Bogong Moth Aestivation Sites as an Archive for Understanding the Floral, Faunal and Indigenous History of the Northern Australian Alps

by
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Declaration

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university, and contains no copy or paraphrase of material published or written by another person, except where due reference is made in the text.

Benedict Keaney
‘Come then, my love,
My lovely one, come.
My dove, hiding in the clefts of the rock,
In the coverts of the cliff,
Show me your face, let me hear your voice;
For your voice is sweet, and your face is beautiful.’

The Song of Songs 2:12-14
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Ben Keaney acknowledges the traditional owners of the country studied. It always was, and always will be Aboriginal land!

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I would like to thank both of my Fathers, my Mother, my Sisters and my Brothers for their kindness and love.

I dedicate this work to My Mother- Margaret Mary Keaney (née O’Flynn), I miss you dearly.

Finally thanks must go the Bogong Moth, Agrotis infusa.
Abstract

The research detailed in this dissertation focuses on plant and faunal remains preserved in the accumulating sediments at aestivation sites of the Bogong Moth (*Agrotis infusa*), in the crevices of granite tors in the northern Australian Alps. Analyses have confirmed the preservation of a diverse range of fossil material, including bird feathers, hairs of small marsupials occupying the rock crevice niche, fossil pollen and spores derived from the summit vegetation, and charcoal from fires in the immediate vicinity of the aestivation sites.

The fieldwork focused on the sampling of deposits at various aestivation sites representative of different biogeographical areas to ascertain the sedimentary characteristics of each region. Three aestivation study areas were located and sampled for the study, the Brindabella Ranges, the Bogong Peaks and the Tinderry Range in NSW. The Tinderry Range sites represent the most easterly geographical region, while the Bogong Peaks site and Brindabella Ranges sites represent, respectively, the western and central aestivation site regions of the northern Australian Alps area. Since preservation of organic material typically occurs in a stable low oxygen environment, investigation into the depositional environment is an important aspect of the study to taphonomically contextualise the environmental proxies.

The palynological preparation of material from the three regions revealed abundant pollen derived from local vegetation. A rich assemblage of mammal hair was found in the Bogong Peaks and Mt Gingera sediments. This record provides a unique faunal proxy of sub-alpine ecosystems. Levels of charcoal in the sediments reflect past fire frequency, and are presented in both micro- and macro-charcoal graphs.

Aestivation site deposits are a unique terrestrial archive recording ecological change in the montane and sub-alpine environments for over 1000 years. Despite some chronometric difficulties, they provide an excellent record of the effects of local disturbance, such as fires, on the biome and provide insights into the impact of European settlement, on both vegetation structure and faunal biodiversity. The study provides evidence of massive cultural, ecological and climatic upheaval at sub-alpine elevations in the northern Australian Alps from the late Holocene up to the present, and illustrates the great value that aestivation sites hold as terrestrial archives, signalling a
need for further utilisation and investigation in light of rapid human induced climate change.
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1) Introduction

This thesis is part of ‘The Mountain Occupation Project’ undertaken by the Department of Archaeology and Natural History in the College of Asia/Pacific at the Australian National University, under the direction of Emeritus Professor Geoffrey Hope. This project seeks to place into a context of a changing environment the human habitation of the South-eastern Highlands, using environmental proxies from terrestrial archives. The environmental context of human occupation is an integral part of understanding prehistoric cultures. In the South-eastern Highlands using calibrated dates from Flood et al. (1987), it has been found that humanity has been present in the area for over 25,000 years (Theden-Ringl, 2016). Pollen and charcoal records from montane sedge fens and sub-alpine bogs have records dating back over 15,000 years, and have proven invaluable in the understanding of past environments of the area. The current study will build on and complement prior palynological work, giving a detailed view of the past 1000 years with localised pollen sources recording changes on mountain peaks rather than valley floor deposits. The addition of localized hair and charcoal records at aestivation sites allows an in-depth analysis of ecological changes in another landscape unit type, using several independent environmental proxies. Site specific proxies provide evidence about changes in the past environments at the site, including charcoal as a signature of past local and regional fire events, pollen for tracking changes in vegetation in response to fire, and hair and feathers to track the changes of fauna in response to the effects of fire and the associated changes in vegetation structure and composition.

The importance of fire in the Australian environment is a well-studied aspect of the plant and animal ecology. The responses of both individual species and entire communities to fire can be both tracked and predicted using the information preserved in terrestrial archives. The apparent stability of aestivation sites, both environmentally and taphonomically, does enable a very useful reference point for both past and future ecological change. There has been a vast amount of ecological change in the past 1000 years in sub-alpine ecosystems in South-eastern Australia, much of it as the result of the arrival of European invaders. A number of important questions are prompted by this study, such as what was the fire regime prior to European arrival? How was that regime affected by European arrival? What effect have the different European land management
practices had on the flora and fauna of the mountain peaks? It is important to ascertain the nature of these changes, their timing and the response of individual species, as much for scientific endeavor, as for the provision of predictions that will assist the conservation of that ecosystem under the impact of massive environmental change predicted from global climate change stemming from the burning of fossil fuels.

The unique preservative conditions prevalent at aestivation sites provided a valuable environmental proxy assemblage with pollen and spores from proximal vegetation, local faunal hair and feathers and charcoal from local fires. A great strength of using these proxies to interpret past environmental conditions lies in a measure of their independence, their sources and methods of deposition vary, but they are bound by the same organic matrix and provide different perspectives of the same ecological temporal point.

This novel terrestrial archive and new integrated approach to the environmental proxies contained within allows a deeper understanding of ecological relationships in the sub-alpine environment of South-eastern Australia over a long time period, where several forest structural successional cycles are preserved and can be compared and contrasted through time. The presence of aestivation sites in the landscape, their position, their unique fauna and quite specific local flora, all contribute to the possibilities for the understanding of changes both in the past and in the future. The current research sampled and dated a number of aestivation sites to understand the depositional environment at the sites, and while intensively analysing environmental proxies at fewer sites, it was found that these sites provide a very useful source of data, and that aestivation site sediments deserve more research.

This thesis starts by reviewing some basic information on the ecological phenomenon of aestivation of A. infusa before describing the experiments conducted on the sediments present at the aestivation sites. In the chapter ‘The Natural History of the Bogong Moth’ a background to the phenomenon of the aestivation is provided, firstly detailing the lifecycle and migration of A. infusa, then specifically looking at the environmental context of the migration and aestivation, with a section on environmental differences between the cave and the open environment. The literature on natural history using invertebrates is then explored. Next the ethnographic literature on the Bogong Moth is examined for anecdotal accounts of the aestivation and moth harvesting by the traditional owners, and also to illustrate the social dynamics of contact period. The archaeological and palaeo-environmental context of
the South-eastern Highlands is also discussed.

In chapter 3, ‘The Bogong Moth in the landscape’ the climate of the study areas is discussed. The study sites are described, with location maps, colour plates and descriptions of the morphology and vegetation at each site. These include The Bogong Peaks site, the Mt Gingera area and the Tinderry Ranges. A short diagram of the Mt Coree record is presented to contrast the local site environment with the pollen and hair record. Following that a section on the air-pollen sampling experiment, which describes both the method, the sites and the results, and illustrates that pollen deposition in the cave sites is predominately from local sources.

In chapter 4, ‘The Bogong Moth as a preserver’ the sediment characteristics of study sites are provided. The principal objective was to profile their biophysical features to better understand deposit taphonomy. Sediment analyses included carbon-nitrogen (C/N) content of the organic fraction, ether extraction of oil and wax content, pH, Loss on Ignition (LOI) and magnetic susceptibility. Finally dating methods are described, and are followed by the presentation of the age models for the study sites. The AMS ages of these deposits suggest that all of them are of relatively recent origin, and are less than about 1000 yr BP. The age depth models were formulated by OxCal Version 4.2 (Bronk Ramsey, 2013), which uses Bayesian statistics to show the relationship between selected stratigraphic dates.

Chapter 5, ‘The Bogong Moth proxy record’, describes the methodology employed for the principal three main environmental proxies investigated, that are pollen, hair and charcoal. Some theoretical background to the use of each of the proxies is discussed. Descriptions of field sampling, proxy isolation, mounting and analysis are discussed, as well as the sampling of the pollen load of moths, the identification of mammal hair, using the Tasmanian Devil, Sarcophilus harrisi, as an example, and the interpretation of charcoal in sediments as a marker of social change.

Chapter 6, ‘Bogong Moth deposit findings’, presents the results of the pollen, hair and charcoal analysis from the four main sedimentary cores, that is Bogong Peaks 1 and 2 (BP1 and BP2), Mt Gingera Cave 4 (G4) and Mt Gingera Big Cave (GBC), using diagrams generated by the programme Tilia (version 2.0.32) (Grimm, 2004). Two types of diagrams are presented for each of the cores, that is a diagram of pollen percentages and a diagram of faunal remains present in the deposit. Both of the diagram types are drawn on a time axis and include magnetic susceptibility, macro-charcoal and micro charcoal curve. The percentage pollen graph is organised by vegetation types, that is wet forest, dry forest, shrubs, regional, herbs and introduced.
In the penultimate chapter 7 titled ‘A new landscape history informed by Bogong Moth deposits’ the results of the analysis of past environmental proxies is discussed in terms of the impact of European land management, and changes to vegetation, fauna and fire regime. The preserved record is analysed in light of this, where fire disturbance and vegetation structural succession as well as introduced animals directly impact the faunal populations recorded at each site. The record of human hair is also discussed. Finally future environmental change is discussed with the threats and challenges facing subalpine ecosystems.

The concluding chapter firstly presents a summary of how the detritic sediments present at aestivation sites have provided evidence for a different outlook on the forest structural dynamics and ecology, one where structural succession of the forest is key to the composition of both fauna and flora. Then the chapter raises the issue of the impacts of past and future management on the sub-alpine areas. It calls for an understanding of these dynamics, especially when confronted with the effects of human-induced climatic change, where records of past ecological change can inform land managers of today about the reactions of ecological communities tomorrow.
2) The Natural History of the Bogong Moth

‘Remember now the world where you were born;
The month of your return at last is here.’
From ‘The Return of Persephone’ by Alec Derwent Hope.

2.1- The Bogong Moth and aestivation

Moths and butterflies belong to the order Lepidoptera, which is divided into four sub-orders which in Australia is dominated by the sub-order Ditrysia. The Bogong Moth, *Agrotis infusa* (Boisduval) family Noctuidae, is a ‘cutworm’ moth. Noctuidae is the largest family of moths, itself having nineteen sub-families. Worldwide this family contains some 25 000 species falling into 4000 genera. In Australia there are about 11 500 described species and about 380 genera (Common, 1990). *A. infusa* is found across southern Australia from west to east coast, and has been recorded in New Zealand. Common (1990) records *A. infusa* as being found south of the Tropic of Capricorn both on the Australian mainland and in Tasmania, as well as Norfolk Island.

Unlike other cutworms *A. infusa* does not migrate to breed. Instead it migrates and enters a state of relative dormancy in the cool mountain environment for the duration of hot summer weather in its breeding grounds. This summer dormancy is termed an ‘aestivation’. Aestivation of *A. infusa* is an example of a behaviour that has evolved due to climatic and environmental variability, so that in spring, before the heat of summer eliminates broad leaved pasture plants, which are the main larval food, individuals migrate and gregariously aestivate in cooler situations prevalent at higher altitudes in the mountains of South-eastern Australia (Common, 1990).

Hughes (1975) described the larvae of *A. infusa* as feeding on broadleaved weeds and pasture plants including Capeweed (*Arctotheca calendula*), Lucerne (*Medicago spp.*), and the saltbushes (Chenopodiaceae). Food plants of cutworms listed by Common (1990) include Wheat (*Triticum spp.*), Barley (*Hordeum vulgare*), Lucerne, Pea (*Pisum spp.*, Fabaceae), Cabbage and Cauliflower (*Brassica oleracea*), Linseed (*Linum usitatissimum*) and Potato (*Solanum tuberosum*). Common (1954) found the greatest abundance of larva was in Lucerne, and least abundance in areas with a dominance of grass species. Saltbushes are the most widespread native food plant listed, and is the most likely candidate for sustaining a large population of *A. infusa* in pre-European times.
An early hot period is most likely to affect *A. infusa* populations adversely through a high mortality of host plant seedlings. Cawood *et al.* (1996) differentiated between two types of extreme heat in the South-eastern Australian cereal belt, firstly progressive seasonal summer increases and secondly sudden springtime temperature increases. Sudden springtime temperature increases of 10-15 °C can last a few days, and visibly wilt the drought intolerant species. A complete drying of seedlings and shoots, without regrowth, before the fatal progressive prolonged seasonal summer temperature increases, could delay and then limit recruitment for aestivation. Larvae of *A. infusa* will usually moult through five instars before pupating, but on a diet of grasses the number of instars can increase to eight. The maturation of eggs in late autumn coincides with the sprouting of broad-leaved pasture plants, but if winter development is slow, the final instar reached from late August to September (Hughes, 1975).

The seasonal migration to escape harsh climatic conditions in the breeding grounds distributes the species biomass into a localised area for the duration of the unfavourable seasonal conditions in the breeding grounds. Keaney (2006) characterised aestivation sites as permanent, those used for temporary shelter during migration and archaeological sites, based on the concentration of micro-remains of *A. infusa* in the soil profile, by using the method of Clark (1982) for the quantification of charcoal in sediments. Other indicators of permanent aestivation sites from deposits included high soil acidity, the presence of nematodes and the high frequency of soil fungi, but it should also be stressed that environmental and geographical characteristics of aestivation sites are very specific. Aplin *et al.* (2010) characterised a site (Y259) in the Yarrangobilly area with an altitude of 1100 m and situated in a limestone doline as a minor aestivation site based on the presence of the visible remains of *A. infusa*. They postulated that more significant diurnal temperature variations present at the smaller and more open site as opposed to other sites lacking moths and the cold overnight temperatures of cave might benefit the aestivating moths. In this instance the environmental conditions are not suitable for aestivation, and presence of moth remains would be more related to favourable taphonomic conditions and general moth prevalence through the high country, than the very specific syndrome of aestivation. It is less than adequate to postulate that this site ‘clearly harbours seasonal aggregations of Bogong moths (p 206)’ without more evidence than visible remains of moths on the surface, any more so than some windows in Canberra.
Permanent aestivation sites, that is locations that harbour hibernating moths every summer (Keaney 2006), include shelters on Mt Bogong (1986 m), Mt Cope (1837 m), Mt Buffalo (1695 m) and Mt Hotham (1861 m) in Victoria, Mt Jugungal (2061 m), The Rams Head (2190 m), Mt Gingera (1855 m), Jounama (1718 m), as well as sites in the Tinderry Ranges in New South Wales and sites in the Namadgi Ranges in the southern part the Australian Capital Territory. When plentiful, moths will aestivate under boulders and rocks in scree slopes on peaks that lack caves and crevices, and mountains such as Mt Kosciuszko (2230 m) or Mt Ginini (1762 m) can become temporary moth habitat (Flood, 1973), these are contrasted with high quality permanent sites that have consistent annual aestivation of moths (Keaney 2006).

The long-term annual use of specific rock piles on specific mountains for aestivation, such as on Mt Gingera (Plate 2.1), raises questions as to how individual moths are able to find these areas, how the migration is timed for favourable and specific wind conditions, and how this selection is inherited over generations. Navigation is required by *A. infusa* at least twice for aestivation, that is during each leg of the migration. The repeated seasonal selection for aestivation of particular, predetermined destinations incorporates goal-seeking behaviour. The goal of the navigation varies each way, one converging and the other diverging. The flight to aestivate, which is a spring convergence, and the return flight to breeding grounds, which is an autumn dispersal, is dependent on changing seasonal atmospheric environmental parameters.

Plate 2.1- Aestivation boulder pile site on Mt Gingera (Photo A. Wade).
While aestivating each moth rests the foremost tarsi gripping the surface of the rock, with the mid and hind legs on the backs of the moths behind (Plate 2.2). Moths are not completely immobile during the months of aestivation, and it is common to observe wing tremors in stationary moths, crawling and some instances of short flight. Common (1954) ascertained that these flights were not related to feeding, and also documented further regional migrations during summer of moths from Mt Gingera to other aestivation areas, and their return via Mt Gingera, to their breeding grounds in late summer and early autumn by changes in the numbers of moths at the study site.

Plate 2.2- Aestivating Bogong Moths (A. infusa).

2.2- Wind Patterns as a driver of aestivation
It is migration, and a high density of hibernating individuals sheltering in specific habitat, that characterises aestivation by A. infusa, where a large population of moths congregate in specific sites on mountain peaks of South-eastern Australia by utilising seasonal atmospheric conditions. It is not known exactly how A. infusa navigates to these peaks (Warrant et al., 2016), but the origins of this species population movements, and indeed populations of many species of Noctuids, follows the main seasonal air-mass sources (Chen et al., 1989). In the spring migration the numbers of A. infusa increase dramatically behind warm fronts from the north, and the moths disperse in autumn behind southerly cold fronts,
a phenomenon also documented in other noctuid species (Pedgley et al., 1995). The evolution of migration upon winds associated with frontal systems to escape climatic extremes utilises characteristic annual atmospheric circulatory mechanisms. Seasonal wind patterns are important in delivering the moths to the specific aestivation sites. Without the assistance of wind, the migration would not be possible without large additional energy input during the course of the migration, and the migration itself would take much longer. The use of winds to aid migration is an efficient method for the conservation of energy and therefore biomass in a round migration spanning thousands of kilometres (Showers, 1997). The large movement in biomass distribution is made possible by atmospheric movement.

For insect migration, the atmosphere may be characterised into three general layers, that is, the biological boundary layer, which is only a few metres deep, the planetary boundary layer (PBL), in which convective mixing occurs during the day and depth may exceed 1000 m, and the geostrophic layer, which extends upward to the tropopause (Farrow, 1986). Under quiescent night-time surface conditions, the PBL becomes shallow and may develop a strong wind shear between the surface and the geostrophic flow at 100-300 m (Farrow, 1986). Geostrophic winds originate near the top of the PBL, where there is negligible atmospheric friction with the surface of the Earth. Migration of lepidopteran species occurs at the top of the PBL and is assisted by geostrophic winds, in a layered zone directly above a stable PBL. Such migratory formations appear to be a temperature driven phenomenon (Drake and Farrow, 1988).

A type of geostrophic wind, described by altitude, which is directly above the PBL, is a low-level jet stream. These are subject to diurnal variation, and have their maximum values in the early morning (0300 to 0600 hr), when the surface temperature inversion is greatest (Bureau of Meteorology, 1981). They are reduced and stopped during the day by solar radiation destabilising atmospheric conditions close to the Earth’s surface.

The definition of a jet stream is ‘a strong narrow current concentrated along a quasi-horizontal axis in the upper troposphere or in the stratosphere, characterised by strong vertical and lateral wind shears and featuring one or more velocity maxima. The speed of the wind must be greater than 60 knots (111 km/hr) (Bureau of Meteorology, 1975). The criterion for a jet-stream is a minimum speed of 60 knots (111 km/hr), a length of 1000 km or more, a width of 100 km or more, a depth of 1 km or more,
vertical shear of 10-20 knots (18.5-37 km/hr) per kilometre, and a lateral shear of 10 knots (19 km/hr) per kilometre (Bureau of Meteorology, 1981). Jet stream formation is also influenced by the large-scale interaction of the airflow around anticyclones with mountain barriers. Major topographical features, such as the Great Dividing Range, contribute to the development of low-level nocturnal jet streams and make the jet streams more directed, more intense and more persistent (Drake, 1985). Much of the Bogong Moths northward displacement during return migration is fast and with the aid of winds above the PBL, due in part to the deflective effect of the Great Dividing Range. If geostrophic winds are a net west to east flow in South-eastern Australia, they may permit a seasonal autumn northward return-migration along the Great Dividing Range but be less suitable for the dispersal of *A. infusa* into continental Australia than winds in the PBL.

Studies have revealed that Noctuid species may be dispersed directionally, in relatively high densities, and great distances by low-level jet streams. For strong flying insects the most effective means of seasonal long-distance migration are winds derived from the Coriolis Effect (Drake, 1985).

It is interesting that Common (1954) described an northerly exodus of *A. infusa* from aestivation sites where moths went with, against and across the wind. This is explainable as a use of surface winds, and an example of where small scale wind shifts and turbulence becomes an overriding influence (Johnson, 1969). Atmospheric mixing such as occurred in this example this is not conducive for the creation of low level jet streams. Lepidopteran species expend far greater energy to achieve the same distance flying into the wind than with it (Feltwell, 1982). Seasonal wind assisted migration is energetically efficient, in the correct direction and more or less coinciding with seasonal temperature, moisture and vegetation changes that would otherwise be fatal to Lepidopteran larvae.

Moth flight is fuelled by the metabolism of fats, carbohydrates and amino acids (Srygley and Oliveira, 2001), and a store of energy sources is required for long-distance migration and aestivation. Large numbers of Bogong Moths have been seen feeding during the migration in spring on the flowers of several species, including Patterson’s Curse (*Echium plantagineum*) and Yellow Box (*Eucalyptus melliodora*) in the Canberra region, and feeding on the sugary exudate of lerp-forming insects in the autumn migration (Green, 2006), these carbohydrate sources only supplement the energy requirements for a round migration of thousands of kilometres. There is no evidence of mass appetitive flights during aestivation (Common, 1954). It must be
noted that the greatest nutrient intake, and development, of moths is in the larval stages when food plant availability is an imperative. The synchronicity of the emergence of migrant lepidopteran populations from pupae with an abundance and availability of food plants, and conditions that are conducive to aerial transport, defines the major temporal and spatial trends in populations, as well as where population movements may originate and culminate (Raulston et al., 1986). An important determinant of successful migration is the assistance of the wind in either leg of the migration (Showers, 1997). During the migration to aestivation sites moths have greater energy stores than the return journey, when mating and laying eggs impose an energy deficit. It is expected that return journey in autumn is vital for recruitment, and that long term changes in the wind patterns, such as the strength and direction of low level jet streams could influence the evolution of migration as well as the distribution of breeding grounds of A. infusa.

Aestivation maintains the biomass of individual moths for the return journey until weather conditions permit wind assisted return-migration. The timing of the return migration coincides with cold calm autumn nights in Canberra, when atmospheric conditions present are conducive to the production of northerly jet-streams that drive air masses from the south towards the equator. Aestivation of A. infusa is a complex behaviour that occurs within very specific environmental conditions, and is integrally linked to the annual lifecycle of the species. The mechanisms by which aestivation occurs are an important part of understanding the phenomenon itself, both the round migration and the diapause. A two-way long-distance wind-assisted migration with a gregarious summer diapause is a useful way to characterise the aestivation of the Bogong Moth.

2.3- Environmental parameters at aestivation sites
During migration communal roosting of A. infusa occurs during the day, normally in sheltered sites such as fissures, cracks and crevices, but also in the corners and along edges in shaded areas along the migration path. Bogong Moths avoid direct sunlight, and in selected areas can congregate from pairs to several hundred. Many apparent ‘moth camps’ are temporary; these temporary camps include lift-shafts and air-conditioning channels in buildings (Hughes, 1975). ‘Infestation’ of Parliament House in Canberra by A. infusa is not an aestivation as the moths are active, and would attempt further migration if they did not get trapped in the building. Neither high density nor low movement defines aestivation, as aestivation occurs at the terminal
end of the migration, and not during the migration itself. In the years when *A. infusa* is most numerous permanent camps may overflow so that higher altitude temporary camps may be occupied for a season. Truly permanent camps occupied regularly are characterised by a deep layer of silt-like material on the floor of the caves, consisting of moth scales and cuticle deposited over time (Hughes, 1975).

Despite the harsh conditions encountered at higher altitudes, notably exposure to high winds and elevated radiation, aestivation sites are largely sheltered from these desiccating influences, and even in the peak summer temperatures remain both cool and moist. The environmental parameters that are present at permanent aestivation sites are specific and result from geographical factors. The environment is cool, dark and moist. Maximum temperature ranges at aestivation sites in boulder piles are less extreme than those exposed areas in close proximity. The greatest discrepancy between temperature and humidity regimes in the boulder-pile environment, and surrounds, is during highest maximum ambient temperature. Aestivation at Mt Gingera starts with mean monthly temperatures in October and November of around 5 °C, and finishes in April, also with a mean monthly temperature of around 5 °C (Common, 1954). Boulder piles offer some protection against the frost, snow and rain, but the mean minimum temperatures are lower in the boulder pile environments, therefore the timing of the autumn migration before the onset of lethal temperature regimes is paramount.

Aestivation sites have very specific environmental characteristics, and are uniquely placed within the environment, depending on various factors from geology, altitude, aspect, the microclimate within and immediately surrounding the site. The mountain peaks in which they are situated can also be characterised by their environmental parameters.

The environmental parameters of aestivation site areas was modelled for South-eastern Australia using a range of altitudes, that is in the south a Victorian high country (Mt Bogong), an alpine site on the Kosciuszko main range (The Rams Head), in the east (Tinderry Peak), and in the north at a lower site in the Brindabella Ranges (Mt Coree). Plate 2.3 shows the location of the modelled sites, their average rainfall, and mean annual temperature. Climatic parameters were calculated using ‘ANU CLIM Version 6.1’ (Xu and Hutchinson, 2011), and the table of results are presented in Appendix 1.
Plate 2.3- Map of climate modelled sites, with mean annual temperature (°C), and total annual precipitation (mm).

Appendix 1 depicts seasonal rainfall and rainfall patterns, solar radiation levels, humidity and temperature minima and maxima, and is expected to roughly outline the climatic envelope for aestivation site localities in the Alps in terms of temperature, moisture and seasonality, with the sites close to, or at the edge of the geographical distribution of latitude, longitude and altitude. Variation in climate between the localities can be seen to be influenced by both longitude and altitude. At higher altitudes there is higher rainfall, but a similar number of rainfall days, lower maximum and minimum temperatures, higher radiation and less evaporation and lower dew-points, wet-bulb and dry-bulb temperatures. Mt Coree has the warmest temperatures of all the sites but also the largest range of temperatures, the lowest mean moisture index and the highest moisture seasonality index by far. The highest
precipitation of all the sites is at Mt Bogong with its’ lower latitude and second highest altitude influencing climatic conditions. Rams Head is the coldest site, but has the least range in annual temperatures. It has the highest moisture index and lowest moisture seasonality. The Tinderry Ranges are interesting, being the driest, but here the driest quarter is the coldest of all the sites, and the wettest is the warmest, with the highest solar radiation levels. This would tend to indicate a more coastal source for precipitation than the other sites, due in part to the rain-shadow effect of the westerly ranges of the alps, but also warmer, as some convective input is needed to push coastal weather systems inland enough for precipitation to reach the ranges.

The aestivation sites themselves have a thermally buffered microclimate, with more complex boulder-piles having an increased buffering effect. Variability of daily temperature depends on the depth of measurement inside the boulder-pile, with greater stability of temperature with increasing depth (Shi et al., 2015a). Shi et al. (2014) found this buffering of surface temperature maxima to be 2.91 °C at 50 cm and 4.39 °C at 100 cm, with a reduction in temperature range at 50 cm of 3.45 °C in the warmer period and 1.23 °C in the cooler period, while at 100 cm there was a reduction in range of 6.48 °C in the warmer period and 2.05 °C in the cooler period, with vegetation and elevation affecting the thermal buffering of specific points in the boulder pile, while aspect and inclination affected the boulder pile temperatures more generally. The number of rock layers, rock size, cavity size between boulders, vegetation cover and elevation, lead to fine grained thermal variability within the site itself (Shi et al., 2015b). Higher humidity, from a lack of direct sunlight and the storage of a significant amount of moisture in the sediments within the rock-pile, reduces the amount of desiccation by hot and dry westerly winds.

Availability of water is important for the hydration of the moths. Moths have been recorded as drinking the rainwater that trickles through the boulder piles, and this may be the vector for the nematode species (Common, 1990). The evolution of parasitic nematode populations, that is Amphimermis bogongae (Welch) and Hexamermis cavicola (Welch), that use the ephemeral runoff of rainwater, or possibly ponded rainwater as a vector (Welch, 1963; Common, 1990) would indicate the importance of occasional surface water run-off in selection of permanent aestivation sites by A. infusa. The evolution of parasites with a water drip vector to the host in a moist deposit environment illustrates the importance of available water in selection of aestivation sites by A. infusa, and shows that this type of selection has been made for a significant amount of time, which is long enough for evolution of parasitic species.
Permanently wet rock-surfaces are usually avoided by aestivating moths (Common, 1954), but the optimal hydrological condition for aestivation sites is where there is a high level of available moisture, and therefore relatively high humidity. At aestivation sites water may be provided by groundwater emergence, rainwater runoff or snowmelt, which saturates the deposit at the site which provides a store of moisture at the site which lasts through the warm summer months.

2.4- Insects and the sedimentary record
Late-Quaternary pollen analysis, pioneered by Lennart von Post (von Post, 1946), has largely focused on the identification and quantification of fossil pollen and spores, preserved in peat-bogs, swamps and lakes. Such sites are common and widely accessible in North-West Europe and North America. Invertebrates have proven to be very useful in palaeo-environmental reconstruction. The remains of Coleoptera (Beetles), Diptera (Non-biting Midges), Oribatida (Oribatid Mites), and Hymenoptera (Wasps, Bees, and Ants) can also be found in swamps and bogs, and provide a direct chronological proxy of invertebrate activity. Further evidence of climatic and vegetational condition is provided by pollen incorporated into the walls or mounds of social hymenopteran species, or pollen deposited in the sites of gregarious hibernation of lepidopteran species (butterflies and moths).
Chitinous invertebrate exoskeletons are recoverable when buried in stable conditions maintaining either permanent wetness or dryness (Dincauze, 2000). Insect fossils can generally be found in any sediment that contains macroscopic plant remains (Coope, 1977), but the preservation of perfectly preserved insect macro-remains is rarely encountered due to their fragility. The identification of insect macro-remains isolated from within sedimentary layers using morphological characteristics can be a difficult task, and made more difficult with the taxonomic uncertainty of vast numbers of insect species. Chitin, a long-chain polymer of an N-acetylglucosamine, is a structurally stable and slowly degradable protein (Karrer and Hofmann, 1929). It is the resilience of insect skeletons and the sensitivity of insects to the environment that makes them valuable as direct indicators of both local and regional climatic conditions. Individual insect species with a narrow ecological envelope are often the most useful environmental markers.
General morphological characteristics can be used to identify fragmented insect and arthropod sub-fossil material down to a genus level, but an entire species-level
identification of a varied assemblage using morphology is not really attainable. Some individual species-specific identification is possible through the preservation of species-specific morphological characteristics, but these cannot be expected to apply to an entire insect assemblage. The reliability of inferences drawn from fossil material, above other things, is dependent on the taxonomic resolution and consistency (Rieradevall and Brooks, 2001), where the identification becomes more difficult from family or sub-family, to genus and then to species.

Kenward (1978) identified some of the challenges facing palaeo-entomologists. These include inadequate and possibly inaccurate habitat records, variations of the principle habitat in different parts of the range, a wider range of habitats than suggested by the literature, but possibly including a single typical habitat, and the occurrence of specimens away from their habitat. Another shortcoming of using the assemblage composition of macro-remains of arthropod species in sedimentary samples is often logistic, that is the requirement for a substantial sample size, and taxonomic, that is the large number of arthropod species, and finally taphonomic, that is the reliance on the presence of conditions suitable for the preservation of macro-remains (Kenward, 1978).

The sensitivity of insect species in many families to climate change has been used by scientists for the interpretation and reconstruction of a range of past environments. The lag time between climate change and species succession is shorter for insects than it is for vegetation by decades and possibly centuries (Elias, 1994). Quaternary insect assemblages represent a wide spectrum of different available habitats (Coope, 1977). Stenothermic species, that is species adapted to a narrow thermal environment may rapidly colonise a region while conditions are suitable and also disappear rapidly when conditions are unsuitable (Elias, 1994).

Most archaeo-entomological work centres on the Coleoptera, as this is usually the most abundant insect type and many taxa are relatively easy to recognise. The large number of Coleopteran species and their identification from fragments contained in sedimentary material imposes a great task for natural historians. The use of Coleopteran remains for environmental reconstruction has a similar approach to palynology. Environmental parameters for beetle species are ascertained; a library of these environmental parameters for different taxa is compiled, and then used as a reference. If beetle remains are identified in the profile they are cross-referenced with the library of environmental parameters (Porch and Elias, 2000). As a working assumption, remains are seen to represent specific conditions that fall within
the parameters of the current distribution of a species. A reconstruction of past environments can then be attempted.

A review of Quaternary beetle research by Porch and Elias (2000) lamented that palynological studies were unable to answer detailed questions about temperature and seasonality, questions that could be addressed by Quaternary insects, particularly beetles. Porch applied a database built on present day ranges of Australian beetles to the refinement of past temperatures that have been difficult to derive from other proxy data (Kershaw, 2004; Porch, 2007a; Kershaw and Porch, 2005). The application of using fossil beetles for palaeoclimatic reconstruction in Australia has faced difficulties in obtaining fossil bearing material in sufficient quantities from extended sequences (Porch et al., 2001), but the same author was confident of the widespread utility of palaeo-entomology in the Pacific as indicators of pristine environments and human impacts (Porch, 2007b). Denham et al. (2003) recommended large sample sizes (>10 kg) for the representation of rarer taxa.

Research on non-biting Midge, chironomidae (Diptera) has focused on quantifying environmental change using modern analogues of the environmental optimum and tolerance of each taxon, and modelling these for the interpretation of fossil material. Rieradevall and Brooks (2001) modelled water temperature, total phosphorus, anoxia and salinity using chironomid assemblages. Olander et al. (1997) found statistically significant relationships between chironomid distribution, lake water temperature, and maximum lake depth. Broader climatic generalisations, such as relative summer temperatures can also be made (Axford et al., 2005).

Since chironomid distributions are correlated with summer air and water temperature, temperature reconstruction on the basis of chironomid is possible if interference from other environmental variables, including water depth (Heiri et al., 2003), thermal stratification of lakes (Velle et al., 2005), and oxygen concentrations are accounted for. Rolland et al. (2008) used chironomids to infer summer temperatures and to provide information on the timing of the Holocene thermal maximum. Midge-inferred palaeo-temperature can reveal records of late-glacial climate oscillations and subtle Holocene temperature changes (Walker and Cwynar, 2006). Australian midges are reliable and informative biological indicators of water level fluctuations, sediment influx, organic material, oxygen availability and nutrient status (Dimitriadis and Cranston, 2001). Chang, Shulmeister and Woodward (2015) used a chironomid based transfer function for reconstructing summer temperatures in southeastern Australia that was developed from 33 lakes in tropical to temperate climates.
Moss mites, (order Oribatida), are Arachnids. They are typically recovered using kerosene flotation and sieving between 1 mm and 100 µm, but can also be seen on palynological slides (Schelvis, 1990). Identification can be difficult in archaeological specimens that are damaged, so it is essential to have identification keys, some experience and a good reference collection (Schelvis, 1990). They are a reliable indicator of ecological conditions, with the advantage being that they are found in most deposits, they are small and relatively robust, and being flightless, they are usually reflective of local conditions (Schelvis, 1990). Some mite species are primary colonisers that may or may not persist in subsequent succession (Hågvar et al., 2009).

Hymenoptera is an order of insects comprising the Sawflies, Wasps, Bees, and Ants. The name refers to the membranous wings of these insects, and is derived from the Ancient Greek ὑμήν (humén) for membrane, and πτερόν (pterón) for wing. Generally Hymenoptera do not preserve as well as Coleoptera, with the exception in the case of ant heads. Ant heads can be found in a various deposit types and are a useful indicator of environmental conditions including the growth of trees and the arctic treeline (Elias, 1994), or in the case of the South Pacific, Ant introductions give a timeframe for human occupation (Porch et al., 2007).

