

Ecography

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Supplementary material

1 **Appendix 1**

2 Paleobiogeographic summaries for all extant lagomorph genera.

3

4 *Pikas – Family Ochotonidae*

5 The maximum diversity and geographic extent of pikas occurred during the global climate
6 optimum from the late-Oligocene to middle-Miocene (Ge et al. 2012). When species evolve
7 and diversify at higher temperatures, opportunities for speciation and evolution of thermal
8 niches are likely through adaptive radiation in relatively colder and species poor areas
9 (Araújo et al. 2013). Extant Ochotonids may be marginal (ecologically and geographically)
10 but diverse because they occur in topographically complex areas where habitat diversity is
11 greater and landscape units are smaller (Shvarts et al. 1995). Topographical complexity
12 creates new habitat, enlarges environmental gradients, establishes barriers to dispersal, and
13 isolates populations. All these conditions can contribute to adaptation to new environmental
14 conditions and speciation in excess of extinction for terrestrial species (Badgley 2010).

15

16 *Hares and rabbits - Family Leporidae*

17 *Pronolagus*, *Bunolagus*, *Romerolagus*, *Pentalagus* and *Nesolagus* may belong to lineages
18 that were abundant and widespread in the Oligocene and subsequently lost most (if not all)
19 species. *Lepus*, *Sylvilagus*, *Caprolagus* and *Oryctolagus* represent more recent radiations
20 which lost species unevenly during the late Pleistocene. Living species in these four genera
21 display more generalist diet and habitat preferences, and are better represented in the fossil
22 record. (Lopez-Martinez 2008).

23

24

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26 *Island endemics*

27 *Nesolagus netscheri* and *Pentalagus furnessi* are both restricted to islands and threatened.
 28 *Nesolagus* shows a number of primitive morphological features, with no derived characters
 29 that link it clearly to any of the other leporids (Matthee et al. 2004). Both species of
 30 *Nesolagus* are amongst the least-known and rarest mammals in the world (McCarthy et al.
 31 2012). Other lagomorph species confined to islands are three species of *Lepus* and two of
 32 *Sylvilagus* with relatively recent branching time estimates. They occur on islands that
 33 separated from continental landmasses at the last glaciation, or on oceanic islands for which
 34 dispersal from continents is common (Table A1). Ancestral leporids most likely originated in
 35 forested environments. *Nesolagus* and *Pentalagus* are the only genera that are both
 36 plesiomorphic and confined to dense vegetation (Matthee et al. 2004).

Table A1. Lagomorph species endemic to islands. Island type follows Cardillo et al. (2008).

Species and common name	Distribution	Island Type
<i>Lepus brachyurus</i>	Japan	Oceanic
Japanese hare	multiple islands	(~150 km offshore)
<i>Lepus hainanus</i>	Hainan Island, China	Landbridge island
Hainan Hare		
<i>Lepus insularis</i>	Espiritu Santo Island, Mexico	Landbridge island
Black jackrabbit		
<i>Nesolagus netscheri</i>	Sumatra, Indonesia	Landbridge island
Sumatran Striped Rabbit		
<i>Pentalagus furnessi</i>	Amami-Oshima and	Oceanic
Amami Rabbit	Tokuno-Shima Islands, Japan	(~650 km offshore)
<i>Sylvilagus graysoni</i>	Tres Marias Islands, Mexico	Oceanic
Tres Marias Cottontail		(~100 km offshore)
<i>Sylvilagus mansuetus</i>	San José Island, Mexico	Landbridge island
San Jose Brush Rabbit		

38 Phylogeographic analyses of south east Asian vertebrates, and the extinct form *Nesolagus*
39 *sinensis* suggest that the Sumatran striped rabbit (*N. netscheri*) may have descended from a
40 formerly widespread ancestral species on the Sunda Shelf . Rising sea levels and contracting
41 forests in the Pliocene are likely causes for its geographic isolation (Sterling and Hurley
42 2005). The Japanese Ryukyu archipelago was connected with the Eurasian continent during
43 the middle to late Miocene, and became isolated in the Pliocene (Millien-Parra and Jaeger
44 1999). The extinct form *Pliopentalagus* from the European and Asiatic Pliocene supports the
45 ‘refugee’ status of the surviving Amami rabbit (Lopez-Martinez 2008). Molecular data
46 suggests that *Pentalagus furnessi* (and the ancient rodent *Tokudaia osimensis*) maintained
47 relict populations on these islands after divergence and isolation, whilst relatives on the
48 continental mainland went extinct (Yamada et al. 2002).

49

50 *Europe*

51 *Oryctolagus* has the oldest fossil record among extant leporid genera, first appearing in
52 Europe about 3.5 Ma. *O. cuniculus* is first recorded in southern Spain in the Middle
53 Pleistocene (about 0.6 Ma), and associated with a relict, warm-adapted fauna usually
54 restricted to the tropics. In Europe, fossil materials record the extinction of at least five
55 *Oryctolagus* species during this period (Lopez-Martinez 2008).

