A brief review of the life history of, and threats to, *Burramys parvus* with a prehistory-based proposal for ensuring that it has a future

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ABSTRACT

The endangered Mountain Pygmy-possum *Burramys parvus* is an alpine-subalpine specialist and the only Australian mammal entirely restricted to areas above the winter snowline. There are three geographically isolated populations of *B. parvus*: Kosciuszko National Park (South Ramshead - Cabramurra) in New South Wales, and Mt Bogong - Mt Higginbotham and Mt Buller in Victoria. Populations have shown signs of rapid decline over the last 15 years. The duration of snow cover and time of snow melt appear to be linked to the survival rate of the Mountain Pygmy-possum which is under severe threat from climate change. Here we discuss its life history, extinction threats and the potential value of the fossil record in identifying conservation options for the Mountain Pygmy-possum. Also presented is a proposal to establish a breeding facility for the rapidly declining Kosciuszko population in New South Wales. This breeding facility would firstly provide a safety net for unanticipated disasters in the alpine and subalpine zone that might occur in the short term. Secondly, the facility would provide an opportunity to address concerns that climate change will eventually transform the subalpine-alpine zone, making it unsuitable for further survival of *B. parvus* populations. To address this concern, we propose breeding surplus individuals that could be experimentally acclimatised for release into alternate environments.

Key words: *Burramys parvus*, Mountain Pygmy-possum, climate change, palaeocommunities, translocation.

Introduction

The Mountain Pygmy-possum *Burramys parvus* (Broom) was first described in 1895 from dental and cranial materials found in a fossil deposit at Wombeyan Caves in central New South Wales in 1894 (Broom 1895, 1896). Further specimens were found at Buchan, Victoria during the early 1960's (Wakefield 1967, 1972). For seventy years *B. parvus* was regarded as an interesting fossil (Ride 1970). However, the name given by Broom, literally 'small rock mouse', was prophetic as this species would become known to occur almost exclusively in rocky habitat (Mansergh and Broome 1994).

In August 1966 a living *B. parvus* was found in a ski lodge at Mt Hotham, Victoria (Anon 1966, Warneke 1967). Ride (1970) described it as an animal that had 'returned from extinction' and one of the few Australian species that had been given 'a second chance'. Initially it was assumed that the animal had been brought to the lodge in a load of firewood and it wasn't until early 1970 that three *B. parvus* were trapped in the natural environment, near Schlink Pass and Guthega in Kosciuszko National Park (Calaby *et al.* 1971). This discovery directed attention back to Victoria and in February 1971 one possum was trapped near Falls Creek and three were

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captured outside the ski lodge at Mt Hotham (Dixon 1971). In March 1972, 11 *B. parvus* were trapped above the tree line, in rocky habitat just below the peak of Mt Kosciuszko, the highest peak on the Australian mainland (2228 m) (Dimpel and Calaby 1972).

Over the next four decades the Mountain Pygmy-possum was located in three genetically different and isolated populations, separated by low elevation river valleys, in the subalpine and alpine region of southern NSW and eastern Victoria (see Figure 1). Within these populations, in Kosciuszko National Park, the Bogong High Plains from Mt Bogong to Mt Higginbotham, and at Mt Buller, colonies are widely scattered in patches of rocky habitat and associated shrubby heathland (Caughley 1986, Mansergh and Broome 1994, Heinze and Williams 1998, Osborne *et al.* 2000, Heinze *et al.* 2004, Broome *et al.* 2005, Mitrovski *et al.* 2007). Typically, these are accumulations of boulders (boulderfields) formed on or below rocky mountain peaks by periglacial weathering processes (technically block fields or block streams, Rosengren and Peterson 1989).

Breeding females are largely confined to boulderfields at altitudes above 1400 m (extending to a maximum elevation of 2228 m on Mt Kosciuszko) (Mansergh 1984, Broome 2001a, Heinze *et al.* 2004, Broome *et al.* 2005). Occasional records of females, as well as males and juveniles, have occurred as low as 1300 m in the montane zone at Mt Buller (D. Heinze unpubl. data) and 1200 m in northern areas of Kosciuszko National Park (Schulz 2011, Schulz *et al.* in press). The lower altitudinal limit roughly corresponds with the lower limit of the winter snowline, around 1200-1400 m altitude (Slatyer *et al.* 1985, Davis 1998).