Melissopalynology is the study of pollen extracted from bee products, that is, honey, wax or propolis. Propolis is a resinous mixture collected from botanical sources and is used as a sealant in the hive. The interpretation of pollen from honey, wax or propolis requires a different approach than typical sedimentary palynology. Lieux (1980) processed samples of honey using acetolysis. Kavavadze (2006) used fossilised honey for palaeo-ecological reconstruction. The samples were rich in pollen and suggested a warmer climate at 4.5 ka BP signalled by the presence of thermophilic broad leaved forest pollen taxa. The pollen loads of Honeybees (Apis mellifera) has seasonal variation, with most productive pollen collection in the mid to late summer, and there are also distinct seasonal plant use variations (Bilisik et al., 2008), as such environmental reconstructions using melissopalynology require an understanding of seasonal variability of pollen for the interpretation of this environmental proxy. Wax has been used for dating rock art antiquity. Nelson et al. (1995) dated rock-art from the East Alligator River in Arnhem Land using beeswax and returned dates ranging from modern to 4040 ± 80 yr BP. This was confirmed by the study of Watchman and Jones (2002).

Geopropolis is the equivalent to the propolis of the honey bee, but is produced by hymenopterans (Hymenoptera: Meliponinae) (Peña, 2008). Geopropolis can be
distinguished from propolis samples by the identification by microscope of mineral and soil constituents as well as the lack of trichomes (Barth and Pinto da Luz, 2003). Dominant pollen grains in geopropolis sediments are better indicators of a restricted area of activity and season of collection while rarer types provide an image of the regional vegetation (Barth and Pinto da Luz, 2003). As with melissopalynology seasonal variation needs to be factored into the environmental interpretation of the pollen assemblage in geopropolis sediments.

Roberts et al. (1997) studied nests built by Mud-dauber and Potter wasps in rock shelters in northern Australia that were associated with rock-art sites that both overlie and underlie paintings. The oldest nests were dated at 17.5 ± 1.8 ka BP, 23.8 ± 2.4 ka BP and 16.4 ± 1.8 ka BP using optically stimulated luminescence (OSL) dating. Ample pollen and spores were extracted for analysis, and variability between nest types interpreted as reflecting the particular foraging strategies of the wasps and some degradation through time. The researchers were confident that investigations of pollen and phytolith types should allow detailed reconstruction of the local environment for each interval of time represented by a nest. Wallis (2002) analysed mud nests from both wasps and birds, dated within the last 1 ka BP using AMS radiocarbon dating, and found that the nests contained a range of microfossils, and recovered enough pollen in excellent condition for dating of the pollen fraction. She concluded that this method was very amenable for dating rock art, but that for meaningful environmental reconstruction sampling would need to be extensive.

2.5- Ethnographic accounts of Bogong harvesting
The vast numbers of moths involved in a migration toward the southeast was recognised by the European settlers by the 1850s, although the taxonomy and ecology of the species was still not widely understood until after the 1920s (Gale, 1926). Clarke (1870) was unclear on the species taxonomy, but recognised the importance of the annual moth migration to the Indigenous people. He apparently did not know about aestivation, and was concerned by the possible threat that the migration posed to crops. There are five main ethnographic accounts of moth harvesting on the Monaro. These are recorded by George Bennett, Richard Helms, William Jardine, T.S. Townsend and R.F. Payten. The accounts were compiled in a NSW National Parks and Wildlife Service publication, Young et al. (2000).

George Bennett lived around Tumut in the early 1830s, and provides the most extensive ethnographic account of Bogong harvesting. His account is from mid-
December 1832 from the junction of the Tumut and Murrumbidgee Rivers, and described riding over the lower ranges to the base of the ‘Bugong mountain’, called ‘Gunundery’ by the traditional owners (Young et al., 2000). Bennett described the height of the ‘Bugong Mountain’ as 2000 feet from its base and 3000 feet above sea level (Bennett, 1834).

At his first stop Bennett described enormous masses of granite rock piled one upon the other, situated on the verge of a wooded precipice, but he found few insects as apparently the area had already been harvested. Journeying further, up a rise and crossing a stream with a dense mat of Lycopodium spp., he arrived at another group of rocks in enormous masses on a gradually declining part of the mountain called ‘Warrogong’. He could see ‘Snow Mountains’ on distant peaks to the southwest. The temperature was sultry on the plain but cool on the mountain. For Bennett the descent from the harvesting areas was much more tedious than the ascent due to the treacherous conditions underfoot caused by stones and logs (Bennett, 1834).

Bennett described the moths as congregating in incredible numbers on the smooth sides and crevices in the granite blocks, and on insulated and peculiar masses of granite. He was unsure of why the moths aestivated, but found this an interesting ‘subject of inquiry’. His description of the moth was 7/8th of an inch long and 5/8th of an inch wide with closed wings, dark brown with two black ocellated spots on the upper wing. The body is filled with yellow oil and covered with down (Bennett, 1834).

Bennett also provides an interesting description of the crows that feed on the moths, and draws comparisons between the Indigenous people and the birds. He asserts that the Indigenous people harvested the “crows” at the aestivation sites by clubbing them in the crevices. The Indigenous people would differentiate between the “highland crows”, ‘arabul’, the ‘fat fellas’, and the “lowland crows” ‘gundagiar’ or ‘worgan’, the ‘poor fellas’ (Bennett, 1834).

Bennett elucidated the harvesting and preparation of the moth. Moths were harvested by lighting fires beneath the moths to suffocate them with smoke, and then were swept up. To cook the moths a fire was lit on the ground to heat the ground, the fire then cleared away and stirred until the wings were removed. The moths were winnowed to separate dust and wings from the bodies, and pounded into cakes, which look like dough made from smutty wheat and fat, and would keep for about a week but may keep longer if smoked (Bennett, 1834).
At the gatherings of different tribes there were frequent skirmishes, and the conquered party would lose their supply of ‘Bugong’ for the season. In February and March the moth-hunters would return the lowlands plump and in fine condition (Bennett, 1834). Bennett also wrote that the first meal of the season causes vomiting and debilitating effects, but then the moth-hunters get accustomed and fatten up exceedingly on the diet and that people assemble from all parts of the country to collect moths (Bennett, 1834). It is interesting that ‘Gubbo’ Ted Thomas, a traditional owner from the Monaro region, described how his people walked through the Snowy Mountains to eat the Bogong moths; that eating the moths would clean out all the old food, and that after a week peoples’ countenance began to shine (Young et al., 2000).

Richard Helms (1842-1914) was born in Germany and migrated to Australia in 1858. He first worked in the Snowy Mountains in the late 1880s and wrote in the *Proceedings of the Linnean Society of NSW* in 1895 about moth hunting from details he had gleaned from early settlers (Young et al., 2000). Helms described moth harvesting occurring from as early as October, as soon as the snow melted hunting parties would procure Bogongs, and that the moth would supply a fattening diet for months. Helms wrote that although the moths were restricted to the highest mountains they can always be found in abundance on the highest and stoniest ridges where the snow lies from 5-6 months a year with scanty summer vegetation. The Bogong moth caterpillar he describes as ‘very voracious’ (Young et al., 2000).

Around Christmas a great gathering would occur on the higher ranges, 500-700 people from different tribes, with some travelling great distances. Helms described how the moths were nutritious, and that the physical condition of the moth-hunters was greatly improved making their skin look glossy, and some were quite fat. Helms also described the harvesting and cooking of moths. The moth hunters would go as far as possible into the rock crevices with smoking branches to stifle congregated moths, which would tumble into a kangaroo skin or net made from ‘Kurrajong’ fibre. ‘Kurrajong’ fibre for the Omeo traditional owners, meant a *Pimelea* spp. Helms went to some length to highlight that in other dialects ‘Kurrajong’ was a *Brachychiton* spp. The collecting nets are described as a fine mesh and manufactured with great care by women. The fibre was stripped and placed in water for several days, then dried in the sun until crisp and then beaten with stones (Young et al., 2000). He gave an account of moth preparation, where the moths were roasted in the hot ashes, and that care and attention needed to be taken not to scorch bodies. When
cooked the moths were dropped into a vessel or skin and the wind allowed to sift it and further cleansed by rubbing with hands and blowing. Helms also provided a description of the crows around the aestivation sites as fattening rapidly on the moths, and that they were also highly prized as food (Young et al., 2000).

William Jardine (1819-1904) arrived on the Monaro in the mid-1840s and wrote an article (Jardine, 1901), and described the moths as so numerous that when they arose in the air they looked like a dark cloud. Jardine wrote that Bogong harvesting started in September and lasted two or three months. Several tonnes of moths were eaten over that time, and after returning from moth harvesting the people looked fat and sleek. He described how nets were used in harvesting, how the moths were cooked in an oven of hot sand that covered the moths, and that at this gathering women were not allowed to eat the moths (Jardine, 1901).

T.S. Townsend was the Deputy Surveyor General and wrote in March of 1846 about the moth harvest. He stated that the Indigenous people visited the Snowy Mountains to get the ‘Bogongs’. Townsend wrote that ‘Bogongs’ means ‘granite mountains’ which is where the congregations of moths occur. He also postulated the consequence of lighting fires for the harvesting of the moths, that is that the whole survey country was burnt, leaving livestock destitute of food and dense masses of smoke in all directions (Young et al., 2000).

R. Forrester Payten was the supervising inspector for the Monaro Acclimatisation Society and wrote to Albert Sherbourne Le Souef (1877-1951) in 1949 and described the ‘Festival of the Bugong moth’. Payten wrote that people from Eden, Bega, Braidwood, Tumut, the upper Murray and Gippsland gather at the foot of the main range for ritual formalities before commencing on a feast of several months duration, and that this migration was an orderly one. Harvesting of moths on the mountain tops was not permitted to proceed until a certain rite had been performed on two large granite rocks on ‘Big Bugong’; Payten suggested that this sacred ritual was for an increase in the species. He could not find accounts of any ceremony to mark the end of the moth harvesting season. Using anecdotal evidence Payten described how the mountain tops of the aestivation sites are alive with millions of moths and then they disappear, and the moths were a food that was plentiful and easily acquired, and the duration of the feast usually last three months, from November to January. Payten felt that the length of travel is testament to the importance of the moths for the people, and that on the mountaintops some groups camped next to the aestivation sites, while others would make daily excursions (Young et al., 2000).
2.6- Archaeology and *Agrotis infusa*

The oldest date for human occupation in the South-eastern Highlands of Australia comes from the study by Flood *et al.* (1987) at Birrigai. This study has raised questions about the nature of human occupation in areas that were possibly treeless and several degrees colder during the Last Glacial Maximum (LGM). In winter at that time much of the highland landscape would have been inhospitable and therefore occupation assumed to be seasonal. Flood (1973) suggested that since the occupation of large parts of the South-eastern Highlands was dependant on the harvesting of the Bogong moth that occupation was seasonal. Argue (1995a) postulated that valley floors were more permanently occupied and more hospitable than the higher plateau areas, valley floors having year round food availability, while forays were made into the higher exposed areas based on resource availability and favourable weather.

Bowdler (1981) viewed the Bogong feast as facilitating the gathering of large numbers of people for ritual and social purposes but that a dependable staple food was also necessary, namely the daisy yam, *Microseris lanceolata*. She questioned the reliability of Bogong aestivation, and highlighted ethnographic accounts of eating moths as a male only activity, drawing attention to tribes coming together in spite of having moth supplies in their own territories. It is significant that a digging stick, such as those used to procure yam-daisy tubers, was found in Namadgi National Park at 825 m altitude (Argue, 1995b, Argue *et al.*, 2001). It was made from a montane *Acacia* spp., and dated to approximately 200 yr BP (years Before Present).

As to whether or not areas above the tree-line were used seasonally seems to be an oversimplification. Exposed areas would make survival for long periods difficult, but the mobility of the prehistoric population is not in question. A number of different survival strategies could be employed which would affect the material culture, for example high mobility at times could limit access to sources of stone suitable for knapping. Another aspect is the seasonal availability of resources, where accessing difficult or dangerous areas is made worthwhile by the possibility of harvesting a single or multiple large, ready and dependable resource. This is related to the carrying capacity of the landscape, which can change very quickly. In the instance of harvesting the Bogong Moth, the carrying capacity of these localities is seasonally increased by the available source of fat and protein. These alpine, sub-alpine and montane areas are otherwise much more limited in their utility. For instance, it would
be exceptionally difficult to survive in alpine areas all winter, but transitionally or in
the case of periods of mild weather it becomes more possible.
Flood (1973) points to a possible hiatus between Pleistocene occupation of the
southern uplands of South-eastern Australia and the advent of the small tool tradition
in the late Holocene, and Bowdler (1981) argued that the Australian small tool
tradition was associated with the first successful exploitation of the highlands. Later
evidence that has been uncovered since these studies that has shed more light on
Aboriginal occupation of the highlands. Aplin et al. (2010), whose excavation was
undertaken as part of the regional survey of the palaeontology of the Australian Alps,
uncovered a small collection of stone artefacts and archaeological faunal remains
dating from 9700-9120 yr BP (cal.), which doubles the age of the previously known
history of human occupation above 1000 m, and well beyond the advent of the
Australian small tool tradition. Feary (1996) studied a burial site near Cooma of two
skeletons dated to 7 ka BP. The collection of artefacts found included 327 pierced
kangaroo and wallaby incisors which had been strung as a necklace, as well as a tool
kit consisting of two hammer stones, five bone points manufactured from kangaroo
fibulae and eight macropod mandibular rami with use wear from scraping, planning
or graving wood or skins.
Environmental change would have greatly affected prehistoric occupation of the
South-eastern Highlands, its’ material culture, its distribution and its population.
The advent of utilisation of the Bogong moth might coincide with the appearance of
nets for catching moths or mortar and pestles in the archaeological record, or possibly
evidence of high levels of exfoliation on suitable hearthstones that could be used to
cook the insect. More importantly the carrying capacity of the land and ability to hold
large gatherings might increase the broad environmental signature of the population.
Changes in the suitability and distribution of Bogong moth aestivation sites through
time would have resulted in variability in the supply of an important food source for
Aboriginal tribes, and for animals such as the Mountain Pigmy Possum and the
Australian Raven.
Prehistoric culture reacted to environmental changes both materially and
managerially. Black and Mooney (2007) studied charcoal concentrations from a 6100
yr BP sedimentary sequence from Wollemi National Park in the Blue Mountains of
NSW. They interpreted a change in the fire regime at 5.7 ka BP as reflecting the onset
of increased climatic variability from ENSO, and a decrease in charcoal at 3 ka BP as
an alteration to Aboriginal management strategies, with an increasing population and
increased fire management. Black (2006) highlighted this point in his interpretation of charcoal records from the Sydney Basin, where a decrease in charcoal particle density at 3.5 ka BP coincided with archaeological evidence of intensified human activity. The lower and less variable charcoal deposition during this period he suggested was the result of the Indigenous people controlling fire activity in response to the increased risk of large intense fires under the ENSO dominated climate.

It is intriguing that increases in charcoal concentrations regionally in the ACT have some coincidence with work done in the Sydney Basin (Black and Mooney, 2007). This broad correlation seems more attributable to climatic factors than anthropogenic causes due to the loose temporal correlation between local ACT sites as well and the significant distance between the ACT and the Sydney Basin, which is manifest as diversity of both environmental conditions and Indigenous culture. A degree of similarity within the charcoal or sedimentary record, regionally and extra-regionally, of itself does not supply an adequate evidential basis for broad assertions about prehistoric anthropogenic burning in an Australian context. The spatial and temporal variability in the fire record excludes generalisations about prehistoric fire regimes (Black, 2006). For example, a broad categorisation of ‘South-eastern Australia’ is culturally and ecologically insensitive unless emphasising a level of diversity which then reduces the meaning of the category. It must be stressed that it is not possible to differentiate between what is natural charcoal and what is anthropogenic, and that charcoal from both natural and human sources may be present in a single sample. The way in which the Indigenous cultures impacted on Australian ecosystems by utilising fire to manage the various landscapes is uncertain (Black, 2006), for instance Eberhand and Schulz (1973) raised the issue of the impact of fire where both absence and regular fires would promote species diversity and abundance. Thomas and Hope (1994) interpreted a careful and deliberate use of fire by the Indigenous peoples in Tasmania, not the careless use of fire alluded to by ethnographic accounts such as Townsend in describing the Monaro tribes on the mainland. Indigenous cultures observed and made use of existing natural fire regimes rather than create new ones (Horton, 1982).

Hope (1978) noted that intervals of pre-historic occupation appeared to have little effect on the vegetation record of Cave Bay Cave in North-western Tasmania, but that fires occurred in the vegetation during unoccupied as well as occupied phases. Price and Sobbe (2005) could find no evidence to support the suggestion that the retraction
of late Pleistocene Darling Downs habitats was due to anthropogenic factors. Bowman (1998) did not see prehistoric Indigenous burning regimes triggering geomorphological instability being recorded in the sedimentary record, and that Aboriginal burning more likely promoted evolutionary diversification of the Australian biota. Kershaw et al. (2002) found that the relative importance of climate and human influence difficult to assess during the mid- to late Holocene, but suggested that climate was the major driving force.

Gammage (2011) had a different approach, and used the idea that pre-European land-use managed the entire landscape for both plants animals, making them abundant, convenient and predictable, with widespread social units that could both trade and give refuge. The carefully maintained ecosystem, within which the Indigenous people lived, made life comfortable, with an abundance of food and leisure time allowing for cultural development and recreation. Australian Indigenous peoples managed their environment in a way that enabled them to not only survive, but to prosper (Gott, 2005).

This leads onto the conjectural theory that Indigenous peoples may have enhanced aestivation sites, either by adding boulders for more space for moths to aestivate, or by moving rocks to improve access for the harvesting of aestivating moths. Individual sites may have had both practices, that is the addition and or removal of large rocks/ boulders, with some aspects of harvesting Bogong moths being apiarist-like, or even semi-agricultural.

The first possibility of adding to rock-piles was theorised to have occurred on Mt Blundell (1230 m), a low altitude site in the northwest of the ACT at the base of a small cliff where the material volume of the boulder-pile far exceeds the possible deposition from the cliff itself, and also some rhyolite boulder-piles on the slopes of Mt Coree. The second possibility, in which access to the labyrinth beneath a complex rock pile is improved by rock removal, may have happened in rock piles on Mt Gingera and in the Tinderry Range which have similar access points. Although boulder and rock movement and placement can be dated using luminescence dating techniques of quarts grains underneath rocks, unfortunately proving anthropogenic responsibility would be impossible at most sites.

It is important to phrase the debate about prehistoric Indigenous land use patterns in a meaningful way. Hiscock and Clarkson (2000) emphasised a need for more discussions about the nature of archaeological investigations, the questions asked, the methodological theory and their connection. A good example is the challenges to the
theory of intensification of the Aboriginal population in South-eastern Australia in the late Holocene, coined by Lourandos (1983). Fanning *et al.* (2008) addressed Aboriginal occupation intensity, mobility and resource use but found complication in the different geomorphic histories at each study location and their varied taphonomic qualities. They attributed the relative abundance of late Holocene archaeological sites relative to older ones as likely to be due to the preservation of landscape surfaces, and therefore as a function of landscape dynamics.

The reconstruction of past environments has a number of applications, both for the past and the future, but in some cases can appear confused in relation to Indigenous culture, where, instead of contextualising material culture, studies may attempt to draw direct correlations between land surface instability and Indigenous land management. One argument is that human dispersal in Australia was accompanied by rapid significant ecological change (Gillespie, 2002). This is an oversimplification of a complex system, as a single overriding factor in slope instability cannot usually be said to exist, apart from volcanism. Vegetation cover, that would be expected to be mostly affected by consistent or intensive burning, is not the only variable surrounded by constants in the equation for slope instability. Interpretation of single fire events, or indeed individual fire behaviour, cannot often be attributed to a single cause, natural or otherwise. So although a bushfire may not be lit by humans, a factor influencing the intensity of the conflagration on a landscape level may be the frequency of fuel reduction burns (Rawson *et al.*, 1985), where numbers of human ignition events interact with natural ignition events, to possibly reduce the impact from a single fire.

The persistence of articles that frame a discussion about Australian prehistoric culture in terms of human impact causing rapid widespread landscape instability after human arrival is as much an indictment of poor scholastic endeavour as it is a social reflection, and both of these can be seen in the article by McIntosh *et al.* (2009). The study repeatedly cites references that highlight the importance of climate in landscape evolution, including Colhoun and van de Geer (1986), Duller and Augustinus (1997), and Wasson (1986), and even acknowledges that the supposed human induced increase in erosion coincides with a natural intermittent ten-fold increase of dust accumulation in the Antarctic Dome C ice core. The researchers infer that the Tasmanian erosion record provides circumstantial support to the interpretation that human dispersal in South-eastern Australia was accompanied by significant ecological change, and they base this on an assumed date of human arrival and the
‘known’ use of fire by the Indigenous inhabitants. In contrast Mooney et al. (2011) compared 223 sedimentary records but could not find a correlation between increased human activity and biomass burning for the past 40 ka BP in Australia. Hope (1985) questioned assessing climate change from vegetation histories which will also be responding to changing fire regimes, but this logic can be reversed to question assessing fire regimes from vegetation histories which will also be responding to climate change. Martin (1973) described an ‘uninhibited’ use of fire and the cutting down of mallee scrub for building materials leading to decline in Mallee scrub cover 5-6 ka BP in the Nullabor, but also admits that a drier climate would have restricted vegetation regeneration, in this case the same frequency but higher intensity of fires would have had a greater impact on the vegetation community. Climate will affect the impact of fires especially in the short term, for example following the 2003 Canberra bushfires the coincidence of intense rainfall events before the recovery of vegetation cover caused massive hillslope movement and a large influx of sediment, and therefore charcoal, into the sedimentary record (Worthy, 2012). If human induced climate change is partly to blame for the 2003 Canberra bushfires, we see that the entire event, and its continued signature, cannot be regarded as either entirely human in origin or entirely natural. Head (1993) argued that human transformation of the physical landscape in Australia should be seen as the outcome of social processes. This is an interesting point in the critique of research that uses evidence of landscape change to directly relate to prehistoric land use patterns, especially if there is uncertainty about the timing, extent and intensity of landscape change, or there is little evidence of the material culture, let alone the active social processes operating.

An important aspect of the assertion that prehistoric cultures ‘did what they had to do to survive’ is that this approach places serious constraints upon cultural richness and diversity, and is the antithesis of studying the interaction between the environment and prehistoric culture. This is not to say that simple functionality is not a useful starting point for the interpretation of evidence of past environments and cultural interactions, but it is not adequate to rely solely upon this approach, where a diverse range of reactions to a changing environment are possible. This is especially important in reference to the extinction of megafauna, where megafauna are regarded as little more than a mobile and accessible source of fillets. However this ‘meat-tray’ approach to megafauna human interaction ignores a number of possibilities, highlighted by cultural diversity, where land management practices
are influenced by thousands of years of cultural adjustment to the landscape, and practices are likely to differ within a given culture both on a large scale and small scale.

In the view of Wroe et al. (2002) the available data on megafaunal extinctions is consistent with extinctions occurring over a long period, and at varying rates and times according to location. They postulated a climate driven model of increasing dryness, and though they did not absolve humans of any responsibility, were unwilling to apportion blame in the context of prolonged climate change. Bowman (1998) attributed the demise of the megafauna as a response to many factors associated with climate change, human colonisation and habitat changes. Trueman et al. (2005) demonstrated the coexistence of humans and megafaunal species on the Australian continent for a minimum of 15 ka BP. This is in contrast with Gillespie (2002) or Rule et al. (2012), both found that the change was sudden and synchronised with the arrivals of the first humans on the Australian continent, and that many species of megafauna from all climatic zones became extinct as people spread across the continent.

Any large sudden ecological change would be expected to be mirrored, to some degree, in the material culture. It is interesting that the extinction of megafauna does not correspond to identifiable changes in the material culture, both as the loss of an important food species or indirectly through landscape change excluding and driving extinct megafauna species, either factor predating a change in the hunter and gathering strategy.

Wroe et al. (2002) refuted the ‘blitzkrieg’ model of ice age extinctions in Australia. Simply put the theory is that globally wherever humans invaded ice age pristine environments they almost instantly eliminated most of the megafauna. This theory is based on the concept of the naivety of large animals to humans, and that if people can exploit a food source they will. The study highlighted that the evidential basis in Australia is one of sustained co-existence for thousands of years based on the date of human arrival around 55 ka BP, a lack of kill sites and an absence of specialised big game hunting weaponry.

It is possible that there were incidents of excessive hunting or over-burning in pre-historic Australia, but it is also likely that in many cases a careful balance was struck between the environment and its inhabitants. It is the latter situation that would prosper, but more importantly, is also the most likely to allow the social exploration required for adaptation to changing environmental conditions. Indigenous occupation
may have periods of traceable impact but this does not necessarily have to be
detrimental in terms of extinctions, indeed the idea of conservation of both species
and ecosystems by Indigenous people seems to have been neglected, perhaps through
academic lethargy.
Over long periods aggressive cultures are not necessarily the ones that prevail, or
those that are extremely territorial, especially where there are low population
numbers. Rather where social units are able to interact, while maintaining
independence, there exists the greatest buffer to catastrophic change, be that
environmental or social, a point made by Gammage (2011). Such open social
relations are likely to foster diversity through change rather than extinction of cultural
complexes.
These trends are expected to be manifest upon the biotal record, where variable
cultural practices leave different evidential footprints. The stark contrast between
European land management and Indigenous land management could not be clearer in
the terrestrial archives, where smaller heterogeneous cultures with less impact over a
much longer period are replaced by a single culture with a much larger population
having a massive landscape scale impact over the short term.

2.7- Palaeo-environmental reconstruction and archaeological context
It is the environment that provides the context for survival strategies and therefore
material culture, as well as serving as the basis for religion, art, language and
interaction of discrete social units. The changing availability of resources due to
environmental change, including the advent of rich food sources, would impact in
different ways upon the cultures that are affected by that change. The long-term
environmental variability of the Highlands of South-eastern Australia has been
extensively studied and supplies an important context to cultural changes. Many
studies in Australian archaeology have employed an ecological explanatory
framework, but since natural history and archaeology operate on different temporal
resolutions these studies need relevant spatial and temporal scales (Veth et al., 2000).
The range of climatic and environmental variability that has occurred since the arrival
of the first humans in Australia around 55 ka BP is staggering, and within this time
there have been periods of rapid change. As an example, Lake George, Australia’s
largest freshwater lake, has changed depths tens of metres a number of times over the
past 25 ka BP (Coventry, 1976; Fitzsimmons and Barrows, 2010). These falls in lake
levels can be explained by both higher rates of evaporation in warmer climatic
periods, and drying during maximum cold periods by reduced precipitation (Singh et al., 1981). These changing environments would directly affect subsistence strategies and therefore the culture of the area. As such cultural diversity in the Australian landscape can be seen as both geographical and temporal.

There is evidence of a prolonged period of warm conditions during the early Holocene from 10-6 ka BP. In describing the Holocene Optimum Macphail (1981) found wetter and warmer temperatures in southern Tasmania during the early and mid-Holocene between 8 and 5 ka BP. The timing of the end of this period however is not clear. In examining the vegetation history of New Guinea, Hope (1973), attributes vegetational change from treeline forest to grassland, which took place after 6.5 ka BP, as ‘a deterioration’ in climate. This greater instability, he maintained, matched glacier advances in Irian Jaya and greater erosion on Mt Wilhelm.

Using climate records from the past 30 ka BP Petherick et al. (2013) found that after 6 ka BP a higher frequency of climatic variability reflected a strengthening of the El Nino Southern Oscillation (ENSO).

A gap in the early- and mid-Holocene alluvial records of South-eastern Australia was demonstrated by Cohen and Nanson (2007). They ascribe this period to an increase in water discharge but a decline in sediment yield. They suggest that the period 8-4 ka BP in the sedimentary record at the fluvial sites reflects the early to mid-Holocene climatic optimum independently recognised in proxy climate data in the region. An increase in transport capacity with wetter conditions and improved vegetative growth and stability reducing sediment yield would be the expected effect of the Holocene Optimum, with the delay in sediment accumulation possibly due to natural lag-time. The Holocene Optimum may have increased the recurrence interval of droughts and the conditions which produce landscape scale fires, creating stability for the growth of human population, as increased vegetative growth would generally be expected to increase productivity of both hunting and gathering.

This idea that population and cultural change can be driven from environmental and ecological change was investigated by Builth et al. (2008). They examined the environmental history of lakes and swamps from southwest Victoria to contribute to the understanding and timing of cultural transformation of the Gunditjmara people, who had developed a socio-economic system based on the modification of wetland ecosystems for the sustainable production and management of the shortfin eel, *Anguilla australis*. In contradiction to the prevailing paradigm for prehistoric
intensification in Australia as being purely socially driven, they considered the sophisticated societal development as a response to external environmental stimuli. Black et al. (2008) proposed that the altered subsistence and resource and land use patterns during the late Holocene in the Blue Mountains of NSW, visible in the archaeological record, is evidence of cultural measures that were adopted to overcome risks associated with the increased frequency of ENSO events, and changes to the fire regime and resource reliability. This includes the more systematic use of fire by the Aboriginal people within a changing climatic framework. Turney and Hobbs (2006) drew similar conclusions, postulating that the onset of modern ENSO activity, approximately 5 ka BP, manifest as an increasingly variable climate, and appears to have forced populations to develop new survival strategies which enabled more efficient extraction of resources from the environment, potentially supporting a larger population, with subsequent population changes mirroring ENSO variability. Ross et al. (1992) on the other hand rejected that Holocene environmental change acted as a trigger to cultural change in arid areas, and that it was the LGM set the boundary conditions beyond which behaviour cannot vary. This argument may also apply in temperate South-eastern Australia, since the record of vegetation change is far greater during the LGM than late Holocene, yet there is more evidence of cultural change in the late Holocene.

The marked resurgence in bog growth around 2.5 ka BP in highland mires of Victoria, southern NSW and the Central Plateau in Tasmania has been interpreted as an increase in effective precipitation, where evidence of an increase in the number of freeze-thaw cycles, that is solifluction in the landscape, is unlikely to be bought about by cloudiness, rather a regional decrease in temperature (Macphail and Hope, 1985). Hope et al. (2009) defined this period of expansion and rapid growth of fibrous peats in mires of the ACT and surrounding NSW from 3.5-2.7 ka BP. It is possible that an increase in nutrients from more fires in the landscape may also have increased this growth (G. Hope pers. comm.). Regardless, it is not clear what effect this increase in precipitation and decrease in temperature would have on the human population of the South-eastern Highlands.

Both the LGM and the late-Holocene are important periods of climatic change, but due to spatial and temporal variability, the landscape and cultural responses differ. The climate of south eastern Australia for the last 5 ka has undoubtedly influenced the ecosystem’s response to land management. The carrying capacity of the country reflects this interaction between humans and the natural environment. The population
and material culture of humans, as two dimensions of carrying capacity, also interplay with environmental change. A change in the material culture therefore can be driven by various environmental changes, and as such, changes in the archaeological record, that is the preserved material record, may signal a crossing of an environmental threshold. The advent of Bogong Moth aestivation is possibly one such example, with its increasing utilisation by Indigenous peoples allowing seasonally higher populations to be maintained in the sub-alpine areas. It might be expected that a change may be seen in the preserved material culture or impact of human occupation of the South-eastern Highlands reflecting the more intensive resource use. The most obvious event of the late Holocene record in mires of South-eastern Australia however is not climatic, but the arrival of European land management. A rise in charcoal, coinciding with the appearance of weed pollen then decline to lower values, reflects widespread deliberate ignition associated with grazing followed by fire suppression in the catchments in the 20th Century in several ACT charcoal records, for example Cotter Source, Snowy Flat and Top Flat (Hope et al., 2009).

The understanding of pre-European culture in the South-eastern Highlands of Australia has been based on three different types of evidence, that is ethnographic accounts, archaeology and palaeo-environmental reconstruction. Ethnographic evidence can appear more substantial than anecdotes, but the distinction between the two is often related to when the account is recorded. The use of this evidence may serve to direct further empirical investigation, and can be important for the formulation of theories, but not their testing. Archaeological evidence on the other-hand may be more or less limited in its testability and applicability, but it is based on material evidence. As such the view of material culture that is presented in an archaeological study is open to critical analysis by other researchers, to the extent that, at least theoretically, entire assemblages can be re-analysed in a different way. The analysis of material culture does have some drawbacks, foremost among these is the interpretation of the assemblage in an exclusively materialist or essentialist manner. It is generally not possible to directly trace a continuity of changes to material culture at a given site, and more so for a region of cultural diversity and dynamic cultural exchange. Palaeo-environmental reconstruction can give an environmental context to prehistoric cultures, and is useful for understanding changes in both culture and the environment.
3) The Bogong Moth in the landscape

3.1 Regional Overview

Bogong Moths migrate south annually in large numbers to the mainland Australian Alps, an area that extends northward from the Victorian Alps to numerous spur ranges in New South Wales and the Australian Capital Territory. Visiting these landscapes and observing the legacy of the moth in cave deposits, which contain plant and animal remains, invites a fresh investigation of the biophysical history of the Australian Alps. High quality aestivation sites are defined by their location in the montane (sub-alpine/alpine) zone, their ridgeline or mountain top positioning in the landscape, the granite boulder-piles the moths shelter within, and the aspect of these sites being predominantly west-facing.

The Alps of South-eastern Australia represent a distinctive biogeographical region, subject to considerable environmental variability, rising to over two kilometres, with plains and deep valleys. High quality aestivation sites are an uncommon feature of the landscape, and the majority of these are located in inaccessible and remote areas. A targeted approach to searching disparate geographical areas was adopted to maximise the chance of locating deposits that reflect altitudinal and latitudinal variability of high country conditions. While the latitudinal extent of the migration of the Bogong Moth is not fully known, key destinations for aestivating moths include the Brindabella Ranges, the ranges further to the west in the Bogong Wilderness and to the South-east in the Tinderry Range. These eastern, central and western ranges are approximately the same latitude, and were selected for comparative analysis (Plate 3.1).
Plate 3.1- Northern region of Australian Alps showing study sites.

Principle Bogong Moth aestivation sites are located predominantly on west-facing granitic peaks within an altitudinal range of 1400-1900 m asl. Common (1954) indicates that the altitudinal range extends down as far as 4000 ft (1220 m asl). Lateritic high-scree slopes and ridges harbour smaller aggregations of moths than the granitic boulder-pile environment. A basic table of site name, depth and location is shown in Table 3.1, and illustrates profile depth variability of sites from 6 cm to 58 cm, an altitudinal variation of over 500 m, and a general westerly orientation of sites. Sites were studied in the Bogong Peaks Wilderness, Northern Kosciuszko National Park, Mt Gingera in the Bimberi Nature Reserve and Mt Coree in the Brindabella National Park, as well as in the Tinderry Nature Reserve in the Monaro. Of these the most intensively investigated were two cores from a single site in the Bogong Peaks, and a single core from two sites on Mt Gingera. These were sampled for pollen, mammal hair and macro-charcoal content, as well as characterised for magnetic susceptibility, loss on ignition, C:N ratio, lipid content and pH. Radiometric dating was focused on these four cores. Other cores from the Tinderry Range and different sites on Mt Gingera, that is North Tinderry Core, Alice’s Restaurant and Gingera Plateau 1 and 2 were also dated, to explore broader trends of regional deposition at aestivation sites. These were also characterised for magnetic susceptibility, loss on
ignition, C:N ratio, lipid content and soil acidity (pH). The Mt Coree site was analysed for pollen and faunal spectra, although shallow its depth excluded intensive dating or magnetic susceptibility. The Mt Coree site does serve as a useful comparison with the air sampling data.