56

57 *Indian subcontinent*

58 The fossil record of the hispid hare (*Caprolagus hispidus*) points to a Pliocene/early
59 Pleistocene origin (Lopez-Martinez 2008). Its distribution is currently restricted to a few
60 remnant fragments of tall, alluvial grasslands in the north of the Indian subcontinent.
61 *Caprolagus* experienced a similar decline in distribution to other grassland mammals in the
62 region, especially the Indian Rhino (*Rhinoceros unicornis*) and pygmy hog *Porcula salvania*,

63 which were associated with ongoing human-mediated changes in grassland land use during
64 the Holocene (Peet et al. 1999).

65

66 *Africa*

67 Ancestral stocks of *Pronolagus* and *Poelagus* differentiated from an Asian leporid entering
68 Africa during the Miocene (Matthee et al. 2004). Red rock “hares” (*Pronolagus*) in southern
69 Africa are the most speciose of the species-poor leporids, with four species. The fossil record
70 for *Pronolagus* is confined to southern Africa and the oldest report is for the early Pliocene.
71 The fossil history of *Poelagus* is uncertain (Winkler and Avery 2010). Plio-Pleistocene
72 climatic oscillations heavily influenced small mammal assemblages in Africa (Montgelard
73 and Matthee 2012), but the rock-dwelling nature of these species may aided their long-term
74 survival in stable microhabitats. Multiple topographical features may have served as
75 widespread refugia for rock dwellers during severe environmental changes. Diversification in
76 *Pronolagus* may be similar to that of other rock-dwelling vertebrates in southern Africa,
77 driven by changes in habitat availability from coastal regression and transgression during the
78 Pliocene, or population isolation during peaks of aridity in later periods (Diedericks and
79 Daniels 2014). *Bunolagus* is a later arrival to Africa, possibly in the middle Pleistocene. The
80 fossil record is unclear, but it appears that the Riverine rabbit has had a consistently restricted
81 distribution in central South Africa (Winkler and Avery 2010).

82

83 *North America*

84 Analysing disjunct distributions of Mexican mammals, Ceballos et al. (2010) suggest that
85 some species in central Mexico became isolated long before the Pleistocene. The Volcano
86 rabbit (*Romerolagus diazi*) and other endemics survived the complex environmental changes
87 of the Plio-Pleistocene in the mountains of the Mexican Transvolcanic Belt. These volcanoes

88 acted as a likely refuge after the species was isolated during late Tertiary aridity. Pygmy
89 rabbits (*Brachylagus*) have a disjunct distribution in boreal sagebrush habitat throughout the
90 American Great Basin. The isolation of *Brachylagus* may be more recent, and has been
91 associated with the loss of sagebrush habitat during end-Pleistocene environmental changes
92 and mid-Holocene expansion of pinyon-juniper woodland within the region (Grayson 2006).

93

Table A2. Examination of the properties of the lagomorph phylogeny. Results obtained using alternate phylogeny (mitochondrial gene tree).

Frequency distribution of clade sizes	Test of equal densities; $p=0.31$
Topological tree imbalance	Colless index = 1.569564, $p = 0.032$
Phylogenetic signal of extinction risk	$D= 0.79$; $p(D > 0) = 0.001$; $p(D < 1) = \text{n.s.}$

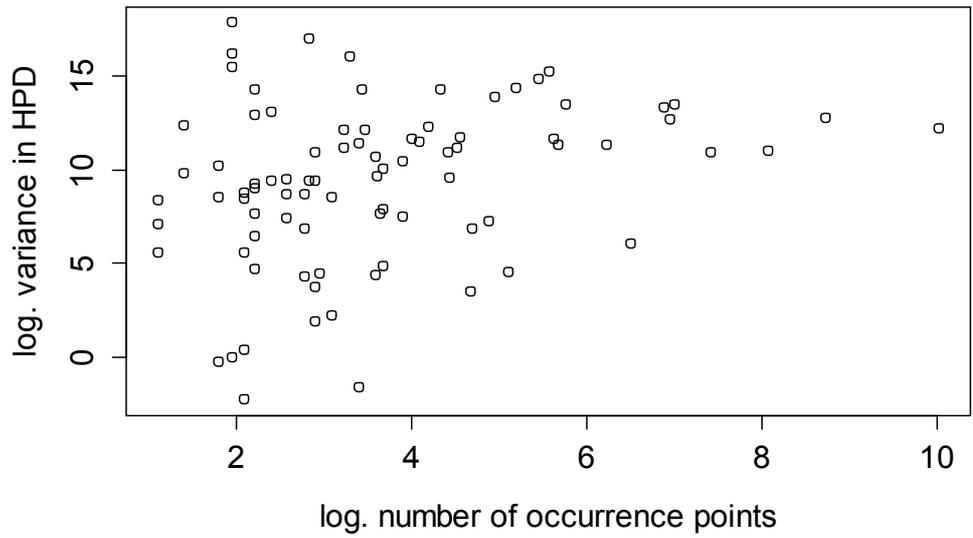
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Table A3. Bayesian Phylogenetic Mixed Model results obtained using alternate phylogeny (mitochondrial gene tree). Parameter estimates and confidence intervals calculated from the highest posterior density.