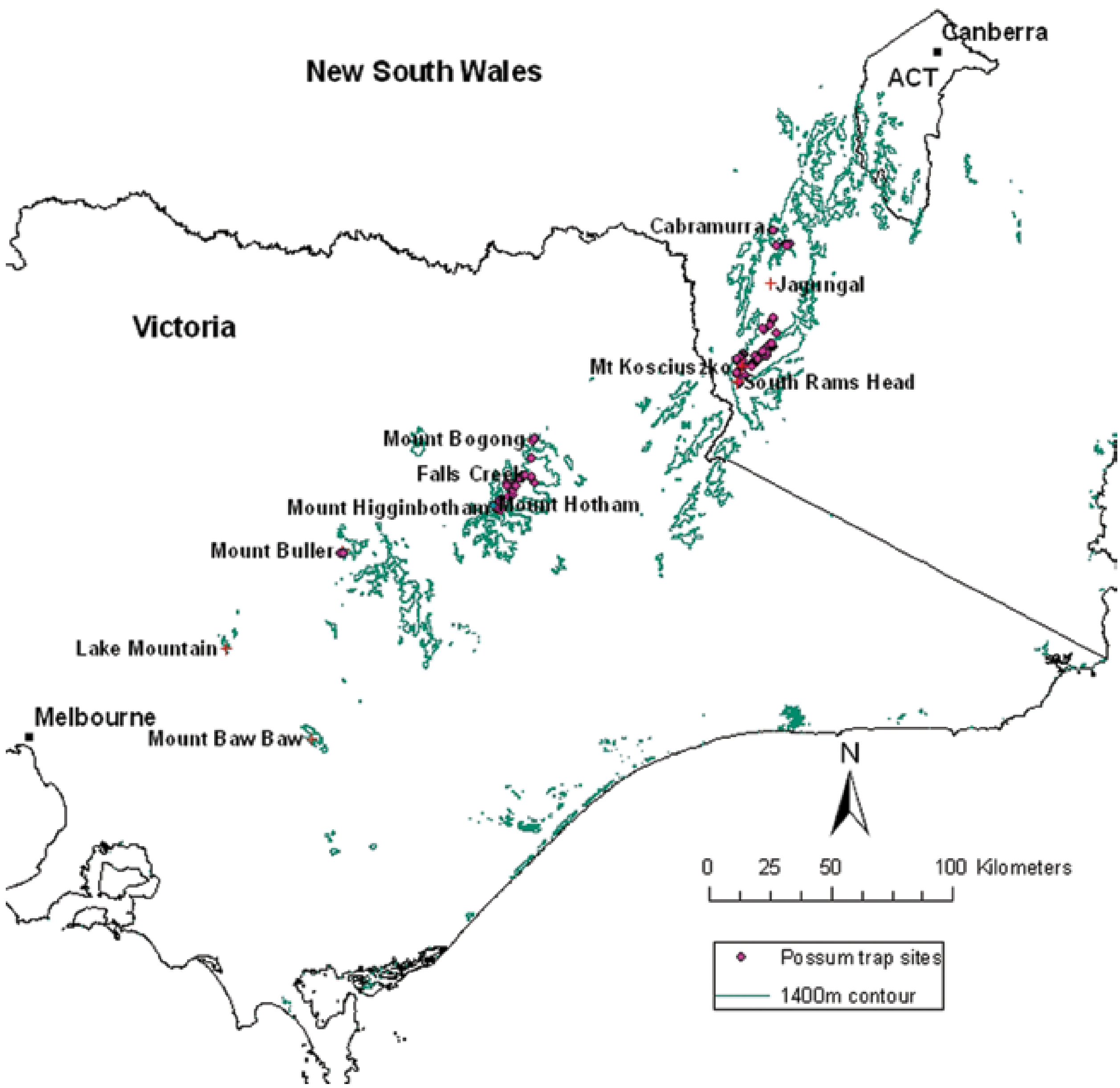

Figure 1. Distribution of the Mountain Pygmy-possum *Burramys parvus*

Adaptation to the alpine-subalpine environment

The Mountain Pygmy-possum is well adapted to living in an environment where there is a marked seasonal availability of food resources and an extended period of winter snow cover. A single (usually) litter of four young is born after snow melt in spring, young grow rapidly through the short summer and individuals fatten extensively in late summer and autumn. The cold months of winter, when food is in short supply, are spent in hibernation for between five (juveniles) to seven months (adults) (Geiser and Broome 1991, 1993, Broome and Geiser 1995, Körtner and Geiser 1998, Walter and Broome 1998, Heinze *et al.* 2004).