<table>
<thead>
<tr>
<th>Site</th>
<th>Site code</th>
<th>Profile depth (mm)</th>
<th>Longitude (degrees)</th>
<th>Latitude (degrees)</th>
<th>Elevation (m)</th>
<th>Orientation</th>
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<td>350</td>
<td>148.7796</td>
<td>-35.5770</td>
<td>1840</td>
<td>W</td>
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<td>AR2</td>
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<td>1820</td>
<td>NW &amp; SW</td>
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<td>W</td>
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<tr>
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<td>W</td>
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<tr>
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<td>-35.3118</td>
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<td>N</td>
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<td>W</td>
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<td>RFC1</td>
<td>180</td>
<td>149.2750</td>
<td>-35.7175</td>
<td>1500</td>
<td>W</td>
</tr>
</tbody>
</table>

Table 3.1- Location data Bogong Moth aestivation cave study sites

3.2- Climatic Conditions

Contemporary estimates of climatic conditions at study sites localities are summarised in Appendix 2 using ANUCLIM. There is some variability in precipitation between geographical areas, with much smaller variation between sites within these areas. Bogong Peaks has the highest annual rainfall of the three areas, with most rain falling in winter and spring; interestingly the Mt Gingera area receives the most summer rainfall. It also has the lowest winter temperatures, which is expected, being the highest in altitude. The Tinderry Range sites have the highest seasonal temperatures and highest evaporation, but surprisingly also the highest
seasonal humidity. Table 3.2 is based on ANUCLIM surface estimates, and illustrates an annual water deficit in the three study regions, with the greatest being in the Tinderry Ranges. The Tinderry sites are characteristically drier and marginally warmer than the higher and more westerly aestivation sites. It is not surprising then that the least amount of mammal hair was recovered from the Tinderry sites, but it is quite possible that there are deposits in that region with a microclimate more amenable to preservation of organic material.

<table>
<thead>
<tr>
<th>Location</th>
<th>Rainfall (mm/mo)</th>
<th>Median temperature (°C)</th>
<th>Evaporation (mm/mo)</th>
<th>Radiation allowing for cloud cover (MJ/m²/d)</th>
</tr>
</thead>
<tbody>
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<td>155</td>
<td>107</td>
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<tr>
<td></td>
<td>Winter 160</td>
<td>-1</td>
<td>22</td>
<td>159</td>
</tr>
<tr>
<td>Bogong Wilderness</td>
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<td>12</td>
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<td>99</td>
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<tr>
<td></td>
<td>Winter 177</td>
<td>0</td>
<td>31</td>
<td>177</td>
</tr>
<tr>
<td>Tinderry Ranges</td>
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<td>13</td>
<td>169</td>
<td>87</td>
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<tr>
<td></td>
<td>Winter 88</td>
<td>-0.5</td>
<td>22</td>
<td>81</td>
</tr>
</tbody>
</table>

Table 3.2- Climatic conditions at aestivation sites.

Since moisture is an important mechanism for anoxia in the deposits, and is integral to preservation, the cave environment is crucial taphonomically. Low light regimes, avoidance of extreme (particularly high) temperatures, low disturbance and moist conditions are important factors in promoting preservation of pollen and hair and maintaining high organic content of cave deposits. In the sub-alpine zone of Kosciuszko National Park the average precipitation ranges from 750-1800 mm per year (Good, 1992), which is conducive for moist sediments, but there is some variability according to season. Deposits need to maintain wetness, especially through the summer months. High quality aestivation sites are protected from wind and solar radiation, and ambient air conditions and maintain cool, moist conditions with low variability.
3.3- Site Descriptions

3.3.1- Bogong Peaks

The Bogong Peak Cave site is the most westerly site investigated in this study. Silurian Granodiorites dominate the underlying geology of the Bogong Wilderness (Degeling, 1977), and are visible as tors and boulder-piles on the mountaintops, resulting from erosive and periglacial activity.

The pre-European Indigenous custodians of the area were the Wolgal, who held large gatherings to harvest the Bogong Moth in the mountains to the east of Tumut (Bennet, 1834), which continued during the European-occupation up until the mid-1860s (Flood, 1996). Plate 3.2 illustrates the topography leading to the study site area from the Tumut side, and the direction of harvest gatherings. The first European settlers arrived in the late 1820s, selectors and farmers arriving in the late 1830s and early 1840s, and bringing with them sheep. Large numbers of people passed through Tumut on the way to Kiandra during the 1860s gold-rush (Larkins 1980).

Access to the Bogong Peaks Cave site was along the Goobragandra Powerline Road (Plate 3.2), then an exertive westerly climb up the higher eastern slopes of the Bogong Peaks to the crest of the range.

Plate 3.2- Bogong Peaks study site looking west, with the Goobragandra Powerline visible as a cleared band (Image Google Earth).
At the base of the slope were frost hollow grasslands comprising *Poa* spp. tussock, *Ranunculus* spp., scattered *Hakea* spp. shrubs and small patches of *Carex gaudichaudiania* fen. A significant Sphagnum, (*Sphagnum cristatum*), shrub bog has developed along the drainage line, with an overstorey of *Leptospermum lanigerum*, scattered areas of *Carex gaudichaudiania* and *Gleichenia microphylla*, along a sandy-bottomed creek line (Plate 3.3), with *Empodisma minus*, becoming co-dominant in the broader and flatter lower gradient sections (Plate 3.4). This is an important ecological area of high conservation value that demands more investigation, including possible pollen and charcoal sampling of peat deposits and surveying for the Northern Corroboree frog *Pseudophryne pengilleyi*. It is likely that this wetland area was more extensive in pre-European times, but is sensitive to disturbance from incision and draining, and a high gradient catchment above will deposit large amounts of sediments at the site if catchment vegetation cover is reduced. As the area accumulates sediment it is very prone to the effect of channel incision arising from the presence of hard hoofed animals, including horses, by ditches to drain the area for grazing or by activities like mining. This ecologically sensitive Sphagnum bog area should be excluded from fuel reduction burns that occur on the eastern edge of the Bogong Peaks wilderness.

![Plate 3.3- Sphagnum development along creek-line at base of Bogong Peaks slope, with a *L. lanigerum* overstorey, and an understorey of *S. cristatum*, *G. microphylla* and *C. gaudichaudiania*.](image-url)
On the lower sheltered eastern slopes was a pure stand Brown Barrel (*Eucalyptus fastigata*) regrowth forest (Plate 3.5), the stand age not appearing to more than 20-25 years, with a substantial understorey component. Mountain Gum (*Eucalyptus dalrympleana*) increased presence and dominance with altitude, with understorey species of *Davesia mimosoides*, *Hibberta obtusifolia*, *Cassinia longifolia*, *Persoonia* sp. (Geebung) and *Acacia dealbata*. Understorey species included *Rubus parvifolius* (native raspberry), *Lomandra longifolia*, *Hovea linearis*, *Poa sieberiana* and *Dianella revoluta*.

On the sheltered midslopes there was a single species Eucalypt overstorey of Alpine Ash (*Eucalyptus delegatensis*), and mixed overstorey of Alpine Ash/Mountain Gum (*E. delegatensis/ E. dalrympleana*) forests, with *E. delegatensis* becoming a single species stand in the more sheltered areas. Snow Gum (*E. pauciflora* ssp. *debeuzvillei*) became more dominant toward the summit. The shrub layer on the slopes included *Coprosma hirtella*, *A. dealbata* and *D. mimosoides*, with herbs species including *Poa* spp., *Stellaria pungens*, *Clematis aristata* and *Viola betonicifolia*.
Plate 3.5- Brown Barrel (*E. fastigata*) regrowth forest on the lower eastern slopes of the Bogong Peaks.

On the ridge and summit the Snow Gum forest, had a dominant shrub understory of *Podocarpus lawrencei*, *C. hirtella*, *Tasmannia xerophila*, *Veronica derwentiana* and *Dianella tasmanica*. The herb and grasses became dominant on the rocky areas on the peak, with *Poa sieberiana*, *Wahlenbergia gloriosa*, *Bulbine glauca* (Rock Lily). Sections of the boulder pile environment may be impassable with the thickets of Mountain Plum Pine (*P. lawrencei*) shrub stems exceeding 30 cm in diameter, together with the complexity of the boulder pile environment, making access extremely hazardous. The fauna of this area is not documented so the hair record from the aestivation sites may signal refugia for uncommon or endangered mammals, where the remote nature and ruggedness of terrain make aestivation site records of mammals in this environment particularly valuable, as representative sampling of mammal populations by trapping under such conditions is extremely difficult.

The lower slopes are Ordovician sediments and metasediments uplifted by Siluro-Devonian Granites (Degeling, 1977). These granites may form extensive boulder piles (plate 3.6) and large tors, such as those found on Jounama (Plate 3.7), and provide prime aestivation habitat for *A. infusa*. The Bogong Peaks site is south of Jounama, the highest peak in the vicinity at 1718 m. The study site is southwest of the major wetland of Big Plain Swamp, which is another valuable terrestrial archive and
major peatland in the northern Kosciusko National Park (Plate 3.8), and one which potentially holds a corresponding record of the ecological changes of the Bogong Peaks Wilderness area.

Plate 3.6- Extensive boulder pile on the ridgeline of Bogong Peaks.

Plate 3.7- Large granite tors and outcrops on the southern side of Jounama.
The study site deposit is nestled 1.5m off the ground in a crevice formed by the leaning of several weathered granite rocks (Plate 3.9), making a cavity that is 20 cm wide at the mouth and tapering for 30 cm to 5 cm at the back (Plates 3.10 and 3.11). The rocks surrounding the deposit are thickly covered in algae and lichen, with smaller deposits filling nearby crevices (Plate 3.12). The central core (BP 2) is shown in Plate 3.13.
Plate 3.9- Bogong Peaks Cave Study Site. A 50 cm section of PVC showing scale the boulder-pile.

Plate 3.10- Bogong Peaks Cave deposit.
Plate 3.11- Bogong Peaks deposit crevice. Deposit was sampled every 10 cm, with a total of three cores taken.

Plate 3.12- Granite boulders surrounding the sampled deposit, with other crevices and deposits visible (50cm tape).
3.3.2- Mount Gingera
The upper slopes of the Brindabella Ranges are a prime habitat for aestivating Bogong Moths. Mt Gingera, located in the 27 000 ha Bimberi Wilderness, straddles a north-eastern section of Kosciusko National Park in New South Wales and the western boundary of Namadgi National Park in the Australian Capital Territory. The high relief topography of the area and the underlying geology of granodiorite (McKeahnie Adamellite) (Gilliagan, 1974), visible in the form of tors, boulder piles and fractured rock faces furnish the moths with numerous aestivating sites on the western side of the mountain peak.
Mt Gingera is a very visible landform. Its dominant position along the range and flat topped shape make a recognisable landmark (Plate 3.14).
A number of caves and boulder overhangs were located and their deposits cored at and near Mt Gingera. They include a cluster of caves close to the Mt Gingera summit at an elevation of approximately 1830 m, a series of small caves on a plateau west of Mt Gingera at 1770 m, and rock crevices at the more northerly location of Mt Coree at 1270 m.

Mt Gingera is an important component in the current pattern of migration of the Bogong Moth, *A. infusa*. Common (1954) found that further migration of moths to more southerly peaks in NSW and Victoria reduced numbers on Mt Gingera in the early summer, and boosted the numbers on Mt Gingera in late summer and early autumn. The geographical position facilitates migration to and from the Kosciusko and Victorian montane areas, with the site being used for both further southward and northward migration by *A. infusa*.

The level ridgeline that runs north/south is visible from Canberra, and has slopes that fall away steeply to the east into Snowy Flats and the Cotter River Valley, while to the west the mountain slopes gently run down to Brumby Flat, which is nestled on the mountain. This plateau-like surface runs further west until it turns into a scarp that drains steeply into the Goodradigbee River (Plate 3.15). On the ridgeline and at the top of the scarp there are a number of significant piles of granodiorite boulders, with
talus slopes occurring further downslope. The more optimal aestivation sites of *A. infusa* are located in the boulder piles rather than the talus environment.

Plate 3.15- Topography of peak of Mt Gingera, with the location of five study sites. (Image Google Earth).

Mt Gingera has a shrubby woodland setting with an overstorey of *E. pauciflora ssp. niphophila*, but is close to the probable altitudinal treeline (1800-1900 m). Over the winter months there is extensive snow-ice, areas of which may persist until November. Over the cold winter months the high moisture content that typically characterises the deposits may freeze in the surface layers, with a frozen crust being observed in some rock-shelters as late as October.

Five sites were investigated on Mt Gingera. Of these, cores from Gingera Cave (G4), Gingera Big Cave (GBC), Alice’s Restaurant (AR2), Gingera Plateau 1 (GP1) and Gingera Plateau 2 (GP2) were examined in some detail and are representative of deposit types and depositional environments. Not of the all sites were investigated fully, since some of the deposits did not appear as promising as others, based on the amount of hair present and the depth of deposit.

3.3.2.1- Gingera Cave
A large granodiorite boulder pile located about 50 m from the Mt Gingera Trig forms Gingera Cave. The cave is located in Snow Gum woodland 10 m below the extensive north/south oriented rocky ridgeline. The exposed woodland adjacent to the upper
entrance (Plate 3.16) has a low shrub under-canopy comprising of stands of *Pimelea ligustrina* and wet *Poa* tussock interspersed with rocky outcrop and patches of Fabaceaceous species, including thickets of *Podolobium alpestre*, prostrate *Oxlobium ellipticum*, and Twining Glycine (*Glycine clandistina*) with Daisy species of Mountain Lettuce (*Podolepis robusta*) and Golden Everlasting (*Xerochrysum bracteata*). Under conditions of low disturbance the shrub component would be succeeded by herbaceous species such as the Mountain Aciphyll (*Aciphylla simplicifolia*), *Stellaria pungens*, *Ranunculus* spp., *W. gloriosa*, Mueller’s Snow Gentian (*Chionogentias muelleriana*) and Rock Lily (*B. glauca*).

Plate 3.16- Vegetation above Mt Gingera Cave site, with a two aged overstorey, a shrubby background of *T. xerophila*, *Podocarpus lawrencei*, *Pimelea ligustrina* and *Prostanthera cuneata*, and foreground of *Poa sieberiana* and prostrate *O. ellipticum* admixed with Golden Everlasting (*X. bracteata*).

The sheltered undercanopy below the west facing cave entrance comprises a thick shrub layer of tall *P. lawrencei*, *Tasmannia* spp. and *P. cuneata*. (Plate 3.17), with occasional patches of *Poa* spp. occupying flatter bench areas. In places *P. lawrencei* forms dense thickets covering boulder-piles, other boulder-pile plants include *Melicytus dentata* (the Gruggly Bush) (Plate 3.18) and *Rumex brownii*. *P. lawrencei* is also a common shrub on the talus slopes to the west side of the mountain.
Plate 3.17- Snow melt among sheltered crevices used for aestivation on Mt Gingera, with mixed vegetation of *T. xerophila*, *Podocarpus* and *E. pauciflora* (Photo Alan Wade).

Plate 3.18- *Melicytus dentata* (Gruggly Bush) amongst boulders at the Gingera Cave Site.
Saprolite soils of insect remains and granite outwash have formed below the site as a small fan that has built up directly under the Mt Gingera study site. The profile here was brown, growing darker and more humic with depth, and was high in organic content, especially roots. This fan that emerges from bottom entrance of the Mt Gingera study site (Plate 3.19) partially buries a boulder pile several metres high, making it logistically difficult to get a continuous alluvial chronology (Keaney 2006).

Plate 3.19- Bottom west facing entrance of Mt Gingera cave (Photo Alan Wade).

The rocks in the pile are of various sizes, up to large boulder size (>3 m). Within the pile itself many rocks are coated with a green algal tinge and film of carbon (Plate 3.20). The cave is 2 m wide and 3.5 m long with the deposit 1.5 m wide at its widest and 2.5 m in length (Plate 3.21). The surface of the deposit is covered with the remains of A. infusa and leaves of P. lawrencei and E. pauciflora (Plate 3.22). The moths themselves shelter among the rocks in the cave (Plate 3.23), with moth debris falling directly onto the deposit surface or being moved from localised transportation by water.
Plate 3.20- Mt Gingera Cave at rear, showing accumulated sediment, green tinge of algal growth on the rocks and film of carbon deposited on rock margins.

Plate 3.21- The width of Mt Gingera Cave deposit, with 1 m tape in foreground. Air pollen sampler is in the background (Photo Frank Ingwersen).
Plate 3.22- Mt Gingera Cave floor, with moth carcasses, *P. lawrencei* and *E. pauciflora* leaves, during a visit in October. The surface of sediments was frozen solid to less than 5 cm, and illustrates the possible erosional effects of frost heave.

Plate 3.23- Aestivating moths from within Mt Gingera cave in rock-pile. Note that some moths are not entirely dormant, and were observed crawling or flying short distances within the cave (Photo Alan Wade).
Common (1954) was not clear about the depth of sediment at Mt Gingera, nor did he describe its’ nature in any great detail, so it is possible that he worked at the current study site. He described debris ‘in places more than a foot in depth’, and dug a trench ‘about 2 ft deep and about 18 in. wide’ at a site on Mt Gingera to facilitate access to the cave. The deepest sample of Keaney (2006) was 39 cm, who described the deposit as ‘very moist, homogenous, high in organic content, of a peaty appearance and dark brown/black coloration’, the 34 cm core of the current study was remarkably similar (Plate 3.24).

Plate 3.24- Mt Gingera 4 Core.

3.3.2.2- Gingera Big Cave (GBC)
The vegetation external to the cave is an *E. pauciflora* ssp. *niphophila* overstorey, with a large boled Snow Gum overhanging the cave. Its size and proximity make it a significant contributor to sediments at the site. Rocky outcrops shelter the area from prevailing winds and may afford some localised fire shelter effect. The dominant understorey species are herbs, notably *P. sieberiana*, *V. derwentiana*, *A. simplicifolia* and *D. revoluta*. Fern species among the rocks include *Polystichum proliferum* and *Blechnum nudum*, which is present at the eastern entrance to the cave (Plate 3.25).
Gingera Big Cave is a westerly facing cave system located beneath a granitic boulder pile situated at the most northerly end of the rocky Mt Gingera summit (about 250 m from the Trig). The cave itself runs east-west with an intermittent roof less than three metres. The cathedral-like cave has limited roof openings (Plate 3.26): the north and south entrances allow easy access but are fairly restricted (Figures 3.27 and 3.28). Moths were seen aestivating in cracks and crevices of the cave.
Plate 3.26- Roof of Gingera Big Cave looking west.

Plate 3.27- The Gingera Big Cave east entrance from inside cave (Photo Frank Ingwersen).
Plate 3.28- Gingera Big Cave western entrance (Photo Frank Ingwersen).

The floor is occupied by an elongate peaty deposit 1-2 m wide, 6 m long and 20-60 cm deep. Plate 3.29 shows vegetable matter, moth litter and other organic material including feathers, along with some granodiorite-based sand, that have contributed to the peat-type matrix. The core was 59 cm and was a homogeneous dark brown/black peaty humus admixed with occasional granodiorite grains. The top half of the core is shown in Plate 3.30. Probing of the deposit was only marginally deeper (>65 cm), with a higher sand component being felt in the final drive of the probe, but coring of the basal layers was limited by buried rocks blocking the corer head. Based on the age depth model the Gingera Big Cave core was the oldest deposit encountered.
Plate 3.29- Gingera Big Cave deposit surface.

Plate 3.30- GBC Core 0-30 cm.
3.3.2.3- Alice’s Restaurant (AR)

Alice’s Restaurant is a cave located beside a large granite outcrop about 150 m downslope and northwest of the Mt Gingera Trig. Peaty deposits were located inside a rock-shelter formed from a granite tor leaning against the large granite outcrop in the hillside, the deposit is trench shaped radiating from the south entrance (Plate 3.31 and Plate 3.32) to the west entrance (Plate 3.33 and Plate 3.34) around the main rockface. There is limited groundwater emergence at the site, as the walls are mostly dry.

The *E. pauciflora* ssp. *niphophila* woodland is a single aged single species forest, that appears to be no older than 50 years. A large *P. lawrencei* shrub is growing down the large outcrop above the southerly entrance, and has some branches hanging into the site itself. The outcrop is covered in moss and lichens. The understorey is open, and made of predominately herb species, including *P. seiberii* and *S. pungens*, with *P. proliferum* growing along the edge of the outcrop (Plate 3.35).

Plate 3.31- Southern entrance to Alice’s Restaurant (Photo Alan Wade).
Plate 3.32- Southern arm of Alice’s Restaurant deposit, with placement of pollen traps (Photo Frank Ingwersen).

Plate 3.33- Western entrance of Alice’s Restaurant.
Plate 3.34- Western arm of Alice’s Restaurant deposit (Photo F. Ingwersen).

Plate 3.35- Edge of rock outcrop at Alice’s Restaurant with *P. sieberiana* and *P. proliferum* in the bottom foreground, *Podocarpus* in the background, and a limb of *E. pauciflora* ssp. *niphophila* in the top foreground.
Four cores were taken from the Alice’s Restaurant site. The deepest profile was core 4, which was 36 cm in depth and composed of dark brown peaty clayey humus, with some sand as a loose band at 6 cm and 16 cm. Rootlets were present from 30 cm (Plate 3.36). This deposit was more humified than the other sampled sites and had a significant colluvial input. Moths were not seen aestivating at the site, which has limited rock fissures and cracks to afford the moths protection. The source of the sediments is theorised to be mostly vegative, which gives Alice’s Restaurant a higher C/N ratio than the sediments at high quality aestivation sites, with the more persistent plant waxes being responsible for the highest average lipid content of all sample sites.

Plate 3.36- Alice’s Restaurant Core 4.

3.3.2.4- Gingera Plateau
This study area is located at the top of a scarp, at the edge of the Mt Gingera plateau about 1 km west of Mt Gingera Trig and at a significantly lower elevation (Plate 3.37).
The vegetation in the area is small boled *E. pauciflora* ssp. *niphophila*, estimated by girth to be less than forty years, with *Poa* tussock (*P. sieberiana*) in both flatter areas and amongst boulders interspersed with thickets of *T. xerophylla* and *P. lawrencei*. Two sites were identified at the edge of the Gingera Plateau scarp located west of Mt Gingera. The larger shelter study site, with a saturated floor, designated Gingera Plateau 1 (GP1) lies above a perched drier shelter/overhang study site, that is Gingera
Plateau 2 (GP2). GP 2 is part of a complex boulder pile, with caves stretching back into the hillslope at least 20 m, however, due to safety concerns the full extent of the caves and crevices was not explored.

Plate 3.37- Mt Gingera Plateau study sites on Mt Gingera looking west (Image Google Earth).

Gingera Plateau 1 (GP1)
The first of the sites, Gingera Plateau 1 (GP1) is a cave formed by the space between two large granite boulders, with some smaller boulders forming the roof. The entrance faces due west, and opens onto a small grassy clearing (Plate 3.38). The cave is 1.5m wide, 3.5m long and 2m tall. In the cave there are some areas of groundwater emergence trickling down the walls, which are green and encrusted with algae (Plate 3.39).
Plate 3.38- Gingera Plateau 1 entrance with 50 cm length cradle.

Plate 3.39- Gingera Plateau 1 Cave.
This site appears to have permanent standing water puddling in depressions, which suggest that it is subject to occasional overland flow episodes associated with major rainfall events, and also likely that groundwater emergence contributes significantly to the water present at the site, as seen by the flow over the rocks on the side of the cave (Plate 3.40). The low surface gradient and areas of depression tend the hydrology of the site toward deposition. The core itself was homogeneous, and was 30 cm deep, comprising of moist dark brown/black peaty humus (Plate 3.41). It should be noted that a nematode *A. bogongae* was recovered at 20 cm (Plate 3.42), which indicates that *A. infusa* uses the many crevices present in the cave for aestivation, although no moths were seen during sampling.

![Plate 3.40 - Gingera Plateau 1 deposit surface, note the presence of nematode in the surface water, and wall wetness from groundwater emergence.](image-url)
Gingera Plateau 2

Gingera Plateau 2 (GP2) is approximately 10 m SW of the GP1 site, and situated in the same *E. pauciflora* ssp. *niphophila* woodland environment. This better-drained and drier site has a rock-shelf overhang which provides some protection from the elements (Plate 4.43). The back crevice between boulders is a temporary moth aestivation site, and the core was taken in sediments that had issued from the crevice.
(Plate 3.44). The core was 30 cm, and comprised of dark brown-black silty-peaty humus (Plate 3.45). The site is not as sheltered as the other study sites with the sediments were more humified.

Plate 3.43- Gingera Plateau 2 Overhang.

Plate 3.44- Mt Gingera Plateau 2 sampling location, with 30 cm tape.
3.3.3- Tinderry Range

The most easterly known moth aestivation sites on the Australian Great Dividing Range are located in the Tinderry Range to the east of the Murrumbidgee River on the Monaro. The mountains in the Tinderry Range are amongst the lowest elevation sites (1100-1500 m) to be regularly visited by aestivating moths. Sheltered east and south facing areas in the upper central range are dominated by wet sclerophyll forest Alpine Ash (*E. fastigata*), Mountain Gum (*E. dalrympleana*) and Snow Gum (*E. pauciflora ssp. pauciflora*). On the northern region of the Tinderry, Tingiringi Gum-Spinning Gum (*Eucalyptus glaucescens – Eucalyptus perriniana*) woodland occurs on exposed ridge-tops in the vicinity of Tinderry Peak (1620 m) and Tinderry Twin Peak (1570 m). The high peaks and ridge-top crevices and caves in which Bogong Moths aestivate along the north-south range are comprised of Silurian to Devonian biotitic granite (NSW National Parks and Wildlife Service 1998). Shelter sites were located in the southern Tinderry and at Tinderry Peaks some five kilometres further north in the northern part of the range (Plate 3.46). Tinderry shelter deposits were generally very dry, and with a high level of disturbance from goats especially at the more southerly Round Flat Cave site (RFC), with an additional large amount of effort required to isolate pollen and hair. This resulted in these site studies...
being limited to characterisation of the soils and recording an overview of shelter features, and limited dating.

Plate 3.46- Study site locations in the Tinderry Range looking east (Image- Google Earth).

3.3.3.1- Tinderry Peak Cave
A number of peaks dominate the northern section of the Tinderry Range. While numerous cave sites were located at lower elevations north and downslope of this cave system, the distances traversed and difficult terrain precluded comprehensive exploration of the peak. There are known to be large seasonal aggregations of moths on the peak in large caves (D. Fordham pers. comm.), these were not located in this study.

Tinderry Peak Cave is located on a hillock on the main ridgeline 500 m to the north of Tinderry Peak. It is situated in a low shrubby woodland (Plate 3.47), dominated by *E. glaucescens*, *Leptospermum micromyrtus*, *Epacris microphylla* and *Poa* spp. The *E. glaucescens* were thin-stemmed mallee-form, perhaps reflecting a low nutrient environment with frequent fire events (Plate 3.48).
Plate 3.47- The vegetation around the boulder Pile at Tinderry Peak Study Site, comprising scattered *E. glaucescens* with the main cover comprising *L. micromyrtus*, *E. microphylla* and *Poa* spp.

Plate 3.48- Stand of mallee-form thin-stemmed Tingiringi Gum (*E. glaucescens*) adjacent to Tinderry Peak Cave study site.
The granite boulder piles were of low complexity compared to the eastern side of the Tinderry Range, but provided some small rockshelter environments that were west-facing and sheltered from the Sun. There was no evidence of groundwater seepage at the site. The majority of surface cover on the deposit was dry leaf matter containing few moth remains, and was deemed to be a temporary aestivation site (Plate 3.49). A number of Antechinus spp. were seen at the site during sampling.

Plate 3.49- Tinderry Peak Cave (TPC) deposit, comprising mainly of leaf-litter, with moth remains being uncommon.

The sediments were sampled using a shovel to extract a 30 cm monolith. The top ten centimetres was a root mat, and difficult to cut through. Below this the sediments were a dark-brown sandy/gravelly humus, with the sand/gravel component appearing to be unweathered grains derived from the local Devonian granite boulders which form the rock-pile itself (NSW National Parks and Wildlife Service 1998) (Plate 3.50). Lower levels of organic matter at the site and a less acidic deposit illustrate sub-optimal taphonomic conditions.
3.3.3.2- Round Flat Cave

Round Flat Cave is located on a ledge at the head of a bluff with precipitous south, west and north facing slopes (Plate 3.51). The deposit has formed on a ledge underneath a large granite outcrop (Plate 3.52), and though Bogong Moths were not seen aestivating at the site the deposit surface was littered with both wings and bodies. The ledge is less than 3m wide and 5 m long and covered with grass species *P. sieberiana* and some thin-stemmed Spinning Gum (*E. perriniana*), <10 cm in diameter. The overstorey on the broader exposed hilltop is Tingiringi Gum (*E. glaucescens*). The area was severely burnt in 2010, and was still in a recovery phase some four years later. Undergrowth became significantly more dense between years 3-4 post fire, making traversing the terrain to regain access to the site more difficult.
Plate 3.51-The topography of RFC viewed northwest towards Brindabella Ranges.

Plate 3.52- The Round Flat Cave deposit showing the pollen trap setup.
The Round Flat Cave core was 18 cm, and comprised dark brown humus, sandy in the first three centimetres, and with a gravel band at 12 cm (Plate 3.53). The exposed location of the site in the driest study region, a comparatively low organic matter and low moisture loss of the sediments suggest taphonomic limitations due to limited moisture. Some groundwater emergence was present at the back of the cave as a puddle amongst the rocks, but this water was localised away from the organic deposit. The presence of sand and gravel layers is derived from episodic overland flow depositing alluvium, and is theorised to be a significant vector of moisture to the site.

Plate 3.53- Round Flat Cave 1 (RFC 1) Core.

3.3.4- Mt Coree

In describing the local prehistory of the ACT and surrounds the Canberra Bushwalking Club (1974) cited ‘Bogong’ or ‘Cori’ as the Indigenous words for *A. infusa*, and that Mt Coree is an anglicised version of this word. Mt Coree is 31 km almost due north of Mt Gingera on the Brindabella Range and, as the one of the most northerly high points of the Australian Alps, is close to the lower limit of elevation for moth aestivation. Most rock crevices face south and west and are located about 150 m below the summit (Plate 3.54). Mt Coree has an underlying geology of Rhyolite (Gilliagan, 1974).
The dominant vegetation of the area is Snow Gum (*E. pauciflora* ssp. *pauciflora*) with an understorey of *V. derwentiana*, *S. pungens*, *P. sieberiana*, *B. bulbosa*, *A. dealbata*, *Cassina longifolia*, *P. proliferum*, Native Raspberry (*Rubus parvifolius*), and at the base of the gully slope is *Tasmannia lanceolata*.

The study site was located in a pile of Rhyolite blocks 3 m high and 7 m in length (Plate 3.55). Basically the landform was caused by erosional activity, but there is a possibility that boulders on the top of the pile were collapsed or rolled there with the aid of human intervention.

Plate 3.54- Location of Mt Coree site, looking northeast (Google Earth image).

Plate 3.55- Rock Crevice mosaic on the southern side of the summit of Mt Coree.
Humic deposits in crevices in the boulder pile were typically shallow (5-10 cm maximum depth). The most accessible deposit for sampling (Plate 3.56) comprised of 6 cm of dark brown clayey humus (Plate 3.57). A pollen trap was also placed at the site to allow a comparison between modern pollen rain and a recent deposit (Plate 3.58).

Plate 3.56- Mt Coree Cave, with groundcover outside entrance of *Poa* spp. and *S. pungens*.

Plate 3.57- The Mt Coree Cave core.
The short Mt Coree pollen and fauna diagram is presented here (Figure 3.1), as it is a very shallow site <6 cm, and has a limited chronology estimated as recent, based on the presence of *Pinus* pollen. The core is comprised of hillslope sediments which began to be deposited well after European arrival, and started during a phase of high burning in the late-19th Century.

Plate 3.58- Mt Coree Cave pollen trap placement.
Figure 3.1 - Mt Coree Pollen Diagram.
The pollen diagram makes for an interesting counterpoint with the aeropalynology diagram (Figure 3.2). The main components of *Eucalyptus, Pinus* and Asteraceae are present in both, but the higher grass component is not reciprocated in the core diagram, and the *Baeckea/Leptospermum* taxon in the core is not reciprocated in the pollen traps. This is not unexpected with *Poa*, both in vicinity of the site and regionally, whereas the *Baeckea/Leptospermum* is less persistent in the air, but is in the immediate vicinity. The remains of a burnt stump of *Leptospermum* is directly above the sampled site. It is possible that this plant contributed pollen into older sediments but was killed in the 2003 fires, and therefore did not leave a signature in the current aeropalynology study.

The faunal record is interesting, with the presence of the Brush-tailed Rock Wallaby *Petrogale penicillata*, a species that became locally extinct in the first half of the 20th Century (Ormay, 1996). The Mt Coree area has extensive cliffs and rocky outcrops, and since there are no large complex boulder piles, such as those in the Tinderry Ranges or on the Bogong Peaks, it might be expected that the species would disappear in the area relatively quickly. The discovery of hair of the species from higher in the core suggests a later local extinction, where cliffs may have acted as a useful method of escape from introduced predators. The presence of *Antechinus* hair is expected, as the genus is made up of common small insectivorous marsupial mouse species, which are known to eat *A. infusa*.

It is not likely the human hair is from the period of Indigenous harvesting of *A. infusa*, which ceased in the late 19th Century, well before the advent of *P. radiata* planting in the area.

### 3.4- Aeropalynology of boulder pile sites

Pollen traps were placed in seven different sites along the Brindabella Ranges to sample the pollen rain in the boulder pile environment along an altitudinal gradient (Plate 3.59). Although pollen traps operate in the same basic manner some differences recorded in the field may be attributed to the design, for example differences in the height of the trap openings above the ground surface may influence the capture of pollen (Cundill, 1998). In this study generally the height of the trap did not influence the species present, rather the concentration of pollen caught in the trap.
Plate 3.59- Location of Pollen trap sites on the Brindabella Ranges
The design of the pollen traps was simple and light (Plate 3.60), being a funnel filled with cotton wool, either raised on a 40 cm PVC pipe or buried up to the funnel lip being flush with the soil surface. The capture medium for the pollen traps was cotton wool, as opposed to the more typical acetate wool used by Cundill (1986; 1998). Sample preparation in the laboratory followed Cundill (1986), by drying the cotton wool, adding acetone, treating the mixture with hydroxide (KOH) and finally acetyolysing the product. Samples were placed in glycerol and mounted with safranin stain; all pollen on the slide was then counted.

Plate 3.60- Pollen trap design

Major vegetation types of the local area can be recorded using pollen traps as the major pollen taxa in pollen diagrams (Cundill, 1986), but pollen traps may need several years sampling before pollen vegetation relationships are revealed (Cundill, 1991). A transect of pollen traps was used to investigate the pollen signature of various boulder pile sites at different altitudes and vegetation types for a single year. Typically the raised pollen trap had fallen by the end of the sampling year (Plate 3.61).
Cundill (1991) used pollen traps and moss polsters to sample atmospheric pollen rain, but found difficulty in the indeterminate age of the moss, and was unwilling to directly compare the two methods. The intent of the current study was not to measure the annual rate of pollen fall-out, rather to correlate fall-out range from extant vegetation communities. The Mt Gingera Puddle (MtGP) was employed as an open site reference, being the highest sampled site on the range at 1857 m (Plate 3.62).
Plate 3.62- Sampling Mt Gingera Puddle (MtGP) near trig (Photo Frank Ingwersen).

Other sites sample include the western slopes of Mt Franklin (Plate 3.63-3.65), that sampled a small boulder pile in Snow Gum woodland, Gingera Cave (Plate 3.21), Gingera Big Cave (Plate 3.61), Alice’s Restaurant (Plate 3.32), Round Flat Cave (Plate 3.52) and Mt Coree (Plate 3.58).

Plate 3.63- Mt Franklin Aeropalynology sampling boulder pile site.
Plate 3.64- Mt Franklin raised and ground level air pollen samplers.

Plate 3.65- Mt Franklin air pollen sampling cave with 1 m measuring tape.