* statistically significant.

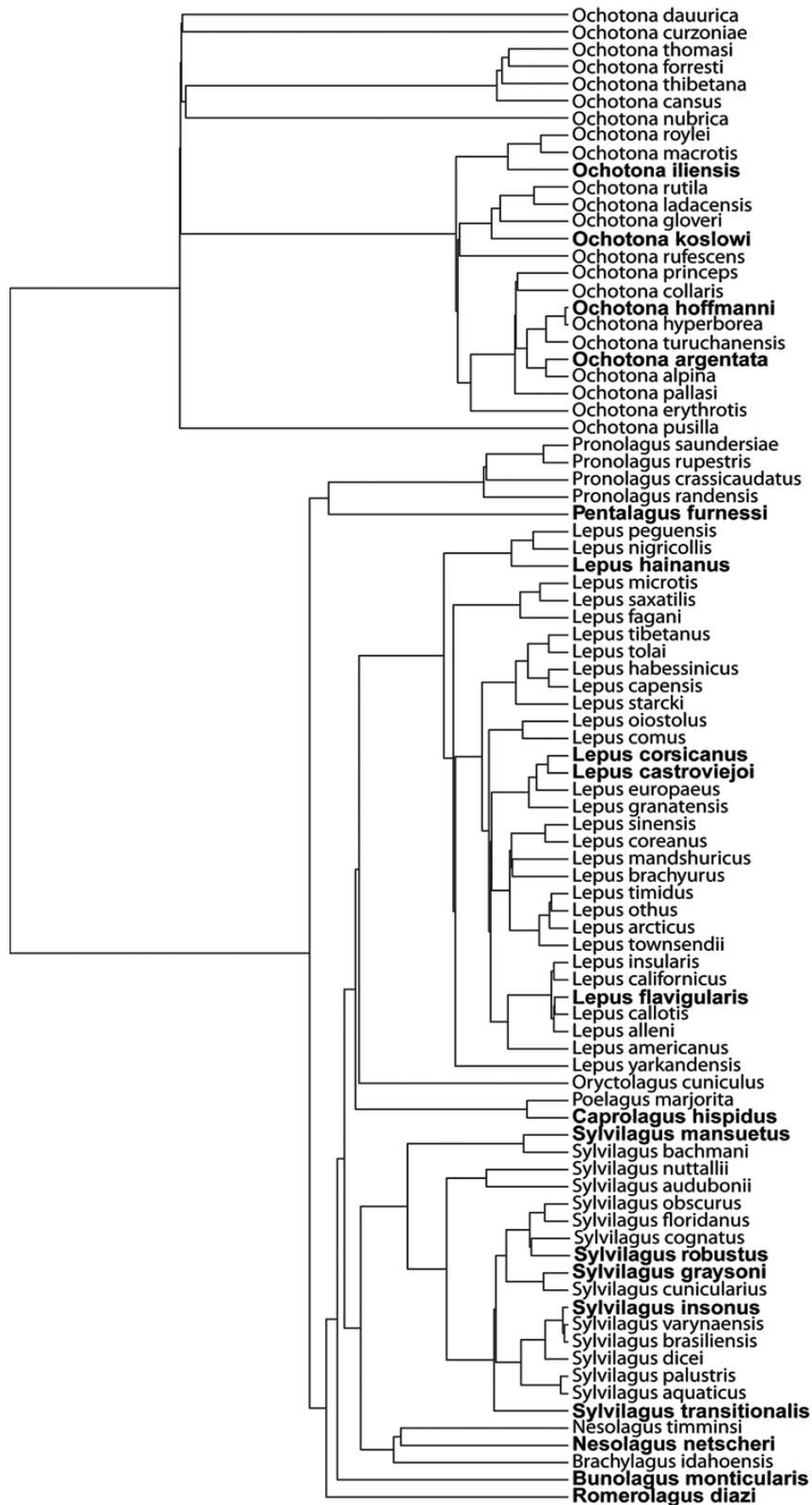
Parameter	Posterior mean	Lower CI (99%)	Upper CI (99%)
Extinction risk			
Intercept	-0.260	-1.201	0.532
Principal Component 1	0.180	-0.042	0.396
Principal Component 2	-0.183	-0.413	0.031
Minimum human population density value	0.016 *	0.006	0.026
Proportion of occurrences in converted habitats	-0.023 *	-0.046	-0.0002
Body size	-0.0002	-0.0007	0.0002
Evolutionary Distinctiveness			
Intercept	0.1779 *	0.0756	0.2847
Sympatric mammal richness	0.0001	-0.0002	0.0004
Principal Component 1	-0.0020	-0.0059	0.0014
Principal Component 2	0.0015	-0.0022	0.0059
Geographic range size	-0.0002	-0.0020	0.0016



98

99 **Figure A1.** Variance in human population density measured for species using occurrence
100 points.

101



102

103 **Figure A2.** Tree topology for the Lagomorpha extracted from the mammal supertree
 104 provided by Rolland et al. (2014). Missing species were added using an expanded tree
 105 approach. Threatened species (IUCN Red List category > VU) highlighted in boldface.

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