The migratory Bogong moth *Agrotis infusa*, which aestivates in its millions in high elevation rocky areas during the snow free season (Common 1954), constitutes a major part of the diet of *B. parvus* from the time individuals emerge from hibernation in spring to late summer and autumn, when seeds and fruits, particularly of Mountain Plum-pine *Podocarpus lawrencei*, Snow Beard-heaths *Leucopogon spp.* and Rice Flowers *Pimelia spp.*, become increasingly important. The Mountain Plum-pine is closely associated with the rocks at mid elevations and provides a rich, high energy food source throughout the year. However, there is considerable variation in the diet between sites and years and a range of seeds and fruits from other alpine and subalpine shrubs, nectar, caterpillars, beetles, spiders and other arthropods are included in the diet (Mansergh *et al.* 1990, Smith and Broome 1992, Gibson 2007).

Greatest densities of *B. parvus* are concentrated in well-defined boulderfields at the higher elevations where Bogong moths are most abundant. In these sites sex ratios may be highly biased towards females. However, lower densities, with even sex ratios, do occur in areas of heath with scattered boulders, even without *P. lawrencei* (Mansergh 1984, Broome 2001a,), Heinze *et al.* 2004, Broome *et al.* 2005, Schultz 2011, Schulz *et al.* in press).

The boulderfields provide a cool, moist environment, well protected from predators such as introduced cats and foxes. Daily fluctuations in air temperature are well buffered under shrubs and rocks in the boulderfields and optimal temperatures in hibernacula of 2°C are achievable under boulders and soil. In the coldest months of the year daily temperature fluctuations (which can be as low at minus 20°C at Charlotte Pass) are virtually eliminated under a protective cover of snow (Körtner and Geiser 1998, Walter and Broome 1998, H. Shi unpubl. data).

Population size and recent declines

The total population of *B. parvus* was estimated in 1996 to comprise (Table 1) approximately 2650 adults (2045 females and 605 males) (Heinze *et al.* 2004, Broome *et al.* 2005, D. Heinze, L. Broome unpubl. data). During the last 15 years numbers in the four known subpopulations in the southern Kosciuszko population that exceeded 25 females have declined by between 36-77%, with an overall decline estimated at 43% and a remaining population of around 355 adults (225 females and 130 males) (L. Broome, unpubl. data). Similar declines have occurred in populations in Victoria, especially those within ski resorts. The population at Mt Buller has suffered an estimated 87% decline since 1996. The Bogong High Plains population (Mt Bogong – Mt Higginbotham) appeared to have made a recovery in 2009 following several severe fluctuations in the late 1990s and following fires in 2003, with an overall 3% decline (Table 1).

Table 1. Estimates of Mountain Pygmy-possum total adult population size (females and males) in the three populations.

Year	NSW	Bogong H P	Buller	Total
1996	615	1735	300	2650
2009	355	1680	40	2075
% change	-43%	-3%	-87%	-22%

Recent discoveries of three additional colonies between Jagungal and Cabramurra (Figure 1) in the northern Kosciuszko region during November 2010 - January 2011, resulted in the capture of an additional 29 adults. Resurvey of the same sites during October - November 2011 resulted in the capture of 139 adults, but none were captured at another two potential sites. (Schulz 2011, Schultz *et al.* in press, L. Broome and H. Bates, unpubl. data). At this point, predictions using densities from the successful sites and mapping of potential habitat between Mt Jagurgal and the Brindabella Ranges suggests that locating more than an additional 250 females and 100 males is unlikely (L. Broome and H. Bates unpubl. data).

Relationship with snow cover.

Reasons for the observed declines in Pygmy-possum numbers since the late 1990's are currently being investigated by modelling the combined NSW and Victorian data sets to determine if population fluctuations and changes in survival can be explained statistically by regional climatic variables. However, preliminary modelling of the NSW data suggests that the declines are at least in part related to reduced survival of possums associated with diminishing snow cover and early snow melt.

Annual survival of adult female *B. parvus*, for 1986-2009, calculated as the total number of females recaptured early in the breeding season each year as a proportion of the total captured the preceding year at four sites monitored in Kosciuszko National Park (Broome 2001b) is shown in relation to snow cover duration time of snow melt and start of snow cover in Figures 2a, 2b and 2c. Snow cover duration were derived from weekly readings of snow depth averaged over seven poles that comprise the Snowy Hydro Spencers Creek Snow Course (altitude 1830 m, Snowy Hydro Pty Ltd records). The start and end of snow cover was defined as the beginning and end of persistent snow cover, discounting short periods of snow that lasted less than 2 weeks at the beginning and end of the season. Snow cover duration was defined as the time from the start of persistent winter snow cover to snow melt. The best fit trend lines shown in Figures 2a ($r=0.50$, $n=23$, $p<0.02$) and 2b ($r=0.53$, $n=23$, $p<0.01$) are quadratic, suggesting that survival is reduced at high and low values of snow cover duration and time of snow melt and is optimal at intermediate levels. There was no significant relationship between survival of adult female *B. parvus* and the beginning of the snow cover ($r=0.13$, $n=23$, $p>0.05$), which ranged from early May to late June (Figure 2c). Reduced survival in years of very long snow cover duration and late melt is most likely because hibernating possums run out of stored fat and die before spring. The years of longest snow cover duration and latest snow melt occurred early in the sampling period (e.g., 1991, 1992, 1994, 1996). More recently, low survival has occurred during years of very short snow cover duration (Figure 2a) and early melt (Figure 2b) (e.g., 1998, 1999, 2006, 2008). Snow cover duration at Spencers Creek has reduced by an average of 10 days between the period 1987-1997 and 1998 – 2009 (160 - 150 days) and snowmelt is on average 15 days earlier (10th November – 26th October).