The results of the aeropalynology study are presented in Figure 3.2 as raw counts, with each of the eight samples ordered by altitude along the ordinate axis. The
diagram shows the limitation that the cave environment place upon the depositional rates of pollen. The open site, Mt Gingera puddle (MtGP), collected a larger and more diverse assemblage than any of the sheltered cave sites, although some of the difference can be explained by the fact that sediment was collected and sampled directly, without having the somewhat inhibitive cotton wool. The puddle had also been accumulating pollen for a longer period, albeit an indefinite length of time, as opposed to the annual sampling period of the pollen traps. The largest cave, Gingera Big Cave (GBCG), had the second highest diversity of pollen, followed by the more open Tinderry site at Round Flat Cave (TIND), and then the smallest site of Mt Coree (CORR). There also appears to be some difference between raised (GCR) and ground level (GCG) pollen traps from the Gingera Cave Site, but the limited pollen counts do not provide a robust record. The source of pollen the cave site samples are generally local, a trend clearly expressed at the Mt Franklin sampling site (MTFR) which was located in a Snow Gum Woodland. Results from the Alice’s Restaurant (ARR) site were interesting. This sample had low counts, with both the single pollen grains present at this site having a more non-local or even regional source, which may be imported into the site by the moths themselves, for example Cunoniaceae pollen. Migrating Bogong Moths import small amounts of pollen into aestivation sites from areas along the migration path.

The discovery that aestivation sites preserve predominately local pollen spectra, provides a simple spatial reference for the interpretation of pollen diagrams from sediments at aestivation sites.
Figure 3.2- Aeropalynology Diagram.
4) The Bogong Moth as a preserver

Boulder-piles, scree-slopes and rock-shelters on mountain peaks in the Australian Alps are summer aestivation sites for the Bogong Moth. Some of these sites have well developed peaty deposits. This chapter investigates their taphonomy focussing on the conditions presented by the montane cave and crevice environment and the makeup of these peaty soils. The deposits comprise a mixture of parent rock material, plant detritus in various stages of humification, chitinous material from insects, mainly Bogong Moth, and chitinous fungal remains. The organic fraction of the sediment, termed ‘cave peat’, is composed of strikingly large amounts of insect wing and skeletal remains. The composition of cave peats is investigated here, especially what features of the make-up of cave peats confer on them important preservation qualities, such as the large amount of moth remains, their high organic matter content and their acidic nature. A diversity of organic material was identified in cave deposits, and included seed capsules, leaves, twigs, beetle elytra, moth hamuli as well as mammalian hair and bird feathers (Plate 4.1).

Plate 4.1- Deposit surface, showing remains of A. infusa, Podocarpus leaves, lichens and twigs.
Bogong Moths comprise a large component of the peaty deposits and their influence in promoting preservation of pollen, hair and other potentially useful records of past environmental conditions warrants special consideration. The low temperatures associated with altitude, and the relatively sheltered and moist environment of the caves is conducive to preservation of cave deposits. The deposition of insect remains, that is chitin, skeletal protein, waxes and oils, and plant debris, that is humified fibrous plant material, increase acidity of the deposit. Consequently an important priority for this study was to establish the physical and chemical makeup of cave and crevice peats to better understand the preservative qualities of this terrestrial archive, as well as to ascertain the importance of the presence of Bogong Moth remains for preserving the palaeo-environmental archive.

4.1- Sedimentary characteristics
The taphonomic understanding of deposits is informed by the defining peat characteristics outlined below, deposits that are high in organic matter, highly acidic and generally less than 1000 years old. Sediments were characterised using a range of standard methods to ascertain organic versus mineral content, the size fractions of both organic and inorganic material, the carbon, hydrogen and nitrogen component of the organic fraction and the acidity of each profile. Both continuous and bulk sampling were used. Cores were continuously sampled every 10 mm for loss on ignition, pH and magnetic susceptibility. Testing on the fractionated material was conducted on bulk samples to allow general inter-site comparisons, and this proved to be a quick and effective sampling method. Peat from fibrous plant material was separated into four broad size classes using agitated 150 µm, 250 µm and 355 µm screening after dispersion with 5% sodium hexametaphosphate (Calgon) for 24 hours (Leveaque and Dinel, 1977) and then analysed using CNS (Carbon/ Nitrogen/ Sulphur) to establish makeup of raw peats. The fractionated peat and retained fiber components were ashed to ascertain their organic matter content. The amount of waxes and oils in both cave sediments and dried moth samples were determined by diethyl ether extraction.

The use of bulk composite samples limited the detailed assessment of individual profiles but allowed analysis of inter-site differences in mineral and organic component makeup.

The carbon dating record of cave peat profiles indicates a story of mixed age material, which is a pattern that has also been reported for fluvial systems (Worthy 2012). It is
reasonable to assume that regardless of position in the profile the oldest date is indicative of the maximum age of the deposit. The record at aestivation sites preserved indicators of the presence of animal and plant species during an approximate 1000 year timeframe.

4.1.1- Carbon and nitrogen fraction
Carbon and nitrogen content of whole sediment profile (Table 4.1) and of the different fractions (Table 4.2) were determined using an Elementar Vario Max CNS Autoanalyser. Huber et al. (2010) found similar C: N ratios from grassland and heathland soil on the Bogong High Plains in Victoria (15.9), and slightly higher ratios in an *E. pauciflora* woodland (17.9), reflecting a greater input of C from woody litter and leaves, and may coincide with greater soil moisture. A lower C: N ratio in the G4, BP1 and 2 and GBC1 profiles seen in Table 4.1 reflects a high nitrogen input from *A. infusa*. This theory is supported by Table 4.2 where larger more robust fragments, such as woody litter increase in the C: N ratio. There is a distinct taphonomic and depositional difference between the aestivation site deposits and grassland, heathland or woodland soils studied by Huber et al. (2010).

<table>
<thead>
<tr>
<th>Site</th>
<th>Code</th>
<th>Organic C (%)</th>
<th>Organic N (%)</th>
<th>C/N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gingera Cave</td>
<td>G4</td>
<td>11.10</td>
<td>1.67</td>
<td>6.7</td>
</tr>
<tr>
<td>Alices Restaurant 2</td>
<td>AR2</td>
<td>15.20</td>
<td>1.13</td>
<td>13.4</td>
</tr>
<tr>
<td>Alices Restaurant 4</td>
<td>AR4</td>
<td>18.91</td>
<td>1.26</td>
<td>15.1</td>
</tr>
<tr>
<td>Gingera Big Cave</td>
<td>GBC1</td>
<td>23.33</td>
<td>2.30</td>
<td>10.2</td>
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<td>GP2</td>
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<td>0.51</td>
<td>20.4</td>
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<td>Bogong Peaks 1</td>
<td>BP1</td>
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<td>1.91</td>
<td>5.7</td>
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<td>BP2</td>
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<td>3.21</td>
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<td>RFC1</td>
<td>7.70</td>
<td>0.45</td>
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<td>RFC2</td>
<td>6.80</td>
<td>0.40</td>
<td>17.2</td>
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<td>RFC3</td>
<td>8.71</td>
<td>0.52</td>
<td>16.7</td>
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Table 4.1- Aestivation site chitinous peat profile carbon and nitrogen content by site.
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<th>Organic C (%)</th>
<th>Organic N (%)</th>
<th>C/N ratio</th>
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<td>1.3 ± 1.0</td>
<td>12.8 ± 5.6</td>
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<td>13.2 ± 9.6</td>
<td>1.5 ± 1.3</td>
<td>15.6 ± 9.6</td>
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<td>≥ 250 µm</td>
<td>12.1 ± 7.4</td>
<td>1.4 ± 1.4</td>
<td>17.7 ± 13.2</td>
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<tr>
<td>≥ 355 µm</td>
<td>7.2 ± 5.2</td>
<td>0.83 ± 0.99</td>
<td>30.0 ± 26.8</td>
</tr>
</tbody>
</table>

Table 4.2- Average carbon and nitrogen composition, with standard deviations, for the ten Bogong aestivation cave deposits.

4.1.2- Loss on Ignition (LOI)

Cores were sampled every 10 mm. Samples were air dried in a Labec Incubator at 80 °C for 72 hr in tared ceramic boat crucibles, then pyrolysed at 550 °C for three hours using a Walter Oakes Instrument Co. 0-1100°, Model No. F54B ashing furnace. Results are reported as loss on ignition (LOI) and are recorded, together with other environmental proxies, in both the Tilia pollen and fauna diagrams. Since the peaty samples were acidic, and the granodiorite parent rock acidic, all losses were interpreted as due to organic matter alone and not calcinable material, that is bicarbonate or carbonate.

Parallel records of total organic carbon were determined for bulk deposits of single sites in Table 4.3, and for different size fractions of the sites in Table 4.4. The nature of site shelter affects deposit moisture, with more sheltered sites being permanently moist, while more overhang type shelters, that is Round Flat Cave and Gingera Plateau Overhang were much less moist. These two sites also had the least organic matter, which would suggest that soil moisture is important for organic preservation. The smaller sized fractions generally have significantly higher organic matter content.
<table>
<thead>
<tr>
<th>Site</th>
<th>Site Code</th>
<th>Profile depth (mm)</th>
<th>Moisture loss [110°C, %]</th>
<th>Organic matter (LOI) (%)</th>
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<td>GBC1</td>
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Table 4.3-Loss on ignition for whole deposit samples indicating the overall organic matter content of aestivation site deposits.

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<th>Hemic peat 0-125 µm (%)</th>
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<td>40.9</td>
<td>30.7</td>
<td>17.3</td>
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<td>8.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Round Flat Cave 3</td>
<td>RFC3</td>
<td>28.0</td>
<td>9.4</td>
<td>4.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 4.4- Organic matter for different size fractions on dry weight basis.

4.1.3- Oil and wax content
The lipid content of bulk cave sediments and dried moth samples were determined by diethyl ether extraction. The high oil content of Bogong moths, and the known high oil and wax content of high country eucalypts are not reflected in the peaty deposits (Table 4.5). The values of both oil and wax composition are reduced in the sediments, as the volatility of these compounds limits their ability to be preserved for a great
length of time. From the range in values from the different sites (from 0.17% to 0.041%) and moist character of deposits it seems unlikely that their hydrophobic properties contribute significantly to the preservation at aestivation sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Code</th>
<th>Lipids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gingera Cave</td>
<td>G4</td>
<td>0.054</td>
</tr>
<tr>
<td>Alices Restaurant 2</td>
<td>AR2</td>
<td>0.13</td>
</tr>
<tr>
<td>Alices Restaurant 4</td>
<td>AR4</td>
<td>0.17</td>
</tr>
<tr>
<td>Gingera Big Cave</td>
<td>GBC1</td>
<td>0.087</td>
</tr>
<tr>
<td>Gingera Plateau Overhang</td>
<td>GP2</td>
<td>0.026</td>
</tr>
<tr>
<td>Bogong Peaks 1</td>
<td>BP1</td>
<td>0.049</td>
</tr>
<tr>
<td>Bogong Peaks 2</td>
<td>BP2</td>
<td>0.047</td>
</tr>
<tr>
<td>Round Flat Cave 1</td>
<td>RFC1</td>
<td>0.075</td>
</tr>
<tr>
<td>Round Flat Cave 2</td>
<td>RFC2</td>
<td>0.041</td>
</tr>
<tr>
<td>Round Flat Cave 3</td>
<td>RFC3</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Table 4. 5- Lipid content of Bogong moth aestivation site deposits on dry weight basis. Bogong moths collected in 2012 in Canberra contained 18.5% oil and wax.

4.1.4- Acidity

The pH of samples was measured each centimetre using an Oakton Ph7000 pH/mV/°C/°F meter.

Aestivation peats were generally acidic, but there was some variability between the sites (Figure 4.1). In addition sediments were generally moist, and it seems that these two factors contribute significantly to the preservation of pollen and hair at all sheltered sites.
The range of acidity at all the sampled sites was between 3.3 and 4.9, making the deposits very acidic. This acidity would result in poor preservation of bone and teeth, but is remarkably good for proteins, including pollen and hair. Acid conditions can contribute to preservation soft tissue of human bodies (Bouchet et al., 2003). Table 4.6 shows that within the intra-site pH variability was low.

Figure 4.1 - pH measurements for all sites.
### Table 4.6 - Aestivation site deposit acidity (pH) within sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Code</th>
<th>pH*</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gingera Cave</td>
<td>G2</td>
<td>4.3±0.2</td>
<td>17</td>
</tr>
<tr>
<td>Gingera Cave</td>
<td>G3</td>
<td>4.2±0.3</td>
<td>25</td>
</tr>
<tr>
<td>Gingera Cave</td>
<td>G4</td>
<td>3.8±0.2</td>
<td>32</td>
</tr>
<tr>
<td>Alices Restaurant</td>
<td>AR2</td>
<td>4.0±0.1</td>
<td>32</td>
</tr>
<tr>
<td>Alices Restaurant</td>
<td>AR4</td>
<td>3.9±0.2</td>
<td>17</td>
</tr>
<tr>
<td>Gingera Big Cave</td>
<td>GBC1</td>
<td>4.0±0.3</td>
<td>58</td>
</tr>
<tr>
<td>Gingera Plateau Overhang</td>
<td>GP2</td>
<td>3.7±0.1</td>
<td>30</td>
</tr>
<tr>
<td>Round Flat Cave</td>
<td>RFC1</td>
<td>3.9±0.2</td>
<td>18</td>
</tr>
<tr>
<td>Round Flat Cave</td>
<td>RFC2</td>
<td>3.7±0.1</td>
<td>18</td>
</tr>
<tr>
<td>Round Flat Cave</td>
<td>RFC3</td>
<td>3.8±0.1</td>
<td>11</td>
</tr>
<tr>
<td>Tinderry Peak Cave</td>
<td>TP2</td>
<td>4.1±0.1</td>
<td>30</td>
</tr>
<tr>
<td>Tinderry Peak Cave</td>
<td>TP4</td>
<td>3.8±0.1</td>
<td>5</td>
</tr>
<tr>
<td>Bogong Peaks</td>
<td>BP1</td>
<td>4.2±0.2</td>
<td>18</td>
</tr>
<tr>
<td>Bogong Peaks</td>
<td>BP2</td>
<td>4.1±0.1</td>
<td>27</td>
</tr>
<tr>
<td>Bogong Peaks</td>
<td>BP3</td>
<td>3.8±0.1</td>
<td>13</td>
</tr>
</tbody>
</table>

* pH Average and standard deviation.

4.1.5- Magnetic susceptibility

Magnetic susceptibility is defined as the ratio of magnetisation induced in a sample to the magnetic field inducing it: \( K = \frac{M}{H} \), where \( K \) = the volume of magnetic susceptibility (dimensionless), \( M \) = the total magnetic field per unit volume and \( H \) = the inducing magnetic field per unit volume (de Jong et al., 1998). The measurements of electromagnetic units-CGS are in g/cm\(^3\).

Measurements of magnetic susceptibility were undertaken at continuous 10 mm intervals using a magnetic susceptibility Batington Instruments meter model M52 with a sensor type M.S.2.C. Magnetic susceptibility provides a measure of the relative mineral characteristics within aestivation site profiles, and is a proxy for the relative amount of hillslope deposition processes recorded in the deposit (de Jong et al., 1998 and Dearing et al., 1986). Results are presented for each core in the pollen and mammal hair diagrams.
4.2- Taphonomy of aestivation site deposits

Overall the aestvation sites deposits are acidic, highly organic, with variable total nitrogen and C/N ratios, and a small oil and wax component. Tinderry aestivation sites were least organic, drier and more fibric than at other sites, due to site type and differences in climate to the other geographical areas. Conditions of greater saturation of deposits at sites, such as those on Mt Gingera and Bogong Peaks, are conducive to the preservation of organic remains. Moth remains have a low wet-strength, and when saturated are prone to collapse. It is the exclusion of air, high moisture content and the acidity of deposits that minimises microbial action. In this matrix environmental proxies are preserved, including pollen, fungal spores, other invertebrate remains, mammalian hair and bird feathers.

Aestivation site selection by the moth are in intrinsically good preservative environments, which are sites that are sheltered and moist, often with emergence of some groundwater (Plate 4.40), and are therefore incidentally good for organic preservation. This characteristic of groundwater emergence inside the boulder-pile aestivation site environment is important for B. parvus, as it supplies the species with a source of unfrozen hydration, which reduces the energetic costs of eating the obvious source of water in these environments, which is ice or snow. Cooper and Withers (2014) illustrated the exhaustive energetic requirement to raise the temperature of ice to body temperature, and asserted that there would be underground streams beneath the boulder-pile environment which B. parvus would need to drink. Year-round groundwater emergence supplies both a ready source of hydration for this small marsupial, the Bogong moth and the two nematode species, as well as saturating the deposit to create a stable preservative environment.

Some aestivation sites however do not have significant deposits, where the micro-topography below the aestivation is not conducive to sediment accumulation, either acting dispersively with a high gradient, or being prone to erosive episodes. Larger aestivation sites may have areas both of sediment accumulation and erosion.

Within site selection can increase the density of A. infusa to over 17 000 per square metre (Common, 1954; Flood, 1996). The most preferred spaces may be expected to fill with moth-derived sediment before less preferred spaces, although Common (1954) documented changing patterns of aestivation density within the Mt Gingera site during a season.

Other factors which would influence the within-site deposition include differential mortality within aestivation sites, climatic effects on selection and deposition,
migratory success, population selection pressure, decomposition rates and fire. The selection between and within sites changes through time, depending on factors such as the density of individuals in the more sought-after areas, the seasonal climate, availability of water and availability from sediment blockage. Water would seem to be a major agent in the movement of the sediments at aestivation sites, where places of water pooling or lower gradient areas in the microtopography of the cave below aestivation sites will be more prone to accumulate sediments. This process can be seen in Plate 4.2 where a deposit is being formed on a flat rock along the path of water seepage during a day of heavy rain at the Bogong Peaks site.

Plate 4.2- Process of detritus deposition by surface water at Bogong Peaks site.

A single deposit within the broader aestivation site will accumulate, and have the oldest material on the bottom and the youngest on the top. But there is greater complexity at aestivation site level, where several deposits may be accreting at one time. The law of superposition may not be upheld at this site level resolution, as younger material may not necessarily overlie older material. Spaces higher or lower in the rock pile below the most preferred aestivation sites would accumulate sediment most quickly, possibly collapsing and redepositing lower in the boulder pile from time to time.
4.3- Dating

Dating was undertaken by three laboratories, that is ANU in Australia, Waikato in New Zealand and DirectAMS in the United States. The three main sites, Bogong Peaks (eight dates), Mt Gingera (eight dates) and Gingera Big Cave (six dates), have the highest dating resolution. Less dating resolution was applied to Gingera Plateau cores, Alices Restaurant Core, and the two Tinderry cores of Round Flat Cave and Tinderry Peak Cave. OxCal Version 4.2 (Bronk Ramsey, 2013) was used for the calibration of individual dates, using the SH13 calibration, while modern dates were calibrated using the Queen’s University Belfast’s CALIBomb online calibration calculator using the SH Zone 1-2 calibration (Reimer and Reimer, 2004). A table of all the calibrated single dates is presented in Appendix 3.

The dating of several different sites was aimed at ascertaining variability in depositional process at a number of Bogong aestivation site types across the landscape. The dating used at all the sites was by Accelerator Mass Spectrometry, as there was ample material to sample in the form of charcoal, insect chitin and seed capsules preserved throughout the profile, the majority of dates were made on charcoal. Other chronological markers used include introduced mammal hair, especially Felis catus, and Pinus pollen.

Three dates on insect chitin were made in this study, from the Mt Gingera and Bogong Peaks deposits, and two of these turned out to be modern. Accelerator mass spectrometry (AMS) $^{14}$C radiocarbon dating is the most common method used to provide a chronological framework for studies of sub-fossil insect remains. Usually associated organic remains are dated, not the insects themselves, due to the difficulty in obtaining pure material for dating (Tripp et al., 2004). Porch and Kershaw (2010) compared AMS $^{14}$C dated plant macrofossils, beetles and pollen preparations from two late Pleistocene sites in South-eastern Australia and found consistency in ages of beetle sclerites in relation to plant-macro-fossil ages. They called for more research into pre-treatment methods, taphonomy, and taxonomic effects on dating especially for sites with complex depositional histories.

There were some problems with age inversions in the profile, caused by a number of possible factors, including problems associated with the sampling method which potentially dragged or back-filled modern material down the profile.
A lack of a clear age-depth relationship in a number of profiles in the study suggests that there are both depositional and re-depositional processes occurring, possibly where older carbon present in the landscape is remobilised due to landscape scale disturbance, and older hair redeposited with older charcoal, where preservative conditions have continuity. This re-deposition belies an important taphonomic source of widespread hillslope instability since European settlement, which is an important characteristic of all the deposits. The same processes did occur in pre-European times, although much less frequently. The sensitivity of these sites is due in part to a high hillslope gradient, but also the large number of boulders, which amplify run-off in storm events.

Dating of charcoal and wood using AMS $^{14}$C, can also have greater complexity where the tree species may live for several hundreds of years, such as $P. lawrencei$ and $E. pauciflora$, where there may be a range in age of the wood itself.

Luminescence dates of quartz grains could possibly have provided an interesting control on the AMS dates, an approach adopted by Worthy (2012), but was not used in this study as the sediments did not readily contain large amounts of quartz grains, and these were not able to be discerned from the weathering of the rock of the cave. Some questions have been raised about studies using luminescence dating where rubble may become reworked with sediments and remain undetected (Gibbons, 1997). Wallis (2002) highlighted the problem in a rock-shelter environment that all the quartz grains not being adequately exposed to sunlight. In the case of a Bogong cave environment this may be made more complex where deposits have been reworked a number of times within the boulder pile itself.

The results of dating of aestivation site deposits do not reflect the effect of bioturbation of these deposits by the nematode species $A. bogongae$ (Welch) and $H. cavicola$ (Welch). The size of the dated material was too large for the nematodes to move directly, and even the smaller sized proxies of pollen and micro-charcoal do not seem significantly affected by bioturbation either, but the movement of pollen and micro-charcoal within the profile is potentially greater than the larger macro-charcoal fraction. Micro-charcoal ($<125\mu$m fraction) tracks the larger macro-charcoal ($>125\mu$m fraction) at all sites, and the analysis of the pollen assemblage shows some broad trends and abrupt peaks, which would not be distinguishable with excessive bioturbation. The two nematode species do not behave in the same manner as earthworms, which ingest sediment, but would move the smaller grain sizes in the sediment by contact. In a study by Walch et al. (1970) the displacement of pollen by
earthworms was greatest upward, while downward displacement occurred through the effect of rainwater seepage. Worms relocate pollen grains by ingesting them along with the soil as they burrow, and during wet periods tend to move upward toward the soil surface. Earthworms were found at all study sites except Bogong Peaks, but not in great numbers and were not expected to overly disturb the deposits.

4.3.1- Age Depth Models
The age depth models were formulated by OxCal Version 4.2, using the SH13 calibration (Bronk Ramsey, 2013). This programme is run online by the Oxford Radiocarbon Accelerator unit, and provides radiocarbon calibration and analysis of environmental chronological information using Bayesian statistics to show the relation between selected stratigraphic dates. A minimum 60% confidence interval for the age depth models allowed for a good balance for the working models, without the excessive exclusion of dates or massive age envelope size. The age models used in the Tilia diagrams of site pollen and fauna use the median point of the age-depth envelopes presented here. This method proved adequate in most cases. The AMS ages of these deposits suggest that all of them are of relatively recent origin, and are generally less than 1000 yr BP. Age models are not presented for BP1, AR2 or RFC as these sites had one date each and could not be constrained basally. Modern dates were not included in the age-depth calculations.

The Bogong Peaks deposit was sampled with three cores from the same crevice, with the deepest part of the deposit in the middle (BP2). The date from the BP 1 core near the bottom of the core at 640+/-25 years seems to be from older carbon that has been mobilised, as it is above 16 cm and levels with the presence of *F. catus* and *Rattus rattus* hair. I have not used the age depth model formulated by OxCal in this instance as there is only a single date, and the projected basal date (912-1356AD) is much older than the deeper BP2 section.

The majority of the BP2 core is post-European, with contact (early 19th Century) occurring between 15 cm and 20 cm, with increases in both macro- and micro-charcoal directly following. This charcoal increase is indicative of more frequent fire and landscape destabilisation with increasingly intense European settlement from the mid to the turn of the 19th Century in the area. Using fine-scale palynology it is possible to demonstrate a significant correlation between charcoal particles and tree-ring damage from single fire events (Bowman, 1998).
The problem of older sediment mixing for the interpretation of environmental proxies is not dire due to the post European nature of the core with ample European age indicators, but has proven problematic in dating *Sarcophilus harrisi* hair discovered at 11 cm and 12 cm in BP2. A poorly constrained date nearby and the possibility that the hair itself was reworked expands the possible age envelope to the oldest date of the deposit, taken at 12.5 cm of 1083+/-28 years. It should be noted that this reworking occurred in the age model during the mid-19th Century, which is the time when European land management caused massive landscape destabilisation. The apparent contradiction of dates down the profile can be explained by the movement of old carbon in the landscape, with clusters of dates occurring around 180, 400 and 900-1000 years ago. The interpretation of massive European management landscape destabilisation gives the age depth model for BP 2 (Figure 4.2) a staggered appearance, with a small amount of sediments dating from around 400 years at the bottom, but then depositional rate steeply increasing in gradient. With the arrival of Europeans older carbon was mobilized, and mixed with carbon created from fires lit by the earliest settlers, the older 900 yr+ residual carbon may have been stored in a similar deposit higher in the local catchment of the boulder pile or even further up the hillslope, and is deposited after the erosion. Regardless it does seem that there is a disturbance at 900 years that created a significant carbon signature in the landscape, and a second one that seems to be at the upper limit of age to material in this deposit.
The Gingera Big Cave was the deepest of all the sampled sites, with a sampled depth of 59 cm. It is modelled to have a record of over 1000 years, although basally the dates are not well constrained, nor are they in the upper layers (Figure 4.3). Being the largest deposit the trends of sedimentation in the post European period are not as pronounced as the other sites. There were some anomalous modern dates throughout the profile, but this may be explained by the large amount of charcoal created at the site in the 2003 fires and the sampling procedure of pushing a tube through the sediments, where younger charcoal could have been pushed deeper into the deposit. The top sediments seem to be post European, with the arrival of Europeans reflected in a large micro charcoal and smaller macro charcoal peak at 6 cm. This signature, representing increased burning at the site and regionally, would have served as a trigger for hillslope movement, possibly even slumping of sediments in the immediate
vicinity of the site from a reduction in stability of sediments due to a reduced vegetation cover. Fox hair is present from 14 cm may be the result of the sampling technique pushing material marginally deeper into deposit or possibly backfilling. A Pinus peak from 8 cm is a better indicator of European arrival and impact and is the bottom of Zone 1, with regional plantings dating from the mid to late 19th Century in the region (Mooney et al., 1997). Fire exclusion in the Cotter catchment from the early 1920’s saw a drop in charcoal to very low levels in the top 5 cm (Banks, 1982). It should be noted here that the median point of the envelope method used for the age depth model in the pollen and fauna diagrams would seem to overestimate the age in the bottom of Zone 1.

Figure 4.3- Age Depth Model for GBC (14C age at 40.5 cm excluded).

The Gingera 4 profile extends beyond European settlement, possibly over 200 years, at the extremity of the model predictions (Figure 4.4). The increasing age uncertainty
with depth makes it difficult to assign specific dates to any major fire event, but there is a clear increase in sediment accumulation between 29 cm and 26 cm followed by a reduced accumulation rate directly preceding European settlement at around 21 cm, which is followed by an increase in sedimentation rate. This illustrates the impact of pre-European fire regimes on sediment accumulation, where large landscape scale fires followed by a period of stability. European impact on the other hand, with a more consistent burning consistently input sediment into the deposit, hence the model going from a stepped appearance, with various inflexion points, to a more consistently steep one.

Figure 4.4- Age Depth Model for G4 (14C age at 29.5 cm excluded).

The two Mt Gingera Plateau cores were the same depth, but the majority of the analytical work of sediments was done on GP 2. GP1 was very unconstrained (Figure 4.5), with the first 15 cm from European contact, the second half of the core possibly
stretching back almost a millennium. This highlights the need for further dating of the site.

Figure 4.5- Age Depth Model for GP1 ($^{14}$C age at 28.5 cm excluded).

The deeper sediments at the GP2 site were much more constrained than GP1, with the majority of the deposit accumulating within 100 years of basal deposition around 1600 AD (Figure 4.6). However the relative sedimentation rate at this site may or may not have been greater during the period of European land management, The precision in the age-depth model did not allow definitive conclusion to be drawn , and periods of settlement and exclusion of fire during national parks times could not be compared. The greatest uncertainty in the model is in the first 10 cm, which includes the European settlement period.

GP2 was the most acidic site and had the highest C/N ratio, but one of the lowest organic content matter of all the sites and the lowest amount of waxes and oils. The
site itself was dry, being under an overhang but quite open, and is expected to be greatly influenced by the surrounding hillslopes and the wider environment.

Figure 4.6- Age Depth Model for GP 2.

The Tinderry Peak core (Figure 4.7) has a similar age depth model to both Gingera Plateau Cores, although may have a slightly older initiation and large phase before the rapid sedimentation period around 1600AD. A second period of sedimentation from the 1800s, again similar to Gingera Plateau cores, is attributable to the European settlement period. The stepped appearance, with various inflexion points, of the deposition would indicate the impact of disturbances to a system that is both sensitive, and in the case of European impact, slow to recover. The higher gradient and larger depth of post-European deposition would indicate a larger and longer
period of disturbance than the two disturbances which preceded it, and appear as smaller steps of lower gradient.

![Age Depth Model for TP2](image)

Figure 4.7- Age Depth Model for TP2.

The aestivation site deposits sampled mostly started to accrue in the last 1000 years, and show periods of disturbance and sedimentation in the immediate vicinity of the sites. It seems there is minimal erosion occurring within the sites that were studied, and following that there is minimal truncation of the sediments within the profile, rather periods of greater sedimentation caused by broader landscape scale instability, flowed by periods of higher stability with reduced depositional rates. It does not seem to be a sediment starved system, with low gradient slope wash occurring on the bare soils after soil saturation. The micro-topography of the cave may play a role, the deepest deposits occurring at the most sheltered and low gradient sites, with rocks impeding the drainage and serving to catch sediments that may otherwise continue
further down the slope. The mechanism of frost heave and surface slumping at the less sheltered sites may reduce the effects of deposition, but would not undercut the deeper sediments.
5) The Bogong Moth Proxy Record

This chapter describes the methods used in the thesis, and provides some theoretical background for the interpretation of the data.

It should be noted that at a given site the pollen catchment, charcoal catchment and faunal remains catchment vary spatially and temporally, so any conclusions drawn about the three need to be in accordance with assumptions that can be upheld about depositional mechanisms. In some respects taphonomic information supplies important information about the site itself, and provides the framework for the interpretation of environmental proxies contained within each sample. Preserved material cannot be interpreted on face value, that is without a taphonomic context.

5.1- Methodology

Sediments at aestivation sites were firstly probed to gauge the depth of sediment. For softer sediments a 30 cm lightweight plastic corer was used to sample. The design of the corer was compact to allow for sampling in limited spaces, and incorporates a piston for improved retrieval and ability to extrude the core. Soft profiles deeper than 30 cm were taken using 25 mm diameter PVC extension rods (Plate 5.1). Gingera Big Cave had deeper and denser sediments that were not in a confined space and was able to be sampled by hammering a 90 mm diameter PVC pipe into the sediments using a wooden mallet.

Plate 5.1- Corer used for sampling smaller and softer aestivation site deposits.
In the lab sediment cores were cut into contiguous 1 cm slices.
Pollen

2.5 cm³ was taken from each sample and soaked in 10% sodium hexametaphosphate solution for 72 hours. A tablet of *Lycopodium* spore marker, batch number 1031, (n=20 848) was added to the sample. Samples were fragmented using the sonic water-bath, and sieved at 125 µm, with the filtrate being retained. The filter residue was analysed for macro-charcoal. 5 mL of 10% KOH solution was added to the sample and heated at 80 °C for 20 minutes. The sample washed with H₂O and centrifuged repeatedly until the sample solution became clear. The sample was then filtered at 5 µm, with the filter residue retained. Glacial acetic acid (H₃COOH) was added and sample centrifuged, then acetalised using a 9:1 solution of acetic anhydride (CH₃CO)₂0 and sulphuric acid (H₂SO₄) at 90 °C for 10 minutes. The sample was centrifuged. Glacial acetic acid was again added, centrifuged down and washed twice, and then placed in a glycerol solution. 5 µL was mounted on a slide, and analysed for pollen and micro-charcoal.

A minimum of 300 pollen grains were counted per sample, except where a lack of pollen limited the numbers. Pollen data is presented using Tilia version 2.0.32 (Grimm, 2004) to graph the results as a percentage of a total pollen sum.

Hair

The entire sample was inspected for the presence of larger hair and feathers using a 10x lens. A 1 mL sample was the placed in a petrie dish in water and viewed under a 40x stereomicroscope. Hairs were removed by forceps and cleaned by washing in ethanol, acetone and finally warm soapy water.

Hairs were dried and mounted on glass slide with coverslips and identified using 400x transmitted light microscopy. Hair identification was made using a mammal hair reference collection derived from the CSIRO mammal reference collection, Brunner and Coman (1974), and Triggs and Brunner (2002).

Results are presented using Tilia Version 2.0.32 (Grimm, 2004) as a presence or absence in the samples, in a separate figure from the pollen data.

Charcoal

Macro-charcoal methodology is based on Stevenson and Haberle (2005). The 125 µm filter residue of palynological preparations was treated with 1 ± 0.2 mL of 2.5 %
sodium hypochlorite (NaOCl) to oxidise and remove readily degradable natural organic matter, then stored in a vial for macro charcoal counting. Counting was conducted employing a backlit Zeiss Sterni 2000-C binocular microscope (1.6 x 65 magnification) after transferring the sample to a glass Petrie dish backed by 1x1 mm² grid. Material was as evenly dispersed as possible to facilitate area-aggregated counting. Charcoal was identified as black, angular material and care was taken to exclude heavy dark mineralised material. Where limited material was present all charcoal was counted. With larger amounts of charcoal, care was taken to distribute the graphite particles as evenly as possible: a count was made at least across a 200 mm² background area and the result scaled up to the full area to provide a reliable estimate of the total number of charcoal particles present. Results for the macro-charcoal counting is expressed as particles/ml and presented along with both the pollen and faunal diagrams for easy comparison to the micro-charcoal fraction, vegetation changes and faunal components.

5.2- Pollen

Pollen spectra from terrestrial archives is a useful indicator of past plant communities, where pollen deposition can be compared through the profile and analyzed with an age depth model. Dating of sediments and their pollen analysis provide a window into the integrity of sediments, but it is likely that size fractions may have variable proneness to movement within the profile.

Taphonomy is an important aspect in the interpretation of the pollen assemblages, where site specific factors play a particularly important role in what conclusions are able to be drawn. For instance, if the pollen assemblage at three different types of sites was identical, that is the pollen incorporated in a wasp nest, the pollen in an aestivation site deposit and one in a nearby bog, then the interpretation of each of these would differ in accordance with preservation and with depositional factors. Equifinality, also operates where ecologically distinct vegetation structures can produce identical pollen signals (Bunting and Middleton, 2009), but this can be considered using multiple proxies. More ecological inferences may be drawn when changes in the pollen assemblage are compared to changes in the concentration of charcoal in the sediments, or other proxies such as mammal hair, in the case of Moth aestivation sites.

The preservation of pollen in cave deposits can be limited by taphonomy, where low pollen concentration occurs through limited pollen input or a sub-optimal preservative
Depositional environments in caves may be desiccated by alternating between wet and dry, and they are rarely anoxic, making organic material subject to perturbation and microbial activity.

In cave sedimentary deposits the source of the majority of pollen deposited is from vegetation surrounding the site, that is a limited source when compared to the more open bog and swamp deposits that are typically studied by palynologists. Most of the pollen in a deposit is of local origin if the collecting area is small, although some will be regional and even less from long range dispersal, with surface samples giving some indication of pollen source (Martin, 1973). The annual pollen input in the boulder-pile environment was sampled using raised and ground level pollen traps. Results of pollen trapping are presented using Tilia (Version 2.0.32) (Grimm, 2004) in Chapter 4, and illustrated a predominately local pollen catchment.

