) with the `phyl.pca` function in the package `phytools` (Revell 2012), assuming a Brownian Motion model of evolution. This method corrects for nonindependence of taxa by calculating PC scores after the removal of phylogenetic covariance (Revell 2009; Polly *et al.* 2013). To quantify the phylogenetic signal, Blomberg's K-statistic and Pagel's Lambda (Pagel 1999; Blomberg *et al.* 2003) were calculated using the function `phylosig`. The Cascini *et al.* (2019) phylogeny had the same basic structure as the phylogeny shown in Fig. 1, but unfortunately did not encompass all of the taxa in the original PCA. In order to produce a pPCA incorporating all of the taxa in the original PCA the analysis was run multiple times and a composite pPCA constructed.

The sorting of the taxa by locomotor mode remained stable after phylogenetic correction (Figure S1), with the exception of the basal taxon, *Hypsiprymnodon moschatus* (the Musky Rat-kangaroo), indicating there is very little phylogenetic signal in the data. This observation is corroborated by both Pagel's Lambda and Blomberg's K-statistic (6.61×10^{-5} and 0.59, respectively). These values are a strong indication that macropodid postcranial morphology is strongly influenced by primary locomotor mode, not phylogeny. Although statistical analyses were impeded by lack of individuals (as little as two individuals in the unknown group), for more than half of the indices *Protemnodon* and the quadrupedal taxa were significantly different to the saltators (Online Resource 1, Table S3).

The postcranial morphology of *H. moschatus*, the only non-hopping macropodoid, is distinctly different from all other macropodoids. Its anomalous position in this PCA is likely due to a statistical phenomenon known as "overcompensation", whereby the phylogenetic distance of this taxon from the other taxa is having a disproportionally large effect on the analysis, and the position of this taxon along PC1.

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Fig. S1 Phylogenetic PCA (pPCA) of the 13 osteological indices. PC axes in this plot are evolutionarily independent (Revell 2009). Symbols represent locomotor mode (plus colors in online version). Figure created in Adobe Illustrator by Science Graphic Design (www.sciencegraphicdesign.com)