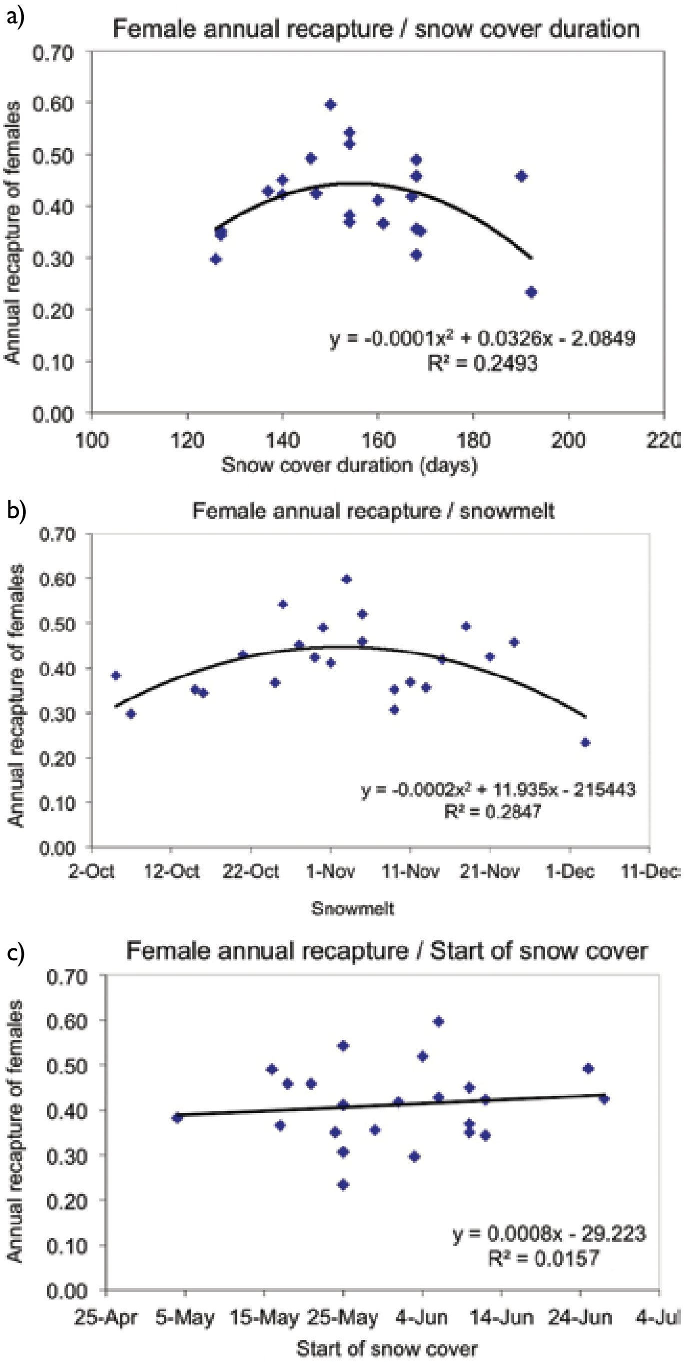

Figure 2. Annual recapture (survival) rates (1986 – 2009) means from four sites of adult female Mountain Pygmy-possums as a function of (a) snow cover duration (b) time of snow melt and (c) start of snow cover measured at the Snowy Hydro snow course at Spencers Creek, in Kosciuszko National Park.