Navarro et al. (2001) studied surface pollen from cave sediments from south eastern Spain, and found that caves with a wide mouth and low depth had homogeneous pollen. They studied deeper and more complex cave systems and found that nutrient rich conditions, in combination with high humidity, had a positive effect on the occurrence of bacteria, and which was responsible for pollen degradation. In contrast the Mt Gingera and Bogong Peaks cores were high in nutrients but also high in pollen, with the quality of pollen preservation being explained by the source of the organic matter. Peaty sediments derived from remains of Bogong moths are the result of high deposition rates and anoxic conditions provided by saturation of the deposit, low evaporation rates and acidic conditions (Keaney, 2006).

Peaty sediments at aestivation sites are not as prone to decomposition as open deposits such as bogs and swamps, since they are sheltered, commonly raised and often located below a spring or associated with groundwater seepage. The sensitivity of peat decomposition in open sites to temperature is increased by feedback between the water-table and peat depth. Peatlands quickly respond to warming climates by loss of labile soil organic carbon during dry periods (Ise et al., 2008).

An important aspect of the palynology of aestivation site deposits for environmental interpretation is to ascertain the pollen load carried to sites by A. infusa. Sampling the pollen load carried by A. infusa was done by collecting individual moths from around Canberra during the late spring of 2013. The head and proboscis of individual moths were removed and crushed. The debris were placed in a solution of 20 ml of 50% ethanol-acetone and 50 mL of water. The solution was boiled to evaporate the ethanol-acetone component and then acetolyzed using the same method as that used
for sedimentary samples. The sampling of the pollen load of *A. infusa* during current seasons provides valuable data for the interpretation of pollen found in sediments at aestivation sites. The comparison of moth samples taken during migration to aestivation, aestivation and return migration would also provide a useful insight into the role of the Bogong Moth in alpine and sub-alpine pollination.

The transport of pollen by migrating animals has been documented by using DNA analyses. Sediments found in Crawford Lake Ontario were shown to be partly derived from dung from Canada geese, *Branta canadensis*, that had fed in Iroquoian fields. These sediments contained *Zea* (maize), *Helianthus* (sunflower), *Curcurbita* (squash) and other agricultural pollen types, as well as spores of *Ustilago cf. maydis* (maize smut) (McAndrews and Turton, 2007).

The relationship between insects and pollen transport is complex, and has evolutionary as well as ecological implications. In an English study it was found that very few individual insects carried more than one *Heracleum* (Hogweed) pollen type, and from this it was deduced that selective foraging behaviour of insects is a barrier to hybridisation between two species of *Heracleum* (Grace and Nelson, 1981). Gregg (1993) used pollen as a marker for the migration of two *Helicoverpa* species from western Queensland. The researcher found that following migration the moths have large quantities of local pollen, indicating that moths fed soon after arrival. 95% of noctuid moths studied by Gregg (1993) carried pollen. It should be noted that pollen retrieved from moths marks only adults and does not indicate larval host plants (Gregg, 1993).

The pollen load carried by *A. infusa* was found to be low, not unexpectedly. This is in agreement with the theory that the greatest nutrient intake during the lifecycle is during the larval stages, and that little feeding takes place during the migration. The pollen load of moths was ascertained by acetolysation of batches of twenty individual moth heads, including proboscis. Moth heads alone were used to sample the pollen that the moths consumed during migration, rather than the entire body and legs than the legs which would include pollen from any surface that the moth has landed. The results are shown in Table 5.1.
<table>
<thead>
<tr>
<th>Taxon</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Dodonea viscosa</em> type</td>
<td>13.0</td>
</tr>
<tr>
<td>Myrtaceous shrubs</td>
<td>38.7</td>
</tr>
<tr>
<td><em>Kunzea</em> type</td>
<td>9.7</td>
</tr>
<tr>
<td><em>Angophora floribunda</em></td>
<td>3.0</td>
</tr>
<tr>
<td><em>Eucalyptus</em> type</td>
<td>3.0</td>
</tr>
<tr>
<td><em>Hypericum graminium</em></td>
<td>6.0</td>
</tr>
</tbody>
</table>

Table 5.1- Pollen load of *A. infusa*.

A total of 31 grains were counted, the vast majority of which were myrtaceous, and of these the most common were Myrtaceous shrubs and *Kunzea/Callistemon* type. The other families present, that is Sapindaceae and Hypericaceae are distributed to the west of the great divide and present in pastureland. *Angophora floribunda* has a significant distribution west of the divide in Northern New South Wales and southern Queensland, including the black soil plains where *A. infusa* breeds.

Pollen identification was based on ‘The illustrated guide to fossil pollen of the Southern Highlands of NSW’ by Macphail and Hope (2002). Taxa classification was also generally based on this work, although in some instances a more generic taxa term is used, such as the broad Asteraceae Tubuliflorae or Asteraceae Liguliflorae. The identification and classification of Myrtaceaee pollen was based on Chalson (1987). In the case of the identification and classification of myrtaceous shrub taxon ‘Myrtaceous shrubs’, the taxon incorporates the species *Leptospermum brevipes*, *Leptospermum micromyrtus*, *Baeckea gunniana*, *Baeckea utilis*, *Baeckea crenatifolia* and *Leptospermum myrtifolium*.

The interpretation of Myrtaceous shrubs in the sedimentary environment is made more complex by the importation of that pollen type into aestivation sites by the moth, however this input is not seen as enough to impose large peaks in the abundance in that taxon in the pollen diagrams. The amount of imported pollen is not great, and the input would be expected to be consistently small.

5.3- Hair

The original discovery of preserved mammal hair in the sediments from the Bogong Peaks site opened a very promising line of enquiry, that is, the identification and interpretation of mammalian hair as an environmental and ecological proxy. The source of mammal hair can be accurately and reliably identified using microscopic morphological characteristics (Lobert *et al.*, 2001). The ecological preferences and
distribution of faunal species was based on Strahan and Van Dyck (2008) and Menkhorst and Knight (2013). A continuous sequence with well-preserved hair, in association with other environmental proxies of pollen and hair is quite novel and informative where a reasonable chronology can be applied. The role of taphonomy is important for interpretation when hair is both present and absent. Hair is expected to be deposited throughout phases of sediment accumulation but its preservation is less certain. Deposition may be direct, as a predator at the aestivation site, or also a species which uses the boulder pile environment without preying on the moth, or possibly both for the same species in the same sample. Indirect deposition still requires shedding or proximity of remains near enough to the site to permit transportation by wind or water, or by predator as predator scat or even as a manuport. Since it is not possible to identify the exact depositional method, deposition of mammal hair is interpreted as the presence of the species within the immediate vicinity of the site.

Previously there has been some work on deposits that preserve hair using Owl pellets, for example Smith (1977) who found evidence of 19th Century mammalian extinctions in the arid regions of Flinders Ranges based on the faunal analysis on bones and teeth. Although that study had fur from a single rodent species, typically only bones and teeth are used. Ellis (1995) employed sub-fossil bones using owl pellets to reveal the existence of Bandicoot and Dasyurid species in Western NSW that are now considered extinct in that state since the arrival of the Europeans. Rich (1982) provides a detailed description of Australian mammal fossils, with discussion about taxonomy and biogeography, based on palaeontology. It included a section on the extinction of the mega fauna, and reference to the morphology of introduced fauna. Wakefield (1972) analysed two subfossil assemblages based on an assessment of habitat of the species recorded, that is Pyramids Cave in Eastern Victoria and Wombeyan Caves in New South Wales, and drew inferences from them regarding vegetation change related to climate change during the accumulation of the deposit in the past 20 ka BP. Aplin et al. (2010) studied a cave in the Yarrangobilly area and also interpreted the mammalian assemblage in terms of environmental requirements of the species.

Direct environmental evidence can also be found using mammalian remains, for example chemical analysis of bone may furnish direct evidence of past climatic conditions since stable isotope values vary in response to climatic change. Isotopic analyses of stable carbon and nitrogen isotopes in bone collagen provide independent
data in association with other palaeo-climatic indicators (Roberts et al., 1999). The spores of dung-fungi can also be used from sedimentary deposits with contemporaneous environmental proxies (Rule et al., 2012). Neither isotopic analysis of hair or dung-fungi assemblages were used in this study.

Hair identification was made using a mammal hair reference collection derived from the CSIRO Mammal Reference Collection, Brunner and Coman (1974), and Triggs and Brunner (2002). In the case of the discovery of Sarcophilus harrisi hair in BP2 at 10-11 and 11-12 cm an additional reference was used in Lyne and McMahon (1951), but comparative photography was crucial for positive identification, and provides a good example of the methods used to identify the taxa of origin. The following photomicrographs (Plates 5.2-5.10) were used to compare key morphological characteristics of medulla with simple with globular vacuoles, an irregular wave scale pattern in the distal half of the hair, and a diamond petal with protruding scales in the proximal half of the hair.

Plate 5.2- Medulla of S. harrisi hair BP2 10-11 cm showing simple medulla with globular vacuoles (100x).
Plate 5.3- Medulla of the proximal section of *S. harrisi* (63x) showing simple medulla with globular vacuoles (reference collection).

Plate 5.4- Distal section of *S. harrisi* hair from BP2 10-11 cm showing irregular wave scale pattern (63x).
Plate 5.5- Distal section of *S. harrisi* hair from BP 2 10-11 cm showing irregular scale pattern (100x).

Plate 5.6- Distal tip of *S. harrisi* hair showing irregular wave scale pattern (63x) (reference collection).
Plate 5.7- Midhair of *S. harrisi* hair 63x showing irregular wave scale pattern (63x) (reference collection).

Plate 5.8- Proximal section of *S. harrisi* hair BP2 10-11 cm showing diamond petal scale pattern (63x).
Plate 5.9- Proximal section of *S. harrisi* hair BP2 10-11 cm showing diamond petal scale pattern (100x).

Plate 5.10- Proximal section of *S. harrisi* hair showing diamond petal scale pattern (63x) (reference collection).
Where possible the identification of hair was to species level, but this was not always possible for two species in the same family or genus with similar hair morphology. The Pygmy-possums are an important example, that is the Burramyidae family, and the similarity of hair between the species *Burramys parvus* and *Cercartetus nanus* should be noted (Triggs and Brunner, 2002). In this case the taxon ‘*Burramys* type’ was used, as the boulder-pile environment and ecology of the aestivation study sites make the presence of *B. parvus* an obvious possibility.

Truncation of hair can also reduce the taxonomic precision of identification by virtue of the absence of key morphological characters. Both degradation and the presence of sediment which obscures visibility can produce uncertainty in terms of identification. A more generic taxon classification may reduce the possible interpretation and extrapolation of data, where a single species with known ecological and environmental preferences are able to be identified. In this case a broader classification may have a larger data set but prove to be less informative.

The reliability of identification of hairs for species with a currently anomalous distribution, especially the taxa *Thylogale* and *S. harrisi* was increased by cross reference to the mammal hair reference collection as well as comparative photographs. It should be noted that cross-sections were not used for identification of hair, and that scale pattern was directly identified rather than using scale casts. There was a limited cross-checking of samples with Barbara Triggs, an expert in the identification of mammalian hair, which proved positive. Genetic analysis was not used in this study, where degradation and age could limit the utility of samples, but may prove to be a rich source of data for future research.

Various interpretations of the hair assemblage are possible, from looking at individual species within a given sample to differences between species, and differences between sites. Each level of resolution provides a different view of the data. Other basic characteristics of the assemblage, such as size of mammal, ecological type or tolerance, and general type, for example carnivorous, rodent or herbivore, or even native or introduced may illuminate characteristics of faunal communities that are not clear upon inspection of a simple species list. Further, the interaction between type and other metadata, such as the pollen data or charcoal concentrations can also provide interesting insights. More experimental categorisations of data such as spatial, temporal or depth provide additional contexts independent of other variables. Groupings have been made around the general size and type of mammal, such as
'possums and gliders’ in faunal diagrams, but the data is also visible as individual species or genera.

Categorisation may limit conclusions that can be drawn from a data set, and in the worst cases cause teleology. But there must be an interaction between those things that lie inside and outside cognitive parameters. Without words and concepts there cannot be thought. It may be an interesting use of typological essentialism, but it seems that variability in arbitrary meta-classification is a useful scientific tool, especially where categories are not contradictory and several analytical approaches may be used.

This idea is replicated in the choice of statistical analysis where different relations within the data can be coaxed out, from variability between single variables to more complex multivariate analysis, such as the use of incremental sum of squares for a stratigraphically constrained cluster analysis by the CONISS diagram. The importance of a CONISS analysis is to provide the zonation within the profile using dissimilarity coefficients between constrained samples (Grimm, 1987). It should be noted that zones have been assigned using pollen data only, as samples sizes are more robust. The zones themselves are clusters or groups of samples that are similar. In this case it is possible to track different responses of the ecosystem through time to the similar environmental stimuli between the zones, for example the different effect that a large fire has on the environment before and after European settlement.

In the case of hair data presence or absence is the most robust basic categorisation, rather than a minimum number of individuals or count of remains within each sample, which would be directly dependent on taphonomic characteristics, where one individual could be responsible for high counts, as much as a large number of individuals contributing a single hair. Species richness on the other hand is more easily directly correlated with ecological diversity, where each species had to be present in the local area to be preserved, regardless of numbers. The presentation of summary data of the hair assemblage in relation to the other data types, including sedimentary characteristics, pollen data and charcoal concentrations, using Tilia 2.0.32 (Grimm, 2004) is to provide greatest ease to contextualise the data set.

5.4- Charcoal

The identification of variability in the charcoal record from the expected climatic conditions based on the dating of the associated sediments, is used for evidence of changes in prior land use by natural historians. The interpretation of charcoal in
sediments as markers of social change has been used to infer many different things about population structure and land use of past cultures. In an Australian setting it is uncertain the extent to which the Indigenous cultures impacted on Australian ecosystems by utilising fire to manage the various landscapes (Black, 2006). It should however be noted that the ignition source of a single fire that created the charcoal in a sedimentary profile cannot be attributed to either to humans or lightning, as the same thermal processes, with the same physical, chemical and ecological impacts take place regardless of ignition source origin. What is important is the reaction of the biome, its signature and its signature’s visibility in the record. For example, the presence of granodiorite flakes in deposits may suggest the occurrence of bushfires, as the mechanism of heat expansion leading to rock splitting is important in rock disintegration in Australia (Ollier and Ash, 1983), but these flakes cannot be taken to infer humans lit a fire that split the flakes off the rockface and that placed them in the profile. A fire regime, that is the impact of a series of fires, is a more explanatory basis for the interaction of humans and the environment.
6) Bogong Moth deposit findings

Results from study sites are divided into vegetation data and faunal data, with a description of results followed by a diagram for each analysed core. A summary table of every site, showing the depth of each deposit, the material dated, uncalibrated dates and single age calibrations is provided in Appendix 3. The Bayesian age depth model for each site is presented on the graph on the left on each diagram, with uncalibrated dates listed adjacent.

6.1 Vegetation and fire data from sediments
The magnetic susceptibility measurements of electromagnetic units-CGS are in g/cm$^3$. Loss on ignition is a percentage of dry weight. Pollen percentages were calculated from the total sum of pollen counted, and both the micro- and the macro-charcoal curves are expressed in particles/ml.

6.1.1- Bogong Peaks 2
The Bogong Peaks 2 record goes back over 300 years and provides a record of changes during European settlement (Plate 6.1). Using the CONISS diagram the profile was divided into three zones, with two of these further sub-divided. Magnetic susceptibility increases gradually up the profile, to peak at 3 cm and then decline, reflecting the removal of a major cause of landscape disturbance when grazing was removed from Kosciusko National Park above 1370 m in June of 1958 (Wimbush and Costin, 1979). For depths greater than 5 cm there is a large variability in the total organics measured by the loss on ignition that loosely follows the micro- and macro-charcoal, suggesting limited selective decomposition, rather periods of higher inorganic input. The entire core is highly organic with some peaks over 60%. Several of these were highly organic layers were dated, and found to be between less than 200 years to over 1000 years in age. Both of the dated sections of the core which had low organic content were less than 50 years old which suggests some backfilling may have occurred, an assertion supported by the presence of introduced faunal hair in the same lower sample.

Zone 1a - Pre-European Period A (27 cm -23.5 cm)
There are low levels of micro-charcoal, which fall to very low levels at the base of the zone. The macro-charcoal has a large peak at 25 cm (320yr BP+) and then steadily
declines until the settlement period. This large local event places a significant amount of reservoir carbon in the system. Fluctuating levels of Myrtaceous shrubs from lower levels to a peak at the upper boundary following this event, while *Eucalyptus* decreases and *P. lawrencei* increases, possibly following some localised damage to the resilient *Eucalyptus* overstorey. There is a diversity of shrub taxa in this zone, including *Pomaderris aspera*, *Euphorbiaceae* (*Micrantheum* spp.), *Ericaceae*, *Calytrix*, *Rutaceae*, *Sapindaceae*, *Kunzea*, *Leptospermum*, *Lomatia* and *Pimelea*. Herb taxa are dominated by *Poa* spp., Tubuliflorae daisy and *Haloragis*, which follow directly after the macro-charcoal peak. A greater diversity of species is present before this event, including Liguliflorae daisy, *Brassicaceae*, *Stellaria*, *Lomandra*, *Plantago*, *B. bulbosa* and *Arthropodium* spp. There was some *Eremophila* pollen found in this zone. As this is an arid taxon (Jacobs, 2009) this pollen is theorised to have been be imported into the site by *A. infusa*.

Local fire recurrence intervals at this stage are long, in the order of 100 years, with a strong *E. pauciflora* overstorey and predominately herbaceous understory. The fire regime is characterised by rare larger scale events, where structural successional processes can unfold for long enough for individual trees to reach maturity and senesce, and only small areas within the landscape contain regrowth or a persistent understory.

Zone 1b - Pre-European Period B (23.5 cm -17.5 cm)

There does not appear that there was a local fire event at the site during this zone as recorded in the macro- or micro-charcoal record, with the low levels of macro-charcoal being likely due to re-deposition of residual charcoal from larger earlier events, which explains the older date seen at the beginning of the zone. There are two smaller micro-charcoal peaks, the lower showing some regional burning signature prior to European contact, while the second just prior to the arrival of Europeans. In this zone *Podocarpus* increases at first then stabilises and falls in the top sample, while *Eucalyptus* slightly increased throughout. A diversity of ferns develop in the absence of fire including *Blechnum*, *Cyathea*, *Gleichenia*, *Lycopodium* and *Pteris*. There are falling levels of Myrtaceous shrubs and *Tasmannia*, but also the highest diversity of shrubs, including *Pomaderris*, *Euphorbiaceae*, *Rubiaceae*, *Rutaceae*, *Sapindaceae*, *Acacia*, *Calytrix*, *Ericaceae*, *Hibbertia*, *Loranthaceae*, *Pimelea* and *Kunzea*. Herb taxa are also diverse and include *D. revoluta*, *Acaena*, *Apiaceae*, *
Boraginaceae, Brassicaceae, Chionogentias, Haloragis, Plantago, the lily Arthropodium and Urtica. The amount of shrub taxa decreases higher in the profile, as structural succession to a grassy and herb understorey progresses.

Though-out most of this zone Podocarpus pollen is relatively high while Eucalyptus pollen is relatively low. This would be expected in a sub-alpine climax community, in which a wide spaced mature Eucalyptus overstorey would have less pollen input into the boulderpile environment than the more proximate Podocarpus. This theory is supported by the diversity of ferns, consistently high levels of Poa and a gradually decreasing shrub layer. The top sample of the zone records an increase in both micro- and macro-charcoal and is theorised to represent a disturbance directly before the arrival of Europeans, where there is an increase in Eucalyptus and decrease in Podocarpus.

Zone 2a - Contact/Early Settlement Period (17.5 cm -12.5 cm)
The first half of the zone has a low amplitude increase in the levels of macro-charcoal. The large micro-charcoal spike may date from the 1840s, and also follows a higher threshold of micro-charcoal levels. Eucalyptus is the dominant pollen type, while Podocarpus maintains low levels.

Shrubs quickly increase following peaks in macro-charcoal, with Myrtaceous shrubs increasing in two distinct peaks. Other common shrub taxon include Fabaceae and Tasmannia. Herb taxa include local disturbance indicator Plantago, and Poaceae, both of which correspond to the micro- and macro-charcoal peak, while Tubuliflorae daisies declined in the higher sample. Other herb pollen types include Stellararia pungens, Cyperaceae and Ranunculus.

Levels of Eucalyptus pollen are consistently high, and Podocarpus low, as the recovery and endurance of the large-boled Eucalyptus in landscape responds more quickly to more frequent fire. This is a temporary response however, as the overstorey is gradually weakened by more frequent less intense fires. The dominance reflected in the consistently low levels of Myrtaceous shrubs, as the overstorey could still exert a lot of pressure for water and nutrients on the understorey.

The smaller increase in macro-charcoal in the bottom half of the zone begins from contact period, but during this zone levels of disturbance are smaller, as European land management had not been fully imposed on the area and the vegetation was resilient and able to recover. The large micro-charcoal spike dates from around the 1840s, and it follows a higher threshold of micro-charcoal levels which indicate the
more common number of ignition sources regionally. This lead to both smaller scale
fires and catastrophic fires as the forest structure began to change towards a more fire
regrowth form, and the landscape stability was increasingly challenged with more
fire. This is the period of transition from Indigenous burning practices to European
land-management. The locally derived macro-charcoal increases throughout this
zone, and has a long peak that stretches into the later settlement period, during which
fires are frequently set to ‘green’ the landscape for stock feed and ease of transport, a
technique used by graziers worldwide (West, 1965). The large and long macro-
charcoal peak beginning in the top section of this zone is indicative of a changing fire
regime, a change from long interval large catastrophic fires to many more seasonal
smaller scale burn-offs, with a large number of fires lit by graziers and for
prospecting for mining.
Herb representation tracks macro-charcoal tightly. It is interesting that the proportion
of herbs is marginally reduced at the top of the zone, which may illustrate the
tendency for the shrubby understorey to respond quickly to any reduction in the
frequency of burning.

Zone 2b- Later Settlement Period (12.5 cm -7.5 cm)
Macro-charcoal is maintained at high levels from base of zone following on from
Zone 2a, but levels significantly drop mid-zone, coinciding with a large peak and
decline in micro-charcoal.
In this zone Eucalyptus declines sharply while Podocarpus marginally increases. This
zone has the highest shrub species richness and highest proportion of shrubs, which
include Baeckea, Fabaceae, Rutaceae, Sapindaceae, Pimelea, Ericaceae and Banksia. Calytrix increases toward the upper boundary.
There is a diversity of herb species in this zone, but the concentration of herb species
is greater lower in the zone, when the charcoal concentrations record largest amount
of fire. Daisies are high throughout the zone, with other herbs including Rumex,
Haloragis, Plantago, Stellaria, Dianella revoluta and Apiaceae.
Regionally this is the transitional period where the sub-alpine zone vegetation
changes from a climax community into a disturbance community, as much of the
large-boled overstorey weakens and dies under the pressure and damage of much
more frequent burning. This is reflected in the lower and mid zonal section with a
reduction in Eucalyptus and increase in Podocarpus. In the upper part of the zone, a
slight increase in Eucalyptus may be the result of a limited regrowth during slightly
longer fire intervals. The response of shrub regrowth occurring more widely in the landscape, as opposed to a more heterogeneous manner previously, is evidenced from levels of Myrtaceous shrubs being at their highest levels in the entire core during this period, and greatly increasing toward the top of the zone.

Zone 3- The 20th Century (7.5 cm -0 cm)
Micro-charcoal has two relatively shallow peaks in the past 100 years, the most recent around 30 years, which sees a decline in charcoal concentrations until the present. The macro-charcoal is low throughout this zone, with three very minor peaks representing some low intensity fires at the site, two of these peaks do coincide with micro-charcoal spikes. *Pinus* is at low levels throughout this zone, but increases exponentially towards the top of the profile, as widespread plantations start to dominate regional pollen rain. The 20th Century sees variable levels of *Eucalyptus* with a steep decline in its representation in the latter half; this is alongside a reduction in charcoal particle densities, and a corresponding increase in *Podocarpus*.

There is a decrease in shrubs with time in this zone, including *Acacia*, *Banksia*, *P. aspera*, Euphorbiaceae, Rutaceae, *D. revoluta*, *Pimelea* and Sapindaceae. Herb species do increase in representation slightly, this coming mainly from an increase in grasses towards the surface. Major herb taxa, are *Rumex*, *S. pungens* and *Haloragis*. The Tubuliflorae daisies, which form a significant proportion of herb type pollen slightly decreases through the zone.

The regional pollen taxa of *Casuarina* and Chenopod mirror each other in a gradual increase during this period. This may be due to improved taphonomic conditions, reduced local pollen production or more input from western NSW. The fern species in this zone are not well represented, but include *Blechnum* and *Cyathea*.

The 20th Century was a period of gradually decreasing local disturbance at Bogong Peaks, from a small macro-charcoal peak at the bottom of the zone possibly representing an increase in seasonal grazing in the 1920s following the First World War, until gazettal in the Kosciusko National Park mid-zone, with a decline in both micro- and macro- charcoal in the top section. During this time fire frequency was reduced, but larger more intense wildfires resulted from fire exclusion, with two or possibly three large fires occurring at the site in the past 100 years. The homogeneous reaction of the landscape due to sensitivity to fire of the overstorey, and resulting
widespread and persistent shrub growth is visible in increases in the shrub component in the diagram directly following the three small charcoal peaks in the zone. The other important landscape management change regionally in the 20\textsuperscript{th} Century is the advent of plantation forestry (Forestry Corporation of NSW, 2016), which can be seen in the \textit{Pinus} curve which dominates the upper section of this zone.
Figure 6.1 - Bogong Peaks 2 Pollen Diagram.
6.1.2-Bogong Peaks 1

The 18 cm core was divided into three zones using CONISS (Plate 6.2), all of which are post European contact. The age model proposed by OxCal (Bronk Ramsey, 2013) is shown in the diagram, but was not used, as it was based on a single AMS date. The sedimentary, pollen and faunal evidence supported a much younger age-model, that is less than 200 years.

The magnetic susceptibility plot is a smooth curve, with lowest measurements on the bottom and at the top of the profile, while the carbon content gradually declines through the core to the top, that is a feature seen in other young profiles. The organic content is distinctly less, and much less variable, than the BP2 core. It is interesting that the organic content increases with depth, where the organic nature of the sediments helps improve preservation, and that, in the bottom half of the core, the pH decreases with depth.

Zone 1- European Contact Period (18 cm -16.5 cm)

The record of the site is limited by the shallow deposit depth. The zone has higher levels of *Eucalyptus*, lower *Podocarpus*, a significant grass component, and a diversity of herbs, including the presence of *Microseris*, Apiaceous species and Stinging Nettle (*Urtica*).

The micro-charcoal and macro-charcoal are both highest basally and signal the beginning of the settlement period and some landscape destabilisation. This fire event seems to be at a landscape scale, being reflected in both charcoal curves.

The high *Eucalyptus*, increasing herb component, as well as a lower diversity of shrub species would seem to indicate a resilient dominant overstorey structure that could drive understorey successional dynamics following disturbance. Herb taxa of *Urtica* and Apiaceae are indicative of a lower impact of introduced grazing animals than later in the record.

Zone 2- Later European Settlement Period (16.5 cm- 7.5 cm)

During this zone there is a consistent but low input of micro-charcoal, while macro-charcoal is high throughout. There is a pulse of shrub species in the bottom half of the zone following a peak in herbaceous taxa, which coincides with a drop in *Eucalyptus* pollen. Herb taxa have three peaks in the zone, gradually declining towards the top.
Podocarpus levels are variable, and reach a minimum below the upper zonal boundary in conjunction with low levels of Cyathea and a drop in Myrtaceous shrubs. The lower micro-charcoal levels may indicate a more frequent but lower intensity fire regime, with burning by graziers and miners able to reduce fuel loads at a landscape level. Although the macro-charcoal is consistently high in this zone, peaks at 115 and 130 years indicate that two fires burnt locally within 20 years of each other, the latter being loosely reflected in the micro-charcoal curve, and both possibly at landscape scale. The fact that these larger charcoal inputs occur in the upper section may indicate some reduction in fire frequency in the late 19th Century and into the 20th Century in the area, with low amplitude pulses in shrub taxa following both macro-charcoal peaks. Ignition sources were more common in this period during catastrophic fire weather conditions would increase the likelihood of a major conflagration, and a trend of increased forest flammability would be encouraged by recovery in the understorey.

Shrub species are both dominant and diverse starting from the bottom of the zone, and continuing throughout, especially Myrtaceous shrubs and Fabaceous taxa. The slight decline in Eucalyptus pollen in the lower part of the zone may represent the weakening of the old growth overstorey by excessive burning during the early settlement period. The consistent presence of Rumex implies that there was a significant amount of fire disturbance in the lower section, while its decline might imply increased grazing pressures. Herb diversity generally is not as great higher in this zone, reflecting that the Bogong Peaks area was open to heavy seasonal grazing and the increased grazing pressure from Rabbits. The presence of Cat and Fox hair at the lower boundary would place it in the mid-19th Century. Taraxacum species appear at 10 cm, and serve as a marker for both the significant disturbance of heavy grazing and burning to allow for weed establishment, and grazing animals as a vector.

Zone 3- 20th Century (7.5 cm -0 cm)
The micro charcoal concentration in this zone peaks at 40 – 50 years and declines drastically to the present, roughly coinciding with the macro-charcoal. This pattern is replicated in the BP2 core. Podocarpus increases throughout this zone, while Eucalyptus remains consistently high. There is a pulse of shrub taxa in the lower part of the zone following a peak in herbs, but generally shrub representation decreases, as Podocarpus increases. Pinus has a small peak at 70 years, but increases exponentially from 50 years ago.
The presence of a consistent *Pinus* pollen curve defined this Zone as the 20\(^{th}\) Century, when extensive plantings of *P. radiata* took place in the region, and much of the time was spent under the management of National Parks. The regional pollen taxa of Chenopod and *Casuarina* peak at the bottom boundary, illustrating a significant regional pollen input. Regionally the 20\(^{th}\) Century was at first more frequently burnt, but then less so, leading to higher fuel loads, fire-loving vegetation and less common higher intensity blazes. This trend was worsened by intensive forestry practices very close to the site. The large charcoal peak may indicate the ‘Tumut Gorge fire’ of 1965 which burned 75 000 ha from the 3-13\(^{th}\) of March (Cheney, 1976). There is a diversity of shrub, and herb species resulting from prior burning with a reduced grazing pressure. Grass is consistently a minor component of the pollen spectra in this zone, acting more as a post fire recovery species and not a dominant terminal structural successional vegetation component. The frequent prior disturbance at this site has changed the forest to a vegetation community that reflects the effects of frequent fires. *Podocarpus* seems to have made a significant recovery under National Parks management and general reduction in the fire frequency, and currently dominates the understorey at the site.
Figure 6.2- Bogong Peaks 1 Pollen Diagram.
6.1.3- Mt Gingera 4

Using the CONISS Diagram (Plate 6.3) the 34 cm core was divided into four major zones, with the upper two further subdivided.

The magnetic susceptibility is low in the bottom zones, gradually increasing until a very broad peak at 8 cm, during the early 20\textsuperscript{th} Century. Loss on ignition predictably inversely mirrors the magnetic susceptibility, where alluvial deposition of less organic sediments becomes relatively more dominant. Interestingly this is not reflected visibly in the sediment, the gradual nature of mineral increase and high organic content of the sediment masking this change. In the section closest to the top, that is the later 20\textsuperscript{th} Century, the magnetic susceptibility falls and organic content once again increases.

Zone 1- Pre-European (300-350+ yr BP) (34 cm -29.5 cm)

There are no major macro-charcoal peaks in this zone. Charcoal levels decline with depth, illustrating a much longer timescale between major fire events at the site. One, or possibly two, major regional fires are recorded in the micro-charcoal concentrations in the last 100 years of the core. Macro-charcoal does not have a major signature during that period; although a small peak and fire occurred at 33 cm. The shrub species in the bottom of the zone are less common until that point when they increase, while the herb species increase until this fire and then decrease.

Shrub species include \textit{Pimelea}, \textit{Ericaceae}, \textit{Tetratheca} and Myrtaceous shrubs. Three unusual shrub pollen taxa present in this zone are \textit{Eremophila}, \textit{Elaeocarpaceae} and \textit{Sambucus}. These are possibly bought to the site by the migrating moth.

Herbs increase in this zone, and at the base of the core there is a spike of \textit{Tubuliflorae} daisies. The grass component is also greater. Other herb species include \textit{Stellaria}, \textit{Geraniaceae}, \textit{Stylidium} and \textit{Dianella}.

In this zone the overstorey is strong and forest structural successional dynamics healthy. Variability in the \textit{Eucalyptus} and \textit{Podocarpus} following disturbance, as well as changes in the shrub and herb component, progress in a classical structural successional manner, where fire disturbance changes a clearing herbaceous understorey into shrubby regrowth.

Zone 2- Contact/ Pre-European (220-300 yr BP) (29.5 cm -22.5 cm)

The micro-charcoal is consistently higher throughout this zone than the previous.

There is one macro-charcoal peak in this zone at 25 cm, which is around 250 years
ago. *Podocarpus* peaks just before and *Eucalyptus* concurrently with this peak. *Baeckea* and Fabaceae are high before but drop markedly after this event, and then peak again near the top of the zone, while *Pimelea* is high during this charcoal peak. With other tax including Rutaceae, Sapindaceae, *Acacia* and *Prostanthera* present. Tubuliflorae Daisies have high concentrations at this time, and grass, although less than higher in the core, increased in response to the macro-charcoal peak. Herb species in this zone include *Microseris*, Apiaceae, Boraginaceae, Brassicaceae, *S. pungens*, *Haloragis*, *Dianella*, *Arthropodium*, *Rumex*, *Veronica*, *Dianella*, and Cyperaceae.

The high micro-charcoal throughout this zone may indicate more regional usage of fire by the Indigenous people, the stochasticity of concentrations representing major regional fires, which do not appear to have affected the site. The one macro-charcoal peak in this zone at 25 cm (250yr BP), is likely the result of a major landscape scale fire during this period. This fire, which occurs before European exploration and settlement of the area, places a large amount of carbon in the environment dated to this time. There is a micro-charcoal peak in the BP2 core that is possibly a signature of this same fire event, and this event falls within the envelope of a landscape scale fire given by Worthy (2012) at 209 ± 59 years. Pryor (1939) estimated tree-stand ages from this same period in the Brindabella Ranges.

The structural successional dynamics in this zone are consistent with a large fire in a mature community forest, with high levels of *Podocarpus* dropping rapidly following the fire, with a slight increase in herbaceous species and the *Eucalyptus* overstorey, perhaps from a triggered regrowth response to the disturbance, this is followed by a pulse in the shrub species as understorey regrowth is also triggered by the disturbance. This pulse reduces in amplitude as *Podocarpus* again increasingly dominates the understorey.

Zone 3a- Earlier 19th Century (22.5 cm -18.5 cm)
Macro-charcoal increases through this zone, but is consistently high, while micro-charcoal rapidly decreases. The *Eucalyptus* component marginally decreases while *Podocarpus* steadily increases throughout this zone. Shrubs and herbs remain consistent, although Myrtaceous shrubs increases in response to the high charcoal at the top of the zone, as does the more regional fern spore type *Cyathea*. Other ferns in this zone include *Hymenophyllum*, *Pteris* and *Blechnum*. Dominant shrub taxa include
Ericaceae, *Pimelea* and *Sambucus*. Herb species in this zone include, Apiaceae, Chionogentias, Geraniaceae, *Veronica*, Cyperaceae, *Plantago* and *Haloragis*. The reduction of micro-charcoal in this zone may record the period during which the regional land management changed from Indigenous to European. That is when the Indigenous population is dramatically reduced under the impact of the introduction of European diseases, possibly including smallpox, which may have more than halved the population of the Monaro (Young *et al.*, 2000), with a delay before widespread and more intensive European settlement and the introduction of livestock. Tubuliflorae-Daisies have a peak during this period, before the widespread introduction of livestock.