Habitat restriction and possible causes

Why survival of the Mountain Pygmy-possum appears to be linked to the presence of snow, and the timing of snow melt and not the start of snow cover, may be related to energy conservation, food availability and predation. Providing they have sufficient body fat adult possums begin to hibernate in March or April, well before the May – June start of winter snow cover. Although hibernacula appear to be well insulated even without snow, a good cover of snow (>50-100cm) provides additional insulation during the coldest part of the winter and promotes prolonged torpor in hibernating possums. Shallow snow cover, particularly when associated with warmer temperatures that result in rain filtering through to the hibernacula, reduces temperatures and leads to more frequent arousals, thus depleting energy stores and decreasing winter survival (Broome and Geiser 1995, Körtner and Geiser 1998, Walter and Broome 1998). These conditions also lead to early spring melt. Early snowmelt in spring, observed in some years to occur before the arrival of migratory Bogong moths, may leave Pygmy-possums with little food during the critical early spring period of final arousal from hibernation and the beginning of breeding. Foraging for alternate food in the shrub lands outside the shelter of the boulders where the moths gather may also lead to high levels of predation from feral cats and foxes, especially around ski resorts where these predators concentrate. The survival of foxes and particularly cats, which probably suffer high mortality during years of very heavy snow cover, may also be increased in years with less snow.

The advantages conferred by conserving energy during winter by hibernating (Geiser and Turbill 2009), coincident with a plentiful food supply of Bogong moths and Mountain Plum-pine seeds, may be sufficient to explain the correlation of high Pygmy-possum population density with high elevations and snow cover (Broome *et al.* 2005). However, we still do not understand what limits the Mountain Pygmy-possum at the lowest elevations. The broad range of diet of the possums should enable them to persist in the absence of these food items, albeit at low density. Hibernation appears to be flexible rather than obligatory, with torpor bouts varying by sex, age and temperature. In captivity some individuals do not hibernate at all (Geiser *et al.* 1990, Geiser and Broome 1991, 1993, Körtner and Geiser 1998, Walter and Broome 1998). Females are polyoestrus and are capable of producing two litters in a season, as has been seen occasionally in recent years in populations found at Mt Buller and Kosciuszko (D. Heinze, L. Broome unpubl. data). The reproductive strategy of the Mountain Pygmy Possum is similar to many Australian marsupials found in less predictable habitats than the temperate forests found along the Eastern seaboard, and allows possible replacement of lost litters and also to take advantage of years of abundant resources (McAllan 2011). While their potential to increase reproductive output is indicated and they appear pre-adapted to a longer breeding season than normally experienced in their present environment, increase in populations appears to be limited by other factors.

The question of why the Mountain Pygmy-possum does not occur below the winter snowline is intriguing and is currently the focus of several PhD student projects, examining climate extremes, food supply and interactions with potential competitors and predators which may be less well adapted to living in snow and gain an advantage in the absence of snow. One possibility is that the climate at the edge of the snowline, without the insulating benefits of snow during winter and with high summer peaks (*B. parvus* become hyperthermic at temperatures above 28 °C Fleming 1985) is simply too extreme for it to cope with physiologically. Yet, another small mammal species well adapted to living under snow in the alpine-subalpine environment, the herbivorous Broad-toothed Rat *Mastacomys fuscus*, also occurs in cool, moist environments down to sea level in Victoria and Tasmania (Happold 1995, Green *et al.* 2008). Could the current restriction of *B. parvus* to areas above the winter snowline be an accident of prehistory (see below)?

Projected trajectory of populations with climate change

Data presented by the Bureau of Meteorology (2010) show that since 1960 the mean temperature in Australia has increased by about 0.7°C, with the strongest warming occurring in spring (about 0.9°C). The last decade (2001 – 2010) was the warmest decade on record, averaging around 0.52°C above the 1961-1990 average for Australia (Bureau of Meteorology, 2010, 2011a). The period from 1996 – 2010 was also the driest 13-year period on record across south-eastern Australia (CSIRO 2010). A climate modelling study by CSIRO (2010) provides evidence that these trends are related to changes in large-scale atmospheric circulation affecting south-eastern Australia associated with global warming.

The Mountain Pygmy-possum is the only Australian mammal entirely restricted in its distribution to areas above the winter snowline. It appears to be an alpine-subalpine specialist, dependent on snow cover and therefore under severe threat from climate change (Geiser and Broome 1993, Körtner and Geiser 1998, Walter and Broome 1998). Modelling by Brereton *et al.* (1995), using climate surfaces developed for the 1986 version of BIOCLIM (Busby 1986), indicated that the bioclimatic range of *B. parvus* will disappear with a 1°C rise in mean annual temperature. A time series analysis of Australian-average annual mean temperature anomalies relative to 1961-1990 by Hennessey *et al.* (2008) suggests that around 0.5°C of warming has occurred since 1980. However, the rate of warming in south eastern Australia is higher than the Australian average, with a warming trend within the range of the possum of 0.1-0.3°C per decade. A similar time series analysis of annual mean temperature for the region of Eastern Australia that is bounded by 139.5° E to 148.5° E and 30.5° S to 37.5° S (the range of the possum) by H. Shi (unpubl.; data sourced from Bureau of Meteorology 2011b) indicates an average rise of 0.7°C above the 1986-1990 mean temperature in 2010, with peaks of 1.1°C and 1.2°C above the 1986-1990 mean in 2007 and 2009.

Examination of data from the last 30-40 years indicates that snow depth and duration in the Australian Alps is diminishing, particularly in spring (Davis 1998, Nicholls 2005) and climate change models predict large reductions in snow depth and duration, with increasingly early snow melt by 2050 (Hennessy *et al.* 2003). Given the apparent relationship between Mountain Pygmy-possum survival and snow, this is likely to have a large impact on the possum. Figure 2a indicates that optimal snow cover duration, measured at Spencers Creek, is about 150 days for survival of adult female Mountain Pygmy-possums. The actual duration on each of the trapping sites varies because of differences in elevation, aspect and topography (e.g., in 2010, when duration at Spencers Creek was calculated as 148 days, duration on the monitoring sites ranged from 102 – 150 days, H. Shi unpubl. data). Hennessey *et al.* (2003) predict that the total alpine area with at least 100 days of duration of snow cover decreases by more than 60% with a 1° C rise in temperature above 1990 levels and is non-existent with a 3° C rise. McCarthy and Broome (2000) predicted that long-term reduction of the 1987-1997 possum survival and recruitment rates by more than 20% was likely to lead to severe population declines. Between 1998 and 2009 both survival and recruitment declined by 11% on average (L. Broome, unpubl. data). However, in the earliest snowmelt years (1998, 1999, 2006, 2008) survival was 20% below the 1987-1997 mean and for years where snow duration at Spencers Creek was less than 130 days (1998, 1999, 2008) survival was reduced by 25%.

The observed declines in Mountain Pygmy-possum numbers since the late 1990's have not yet resulted in the extinction of any of the monitored colonies and therefore a discernible reduction in range, although one colony in each of the Kosciuszko and Bogong High Plains populations (Mt Blue Cow and Mt McKay) and the entire Mt Buller population have come perilously close. As pointed out by Brereton *et al.* (1995) the scale of the climatic surfaces used in their model was quite broad (*ca* 10 X 10 km blocks) and elevation was the mean for each block. The analysis did not take into account small scale variations in elevation, slope, aspect, geology or vegetation, all of which are likely to modify temperatures within the microhabitat of the Mountain Pygmy-possum. The boulderfield habitat has a capacity to buffer air temperatures and temperature within the micro-environment of the boulders are less extreme than recorded air temperatures (Shi *et al.* 2010). Never-the-less, given the apparent link with snow, the prognosis for the future viability of *B. parvus* in its present environment under predicted continuing climate change, which increasingly appears to be tracking the worst case scenarios (Steffen 2009), i.e., 1° C projected temperature change by 2020 and 3° C by 2050 under the Hennessey *et al.* (2003) snow duration model, is clearly cause for concern.

Burramys and the fossil record: using the dead to save the living

Archer *et al.* (1991), in a paper exploring the potential value of the fossil record to conservation, noted that this record might well be relevant to improving the chances for survival of the Mountain Pygmy-possum. In a paper in preparation (Archer *et al.*), reasons are given in detail for why it seems highly likely that this alpine species would almost certainly be able to adapt to and thrive in cool temperate lowland rainforests with specific additional attributes.

For the last 26 million years this lineage has been represented by four barely distinguishable chronospecies that have succeeded each another through time, all in cool temperate lowland rainforests most commonly developed on rocky substrates. These include: *B. triradiatus* from central South Australia in the late Oligocene; *B. brutyi* from Riversleigh, Queensland, in the early to late Miocene; *B. wakefieldi* from Hamilton, Victoria, in the Pliocene; and *B. parvus* from southeastern Australia in the Pleistocene and Recent (Brammall and Archer 1997, Pledge 1987, Turnbull *et al.* 1987, Archer and Beale 2004). The record documented from the World Heritage Riversleigh fossil deposits is particularly striking with one species (*Burramys brutyi*) spanning at least 10 million years in palaeohabitats interpreted from a range of different datasets to have been cool temperate lowland rainforest that never dried out and never froze (Archer *et al.* 1991, Archer and Beale 2004). Further, there has never been more than one species known to have existed at any one time. Hence we appear to have in effect one species transforming through space and time from the late Oligocene to the present.

Each of the succeeding species spanning this 26 million-year-long interval has maintained the specialised dental feature of this lineage: a unique (among possums) plagiaulacoid (circular-saw-like) third premolar in each quadrant of the dentition. This conserved specialised feature in each of the succeeding species suggests that these possums have occupied a unique but persistent niche within the communities of which they have been a part. It is possible that this dental specialisation makes it easy for them to slice open hard seeds to access the energy-rich food within.