Zone 3b- Mid-to-late- 19th Century (18.5 cm -9.5 cm)
There are four peaks in the macro-charcoal curve in this zone, the highest magnitude being in the lower section, while micro-charcoal increases from low levels at base of zone. *Podocarpus* drops rapidly, while *Eucalyptus* has high levels throughout slightly trending down. Shrub pollen numbers in this zone are reduced. But the responses of individual taxa are variable. *Baeckea* increases, while *Tasmannia* declines sharply then slightly recovers. *Pimelea* is quite consistent, with some increase higher in the zone. *Banksia* is present at the start of the zone but then falls away, replaced by taxa like *Calytrix* and Sapindaceae. Fabaceae responds quickly during this period, but then declines, while Ericaceae responds higher in the profile. Other taxa in this zone include Rhamnaceae, Rutaceae and *Leptospermum*. Herb pollen increases throughout this zone, with taxa in this this zone including *Dianella, Arthropodium, Haloragis*, Brassiceae, *Rumex* and *Stellaria*. Grass is at its greatest level in the profile, and increases throughout the zone.
This zone has the highest levels of macro-charcoal, and therefore local site disturbance. There are four peaks in the macro-charcoal, these are the highest in amplitude of the core, and represent at least four major fires at the site during this period of less than 100 years. *Podocarpus* drops rapidly in the bottom of this zone, being sensitive to an increase fire frequency. The species recovers marginally with a weakening *Eucalyptus* overstorey. So while *Eucalyptus* does have high levels throughout this zone the trend is a declining one, as individual trees in the overstorey succumb to excessive burning and any young regrowth is sensitive to burning. There are four shrub pulses, the largest occurring in the mid to late 19th Century, possibly during the gold-rush period.
Herb taxa become a much more dominant component in this zone, and increase toward the top of the zone, with the impact of seasonal livestock grazing and the introduction of Rabbits encouraging the herbs. Interestingly Tubuliflorae- Daisy pollen falls in this zone, possibly the result of grazing pressure.

Zone 4a Early 20th Century (9.5 cm-5.5 cm)
There are very reduced macro-charcoal concentrations in this zone, but the regional signature of micro-charcoal concentrations is at relatively high levels. Higher in the zone Tasmannia and Myrtaceous shrubs have high numbers. Other shrub taxa which respond are Fabaceous taxa and Ericaceae. Herbs are very well represented, especially at the base of the zone following high macro-charcoal concentrations at the top of the previous zone (3b). Grasses peak in the bottom half of the zone, and then gradually decline towards the top. Lower in the zone taxa such as Plantago, Euphrasia, Rumex, Stellaria, Apiaceae and Boraginaceae respond quickly, while the signal for Tubuliflorae Daisies, Liguliflorae Daisies, Dianella, Chionogentias and Geraniaceae took slightly longer to increase. 
Ecological changes in this zone can be seen to stem from the introduction of the Canberra water catchment’s policy of fire exclusion. Interestingly the regional signature of micro-charcoal concentrations are at relatively high levels, as areas of the high country are still used as a Cattle run in the warmer months during this period. Locally seasonal grazing would have been excluded for the vast majority of this zone. The response of the vegetation is variable and with a variable lag time. For instance, Podocarpus levels respond to this grazing and its removal by increasing higher in the profile. The Eucalyptus pollen concentration also responds well to the removal of grazing, but regrowth does take some time to produce significant amounts of pollen, and therefore is delayed in the recovery to higher levels in the pollen sum after the increased burning of the lower levels. On the other hand the highest concentration of herb pollen is found at the base of this zone, and coincides with heavy grazing pressure and high fire disturbance. With the removal of burning and grazing to protect the Cotter catchment in the early 20th Century, the herb component decreases and Podocarpus dramatically rises, then slowly falls towards the upper zonal boundary as Eucalyptus regrowth becomes more dominant.
Zone 4b Modern (<50 yr) (5.5 cm -0 cm)
In this zone there are low levels of micro-charcoal, except for a surface spike. There are also low levels of macro-charcoal. The *Eucalyptus* pollen has a peak then decline to the surface, while *Podocarpus* has a drop then rise during this time. Shrub species decline, including *Baeckea*. Major shrub taxa in this zone are *Tasmannia*, Fabaceae, Ericaceae and *Pimelea*. Herb species are consistent in this zone, with a minor drop just below the surface, which is the result of a slight drop in grass pollen numbers; otherwise the trend for grasses was increasing. Herb taxa include a low number of Tubuliflorae Daisies, *D. revoluta*, *Acetosella vulgaris*, Boraginaceae, Brassicaceae, *S. pungens*, *Wahlenbergia*, and Cyperaceae. The most obvious pollen element is the *Pinus* curve, which increases linearly from the base of the zone, and reflects the large planting undertaken in the second half of the 20\textsuperscript{th} Century.
In this zone there are low levels of micro-charcoal, except a surface spike, perhaps representing 2003 fires. Prior to this declining the micro-charcoal represents the improved land management regionally under the parks system. There were also low levels of macro-charcoal. Interestingly this fraction was without a significant 2003 fire signal. This is to be expected, as the site itself was not burnt in that fire event, but the proximate area was burnt.
The increase in *Podocarpus* higher in the zone would indicate that its recovery during the period of fire exclusion is less immediate than *Eucalyptus*. The decline in shrub taxa illustrates some forest dynamics, where under conditions of low disturbance the forest structure moves toward gradual clearing of the understorey. The herb component remains consistent, with largest variability being in the *Podocarpus* and *Eucalyptus*. 
Figure 6.3 - Mt Gingera 4 Pollen Diagram.
6.1.4- Mt Gingera Big Cave
Using CONISS this profile was divided into five major layers (Figure 6.4), with Zone 4 further sub-divided into three sub-zones. This is the deepest and oldest core, of 59 cm stretching back over 1300 years.

The magnetic susceptibility decreases significantly from 30 cm to the top of the profile, possibly as a result of the size of the deposit reducing the ability of the slope wash to be transported onto the central parts of the deposit surface. During sampling it was apparent that a greater sand component was present basally, and that these sediments are proximal to the basal granodiorite saprolites. It would be expected that more mineral material would be found towards the base of the deposit. As such it would seem that this core is the most complete representation of the broader aestivation site deposit.

The loss on ignition curve behaves as expected with a deeper and older sediment core, becoming increasingly organic toward the deposit surface. The longer residency time of the deposit may allow relatively more humification or selective decomposition to take place deeper in the core relative to the other sampled sites. The lack of faunal remains in the core below about 25 cm does support the assertion that there is some decomposition in the bottom half of the core.

Zone 1- (1220-1320+ yr BP) (58 cm -54.5 cm)
This zone spans at least 100 years. During this time there is a record of some local fires from macro-charcoal. The micro-charcoal has two peaks, the second basally, and represents regional fire activity, with the peak higher in the zone being larger. The macro-charcoal peak is low amplitude. *Eucalyptus* pollen concentration is low in this zone, while *Podocarpus* is high.

Shrub species are high throughout this zone until the uppermost samples. The more common shrub species in this zone include *Pimelea* and *Baeckea*, which is comparatively high and then drops at the upper boundary. Other species present include *Callistemon pallidus*, which is only found in this zone and is more common in lower altitude boulder piles, as well as *Dodonea* spp. and *Kunzea*, all of which are found at low levels throughout the zone.

Fern taxa include *Polystichum proliferum*, and *Blechnum* spp. in the upper section, and both are local taxa that are present at the site today.
Poaceae is high at base then drops, before slightly increasing at the upper zone. There is a limited diversity of herb taxa in this zone, including Microseris, Brassicaceae, S. pungens, Haloragis, Urticaeae and Wahlenbergia.

The macro-charcoal peak is low amplitude which may reflect a low local impact from a possible large magnitude landscape scale event.

At this stage a well-developed Eucalyptus overstorey is theorised to have reduced pollen input in the boulder pile environment, as the wide spacing would make it more of an extra-local pollen source. This is in contrast with the rock-pile loving Podocarpus, which would prosper in the sheltered rocky environment in a stable community situation.

It would seem that the entire structural successional cycle is recorded in this zone, with the lower samples contain higher levels of Eucalyptus and a significant amount of shrubs, which results from a disturbance that does not appear to be recorded. This community has some time to recover, as shrub species fall, but then increase again in line with a low intensity local fire. Herbs also follow this successional pattern, with a later increase at the very top of the zone.

Zone 2- (890-1220 yr BP) (54.5cm -37.5 cm)

This is the largest and longest zone in the profile, and stretches for over 300 years.

Both macro-and micro-charcoal have a number of peaks in this zone. In this zone Eucalyptus pollen is consistently low, although slightly trending toward increase, and Podocarpus consistently high.

Shrubs are low throughout this zone, while herb pollen is relatively common. Pimelea is present throughout the zone. Myrtaceous shrubs, has four distinct peaks occurring behind the macro-charcoal peaks. Shrub species themselves vary between the top and bottom section. In the bottom section the taxa include Rutaceae, Fabaceae, Sapindaceae, Leptospermum, Kunzea and Prostanthera, while in the top section taxa include Rubiaceae, Acacia, Banksia, Epacris, Leptospermum, and Haloragodendron. Fern species are the most diverse in this zone, Blechnum reacting to the fire regime with three small peaks. Fern taxa in this zone include Lycopodium fastigatum and Histiopteris. Regional fern Dicksonia antarctica mirrors another regional component, Casuarina, coinciding with increased macro-charcoal and possible localised temporary defoliation.

Herb species are diverse in this zone, and include a constant signature of Stellaria and Tubuliflorae Daisies. Herb taxa this zone include, Acaena, Apiaceae, Microseris.
Brassicaceae, Ranunculaceae, Viola heteracea, Lomandra, Dianella, Hypoxis, Arthropodium, Prostanthera, Plantago, Rumex, Veronica.

Mean macro-charcoal fire intervals are about fifty years, with variable intensities, while micro-charcoal illustrates that regionally large fires occurred slightly more frequently. However, the slightly increased frequency of high intensity burns in this zone did not kill the old growth Eucalypt overstorey, and allowed enough nutrients movement for Podocarpus to prosper in the immediate boulder-pile environment.

The frequency and intensity of fires in this zone produced a diversity of pollen taxa. So while Poa is generally high in this zone, towards the upper boundary a drop in the concentration of the species and an increase in shrub taxa may indicate a period of more frequent and/or higher intensity burns, which triggered a drop in grasses and more persistent and widespread shrub regrowth.

Zone 3- (720-890 yr BP) (37.5cm -29.5 cm)
This is a period of very low charcoal input of either fraction, with a slightly increasing macro-charcoal curve towards the top. Eucalyptus pollen gradually increases in this zone.

There is a steady increase in the shrub taxa representation in the middle and top half of the zone, following a smaller numbers but a greater diversity of shrub taxa in the bottom section of the zone. Taxa in the lower section include Banksia, Calytrix, Hibbertia, Prostanthera and Sapindaceae. Tasmannia has a weakened representation in the upper section. While pollen types distributed throughout the zone include Rubiaceae, Fabaceae, Rutaceae, Kunzea and Epacris.

Fern taxon Blechnum is also greater in the lower section, and there is the presence of a regional spore type Cyathea mid-section.

Poaceae increases gently from the bottom of the zone, has a small dip mid-zone and stays at generally high levels until the upper boundary. Tubuliflorae daisies on the other-hand has two distinct peaks one at the top and the other in the bottom half of the zone. There is a high diversity of herb taxa found in this zone, with the more common taxa being Brassicaceae, Veronica, Arthropodium and S. pungens. There is a constant Dianella signature in this zone. Taxa in the top of the zone are distinct from the bottom, with Plantago, Polygonaceae, Euphrasia, Veronica and Stylidium in the lower section, and Microseris, Ranunculus, Drosera, Goodenia, Dianella, Haloragis and Montia in the top half.
The fire regime of this section is regular enough to promote a number of undergrowth species while still allowing overstorey dynamics to thin species out, within the space of approximately 170 years. Interestingly a large spike in Eucalyptus coincides with a small spike in macro-charcoal concentration just before the top of the zone, where a fire or series of fires may have been large or frequent enough to seriously damage the Podocarpus and to trigger regrowth from the Eucalyptus overstorey.

Fires of variable intensity with variable recurrence will have a variable impact on the flora depending at which part of the successional cycle they occur, for example when the recurrence interval between the fires is less than the time it takes for individuals of a species to set seed (Gill, 1981). A possible example of this can be seen in the steady increase in the overall shrub taxa represented in the top half of the zone from a smaller number of taxa types, following a greater diversity of shrub taxa in the bottom section of the zone.

Zone 4a- (610-720 yr BP) (29.5 cm -19.5 cm)

From a macro-charcoal peak in the top of Zone 3, just below the start of this zone, levels remain consistently high until they drop to low levels at 24 cm, and then rapidly peak until the upper zonal boundary. Micro-charcoal has a small peak in the bottom section of the zone at 28 cm, gradually falling until a small drop and increase at the top of the zone.

At the base of the zone Podocarpus increases rapidly, while Eucalyptus decreases, this trend is maintained until the uppermost part of the zone when there is a large peak in macro-charcoal, a fall in Podocarpus and increase in Eucalyptus.

Shrub taxa pollen percentages increase, while herbs decrease, then have a small peak and then gradually increase to the top of the zone. There is a diversity of shrub species in this zone, with common shrub taxa including Pimelea, Kunzea, Rubiaceae, Fabaceae, Rutaceae, Epacris and Leptospermum. Both Tasmannia and Prostanthera have a discontinuous presence, possibly being succeeded by grass mid-zone.

Most of the herb species are generally discontinuous as well, apart from Tubuliflorae Daisies, and Poa. Tubuliflorae daisies are consistently low in this section, while grass increases in the upper portion of the zone with a distinct peak mid-zone. Plantago is present at both the top and the bottom of this zone, while Stellaria is present throughout zone. Herb taxa include Polygonaceae, Acaena, Microseris and Brassicaceae, with Goodenia hederacea, Veronica and Arthropodium at the bottom of the zone.
Regional pollen types are the most common compared to the other zones, both *Casuarina* and Chenopodiaceae have two small peaks. *Dicksonia antarctica* presence also coincides with the lower peak. This trend roughly tracks the macro-charcoal, where the increase in regional pollen sum may be due to a lag time in the recovery of local plant communities to defoliation by localised fire. After a single large peak, both macro- and micro-charcoal drop away to much lower charcoal input, before another fire event signature at the top of the zone. Fire recurrence has a 90 year timeframe, with at least one structural successional cycle being recorded in this zone, where some of the regrowth from the overstorey species following disturbance is able to mature. The fastest deposition period, and the most constrained, is from around 600 to 700 years BP, which is Zone 4a, which coincides with the high average macro charcoal levels, with three or possibly four local fires occurring that century. Large fires destabilise the landscape, which would regain stability with the return of vegetation cover of the ground. Significant hillslope deposition is visible from the magnetic susceptibility, which is greater during this period than higher in the profile. The bottom of the Zone 2c has a visible dip in magnetic susceptibility values. The large increase in *Podocarpus* at the base of the zone and rapid decrease in *Eucalyptus*, is possibly as a result of a large conflagration, such as a crown fire destroying or greatly weakening individual old growth trees at the site, the *Eucalyptus* regrowth being closer to the boulder-pile will input more pollen into the boulder-pile environment. This regrowth within and near to the rocky environment is succeeded by a resurgent *Podocarpus*, which again dominates the local pollen spectra. This trend is repeated at the top of the zone during a large macro-charcoal peak. The forest successional dynamics are again recorded in this zone, where herbaceous taxa peak after a macro-charcoal peak, then drop and slowly increase, reflecting that the understorey is originally cleared by disturbance into a grass and herbs dominated layer, then undergrowth increases for a period until the overstorey can recover and start to outcompete the shrub layer. This gradually shifts the understorey structure towards a herb and grass understorey between large boled multi-stemmed *Eucalyptus* on the sub-alpine mountain slopes, with *Podocarpus* being most dominant in the boulder pile and tor environment.
Zone 4b- (550-610 yr BP) (19.5 cm-15.5 cm)
Macro-charcoal has a peak basally, which falls throughout the zone. Micro-charcoal has a major spike in the top half of the zone.
The *Eucalyptus* component decreases throughout the zone, while *Podocarpus* increases, reaching the highest levels in the core at the upper boundary of the zone. There is a pulse in shrub taxa, which drops away rapidly in the top section. *Beakea* has a broad mid-zone peak, while *Tasmaninia* gradually declines throughout this zone. *Kunzea* and *Pimelea* are both present through this zone. Other taxa present include *Epacris*, *Hibbertia*, Sapindaceae, Fabaceae and Rubiaceae.
The herb taxa component is high at the bottom of the zone, falls and then increases at the top. Poaceae matches these trends going from high to low to high abundance. Tubuliflorae Asteraceae peaks higher in the zone. *Stellaria* and *Rumex* are present through the zone apart from the top and bottom samples where fire impact is possibly the greatest. Herb species include *Acaena*, Boraginaceae, *Chionogentias*, and *Arthropodium* at the bottom of the zone, with *Haloragis* and *Clusiaceae* at the top of the zone.
Fern abundance is greatest mid-zone; with *Calochlaena dubia*, *Blechnum spp.*, and regional spore type *Dicksonia antarctica*.
This zone is close to containing a single structural successional timeframe, where a large macro charcoal concentration peak falls away, during this time there are two smaller micro-charcoal peaks and one large one representing some regional fire activity. The idea of an over 60 year structural successional model comes from two peaks of *Eucalyptus* at either end of this zone, coinciding with two drops in *Podocarpus*. While shrub species go from low to high to low, and herb species from high to low to high. This pattern is what would be expected following a local fire that increased the *Eucalyptus* regrowth closer to the boulder-pile, and then an increasing the *Podocarpus* and decreasing *Eucalyptus* as *Podocarpus* gradually reclaims more of the boulder pile. The herbs would be expected to have a strong signature directly following fire, after which shrubs would increase until the understorey transitions to a more grassy and herbaceous one.

Zone 4c- Contact/ Pre-European (200-550 yr BP) (15.5 cm-7.5 cm)
There is a large micro-charcoal peak at top of zone, and much smaller peak at bottom of zone. Macro-charcoal is consistent but low, with two small peaks at either
boundary. *Podocarpus* is the dominant pollen type in this zone, while *Eucalyptus* is at its lowest levels in the profile in this zone.

Numbers of shrub pollen are also much reduced in this zone, a trend very visible in the Myrtaceous shrubs numbers. *Kunzea* and *Pimelea* are present throughout the zone. At the base of the zone there is a high diversity of shrub pollen types, including *Banksia*, *Calytrix*, *Epacris*, *Hibbertia*, *Leptospermum*, *Lomatia* and Fabaceae, which coincides with a slight increase in *Eucalyptus* and decrease in *Podocarpus*.

There are variable proportions of herb species in this zone. *S. pungens* is present throughout this zone apart from the level with the large micro-charcoal peak. At the bottom of the zone an increase in Poaceae occurs at the same time as a small peak in both macro and micro-charcoal. Other taxa which follow directly after these charcoal peaks include, *Acaena*, Brassicaceae, *Urtica* and *Chionogentias*. The lily *Arthropodium* is present mid-zone.

Lower in this section what fire does occur at the site does not seem to dramatically impact either the charcoal record or the vegetation. There is little evidence of disturbance in this zone until near the upper boundary, when there is a small spike in the macro-charcoal, a large spike in micro-charcoal and herb taxa virtually disappear. There are variable proportions of herb species in this zone, especially the unusual minimum herb component in the upper part of the zone. Poaceae drops directly following this spike, and rapidly peaks back in line with the possible higher fire frequency. This may be the signature of the regional fire that is recorded in the upper part of Zone 2 in the Mt Gingera 4 diagram.

The presence of a significant *Pinus* curve in the upper part of the zone indicates some modern contamination of samples, where a regional pollen type is over-represented in a local pollen dominated record.

**Zone 5- (0-200 yr BP) (7.5 cm-0 cm)**

In this zone there are two peaks for micro-charcoal, one large micro-charcoal peak towards base, and a smaller one mid-zone. A macro-charcoal peak coincides with bottom zonal boundary.

*Eucalyptus* is the dominant pollen type in this zone, while *Podocarpus* decreases linearly. Shrub numbers in general peak mid-zone with main pollen taxa being Fabaceae, Rubiaceae, Rutaceae, Ericaceae and *Kunzea*.

The fern species *Blechnum* is present in the first half of the zone, and is still present at the site.
Herb species are very low at the bottom of the zone, after European contact, and shadow the Poaceae by increasing toward the top in increments. Tubuliflorae daisies have two peaks in this zone, during the later 19\textsuperscript{th} Century and the second half of the 20\textsuperscript{th} Century. Other taxa in this zone include \textit{Rumex}, which is present at the bottom and top of zone. \textit{Veronica, Microseris} and \textit{Urtica} all are present at the surface of the zone, while Brassicaceae, \textit{Chionogentias} and \textit{Haloragis} are more common lower in the zone. \textit{S. pungens} is present throughout. \textit{Eucalyptus} increases dramatically at the bottom of the zone, with a slight drop to from the mid-19\textsuperscript{th} Century, then another steep rise, as the majority of the 20\textsuperscript{th} Century saw a removal of grazing and mining from the area. Overall \textit{Podocarpus} has decreased with a slight recovery in the early part of the 20\textsuperscript{th} Century; this is in association with a peak in \textit{Tasmannia}. These changes in the pollen can be explained by the changing structure of the forest from a climax community of large wide-spaced \textit{Eucalyptus} trees to regrowth forests with a high number of stems per hectare that are very proximal to the boulder-pile. The persistence of high \textit{Eucalyptus} counts is indicative of the damage done to the overstorey, where forest dynamics and recruitment of individual trees to a mature overstorey have slowed or even stopped. Tubuliflorae daisies have two peaks he first being due to regular burnings when there is a reduced the shrub layer, while the second is due to the gradual structural succession from a shrubby to more herbaceous understorey. In both instances it reacts for quickly to the change in fire regime than Poaceae. This is in contrast with \textit{Pimelea}, which has a later signature as a secondary undergrowth succession, apparently being more tolerant of nutrient and water competition. \textit{Baeckea} also has two spikes in this zone, coinciding with the charcoal peak at European arrival and after the removal of grazing when the understorey was not as constrained under a weakened overstorey. \textit{Pinus} goes deeper than expected with the age model presented in the Tilia diagram, that, as for all the diagrams presented, is the median of the predicted age-depth. It does fall within the full age depth envelope (Figure 5.3).
Figure 6.4- Mt Gingera Big Cave Pollen Diagram.
6.2- Faunal data from sediments
In the faunal diagrams the magnetic susceptibility measurements of electromagnetic units-CGS are in \( g/cm^3 \). Loss on ignition is a percentage of dry weight. Faunal taxa are represented as a presence or absence, and the micro- and the macro-charcoal curves are expressed in particles/ml.

6.2.1- Bogong Peaks 2
The Bogong Peaks 2 has a continuous record of mammal species since before European occupation, and has a good chronology of the arrival and impact of introduced species (Figure 6.5). The presence of hair from the introduced species the Cat, *Felis catus*, and the Pig, *Sus scrofa*, at 23 cm is in association with a date of less than 50 years, and the result of contamination occurring during sampling.

Zone 1a- Pre-European Period
In this layer the Long-nosed Bandicoot, *Perameles nasuta*, and the Long-nosed Potoroo, *Potorus tridactylus*, are the dominant hair type. There was Human, *Homo sapiens*, hair discovered, as well as some Dingo, *Canis lupus*. Other species include *Rattus fuscipes* and *Wallabia bicolor* higher in the zone and *Acrobates pygmaeus* and the Common Bentwing Bat *Miniopterus shreibersii* basally. The faunal assemblage in this zone is adapted to large infrequent fire events, with Bandicoot and Potoroo hair occurring during a period of higher *Podocarpus*, which would provide ample habitat cover. Bush Rat, *Rattus fuscipes*, hair was also recovered concurrently, and is a species which predates *A. infusa*. It is likely to have also have benefitted from an increased *Podocarpus* shrub cover. Human hair is likely deposited from the activity of gathering moths at the site, although it is possible that the site was also used for shelter as well, as Dingo hair was found in the same sample.

Zone 1b- Contact Period
The most significant faunal type in this zone is *P. tridactylus*. The macropod species *P. penicillata* is present. There is one species of glider, *Petaurus australis*, the Yellow-bellied Glider, and also a consistent *Burramys* type signature, as well as the *Antechinus* species *Antechinus agilis*. It does not appear that there was a major local fire during this period with structural successional processes gradually increasing the herbaceous component of the
vegetation, and slowly diminishing the *Podocarpus* curve. Conditions of increasing herbs and grasses would favour small macropods such as the Brush-tailed Rock-wallaby, and less so Potoroos. Taxa which predate on the Bogong Moth are represented, including gliders, Pygmy-possums and *Antechinus*. Human hair discovered here is almost certainly from Indigenous harvesting of *A. infusa* at the site. The presence of *F. catus* and *S. scrofa* at the bottom boundary are likely dragged down or backfilled during the sampling process, and are contaminants. Introduced species are not consistently found in the profile for another 10 cm.

Zone 2a- Early Settlement Period
The faunal assemblage diversity is greatly reduced in this zone although the Brush-tailed Phascogale, *Phascogale tapoatafa*, hair was found at the top of the zone. Other taxa in the zone include Dingo, Human, *Vulpes vulpes, R. rattius, P. nasuta, P. tridactylus, Burramys* type and *A. agilis*. *C. lupus* is present throughout the zone. One human hair was found at the top of the section, and is likely from an Indigenous group, who would have used the site to harvest *A. infusa*. Introduced species are present only in the upper section of the zone, that is *V. vulpes* and *R. rattiuss*, which appear after 1850 and the advent of local fire disturbance. Bandicoots and potoroos are the more dominant faunal types in this zone, with the only possum taxa being *Trichosurus caninus* and *Burramys* type. The *Antechinus* species also changes from *Antechinus swainsonii* to *A. agilis*.

Zone 2b- Later Settlement Period
*F. catus* and *V. vulpes* are present in this zone, but the main predatory species in this zone is *C. lupus*. The Long-nosed Bandicoot *P. nasuta*, and two Potoroo species *P. tridactylus* and *Potorus longipes* are present in this zone, as well as the Swamp Rat, *Rattus lutreolus*, and bat species *M. schreibersii*. Quolls (*Dasyurus* spp.) are also present in the lower section of the zone. The predominant mammal type in this zone is possums and gliders, and they form a consistent presence throughout the zone. There are several species of gliders and possums, including *T. caninus, Petauroides volans, P. australis, Petarurus brevipes* and *Burramys* type. All taxa, except for *B. parvus* itself, are arboreal and above the
majority of the predation of ground based introduced predators, and would have minimal exposure to pathogens that use the introduced species as hosts.

The discovery of *Phascogale* hair is also interesting, as the site is on the edge of their recorded range, but the species is also largely arboreal.

An interesting absence in this level is the macropods, comprised of taxon which would suffer greatly from predation, burning and grazing pressure. Although they are present higher in the profile, the macropod population numbers would have been dramatically affected in this zone by European land management practices, especially the frequent and low intensity burning regime, which would limit cover from the introduced predators and temporarily limiting food in the recently burnt areas, as well as competition with Cattle, Sheep and Rabbits.

Perhaps the most startling discovery in this zone is hair from *Sarcophilus harrisi*, at the bottom two samples of the zone. Although the age depth model places those levels at around 150 years, the dating of charcoal from the lower of the two layers is 1083±28 yr BP (cal.). This fact along with the lack of more *S. harrisi* hair deeper in the profile may represent a redisposition of organic material from an older deposit.

**Zone 3- The 20th Century**

At this stage the vegetation is recovering from the land management of the late 19th Century, but the largest impact is the ecological consolidation of introduced species.

In this zone introduced species are make a significant proportion of the faunal assemblage. These species include Fox, Rabbit (*Oryctolagus cuniculus*), Cat, Cattle (*Bos taurus*) and Black rat.

Both Dingo and Fox are present throughout the zone.


Some less common taxon are present in this zone, such as *Dasyurus*, and the Smoky Mouse, *Pseudomys fumeus* which are both difficult to sample. *Dasyurus* could be expected to utilise the aestivation sites for food. The distribution of *P. fumeus* is not known to contain the Bogong Peaks area.

Two potoroo species are present in this zone the Long-nosed Potoroo, *P. tridactylus* and the Long-footed Potoroo, *P. longipes*; Bogong Peaks is on the edge of the current distribution of both species.
*P. nasuta* is present in the bottom half of the zone, which would indicate that even during the 20\textsuperscript{th} Century there was a diversity of small mammals present around the site. The same sort of scenario occurs with *P. penicillata* as well, which is present at the base of the zone, that is less than 100 years ago, but not recorded higher in the zone, where it is possible a local population is still extant.

The presence of *Burramys* type fur is interesting as this site and could have either been the Mountain Pygmy-possum, *B. parvus*, or the Eastern Pygmy-possum, *C. nanus*. The remoteness of the site and the difficulty of the terrain, which includes extensive boulder piles and a very dense stand of mature *P. lawrencei* on the northwest edge of the peak make trapping or filming either species difficult.

The change in dominant taxa type from terrestrial to arboreal may be due to a number of reasons including introduced diseases, more specifically Toxoplasmosis, caused by *Toxoplasma gondii*, with the presence of both the main host *F. catus* and the intermediate host *R. rattus*. Arboreal species are not as exposed to parasite transmission, and are less affected than terrestrial populations.
Figure 6.5 Bogong Peaks 2 Fauna Diagram.
6.2.2- Bogong Peaks 1
This 18 cm core records from post-European contact, and supplies a good insight into the impact of European land management strategies (Figure 6.6). There is no appreciable decline in faunal diversity with depth, as the younger nature of the core compared to BP2 means that the preservative properties of the profile are relatively unchanged.

Zone 1- European Contact Period
The large predator species in this zone is *C. lupus*, with smaller marsupial predators including *Phascogale* and *A. agilis*. *R. fuscipes* is omnivorous and predatorial of *A. infusa*.

The only record of *Macropus giganteus* in the profile is in this zone, perhaps reflecting the significant grass component of the vegetation. Apiaceous species and Stinging Nettle (*Urtica*), is indicative of a lower impact of introduced grazing animals.

The sample size of two is limiting though. In this zone there is no evidence of introduced species, and no human hair.

Zone 2- Later European Contact Period
The presence of *F. catus* and *V. vulpes* hair place the lower boundary around the mid-19th century. Interestingly the most consistent introduced species in this zone is *R. rattus*, being able to expand to a landscape level along with settlement huts and European practices of storing grain.

Macropods are conspicuously absent from the top of the zone, with *P. penicillata* present in the bottom half of the zone. Smaller ground dwelling fauna, that is bandicoots and Potoroos, *P. nasuta* and *P. tridactylus*, are present in the zone. *P. tridactylus* is more consistent, but not found mid-zone during a period of high herbaceous taxa.

Possum and glider taxa in this zone include the Common Ring-tailed Possum *Pseudocheirus peregrinus*, *Burramys* type, the Feather-tailed Glider, *Acrobates pygmaeus* and the Yellow-bellied Glider *P. australis*.

The major large predator in this zone is *C. lupus*, although the Eastern Quoll, *Dasyurus viverrinus* is present as well in the mid-zone. *P. tapoatafa* is present, as are *A. swainsonii* and *A. agilis*, which is the more common of the two species. Two bat species are present in this zone are the Eastern Horseshoe Bat, *Rhinolophus*
megaphyllus and the Common Bent-wing Bat, *M. schreibersii*, both species eat *A. infusa*.

Native rodent hair is less common, with *P. fumeus* throughout the zone but *R. fuscipes* is present in the lower levels and the Broad-toothed Rat, *Mastacomys fuscus* is present only at the bottom boundary. This may be evidence for predation by Cats and Foxes, or possibly competition with *R. rattus*.

During this zone the Bogong Peaks area was open to heavy seasonal grazing from introduced herbivores, including, sheep, Cattle and Rabbits.

The presence of human hair in this zone most likely post-dates the large Bogong festivals, but is still possibly of Indigenous origin, dating from around the late 19th century.

Zone 3- 20th Century

This zone is dominated by introduced species *F. catus, V. vulpes* and *R. rattus*. There was a single human hair discovered in this zone, and *C. lupus* is common.

Possums and gliders are a major faunal component, with *A. pygmaeus* and *Burramys* type both consistently present in this zone, other possum and glider species include *P. peregrinus, P. brevipes, P. australis* and *P. volans*.

There are two quoll species, that is the Spot-tailed Quoll, *Dasyurus maculatus* and *D. viverrinus*. Another interesting species in several samples in this zone is the Brush-tailed Phascogale, *P. tapoatafa*, as the site is on the limit of its altitudinal distribution as currently understood.

Native rodents are not well represented in this zone, the two species being *R. fuscipes* and *P. fumeus*, with the latter being on the edge of its western distribution on the Great Divide.

Hair from the bat species *M. shreiber*ii was found throughout the zone, and there was a continuous presence of *Antechinus*, both *A. agilis* and *A. swainsonii*.

*P. penicillata* is present mid-zone, illustrating that the species was present at the site least until the mid-20th Century. Of the other macropods in zone, that is *Wallabia bicolor* and *Thylogale billardierii*, the latter is of some interest. The mainland range of the species has greatly receded, but the species would appear to have been present in this area until the early 20th Century, when introduced predators had really gained a strong foothold in the area. Bandicoots and potoroos are also present in this zone, with *P. tridactylus* present at 2 cm, making it possible that the species is still extant in the area.
The change in the dominant taxa type in this zone from Bandicoots and Potoroos to arboreal taxa like gliders, and semi-arboreal quoll species, may result from an outbreak of Toxoplasmosis in the faunal populations during the early 20th Century.
Figure 6.6- Bogong Peaks 1 Fauna Diagram.
6.2.3- Mt Gingera 4
The Mt Gingera Peak deposit has less diversity and less numbers of hairs than the Bogong Peaks site, but hair is present in all zones in the core (Figure 6.7).

Zone 1- Pre-European (300-350+ yr BP)
Taxa in this zone include *P. nasuta, P. tridactylus, Burramys* type and *C. lupus*. A small macro-charcoal peak, and theorised low intensity burn at 33 cm, which sees a peak in herb species, *P. nasuta* is present. This coincides with a regional signature and may represent a landscape level fire but that was of low intensity locally. In the following higher samples *P. tridactylus, Burramys* type and *C. lupus* are present as shrub species increase in response to the disturbance.

Zone- 2 Contact/ Pre-European (220-300 yr B.P.)
This zone stretches for around 80 years and has a diversity of species, including Humans, *P. brevipes, Burramys* type, *P. penicillata, P. nasuta* and *A. swainsonii*. During the macro-charcoal peak in the upper half of the zone, hair from *H. sapiens, P. brevipes*, and *Burramys* type was present. As the ecosystem recovered in the following higher samples *P. tridactylus* and *P. penicillata* are present during a pulse in shrub taxa. Increased shrub taxa at the bottom section of the zone also coincide with the appearance of *P. nasuta* and *A. swainsonii*. The shift from high shrub dominance to higher numbers of herbaceous taxa, is indicative of healthy forest structural dynamics and understorey succession, and is associated with greater mammal diversity.

Zone 3a- Earlier 19th Century
Taxa present in this zone include *P. penicillata, P. nasuta, Burramys* type, and *C. lupus*
This is a small zone, but it is interesting that in the bottom half there is the presence of both *P. penicillata* and *P. nasuta*, both of which suffered heavily under European land management strategies. *Burramys* type hair was also present, and is a taxon which may also have had a range contraction due to European land management. Local populations of *P. penicillata* were sensitive to the effects European land management where boulder piles in the immediate vicinity were not complex. All these taxa are present during a macro-charcoal minimum and minor increase in herb species
C. lupus maintains its dominance as the apex predator is this zone.