It seems probable that at some time during the last two million years, during one of the four interglacial warm periods of the Pleistocene, lowland rainforests, with populations of *Burramys parvus* (or an as yet unknown species ancestral to *B. parvus*), expanded up into the alpine zone. With the onset of the next cold and dry glacial interval, the rainforest would have contracted back into the warmer, wetter lowlands leaving behind several of the most resilient of its former inhabitants including the Mountain Pygmy-possum and possibly other taxa such as the Southern Corroboree Frog (*Pseudophryne corroboree*). A similar history of rainforest comings and goings has characterised the high Atherton Tableland in northeastern Queensland (Kershaw *et al.* 2007) although in these higher latitude areas rainforest has been able to persist for longer intervals than has been possible in the Southeast.

In the palaeocommunities where species of *Burramys* previously existed, one other attribute was common: rocky substrates underpinning the rainforest. Given the modern species' use of rockpiles for a range of life strategies, it seems probable that earlier chronospecies used the same behavioural adaptations to reduce competition and predation within those palaeocommunities. As the alpine rainforest vegetation in New South Wales and Victoria subsequently changed to open woodlands and shrublands, the open framework of the boulder piles in these areas enabled the resilient possums to survive the retreat of the rainforest.

Their current ability to hibernate to survive the wintry conditions is inherently present in burramyids in general. Geiser (2007) demonstrated that the Eastern Pygmy-possum *Cercartetus nanus* can be induced to hibernate without apparent harm for more than a year. Conversely, it is evident from previous husbandry efforts that *B. parvus* are not likely and do not need to hibernate at temperatures above 12°C (Geiser *et al.* 1990, Geiser and Broome 1993). Hence the species clearly has a much greater metabolic plasticity and behavioural repertoire than individuals in their current environments would suggest. Further, captive populations have thrived on a wide range of foods not present in their alpine habitats suggesting that they are not tied to these alpine resources.

Biodiversity of the palaeocommunities in which previous species of *Burramys* lived has always been much higher than the diversity of the communities in which *B. parvus* survives today. The specialised nature of the dentition of all species of *Burramys*, as noted above, suggests they have occupied a specialised, persistent niche in these biodiverse communities. Similarly, although currently predated by feral cats and foxes as well as native snakes and birds, the number of predators in the palaeorainforest communities where species of *Burramys* previously thrived was far higher with many types of carnivorous dasyurids, thylacinids, perameloids and thylacoleonids among mammals as well as many more kinds of snakes, crocodiles, varanids and predatory birds. Presumably their ability to spend a major portion of their time within the rocky substrate of their ancient as well as modern environments has until now afforded them sufficient refuge from predation.

Putting this together, Archer *et al.* (1991) and Archer and Beale (2004) suggested that translocated populations of *B. parvus*, threatened by climate change in their current alpine habitat, should be able to adapt with minimal impact on other species if introduced into modern cool temperate lowland species-rich rainforests developed on rocky substrates. This would be a return to what has been their optimal habitat for at least the last 26 million years and would, in theory, provide a more secure environment for this lineage to continue into the future.

Growing awareness of the threats to modern species from climate change are leading conservationists around the world to consider the potential need for assisted translocations (e.g., Thomas 2011, Lachlan et al. 2007, Hoegh-Guldberg et al. 2008 and Isaac et al. 2011). The proposal we are floating here, would be a similar response to potentially an even more urgent climate change challenge.

The proposal

As more comes to be understood about the past and present environments occupied by species of *Burramys*, the biology of the living species *B. parvus*, the current decline in its numbers and the looming threat of climate change, the need to act to avert extinction becomes ever more urgent.

The operational plan we propose for aversion of extinction starts with establishment of a breeding facility for the rapidly declining Kosciuszko population in New South Wales. The goal of establishing this facility would be two-fold.

First, it would provide a safety net for unanticipated, short-term disasters in the alpine and subalpine zone which might occur in the immediate future. These could include an extreme year without sufficient snowfall to insulate hibernating *B. parvus* or failure in one or more years for the Bogong months and other key alpine foods to appear when the possums emerge from hibernation. Having a secure, breeding colony could provide individuals for release into those temporarily inhospitable areas after the limiting factor is gone.

Second, on the assumption that climate change will eventually transform the subalpine-alpine zone to make it unsuitable for further survival of *B. parvus* populations in those areas, a lowland breeding facility would provide the opportunity to produce surplus individuals that could be acclimatised for release into cool temperate lowland rainforests with rocky substrates.