Zone 3b- Mid- to late- 19th Century
F. catus hair was found in this zone. C. lupus continues to be present, although has a hiatus mid-zone.
P. brevipes is present higher in the zone, while P. tridactylus in present mid-zone. Two bat species were also found the Lesser Long-eared Bat, Nyctophilus geoffroyi and the Eastern Horseshoe Bat, Rhinolophus megaphyllus, the latter outside its currently accepted historical range of the east coast and central Victoria. During this period there was increasing regional fire usage for both grazing and in association with mining. This zone has the greatest disturbance from burning and the introduction of new species; consequently it has the lowest diversity of all the zones. The presence of P. tridactylus below the arrival of the Cat and P. brevipes in the same sample may reflect a pattern of faunal dominance at the site changing from terrestrial to arboreal in response to the introduction of toxoplasmosis.

Zone 4a- Early 20th Century
V. vulpes was the only introduced species recorded, and C. lupus again was dominant. The native mammal taxa were limited to P. nasuta and Burramys type. Following the policy of fire exclusion for the Cotter River Catchment this part of the assemblage is theorised to be recovering from the high disturbance of the previous zone.

Zone 4b- Modern (<50 years)
There are two introduced species in this zone V. vulpes and R. rattus, although F. catus have been seen on Mt Gingera after the 2003 fires (A Wade pers. comm.) as well as some very healthy specimens of S. scrofa during fieldwork. C. lupus hair is also present.
The hair assemblage in this zone is interesting, containing species which are thought to be locally extinct or absent, including P. penicillata, P. tridactylus and Burramys type. Hair from the uncommon P. fumeus was also found. The reduction of impact from grazing and fires for an extended period may have created a refugium for rare or uncommon faunal species on Mt Gingera. The evidence of the recent presence of these rare types warrants some investigation into the possibility that they are still extant in the Mt Gingera area.
Figure 6.7- Mt Gingera 4 Fauna Diagram.
6.2.4- Mt Gingera Big Cave

The faunal record of Mt Gingera Big Cave is concentrated into the upper layers of the deposit by taphonomic constraints. Hair is theorised to be deposited throughout the record, but not necessarily preserved. The majority of this record is pre-European (Figure 6.8).

Zone 1 (1220-1320+ yr BP)
No mammal hair was found in this zone, due either to the requisite preservative conditions not being present, or the possibility that there is a limited amount of time that the site is able to preserve faunal remains even under good taphonomic conditions. Also it is possible that the site was used for human occupation, which prevented the preservation of faunal remains.

Zone 2 (890-1220 yr BP)
Although this is the largest and longest zone, it appears that the faunal assemblage has begun to be limited by preservative conditions.
Only two taxon were found in this zone, and in the top sample of the zone, that is C. lupus and P. penicillata. This change may be as a result of changes in taphonomy of the site being used as a den for C. lupus, or possibly being used for human occupation.

Zone 3 (720-890 yr BP)
No hair was found in this zone, as hair has not been preserved. Similar to the previous zone, this may be due to the effect of occupation, both on the taphonomy of the site, and on the interaction of the local fauna with the site.

Zone 4a (610-720 yr BP)
Human hair was discovered in this zone, as well as C. lupus and M. schreibersii in the sample above it.
It is possible that taphonomic conditions could be limited by human habitation at the site. The only hair discovered mid-zone was P. tridactylus, in association with rapidly decreasing charcoal and a rise in the representation of shrubs.

Zone 4b (550- 610 yr BP)
C. lupus, P. tridactylus, the bat species M. schreibersii and Burramys type are all present in this small zone.

The large macro-charcoal peak at the base of the zone would appear to be a large fire that heavily impacted the local ecosystem. No mammal hair was found in this sample, although some parts of feathers were discovered. In the samples immediately after this event the herbaceous taxa component starts to peak following a rapid increase in shrubs. C. lupus, P. tridactylus, the bat species M. schreibersii and Burramys type all appear. These species remain throughout the zone after appearance.

Zone 4c (250-550 yr BP)
This zone has the greatest diversity of faunal remains. C. lupus is present throughout the zone. The highest diversity of species is at the bottom of the zone where there is less input from herb species, with taxa present being P. nasuta, P. tridactylus, Burramys type, two bat species N. geoffroyi and M. schreibersii and the Antechinus, A. swainsonii. The Brush-tailed Rock-wallaby, P. penicillata is present and then disappears mid-zone as herb species gradually increase. M. fuscus and P. nasuta are present at the top of the zone, when herbs decrease suddenly and Podocarpus increases.

From the steady presence of Dingo one may infer that the site was used as a den, with the faunal assemblage reflecting prey taxa. This taphonomic mechanism would sample larger mammals, and smaller ones such as bats and Antechinus less so.

The presence of V. vulpes much deeper in the profile than European settlement is presumably the result of the coring mechanism pushing material further down the profile, especially as Fox is common in the surface sample and hair is easily pushed down the profile on the edge of the probe.

Zone 5 (0-200 yr BP)
In this zone the arrival of introduced predators F. catus and V. vulpes is an important ecological change. C. lupus is also present as the largest predator.

The combination of both a micro and macro-charcoal peak at the bottom boundary highlights the disturbing effect of European land management strategies, with what appears to be a landscape level fire that affected the local area. The only native hair taxa present at the time of disturbance is the bat species M. schreibersii, which would be mostly unaffected by the absence of fresh vegetation for food, or shelter following a frequent local intensity fires and grazing pressure. A damaged overstorey could in
fact be beneficial for micro-bat taxa with increased roosting site availability in the hollows of damaged trees.

The marsupial taxa present in this zone are *P. tridactylus*, *P. longipes*, *P. volans* and *Burramys* type. These taxa are at or near the surface, and were at the site in the recent past or possibly even currently as a remnant population. Population numbers of these taxa may have been able to make some recovery during the mid to late 20th Century during a period of inferred low fire disturbance.
Figure 6.8- Mt Gingera Big Cave Fauna Diagram.
7) A new landscape history informed by Bogong Moth deposits

The new landscape history offered by the terrestrial archive at aestivation sites of the Bogong Moth A. infusa comes from the unique conditions prevalent at the study sites, their position, and ecology, which allow the simultaneous preservation of multiple environmental proxies. This adds a level of complexity to their interpretation. Indicators of vegetation change, such as pollen or seeds, must be interpreted in the context of the changing proxy of fire, that is charcoal, and both directly affect the faunal community, that is the hair assemblage, and the faunal community may affect the vegetation and fire regime, for example humans or livestock can affect vegetation. The temporal and spatial context of the assemblage also influences palaeoenvironmental and ecological interpretation. For instance, the impact of Europeans or even the date of their arrival is a major question for all the study sites; while the longer records may also have climatic or stochastic trends. Spatially, local and regional extinctions or range contractions provide an informative interpretive context. Single landscape scale events such as fires, inferred from similar trends in concentrations of macro and micro charcoal at one or more sites, or erosive events where a section of a record is missing, reflect possible floods and my offer possible points of correlation between regional sites.

7.1) The Record of Fire at Aestivation Sites

Extra-local events seem to be recorded from the two sites on Mt Gingera, that is Mt Gingera Cave (G4) and Gingera Big Cave (GBC), and form an interesting counterpoint. This may be especially the case where a landscape or regional scale event is recorded at one site and not the other due to the limits placed on resolution by local taphonomic conditions. This may be the case with the larger Gingera Big Cave site, which is perhaps less sensitive to disturbance due to its larger dimensions. The dynamics of Holocene fire-climate-vegetation linkages are understood at individual sites by comparing charcoal and pollen records with other palaeoenvironmental reconstructions (Whitlock et al., 2007), in this case swamp and bog pollen diagrams or fluvial charcoal records from from the South-eastern Highlands. Although correlations between different site types is difficult for a single event, since different site types are impacted by, react to and record disturbance differently, some broad trends are still visible. The charcoal input from ACT bogs, swamps and mires increases with European arrival, reflecting widespread deliberate ignition associated
with grazing practices in the late 19\textsuperscript{th} century, followed by a decline to historically low values with fire suppression in water catchment areas in the 20\textsuperscript{th} Century (Hope \textit{et al.}, 2009).

A fluvial geomorphic study in the upper Cotter River Catchment by Worthy (2012) provides some information on the dates of major fire events and concomitant erosional events. The specific OSL dates found by Worthy (2012) are a useful reference for landscape scale events, but these events may have a variable signature in the records at aestivation sites, where localised depositional conditions of the boulder-pile environment and the heterogeneity of the impact of the fire may limit the carbon input into the deposits.

The major fire/erosive events listed by Worthy (2012) in the last millennium in the Cotter Catchment (yr BP) are 57 ± 25, 106±55, 108±58, 166±27, 209±59, 310±16, 394±20, 527±16, 709±28, 925±19 based on a Finite Mixing Model OSL record for the Cotter River catchment. The inversely exponential nature of these dates does not reflect high fire frequency throughout the late-Holocene, but seems to be taphonomic, where deposits that contain older material are less common than those that contain recent material. This trend is exacerbated by the recent arrival of European settlers, who destabilised much of the landscape.

Neither of the Mt Gingera sites have an inversely exponential distribution of either macro- or micro-charcoal peaks that match Worthy (2012). Records of single charcoal peaks at Mt Gingera 4 that roughly correlate with Worthy (2012)’s data are a small macro charcoal peak at 57 ± 25 yr BP, both a macro and micro- charcoal peak at 106±55 yr BP and 108±58 yr BP, a small peak in both around 166±27 yr BP and a larger micro- with small macro- charcoal peak around 209 ± 59 yr BP. Records of charcoal peaks at Mt Gingera Big Cave that correlate are a small macro peak and larger micro- charcoal peak at 166±2 yr BP, with the dated layer (184±34 yr BP at 5-6 cm), although a lack of resolution in the top layers limits the ability to correlate with events. Deeper in the core small coincidental peaks of both micro- and macro- charcoal occur around 527±16 yr BP, with a larger macro- charcoal peak around 709±28 yr BP, and smaller one around 925±19 yr BP.

Though the Bogong Peaks site is more distant from the Cotter catchment there are some interesting correlations with the charcoal record. Bogong Peaks 1 (BP1) has a large macro-charcoal peak that correlates to 57 ± 25 yr BP, while Bogong Peaks 2 (BP2) has a smaller macro- charcoal peak at that time. It has a large micro- charcoal
with smaller macro-charcoal peak correlating with the 166±27 yr BP, with a micro-charcoal peak at 209 ± 59 yr BP.

The 1939 fires only appear to be recorded in the BP2 core, the BP1 core having high level of carbonised particles but no peak at that time, whereas the Mt Gingera sites do not seem to have elevated levels during that period.

Pryor (1939), who wrote before this fire, estimated fires at 75, 85, 90, 185 and 275 years ago (rounded to the nearest five years), using stand ages of *E. delegatensis* in the Brindabella Ranges in the ACT. The Mt Gingera Cave (G4) macro-charcoal record of local fires has a large peak around 185 years ago, with a smaller peak around 275 years ago, which may be expected where later settlement-era fires are smaller, less intense and therefore less likely to be recorded.

The most outstanding event of the past 1000 years in mires of South-eastern Australia is the advent of European land management practices (Hope *et al*., 2009). Early settlers had arrived in the Kosciuszko region in the early 1800s (Larkins, 1980). They sought permanent water supplies and mountain grasslands for stock. Large numbers of miners also flocked to the goldfields in the 1860s, but these goldfields largely abandoned by the late 1800s, and grazing again dominated exploitation of the high country (Larkins, 1980). Kosciuszko National Park was gazetted in 1967 which restricted land use, although had been recognised as a State Park since 1944. This pattern is also reflected in the pollen and charcoal records of several ACT wetlands where increased charcoal, which coincides with the appearance of weed pollen, then declines to lower values, reflecting widespread deliberate ignition associated with grazing and mining followed by fire suppression in the catchments in the 20th Century (Hope *et al*., 2009). European land management has also affected the ability of ecosystems in South-eastern Australia to recover after disturbance (Dodson and Mooney, 2002), for example, increased fire frequencies which the weakened and killed the overstorey, altered forest dynamics so that thinning regrowth is much less efficient (Florence, 1996).

The valley floors in the Australian Alps were perhaps the part of the landscape most affected by European settlement. Wetlands are especially fragile, and under European land management large numbers of valley bottom sedge-lands were degraded by draining, burning or hydrological change caused by goldmining, which turned many into grasslands. The impact this disturbance also allowed the proliferation of introduced weed species associated with stock. Damaged bogs are the main source of dried peats common in the Australian Alps (Grover *et al*., 2005).
The vulnerability of the landscape to erosion during earlier European occupation was magnified by a disregard for erosional processes, such as the effect of the introduction of hard hooved grazing animals or burning drainage lines in sensitive high gradient country. It is therefore important to contrast pre-European and post European burning regimes in the high country. Leigh et al. (1987) argued that occasional large wildfires are preferable to repeated low intensity fires for the protection of subalpine catchments. Many fire-sensitive species decline under more frequent burning, which has harmful biodiversity conservation outcomes (Enright and Thomas, 2008).

The timing and effect of European land management of burning and grazing the landscape is recorded in the proxy records of aestivation site deposits. BP2 records the transition from pre-European land use, to a period of grazing and burning during the settlement, through to the present period of restricted high country grazing and the declaration of national parks in the latter part of the 20th Century. Fire recurrence intervals go from close to 100 years to around 25 years, marginally re-lengthening in the upper part of Zone 3. This story is replicated in the BP1 record albeit at a higher resolution with at least 4 local fires in the first hundred years of settlement, and two in the second.

Mt Gingera 4 (G4) record also closely follows this narrative, with the occurrence of five fires in the first 100 years of settlement, declining to two in the 20th Century when there is a historical record of fire suppression in the Cotter catchment to protect the Canberra water-supply (Worthy, 2012). The Mt Gingera 4 record also corroborates the pre-European trend of a fire interval of around 100 years, but has a limited record spanning just 350 years. The BP 2 core is also similar with a fire interval in Zones 1a and 1b of 100 years, but again with an age limit to the record of around 350 years.

The fire record of Mt Gingera Big Cave (GBC) is the longest but has a limited European record, possibly as a result of the smaller nature of fires during that period, as frequent burns lit by graziers and miners led to less intense conflagrations. It does however provide a reference for the late-Holocene, with large cycles of charcoal peaks and troughs occurring around every 100 years. A cycle of large scale events occur from after 900 to 1100 yr BP, events that not only produced a large amount of charcoal, but also a lot of vegetation regrowth dating from that time. It is this carbon reservoir that features so prominently in dating material from across the landscape, including BP2 and Mt Gingera 4, and reflects rare large-scale landscape fires.
It may be deduced then that in the sub-alpine zone before Europeans large fire events were extremely rare compared to modern levels, in the range of one fire in every hundred years. Sub-alpine, alpine and high frost hollows were not burnt in Aboriginal fire regimes (Zylstra, 2006). This is an interesting point in terms of erosion, where frost heave is a major contributing factor to soil surface instability, and areas in the landscape that were prone to it would have been more severely impacted by the post-European fire regime.

Another interesting point is the randomness of fire-intervals, that is a forest with a mean interval of 100 years will have patches that may not have burnt for 500 years, while in other areas the interval is short enough to eliminate species. The chances of effective dispersal and establishment of plant species will be reduced where fire intervals are short and fires large, and therefore vulnerable to extinction (Gill and Catling, 2002).

An important question here is what were the characteristics of the pre-European burning regimes in the Australian Alps? Generally this could be divided into two periods, that is longer term fire regimes, that is before human settlement, and following aboriginal occupation. There may be some difference between the two, such as in Western Australia, where humans increased fire frequency in an already fire-prone landscape (Atahan et al., 2004). In the less fire prone alpine and sub-alpine areas these two periods would be very similar, with rare landscape scale fires sweeping across the landscape, rather than frequent natural or man-made fires.

There are a number of broad sweeping accounts of explorers and ethnographers about Indigenous burning practices, but Zylstra (2006) was sceptical of ethnographic descriptions of Indigenous burning regimes. Many of these ethnographic and explorer accounts arbitrarily attribute frequent and large scale bushfires to fires started by Indigenous people, but some of these were likely to have been campfires or signals, or even burn-offs lit by squatters for seasonal pioneering grazing. The largest recorded fire in the Alps, that is the 1939 fires are known to have started from graziers and settlers.

Landscape scale fire in the alpine and sub-alpine vegetation occurs in exceptional circumstances, and the low frequency of fire in the Australian alpine landscapes is a function of the low to moderate fire weather conditions that occur at higher altitude compared to the lower altitudes (Wahren et. al, 2001). The most likely time for large landscape scale fires to occur is when fuels have reached maximum quantity, are continuous over a large region, are extremely dry, subject to a strong wind and in an
unstable atmosphere (Gill 2005).

The phenomenon of many thousands of hectares burning the South-eastern Highlands of South-eastern Australia in a single event only occurs when multiple ignitions create an effective fire-line across the east/west direction of travel and on the upwind side of fuels, a prime example being the fires of February of 2003, with these landscape scale fires being controlled the occurrence and pattern of ignition. Gellie (2008) based the susceptibility of the ACT landscape to large fires on the coincidence of seasonal landscape dryness, potential fire spread and sources of ignition. So although the drought and weather conditions associated with the fire naturally occur with some regularity, the dry lightning storm of 2003 that ignited the Alps is uncommon. In contrast, the presence of untended fires during extreme fire danger conditions during the early European period created multiple opportunities for large fires by increasing the sources of ignition (Zylstra, 2006).

Landscape scale fires are a relatively rare event as the weather conditions associated with them occur approximately five times per century, and natural ignition sources even less, possibly twice (Wahren et al, 2001). The presence of an ignition source may be seen as the difference between recovery of landscape, and not, or between been a recurrence interval of 50+ years to possibly 20 years, where recovery of shrub-land can take 15 years, during that time remain vulnerable and sensitive to physical disturbance, such as grazing or frost heave.

The high country fire regime changed radically with European settlement. Zylstra (2006) cites Aboriginal lore and accounts of some of the early explorers that describe a landscape characterised by rare high intensity fires, and a landscape with some fuel-load present. In contrast with the South-east, in northern Australia Indigenous people burnt so regularly that fire intensities are mild even on extreme days because of low fuel levels (Cheney et al., 1993).

7.2) Change in Vegetation Structure

In the 19th Century Snow Gum woodland was more open than present (Barker, 1988). Under European management the vegetation of the high country was frequently burnt to maintain fresh herbage for sheep and Cattle, with fires hotter and more frequent than during the pre-European times (Florence 1996). The gradual destruction of dominant individuals in the overstorey and incomplete site occupation by them is followed by a rapid increase in undergrowth density, which typically includes stems of regrowth of the overstorey species and a Papilionaceous element. This
understorey did not progress to well-spaced; as it was burned before it could proceed along the structural succession pathway of thinning (Pryor, 1939).

Under earlier European land management there were a large number of low intensity fires, that were frequent enough to reduce the fuel load landscape-wide, but when stopped created stands of dense regrowth. While Aboriginal burning would have promoted climax grass/herb dominated alpine and subalpine areas, early European fire disturbance promoted flammable shrub and heath communities (Zylstra, 2006).

While it is generally understood that fires were mainly lit by graziers for the short term gain of ease of travel for stock, a flush of green growth for pick in the next season, and to reduce the threat of catastrophic fires, gold prospectors also frequently lit fires to expose mineral soils. Indeed, from the 1850s many thousands of people seeking gold in the Alps would burn the landscape in the search for precious metals, as it was a cheap and easy to use method (Banks, 1989). During this later settlement period mountain ranges burned as often as they would sustain a fire (Florence, 1996).

The response of the undergrowth species and structure to a single fire is dependent on the broader fire regime, for instance, a strong overstorey is more likely to turn a shrubby understorey layer into one dominated by herbs and grasses more quickly than a forest with a weak or highly disturbed overstorey.

In the Bogong Peaks 2 record during the early settlement period, *Eucalyptus* levels are consistently higher, with *P. lawrencei* lower and consistently low levels of Myrtaceous shrubs, as the overstorey could still exert a lot of pressure for water and nutrients. At this time the recovery and endurance of the large-boled *Eucalyptus* in landscape were still able to respond quickly to frequent fire. This was a temporary response, as the overstorey was gradually weakened by more frequent less intense fires, so that by the later settlement period Myrtaceous shrubs pollen is at its highest levels in the record. This vegetation type increases toward the top of the Zone 2a and into Zone 2b, as the vegetation changes from a climax community into a disturbed one, with a much weakened overstorey, and coincides with an increase in *P. lawrencei*, as much of the large-boled overstorey weakens and dies under the pressure and damage of much more frequent burning.

*P. lawrencei* is sensitive to fire, having low levels of re-sprout regeneration and low numbers of seedlings, but it also burns less intensely than surrounding shrubs (Tolsma, 2005). It is also possible that fire sensitive species, for example some rainforest species in central Victoria, are able to respond more quickly to crown fires and increase seedling recruitment (Baker et al. 2012). A similar mechanism may
apply in this instance, where in the BP1 core in Zone 2 directly following two macro-charcoal peaks there is an increase in *P. lawrencei*. Both *P. lawrencei* and *Tasmannia* spp. can co-exist with *Eucalyptus* as mid- and understorey elements in montane and subalpine sites, and may also become the dominant vegetation association in blockstreams, boulder-piles and scree slopes near and above the tree-line. Barker (1991) found that *P. lawrencei* attained best development with a broken canopy and in the long term absence of fire.

Since pollen deposition at aestivation site deposits appears to be locally controlled, an increasing dominance of *P. lawrencei* and *Tasmannia* spp. may be interpreted as a less localised mature *Eucalyptus* overstorey. Conversely periods of high concentrations of *Eucalyptus* pollen, or changing *Eucalyptus* pollen taxa may be indicative of the presence or changing dynamics within forest tree species. In instances of a traditional structural successional model a reduction in *Eucalyptus* pollen spectra may signal a strong overstorey of widely spaced large-boled mature trees, whereas an increase may represent a forest recovering from a major disturbance, with an even aged closely spaced overstorey in close proximity to aestivation sites maximising local *Eucalyptus* pollen input.

Purdie and Slatyer (1976) found that dry sclerophyll forest were prone to change structurally in response to disturbance, rather than changing species composition, and that prior land-use and initial floristic composition dictated the successional pathway taken. Pollen data at aestivation sites is consistent with this model in that elements of wet forest, dry forest, shrubs, herbs and ferns were present in all samples, but that proportions of them change through time, illustrating structural successional dynamics.

Regrowth gives rise to communities whose floristics are remarkably similar to that of the vegetation before burning, and changes in floristic composition with an increasing inter-burn interval can be attributed to differences in species longevity and growth rates of seedlings and resprouts (Purdie and Slatyer, 1976), so although different species in the same environment may have different adaptive traits they may persist for some time, with equal success (Gill, 1981). A period of widespread rapid change, such as that precipitated by European occupation, with greater landscape homogeneity and an increased disturbance frequency, is more likely to have induced both structural and species change. For instance, if the fire recurrence interval for several fires is less than the time taken for obligate seed regenerators to reach sexual maturity species are lost (Gill, 1981).
The impact of European land management practices can be seen in both the BP2 and Mt Gingera 4 records as larger and more frequent charcoal peaks, especially in the early settlement period as the number of ignition sources increased dramatically. The charcoal concentrations decline later as the frequency of burning in the landscape radically reduces fuel loads and alters the forest structure. The later settlement period is associated with frequent burning and promotion of a herb and grass dominated landscape. Fire sensitive woody species decline under more frequent burning (Enright and Thomas, 2008). Herb frequency and diversity reached its zenith in the mid to late 19th Century and early 20th Century. As disturbance decreased in the later 20th Century shrubs had enough time to grow between fires and become a more dominant part of the flora. More recently the shrub component has been giving way to grasses and herbs.

The BP1 record is interesting in that it is a solely post-contact record, where the macro-charcoal record begins after the original impact with a high shrub component, low herb, but high *Eucalyptus*, where fire has induced understorey growth and widespread growth of *Eucalyptus* from rootstock in Zone 1. At this point the overstorey is not weakened. The degradation of the overstorey occurred during the first part of Zone 2, where a close proximity to the boulder pile of dense *Eucalyptus* stems may be inferred from a consistently high *Eucalyptus* count following at least two fires. Directly following these is a short period with a high herb component as the landscape is frequently burnt by graziers and miners. Fire frequency increased appreciably from 1850 to 1870 with much more frequent burning for stock and better access for gold prospectors (Banks 1982). Later in the early 20th Century as high country grazing was reduced and a regime of fire suppression emerged the formerly clear grassy understorey is replaced by a dense shrub under-canopy.

A considerably longer record, preserved by Gingera Big Cave, is characterised by a number of forest structural successional cycles, where herbs and grasses recover quickly after fire which are then are replaced after a few years by a shrubby understorey. Under the pressure for nutrients and resources by the overstorey this shrub layer senesces, and the understorey becomes grass/ herb dominated. In zones 1, 2 and 3 in the Gingera Big Cave cycles of larger fire disturbance are recorded with a long period of recovery. These cycles have a signature of peaks and troughs in the macro-charcoal concentrations, which for the majority of pre-European fire recurrence intervals may be between 50 and 100 years.
An interesting trend in the Gingera Big Cave pollen diagram is the increase in *Eucalyptus* in Zone 5, and reduction of *Podocarpus*. Although seemingly counter intuitive this is theorised to be from a weakening overstorey, with greater numbers of stems per hectare, the result of disturbance and change from a climax community at the sites. So under these circumstances the proximity of a large number of stems to the boulder-pile makes larger amounts of *Eucalyptus* pollen much more likely to be preserved, where pollen deposition was shown to be very localised by the air pollen sampling in the boulder pile environment. The wider spacing of trees in a climax community may reduce *Eucalyptus* pollen input into the site.

It was the frequent low intensity burning that altered the forest so dramatically, leading to a change of state, where the disturbance community became the norm. Even with variable fire recurrence intervals from 60 to 100 years the recovery of the forest was enough between major events to maintain its structure. This has serious implications for frequent low intensity fuel reduction burns. More frequent burning may have harmful biodiversity outcomes if instituted without ecological consideration (Thomas and Enright, 2008).

These frequent burns may appear less damaging ecologically than a single seldom higher intensity landscape event, but over a period as long as a single pre-European disturbance cycle the health of the forest overstorey may be drastically compromised. Where the recovery of the overstorey is not achieved between burns, the impact of any fire is greatly increased. Indigenous land management practices in the sub-alpine zone of minimal burning promoted a healthy climax overstorey.

The same trend occurs in the Mt Gingera 4 diagram, which sees *Eucalyptus* respond positively to large macro-charcoal peaks and *Podocarpus* negatively throughout the profile until the top of Zone 3a. This record is taphonomically more sensitive to frequent low intensity fires than Gingera Big Cave. By Zone 3b much of the overstorey of large *Eucalyptus* trees, which has been gradually declining as a weakening overstorey, are killed by the frequent low intensity burns. *Podocarpus* increases as it is released from the competition of a large healthy overstorey until the later 20th Century where the *Eucalyptus* component increases again, as the regrowth from the rootstock located close to the site matures.

Banks (1982) studied the dendrochronology of *E. pauciflora* in the Brindabella Ranges in the Australian Capital Territory and found that fire frequency was low during the pre-European period, but increased in frequency from the 1850s, peaking at highest levels in the early 20th Century, the gradually dropping until the 1970s.
when there was a sharp decline because of changing approaches to land management. Pulsford (1991) studied the dendrochronology of *Callitris* in the lower Snowy River Valley, and found no fire from 1790 to 1845, after that there is the first recorded fire, and from then on a fire recorded an average of every six years. Banks (1989) also used dendrochronology backed by historical records to show an increase in fire years from 1730 of one fire year in 130 years, to thirteen fire years over 80 years from 1860. Smaller but more frequent spikes in charcoal particle counts occur around this time at Bogong Peaks and Mt Gingera 4, coinciding with the European settlement in the area in the late 19th and early 20th Century.

So by 1860 the forest dynamics had changed in both Kosciusko National Park and the Brindabella Ranges (Banks, 1988), in an ecological process that was described by Zylstra (2013), where future flammability is related to the way forest structure has been modified by past fires to affect the probability of crown fire. A positive feedback may exist, where mature Snowgum forests are significantly less flammable than recently burnt areas. Dynamic and persistent ecosystem change occurs where human activities increase landscape flammability through fire-vegetation feedbacks (McWethy, 2013).

In the high montane environment of the Australian Alps past European forest modification may promote the spread of fire through the landscape, for example the relatively fire resistant old growth and multi-aged ash-type forests that traditionally occurred have been replaced by dense stands of regrowth trees that are significantly more likely to re-burn and burn at higher intensities (Lindenmayer, 2009). The age at which young trees were killed by fire has also became progressively younger (Pryor, 1939).

In the sub-alpine zone before European settlement fires were relatively infrequent and the forest largely even-aged with an open grass and herb flora, with shrubs being more persistent on poorer sites (Banks, 1982). There was some range in tree ages and growth stages in stands with regeneration developing where fires or storms had killed or weakened individual large trees or small patches or trees (Florence, 1996).

An effect of even a small increase in low intensity fires is to change the forest from a climax community to a community of post-disturbance coloniser species. Increased frequency of fire events can shift landscapes to become fire-prone landscapes with new alternative state communities (McWethy, 2013). In pre-European times dry sclerophyll forest would contain trees of several ages classes, each age class representing a response to fire, (although every fire may not have elicited a response),
the stand dynamics involving the progressive replacement of severely fire damaged or senescent trees, individually or in patches (Florence, 1996).

Change in forest structure elicited a change in the form of the individual trees themselves after the advent of European land management practices. In the 1860s Europeans started to radically alter the fire regimes of the Brindabella Ranges (Banks, 1982), so that the form of trees established before 1860 in the Brindabella Ranges is very different to those that became established later (Pryor, 1939). Shorter boles and spreading crowns of old trees suggest development in a gap with minimal amounts of side competition, while the younger branch-free straight boles of younger generations reflect more extensive even aged stands (Florence, 1996).

This type of even aged regrowth can be seen on Mt Gingera (Plate 7.1), which has regrown in approximately the last 50 years following a period of high fire frequency documented by Banks (1997) from 1860 to 1950. Stem-thinning problems of mature lignotuber sprouts may be increased by the flush of seedling growth following removal of grazing (Barker, 1988).

The forest dynamics, fire conditions and structural succession that led to recruitment of trees like that in Plate 7.2 do not operate in large areas of widespread regrowth. These large-boled squat, multi-stemmed trees that comprised the overstorey were able to exert local competition for nutrients and water to thin regrowth out. Now, due to the frequency of fires, such trees are weakened or killed. As such recruitment to large boled trees is slowed or even stopped; a feedback loop is created that has the potential to lock up the forest dynamics entirely. Even with fire exclusion it would take at least 100-200 years before stem densities in much of the sub-alpine zone approach those of pre-European disturbance (Barker, 1988).

Green and Osborne (1981) rightly raised the issue of fire as a possible threat to the Mt Gingera biome. Fire changes ecosystem dynamics, and as much as changing species composition it changes the structure of the vegetation itself. This has serious ecological consequences, from an increase in the likelihood of large fires, to limiting mammal habitat and increasing landscape degradation through erosion or nutrient loss.
Plate 7.1 - Dense *E. pauciflora* regrowth on Mt Gingera triggered within the last 50 years.

Plate 7.2 - An old growth multi-stemmed *E. pauciflora* on Mt Gingera. This tree was killed following the 2003 fires.

With the gazettal of Kosciuszko National Park stock grazing was removed in areas above 4000ft (1220 m), and patterns of disturbance changed back towards the pre-European burning regimes. The removal of grazing was a great boon for the ragged ecosystem, but the system had changed. Changed forest dynamics, fuel loads and
different land use values had changed not only the response to fire by the vegetation, but also the response of humans, who could now actively suppress fires. This can be seen for a longer period on Mt Gingera from the policy of fire exclusion of the Cotter River catchment and the Canberra water supply, where human ignition sources during extreme fire conditions are much reduced. Although bushfires started from lightning cannot be prevented, some of these may also be quickly brought under control by rural fire-fighting units, but landscape scale fires still occur rarely. There were three landscape scale fires in treeless vegetation of the Victorian Alps in the 20th Century, in the years 1939, 1985, and 1998 (Wahren et al., 2001), and more recently in 2003 and 2009. These reflect changing management strategies, and potentially human induced climate change. A real threat posed to these areas is human induced global climate change, which is predicted to increase temperatures in the Australian Alps (Whetton, 1998). Predictions of increases in droughts and number of extremely hot days would significantly increase the fire-weather risk (Hennessy, 2005). In the sensitive sub-alpine forest ecosystem, global warming could prove cataclysmic for the remaining mature trees, the forest dynamics and for the creation of a forest flammability feedback loop.

Fire is an integral part of the Australian landscape, with the ability to promote a healthy and diverse ecosystem, but can also prove catastrophic in both the short term and the long term for the flora and fauna of an area. Contemporary fire patterns, often in conjunction with introduced predators, are a likely cause for the regional population decline in small to medium sized mammals in northern Australia (Firth et al., 2009). There is a strong correlation between small mammal survival and fire timing and intensity (Pardon et al., 2003). Records of fire, vegetation change and faunal populations at aestivation sites provide an important record of the ecological impact of changing fire regimes from the transition from Indigenous burning practices to European land management.

7.3) The Record of Changes in Faunal Communities
The importance of aestivation sites for populations of mammals, including B. parvus, M. fuscus and many other species, and their ability to preserve some record of those populations, makes the sedimentary characteristics of aestivation sites and their position in the landscape important in ecological studies of the sub-alpine areas. Although there was the discovery of Tasmanian Devil, Sarcophilus harrisi, hair in the profile of BP2, at a level with an age estimated at 150 years using the age depth
model, its chronology is at best loosely constrained to the past millennium. The depositional environment of sediment mobility post-European arrival may permit the movement of older sediments and their deposition into younger sediments, so-called ‘old’ charcoal and organic matter. This movement is more prolific with material that is hard to destroy, like charcoal, but is also theorised to occur with more sensitive materials as well, such as hair. The presence of *Sacrophilus* hair above the contact zone in the sedimentary profiles at aestivation sites can be expected to be at least as old as or younger than the oldest charcoal dates in the sediments, especially where the charcoal is dated and adjacent to the hair.

The timing of the extinction of the Tasmanian Devil, *S. harrisi*, on the mainland remains unclear. Flood (1983) gives a tentative date of around 500 yr BP in southwest Western Australia-based on Archer and Baynes (1982) but the rigor of this study as the basis of a date for the continent wide extinction of a species has been questioned. Gill (1971) revised a date of 538 ± 200 yr BP for remains of the Tasmanian Devil from a previous article (Gill 1953) to approximately 500 yr BP. The two main studies of the antiquity of the most recent presence of Tasmanian Devil on the mainland are Calaby and White (1967), who dated material to 3120 ± 100 yr BP from northern Australia, and Mulvaney’s work at Fromm’s Landing on the lower Murray River in South Australia with a date of 3240 ± 80 yr BP (Mulvaney 1960; Mulvaney *et al.*, 1964). Brown (2006) rejected recent dates of *S. harrisi* remains on the mainland, citing 3.2ka BP at Fromm’s Landing for the most recent remains in the southeast. The paper was adamant that the extinction was a multi-casual process.