To service these goals, a scientifically-determined number of Kosciuszko individuals would need to be translocated to a purpose-built breeding facility being constructed at Secret Creek Sanctuary, Lithgow, New South Wales. The Sanctuary is circumscribed by a predator-proof fence that does not allow entry to cats, foxes or dogs. The environment within and surrounding the Secret Creek Sanctuary includes cool temperate sclerophyll and closed forest most of which is developed on a deep rocky substrate. Average ambient meteorological screen temperatures at Lithgow range from -0.7 to 28°C. However temperatures in the sheltered valley of Secret Creek are cooler and snow occasionally falls during winter. The area is normally invaded by Bogong moths in spring but is also rich with other invertebrates and suitable foods that could sustain wild-released *B. parvus*.

The *B. parvus* breeding facility would include outdoor enclosures with nest boxes located within insulating rock and soil thermal banks, with a cooling sprinkler system in case of extremely hot days, in addition to enclosed nest box areas with temperatures able to be controlled within pre-defined ranges. The facility would be carefully managed to provide optimal breeding conditions as well as research opportunities for projects focused on optimising the long-term survival of this species.

When the colony is sufficiently large and acclimatised individuals have been wild-released, they will be carefully monitored via radio-tracking and the success of the translocation continually reassessed. If successful, other individuals could be considered for potential release into additional suitable lowland habitats further afield. Given the existence of species of this lineage having occurred in lowland rainforests in Victoria in the Pliocene and Queensland in the Miocene, potential release sites in those states would also be considered to maximise the likelihood of survival of this lineage into the future.

If these translocations are successful, consideration would also be given to similar efforts to save other alpine species from anticipated extinction such as the critically endangered Southern Corroboree Frog *Pseudophyrne corroboree* and potentially other sympatric species that may well have a prehistory paralleling that of *B. parvus*. It is possible that whatever cool temperate lowland rainforest environments turn out to be suitable for the Mountain Pygmy-possum will prove to be suitable for the threatened species with which it currently coexists.

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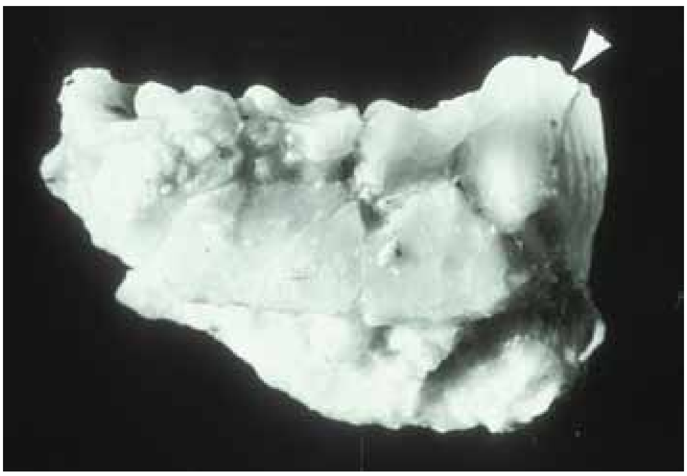
APPENDIX I

A Brief Life History of and threats to *Burramy parvus*: (Linda Broome)



Fragment of a dentary of *Burramys parvus* found in the Broom breccia, Wombeyan Caves, indicating the highly-specialised plagiaulacoid third premolar.

APPENDIX I

Mountain Pygmy-possum on Mountain Plum-pine *Podocarpus lawrencei.*
Photo, L. Broome.

Mount Blue Cow habitat winter 2000.
Photo, L. Broome.

Habitat on the western slopes of Mt Kosciuszko.
Photo, R. Thomas.

Mountain Pygmy-possum eating a Bogong Moth *Agrotis infusa*.
Photo, J. Lochman.

APPENDIX I

Mountain Pygmy-possum in torpor. Photo, L. Broome.

Linda Broome with Mountain Pygmy-possum. Photo, R. Thomas.

Habitat at Charlotte Pass: large bolder fields above roadat top half of photo.
Photo, L. Broome.

Rose Broome (aged 7) with Mountain Pygmy-possum at Charlotte Pass: will the children of the future be able to experience this beautiful animal?
Photo, R. Dunstan.

APPENDIX I

The Mountain Pygmy-possum needs a helping hand.
Photo, R. Thomas.

Proposed site for construction of the *Burramys parvus* breeding facility at Secret Creek Sanctuary, Lithgow: working group members attending workshop on 14 October 2010. Photo, A. Meyer

PhD student Hayley Bates with Mountain Pygmy-possum.
Photo L. Broome.

APPENDIX I

PhD student Haijing Shi with Mountain Pygmy-possum. Photo L. Broome.