Johnson and Wroe (2003) attributed the extinction of the Tasmanian Devil (*S. harrisi*), the Thylacine (*Thylacinus cynocephalus*) and the Tasmanian Native Hen (*Gallinula mortierii*) to a synergistic effect between the arrival of the dingo and mid-Holocene cultural intensification. Brown (2006) went further and attributed the arrival of the Dingo, increased climatic variability associated with the onset of ENSO and mid-Holocene cultural intensification as causal factors in the extinction of the population of the Tasmanian Devil on the mainland. The life history of *S. harrisi* is relatively short lived (>6 yr), where a multiyear event could extend across an entire generation, and the species is prone to carrion variability due to a strengthening ENSO cycle. It is not clear why ENSO increases carrion variability on mainland Australia but is less so on Tasmania, apart from a synergistic effect of the Dingo. The intensification of Indigenous cultures in Australia’s southeast is subject to some
debate as well, and also does not explain the extinction of the northern or western populations. The discovery of *S. harrisi* hair on the mainland in deposits more recent than 1000 years is a significant finding, which would indicate the survival of the species in refugia for a substantial amount of time after the arrival of the Dingo or strengthening of the ENSO cycle. The Bogong moth would have provided a rich source of food, important where competition for a smaller amount of food resources would have placed heavy pressure upon the Tasmanian Devil population. Any impact from Indigenous land management on the species would have varied depending on the type of landscape, where different hunting methods and burning regimes could variously impact populations of *S. harrisi*. If the greatest human impact on the species is from more frequent fires, then the subalpine environment, where the fires in pre-European era were less common, is where it could be expected that conditions would have been conducive to the preservation of a remnant population. The complex boulder pile environment also provides ample shelter in the case of a major conflagration. The age-model for BP2 is not constrained enough to argue for the latter survival of the Tasmanian Devil population as a declining population in the southeast within the last 500 years, or that there were some individuals still on the mainland with the arrival of a raft of introduced mammals 200 years ago. It does seem that there were Tasmanian Devils in the high country of South-eastern Australia in the past 1000 years, or the maximum age of material in the deposit. The BP2 record, although relatively short, has the greatest diversity of all the sites. This may be more the result of more favourable taphonomic conditions and a shorter timeframe than an intrinsically more diverse site fauna. In the 20th Century the obvious change is in terms of amount of hair from introduced species, with much less in the mid and late 19th Century. Fox, Cat and Rat hair are common in the upper section, and gain more of a foothold following high macro-charcoal levels in the top of Zone 2a (mid-19th Century), the populations of these species complementing each other and European land management practices. Exactly what introduced species are currently present in the Australian Alps is debatable, but species generally listed include Horse, *Equus caballus*, Pig, *S. scrofa*, Cattle, *B. taurus*, Cat, *F. catus*, Sheep, *Ovis aries*, Dog, *Canis familiaris*, Fox, *V. vulpes*, Hare, *Lepus europaeus*, Rabbit, *O. cuniculus*, Mouse, *Mus musculus* and Rat, *R. rattus* (Green and Osborne, 1994).
The exact arrival time of introduced species in the South-eastern Highlands is subject to some conjecture, depending on the species. The earliest explorers used horses, but due to the small numbers the direct impact of those is thought to be small. What is known is that sheep and Cattle were run in these areas from the early 19th Century with the first wave of squatters and shepherds around 1820 (Larkins, 1980). Hard hoofed animal impact intensified in the second half of the 19th Century, when the dual impact of burning and grazing started to heavily impact the entire landscape, including the mountain peaks. Livestock and seasonal burning for grazing during the 19th Century caused much damage to catchments in the Snowy Mountains (Leigh et al., 1987).

In the forests and woodlands of South-eastern Australia Leigh and Holgate (1979) found that grazing after burning substantially reduced vegative cover and increased erosion to much higher levels than unburnt and or ungrazed areas.

The inter-relation of fires and grazing may substantially increase the impact of grazing in higher gradient catchment areas. Wahren et al. (2001) studied subalpine heathland in Victoria, and found that for a few years (< 2.5 yr) during the early post-fire period that in grazed areas ground cover conditions were well below the pre-fire levels, and well below the levels necessary to protect the alpine soils from erosion.

An important introduction is the Rabbit, which is only recorded in the uppermost section of the top zone of BP2, but is theorised to be under-represented in the boulder-pile environment. European Rabbits *O. cuniculus* are widespread in the upper Cotter catchment, and in subalpine areas can exert a considerable influence on native vegetation (Leigh and Holgate, 1979).

Rabbits were abundant in the Tumut district before the advent of Myxomatosis. Although this occurrence was widely welcomed as a plus for the ecosystems, the ensuing drop in Rabbit population and resultant hyper-predation by introduced species may have been the final nail in the coffin for the Potoroo, *P. tridactylus* population on Bogong Peaks. There are no native mammals in the top sample except Dingo and *Antechinus*. The role of Rabbits in sustaining the Fox population during the decline of native species is not clear, as they have a high biomass and high rate of increase (Short, 1998), but hyper-predation following the introduction of Myxomatosis was cited as the reason for the extinction of the population of the rock-wallaby *P. penicillata* on the Mt Clear Range in southern ACT (Ormay 1996), and may also have resulted in the absence of the species in the last 60 years in the Bogong Peaks records.
The Rabbit has had a massive impact on the ecology of the subalpine zone since the mid to late 19th Century. After the arrival of the Rabbit in KNP after 1860 there was a decrease in the shrub and herb ground cover associated with heavy stocking, frequent fires and grazing by the Rabbit, a management strategy that continued for around 100 years until burning off ceased (Leigh et al., 1987). It is the frequent burning associated with heavy stocking that paved the way for a massive increase in Rabbit numbers, as fires facilitate large Rabbit populations by increasing the amount of herbaceous foodplants. Leigh et al. (1987) found feral Rabbit populations survived and multiplied on burnt areas but decreased on areas left unburnt.

Native species that increase following inferred large local fires in the 19th Century include Potoroo, Bandicoot and Glider species, coinciding with an increase in shrub species. Quoll hair occurs in the late 19th Century and first half of the 20th Century as lower intensity burns become slightly less frequent. There is a possible there was a greater reliance on the moth population, as food resources change due to habitat modification and inter-specific competition from feral Cats and Foxes. Quoll presence coincides with an increase in the shrub component, then continues with the steady increase in the Podocarpus component as the vegetation responds to a slight easing of the excessively intensive burning practices of the mid to late 19th Century in Zone 2a and lower 2b in the BP2 record.

The Brush-tailed Rock-wallaby, that is Petrogale penicillata, Antechinus and Burramys type taxa do not occur directly following periods of fire, but during the forest understorey thinning phase, when the herbaceous taxa component increases. Brush-tailed Rock-wallaby hair is not present in the upper section of the top zone following the increasingly common presence of introduced predators around in the first half of the 20th Century, with the population retracting from the areas on the peak. It is possible that a population is still maintained in the particularly complex boulder-pile and dense P. lawrencei environment on the upper north-western slopes of Bogong Peaks.

The exact range of P. penicillata, is difficult to ascertain before 1920, but it was once abundant and ubiquitous throughout mountainous country of eastern Australia, extending as far to the west as Cobar. Under the influence of hunting, pressure of goats and predation by Foxes the population crashed. Ormay (1996) lists the species as present in the ACT until the early 1950s. In the South-eastern Highlands of South-eastern Australia, records of P. penicillata exist for the Snowy River at Delegate (1846) and Tharwa (1900) (Short and Milkovits, 1990). Despite its wide distribution
and the diversity of habitats it can occupy, populations are disjunct, possibly due to particular habitat requirements that nowadays are met only in localised and patchily distributed locations. The distribution of the species was probably always patchy (Short 1982). *P. penicillata* is currently locally extinct in the Bogong Peaks Wilderness and the Brindabella Ranges. Ormay (1996) listed the reasons for the extinction of *P. penicillata* in the ACT as predation from Cats and Foxes, competition by Goats forcing Rock-Wallabies away from safe shelters, which may have been a major factor in the extinction of the Tinderry population, fires, grazing and clearing, and poisoning.

The rocky habitat occupied by rock wallabies was divided into three categories by Short (1982), that is loose piles of large boulders containing a maze of subterranean holes and passageways, cliffs with many mid-level ledges and with some caves and ledges covered by overhangs, and isolated rock stacks usually sheer-sided and girdled with fallen boulders. In the subalpine areas of the South-eastern Highlands with granite geology large tors and complex boulder piles are common on mountain peaks and provide substantial areas of suitable habitat for rock wallabies. Local populations at sites with the least complex boulder piles and lacking cliff features, such as the Mt Gingera area, would be more susceptible to the introduction of predators, whereas those with some cliff features, such as the Mt Coree area would be less so. The large complex boulder piles present at Bogong Peaks provides habitat that presents the greatest protection against predators. The habitat requirements of *P. penicillata* for complex rocky habitat, with its refuges of ledges caves and crevices, reflects the importance of predation. Cliffs generally faced north, northeast or northwest, which are slopes receiving sun for much of the day (Short, 1982). As such there is some overlap between aestivation sites of *A. infusa* and the rocky habitat occupied by *P. penicillata*. Sedimentary deposits at aestivation sites could prove a valuable record of rock wallaby distribution prior to the 20th Century, and track the contraction in range of the species at many sites until the mid-20th Century.

Human hair was discovered in two samples in BP2. One was over 200 years old, and associated with a spike in regional micro-charcoal concentration but a fall in macro-charcoal. The other was around 300 years. In the first sample the hair was in association with *T. caninus*, the Brush-tailed Possum and second sample with the only record of the Swamp Wallaby, *W. bicolor*. Both species were important for both food and clothing. This may indicate that the site was used intermittently by people as a sheltered area.
The large macropod species present in the Australian Alps are the Eastern-grey Kangaroo, *M. giganteus*, the Red-necked Wallaby, *Macropus rufogriseus*, the Wallaroo, *Macropus robustus* and Swamp Wallaby *W. bicolor*, and of these *M. robustus* is the least common. Green and Osborne (1981) found direct evidence of *M. gigantus* and *M. rufogriseus* on Mt Gingera. There is some discussion about the relative numbers of *M. giganteus* presently compared to pre-European times, but the records at aestivation sites do not shed light on this debate. It is possible that by using *Sporormiella* from wetland sediment cores some relative population comparisons may be made through time, but appropriate studies have not been carried out.

The BP1 record starts at approximately European arrival. Zone 1 is only short and does not contain any introduced mammal hair. It correlates to the bottom half of Zone 2a of the BP2 record, and starts accumulating around 180 yr BP. Human hair is found in two consecutive samples estimated to date to approximately 120 years ago and 100 years respectively. These records cannot be attributed to the period of Indigenous harvesting festivals with large groups harvesting *A. infusa* as the European invasion and occupation had decimated the human population. They however may represent the last vestiges of continuous Indigenous harvesting practices at the site, possibly as late as into the early 20th Century.

Introduced species of the Cat, the Fox and the Rat are common in Zone 3, although *R. rattus* is absent from the top section of the zone in both Bogong Peaks cores, possibly due to management of the area as a national park and a reduction in direct human impact, which importantly reduced grazing. Regionally the 20th Century was at first more frequently burnt, but then less so, leading to higher fuel loads, fire-loving vegetation and less common higher intensity blazes. These were reinforced by a phase of intensive forestry very close to the site.

This interaction of changed fire management and exotic predation, that is the introduction of the Cat and the Fox, is thought to have caused small mammal decline in northern Australia (Firth *et al.*, 2010), with predation by the Cat and Fox affecting decline and extinction Australia-wide on a range of mammal sizes (Johnson, 2006). For instance Rat-Kangaroo population declines are closely associated with the advance of the Fox from the south (Short 1998). The impact of these introduced middle predators during settlement time was increased by the amount of burning that was taking place across the landscape. This impact not only displaced large numbers of Indigenous small mammals, but also aided the mobility of the predator species. The introduction of new grazing animals further increased the impact of European
land management strategies, by increasing the recovery time of the vegetation, lengthening the window of predation after fire disturbance.

There can be no doubting that the Cat has had a major impact on the fauna of Australia since their introduction, both as a predator and vector for disease. Abbott (2002) proposed that the spread of *F. catus* spread across Australia was diffuse with settlement, and from multiple coastal introductions from 1824-1886. By the 1840s the entire Australian Alps area had been colonised by Cats. It is possible that they were present from the times of the Dutch explorers or Maccassan trading although there is no unequivocal evidence of this (Abbott, 2002). Sightings of Cats are not noted in journals of expeditions beyond settled areas undertaken before 1883, and by 1890 nearly the entire continent had been colonised (Abbott, 2002). Cats are present in the record of BP1 from the 1860s, with all sites recording the species consistently from the late 19th to turn of the 20th Century. This indicates that although Cats were present during the early settlement period their greatest impact was following the disturbance of the later settlement period.

Foxes had a similar spread in the Alps area, but the expansion would appear to be even faster than Cats. Foxes were introduced near Melbourne in the 1860s, and would had populated most of the alps by 1900, with a rapid expansion rate of upto 160km/year (Saunders et al., 2010). Fox hair was present at study site areas from the mid to late 19th century in BP2 and Gingera Big Cave, so that by the 20th Century the species was firmly entrenched in the Australian Alps, assisted no doubt by the increased burning and the spread of other introduced animals like the Cat, Rat or Rabbit.

The Fox is an efficient predator of a range of fauna. Green and Osbourne (1981) studied the diet of Foxes above 1500 m altitude in KNP and found that the genera they preyed upon were *Antechinus*, the Pygmy-possum *Burramys parvus*, the Broad-toothed Rat *Mastacomys* and Native Rats, *Rattus* spp. There is evidence Foxes prey upon aestivating *A. infusa* (Green and Osbourne, 1981). This might locally dampen the effects of ‘hyperpredation’, but also localise a portion of the activity of the Fox in the landscape to aestivation sites. Aestivation sites are important in the ecology of Foxes and other introduced predator species (Osborne and Green, 1981), and as such may facilitate consistently larger predator populations in the same geographical locations as areas of high native animal diversity by providing a stable food source for predator species.
The BP1 record matches that from BP2 well, for instance the Brush-tailed Rock-wallaby disappears from the record around 60 years ago in both. Interesting additional species in the BP1 core are the Thylogale T. billarderii, present at the site until the early 20th Century. Also bat species R. megaphyllus and M. schreibersii are better recorded in this core.

The three native rodent species found in the subalpine areas are the Smoky Mouse, P. fumeus, the Bush Rat, R. fuscipes, and the Broad-toothed Rat, M. fuscus. Native rodent species the Smoky Mouse, P. fumeus, was occasionally present throughout the BP1 core, while hair of the Bush Rat, R. fuscipes, was present in the middle of Zone 1, with the species theorised to still be present at the site. The vegetarian Broad-toothed Rat, M. fuscus, occurred only at the beginning of the contact period in the bottom of Zone 2, coinciding with the first record of R. rattus, indicating that predation or competition may have adversely affect the numbers of the broad toothed rats. Fires also have a detrimental effect on local rodent populations, by reducing individual numbers, reducing resource availability including food, cover and nesting sites, increasing competition, increasing predation and reducing individual fitness (Sutherland and Dickman, 1999). The increased frequency of burning under European land management in the late 19th century and introduction of R. rattus would have compounded trends in population declines of many species, although the apparent resilience of many rodent populations is apparent in their continued widespread distribution in the sub-alpine zone.

High numbers of the Bush Rat, R. fuscipes were found by Gilmour et al. (1987) in the Mt Tennant Blue-Gum Creek area. Helman et al. (1988) Trapped both R. fuscipes and M. fuscus in the Upper Cotter Catchment higher altitude wet heath sites. Although there was a low success rate in small trapping in rock outcrop habitats Green and Osborne (1981) found Bush Rat, R. fuscipes, in boulder piles on Mt Gingera, but no evidence of the Broad-toothed Rat M. fuscus, which is generally found in the ACT in boulder fields adjacent to grassy sites. All sites where evidence of M. fuscus was found had a modelled annual temperature of <10°C, were at or above 1000 m altitude and areas of >1000 mm average rainfall. (Green and Osborne, 2003). Pseudomys fumeus feeds on leguminous seeds, berries and arthropods including A. infusa (Green and Osborne, 1994), and would be expected to be present at aestivation sites. Hogg (1990) lists both M. fuscus and P. fumeus in the northern Cotter Catchment. Helman et al. (1988) captured a Smokey Mouse P. fumeus at 1800 m near the summit of Mt Kelly, which is an area that A. infusa aestivates. The presence of Smokey Mouse hair
in the top zone at aestivation sites on Mt Gingera and Bogong Peaks is a useful indicator of habitat preference and possible current distribution.

The Rat arrived in South-eastern Australia with the first European settlers and were among the first introduced species (Banks and Hughes, 2012). The species then spread in close association with the spread of European settlement. The impact of introduced *Rattus* on fauna is potentially as devastating as the larger introduced predators, both as a predator and competitor and as a source of a diverse range of diseases that affect both humans and wildlife. Evidence suggests that Black Rats have contributed to mammal declines in Australia, including Bandicoots and Native Rodents (Banks and Hughes, 2012). Rats can be both predatory and territorial, and can out-compete rivals by high reproductive rates, especially where food is not a limiting resource, such as during spring and summer at Bogong aestivation sites. Where there is the possibility for rapid population increase and decline, hyper-predation by large predators may occur. This phenomenon is documented as occurring between Rabbits, Foxes and Cats (Pech *et al*., 1995), though there does not appear any reason not to include other introduced mammal species like Rats as well.

There is circumstantial evidence that *R. rattus* play a role in supporting high numbers of introduced predators that impact native fauna, but more research need to be done (Banks and Hughes, 2012).

The Black Rat *R. rattus* was found in BP1 to the same depth as the Cat *F. catus* (16 cm), and appears sometime in the mid to late 19th Century, possibly in conjunction with higher levels of European settlement in the more remote areas providing a stable food source for a larger Rat population. The consistency of *R. rattus* in Zone 2 would indicate that the species expanded to a landscape level along with settlement huts and European practices of storing grain.

The social and ecological impact of *R. rattus* in Australia is not known. Apart from direct competition with native *Rattus* species and preying on eggs of birds, perhaps the greatest impact a population of *R. rattus* would have is as a stable food source for *F. catus*, especially in a degraded post-European landscape.

Rats are also vectors for disease. They carry worms, bacteria, protozoa and viruses including Toxoplasmosis. In this case rodents are an essential intermediate host for the ultimate host of Toxoplasmosis in Cat faeces (Banks and Hughes, 2012). Toxoplasmosis is a disease caused by a protozoan parasite found in the intestine of *F. catus*. Cysts of the parasite can be picked up by either ingesting the Cat droppings or eating herbivores that had eaten cyst contaminated feed. Australian marsupials are
highly susceptible to Toxoplasmosis with deaths recorded in macropods, Possums, Dasyurids, Bandicoots, Wombats and Koalas (Canfield et al., 1990), although it is not considered a major factor in the range retraction of *P. penicillata* (Ormay, 1996). Toxoplasmosis has been related to the disappearance of quoll species in southern Australia (Braithwaite and Griffiths (1994), where eight of nine species of small Dasyurid marsupials were infected by eating raw sheep tissue (Attwood et al., 1975). There is some evidence of population declines in both BP1 and BP2 following the arrival of *F. catus* in the area. Dasyurids and Bandicoots are the most affected, and less so Gliders and the Antechinus *A. swainsonii*. This pattern is consistent with the impact from the introduction of Toxoplasmosis, where susceptible marsupial species under high population pressure are greatly affected, whereas species that are not as exposed, for instance because they are arboreal, and are therefore less affected (Canfield et al., 1990), or have resistance to infection, like *Antechinus* spp. (Attwood et al., 1975). This trend seen at the Bogong Peaks sites is not as evident in either Mt Gingera sites.

In the BP 1 faunal record Bandicoots and Potoroos are present in two sections, following fire and coinciding with increases in the shrub component. The first is during the early European period in the bottom of Zone 2 and the second in the first part of the 20th Century, with a hiatus during the period of highest charcoal influx in the mid to late 19th century. Following a large charcoal peak in the mid-20th Century, possibly the ‘Tumut Gorge fire’ of 1965 (Cheney, 1976) records of Bandicoot ceased. Potoroo hair in the record remained until the late 20th Century, and it is possible there is still remnant populations of both species in the Bogong Peaks area. In 1995 there was the discovery of a previously unknown population of Long-footed Potoroo in the alpine and sub-alpine forests of northeastern Victoria (Claridge et al., 2007). The Long-footed Potoroo, *P. tridactylus*, can be found at elevations above 1000 m, while the Long-nosed Potoroo, *P. longipes*, is found mainly from sea level to 800 m, but in northeast NSW may occur to near double that. Although usually a coastal species the Long-nosed Potoroo may be found in the Grampian Ranges 130km from the sea (Claridge et al., 2007). Both species are found in aestivation site records. The factors for Potoroo distribution are related to access to dense vegetation for shelter (Bennett 1987; 1993) and an abundant supply of fungi for food (Claridge et al., 1993). Potoroo numbers are low or absent immediately after fire, and increase with the time since last fire and improved structural complexity of the vegetation (Catling et al., 2001). Bandicoots and Potoroos are more likely to be found in habitats with a
longer fire recurrence interval (>20 yr). This has implications for prescribed burning, where some burning programs may be too frequent for the creation of suitable habitat for the two taxa (Claridge and Barry, 2000). Absence of fire for long periods (>25 yr) helped remnant populations of the Long-footed Poatoroo, *P. tridactylus*, reach high levels of abundance in the South-eastern Highlands of New South Wales (Norton *et al.*, 2010).

The range of of both Potoroos and Bandicoots contracted following the widespread high frequency of burning during the later settlement period in the second half of the 19th Century, and the clearing of the understorey by graziers and miners. An important factor in the decline in Potoroo populations in New South Wales was the payment of bounties between 1886 and 1920 (Short, 1988). Bounties paid on Rat Kangaroos, including *P. tridactylus*, by the Pasture Protection Board in the Southern Tablelands fell greatly in response to an increase in the Fox population, a pattern repeated throughout New South Wales. The last bounty paid in the Southern Tablelands was in 1909, after peaking in 1900 with over 16000. The demise of the Rat-kangaroos was swift, occurring over a 5-10 year period. Nearly 3 x 10^6 Rat-kangaroos were killed under bounty state wide between 1880 and 1920 in New South Wales. Ongoing control by poison, traps and barrier fences must have had a major impact on Rat-kangaroo population (Short, 1998).

Costin (1954) lists the Long-nosed Bandicoot, *Perameles nasuta*, The Brush-tailed Rock-wallaby, *P. penicillata* and an unknown Potorine as mammals currently or formerly native to the Monaro region of NSW, while Eberhand and Schulz (1973) thought that lack of a Peramelid is typical for a southern NSW valley. Bandicoot species the Southern-brown Bandicoot, *Isoodon obesulus*, the Western-barred Bandicoot, *Perameles bougainville* and the Long-nosed Bandicoot, *P. nasuta* all have fossil distribution in South-eastern Australia in the recent past. The subfossil overlap of distribution of all three species is most likely to occur in the alpine/subalpine regions of NSW (Price 2005). To a greater or lesser extent all three of these species experienced a contraction in range, and suffered localised extinctions immediately following European settlement. The largest of the Rat-kangaroos is *P. bougainville*, which now only occurs on two islands in Shark Bay in Western Australia. It is not clear why a contraction of such a magnitude occurred, although the semi-arid ecology of the species may have made it more prone to European impact than the more temperate Sothern-brown Bandicoot *I. obesulus* or adaptable Long-nosed Bandicoot *P. nasuta* (Price 2005).
European land management was undoubtedly catastrophic for Bandicoots Australia-wide, with introduced predators, hunting and changes in fire regime all placing populations under massive stress. Fire regime is an important determinant of Bandicoot survival (Pardon et al., 2003). It is interesting that there are records of *P. nasuta* at the Bogong Peaks site into the mid-20th Century, with the local population resilient enough to survive both the early and later settlement period, and possibly finally driven to extinction in the mid-1960s.

Other species on the Bogong Peaks affected by the ‘Tumut Gorge fire’, which burned for ten days in March of 1965 (Cheney, 1976), include the Brush-tailed Rock Wallaby, *P. penicillata*, the Balck Rat, *R. rattus*, and the Eastern Quoll *D. viverrinus*. It is possible this was a local extinction event due to the landscape scale of the fire, its high intensity, the widespread temporary reduction of understorey cover and increased predation, and the fact local populations of several species were under pressure, where the threshold for extinction for a number of species was more easily crossed. A decline in mammal numbers following a fire has been attributed to both increased predation and a shortage of food (Christensen et al., 1981).

Species less affected by this event are possums and gliders including the Mountain Pygmy-possum *B. parvus* type and the Feathertail Glider *A. pygmaeus*, which are present throughout the Bogong Peaks records with a seemingly consistently robust population. Most Glider species are not generally associated with the sub-alpine environment but lower altitude forest types, their mobility however, makes it possible for them to reach this zone. Feathertail Gliders *A. pygmaeus* are rarely recorded in the southern tablelands (Gilmour et al., 1987). Glider species have been recorded lower in the study site catchments, for instance Helman et al. (1988) recorded glider species *P. australis* and *A. pygmaeus* in the upper Cotter catchment, but these were at lower altitudes than the sub-alpine.

It is not likely that the glider hair is derived from owl-pellets. Owls could carry remains of gliders large distance and possibly preferentially sample them, but the boulder-pile habitat is not optimal for owls, which seek shelter in the more closed environments of tree hollows and closed caves. The discovery of hair from these species at aestivation sites seems to indicate a wider range for glider taxa than previously thought, but the nature of this range, as a migration or a more permanent residency, is not clear.

The impact of introduced predators on native terrestrial fauna is greater than on arboreal species, a fact that would lead to gliders and possums being the dominant
mammal type in the later settlement period, as the regularity of burning would reduce
the necessary understorey cover for terrestrial species.
Under European land management species distribution would change in the
landscape. For instance, the range of both Phascogale and Dasyurus spp. would have
contracted and they may have gravitated towards moth aestivation sites for food and
shelter under the impact of widespread landscape change and massive reduction of
biomass from burning, and therefore would become more visible in the record.
Braithwaite and Griffiths (1994) recorded a population drop and contraction of the
distribution of the Northern Quoll Dasyurus hallucatus into rocky escarpment areas,
which supported the densest and most healthy populations. There have been few
attempts to document and link patterns of population with species decline, overall
reductions in population abundancies can cause range contraction and fragmentation
(Lawton, 1993), with more the peripheral populations exhibiting higher persistence
during the final stages of range contraction (Channell and Lomolino, 2000).
Antechinus and P. fumeus are consistently present in the upper part of Zone 3 in the
BP1 record, possibly resulting from a reduction of competition with and predation by
R. rattus following National Park gazettal. Antechinus is widespread throughout
Australia. Antechinus stuartii and A. swainsonii were recorded by Gilmour et al.
(1987) from the Mt Tennent – Blue Gum Creek area. Both were trapped in E.
pauciflora woodland and higher altitudinal rocky heath areas. The same species were
also trapped by Helman et al. (1988) in the upper Cotter Catchment. Both species are
widespread, and A. stuartii is present on Mt Gingera (Green and Osborne, 1981). A.
swainsonii hair was found in both GBC and G4 cores. The small size of hair demands
the use of binocular microscope for the discovery of these species hair in the deposits.
The Mt Gingera 4 faunal record is less diverse than either Bogong Peaks records.
This is a more enclosed cave limiting the input of hair to animals that come inside or
occur in close proximity to the entrance. The introduced species are interesting, with
both V. vulpes and R. rattus hair in the top Zone 4b, but F. catus hair is only in Zone
3b. F. catus is still present at the site and visibly identified on the peak after the 2003
fires (A Wade pers. comm.). Green and Osborne (1981) found direct evidence of
Dingos, Rabbits and Hares on Mt Gingera.
In the top zone of Mt Gingera 4, which reflects the second half of the 20th Century, all
the species are rare or locally extinct, such as the Rock-wallaby, P. penicillata, the
Potoroo P. tridactylus, the Pygmy-possums Burramys type or the Smoky Mouse P.
fumeus. It is possible that there may be remnant populations of the Brush-tailed Rock-
wallaby or Long-nosed Potoroo on the much less visited western scarp edge of Mt Gingera. Individuals of either species have not been seen near Mt Gingera peak since before the mid-20th Century. *P. fumeus* is recorded in the Brindabella Ranges at Mt Kelly, and occurs marginally in the sub-alpine zone in Victoria (Green and Osborne, 1994).

The discovery of *Burramys* type hair in the highest samples of the G4 and GBC records is of great interest, as the taxon is present through-out both records, including the surface samples. It is possible that either the Mountain Pygmy-possum *B. parvus* or the Eastern Pygmy-possum *C. nanus*, or both, are still present on Mt Gingera.

The Mountain Pygmy-possum is the only Australian mammal entirely restricted to areas above the winter snowline (Broome *et al.*, 2012), with breeding females mainly found in boulder-piles above 1400 m (Broome 2001). The boulder-pile environment provides stable temperatures and a moist environment, as well as protection from predator species. *B. parvus* is physiologically intolerant of high temperatures, which may explain its present day distributional limitation (Broome and Mansergh, 1989). *A. infusa* constitutes a large proportion of the diet for the species, and supply *B. parvus* with a readily available rich food source that enables winter hibernation (Geiser and Broome 1991, Broome and Geiser 1995). Other important food sources are fruits of *P. lawrencei, Leucopogon* spp. and *Pimelea* spp.

The importance of species conservation of *B. parvus* makes the identification of remnant populations new to science of great importance for their conservation. The current known distribution of *B. parvus* does not include any of the study sites, but there is the possibility of a population in the northern section of the Australian Alps. The discovery of atypical populations is not unheard of. Indeed, in 2010 a population was discovered at around 1220 m in Happy Jacks Valley in a range of different habitats (Schulz *et al.*, 2012). Aestivation site deposits with preserved *B. parvus* hair are a useful guide for ecologists to search for the Mountain Pygmy-possum, as establishing which bouldefields to target for survey is complex (Broome *et al.*, 2013). Eberhand and Schulz (1973) list the Pygmy-possum *B. parvus* and the Tuan *P. tapoatafa* as not recorded in areas adjacent to the Cotter River Valley, but they were optimistic in regard to the presence of *B. parvus* in the area, since suitable habitat is seemingly abundant. Green and Osborne (1981) found an unidentified Burramyid hair in a Fox scat on Mt Gingera, possibly *B. parvus*. But a National Capital Development Commission report (NCDC, 1984) postulated that the occurrence of *B. parvus* in the Upper Cotter Catchment is very unlikely, and Green and Osborne (1981) trapped the
summit of Mt Gingera specifically for *B. parvus* with no result, and also postulated that the occurrence of *B. parvus* in the Upper Cotter Catchment is unlikely.

Caughley (1986) discussed the Pleistocene fossil record of the Mountain Pygmy-possum, *B. parvus*, in relation to the altitudinal tree-line and permanent snow-line, including the fossil sites of Jenolan Caves (Hope, 1982), Wombeyan Caves (Broom, 1896) and Buchan Caves (Wakefield, 1960, 1972), and illustrated that all of these sites fell closer to the Pleistocene tree-line than the Pleistocene permanent snow-line. Although the use of a single straight line to represent treeline or permanent snowline over a period of time is an obvious oversimplification, the study does discuss the possible ecological requirement of *B. parvus* for *P. lawrencei* drupes and pollen, as well as the presence of aestivation sites of *A. infusa*. The palaeo-distribution of aestivation sites might be expected to mirror changes in the distribution of the wider ecologies currently at those sites. This includes species that live in the detritus at the sites, such as the nematode *A. bogongae* and *H. cavicola*, also larger more mobile species that are obligate feeders on *A. infusa*, such as the Pygmy-possum *B. parvus*.

To take this one step further, viewing aestivation sites in granite boulder piles with surrounding *Podocarpus* as a distinct ecological type that can support *B. parvus*, the discovery of evidence of a single element of this ecological type could lead to extrapolation of the presence of the other elements of that system. For example, it would be theoretically necessary to also have both *Podocarpus* and aestivation sites of *A. infusa* near Jenolan Caves, Wombeyan Caves or Buchan Caves during the Pleistocene, as these are places where fossil *B. parvus* has been discovered. Since the Wombeyan Cave deposit was probably accumulated by owls (Ride, 1960), it is possible to extrapolate that the *Podocarpus* ecological type was within the distance of the hunting range of the owl species to the Cave.

Hairs recorded from Mt Gingera come from a sub group of the Burramyid family, that is *B. parvus* or *C. nanus*. In the case of the discovery of Burramyid hair in a modern sample in a sub-alpine habitat, among blockstreams with dense *Podocarpus* scrub it is possible to generalise a high likelihood of the presence of *B. parvus* at the site, and since the species is endangered the discovery of Burramyid hair in the sediment samples warrants a thorough investigation to ascertain its presence. The sample sites are all situated in suitable habitat, such as the presence of *P. lawrencei*, complex boulder piles, and obviously the presence of large numbers of *A. infusa*. Aestivation sites such as these, with extensive deposits may indicate the presence of the Mountain Pygmy possum by the fact that the deposits have been created by the
consistent arrival of large numbers of A. infusa, and hence a long-term stable local food source for *Burramys*.

The other species in the taxon, that is the Eastern Pygmy-possum, *C. nanus*, is not a typical sub-alpine woodland species. The closest deposits containing fossil Eastern Pygmy-possums are at London Bridge on Burra Creek, south of Queanbeyan, and at Yarrangobilly in the north eastern part of Kosciuszko National Park. The accumulating agents for these sites are regurgitated owl pellets and scats of mammalian predators deposited in caves or rock shelters (Harris, 2008). Green and Osborne (1994) described one individual trapped in the south of the ACT at Mt Kelly (1800 m), and say that they are common on the lower altitude northern end of the Brindabella Ranges, but rarely move into the higher subalpine areas, such as Mt Gingera. Hence it is possible but unlikely that a proportion of the Burramyid hair found on Mt Gingera was of this species.

Hair of both the Bandicoot *P. nasuta* and Pygmy-possum, *Burramys* type, is present at the Mt Gingera 4 site in the first half of the 20th Century, following a period of high macro charcoal input, but both disappear in the upper section of zone 4a. The higher pollen counts of *Eucalyptus* indicate pollen input from dense regrowth of the species in close proximity to the cave with the increased herb component dominated by grass. The prior high level of disturbance at the site forced most of the local faunal populations to virtual extinction, so that after the frequent disturbance was removed by the management strategy of fire exclusion for the protection of the Canberra water supply, recovery was prolonged.

Zone 3b in the Mt Gingera 4 record is the period of greatest European disturbance, and has a low faunal diversity. *P. tridactylus* is present before the advent of *F. catus*, at the base of the zone, during a period of high *Eucalyptus* and lower herb species and during the regrowth phase following a spike in charcoal. *P. brevipes* appears later in the zone with a weakening overstorey, where senescent old stems would provide abundant habitat, this may also be a factor in the presence of the bat species *N. geoffroyi*.

Mt Gingera 4 Zone 3a has the lowest diversity of preserved hair of any zone in the profile, a possible reflection of the increased fire impact from early European settlement in the lower half of the zone, as the overstorey is still robust and there is also regrowth from that disturbance. The species composition is interesting though, as it precedes the advent of introduced predator species. Species present included *C.*
lupus, *P. penicillata*, *P. nasuta* and *Burramys* type, the later three benefiting from an increase in shrubs from the base to mid-zone for protection and habitat.

Zone 2 at Mt Gingera 4 is pre-European, and sees a large charcoal peak in the second half of the zone. This coincides with the discovery of human hair. It is not likely that the study site itself is occupied for any length of time, as the hair is interpreted as being from Indigenous people harvesting the moth.

At the Mt Gingera 4 site in Zone 2 there are two cycles of rise and fall for herbs, with the second, higher in the zone, of less magnitude and a shorter timeframe. As such this zone is a record of virtually an entire pyrrhic structural successional cycle. *Antechinus* and *P. nasuta* are basally present when shrubs are a significant vegetation component, but are absent when herb are high. In the upper part of the zone, again with a peak in shrub species, animal taxa include the Potoroo *P. tridactylus*, the Sugar Glider *P. brevipes* and *Burramys* type, representing species that require a shrub layer for predator cover. *P. penicillata* is present at the top of the zone, with increased herbs and *P. lawrencei*.

The basal Zone 1 of Mt Gingera 4 has a minor macro-charcoal peak mid-zone, and experiences a fire recurrence interval of close to a century, with herbs originally colonising with a large increase in *Eucalyptus* as the regrowth phase is triggered. This declines with an increasing shrub component and then an increase in herbs and grasses. The presence of Bandicoot, *P. nasuta*, hair follows quickly after the disturbance, perhaps signalling that Bandicoots actively hunt aestivating moths, especially where other food sources have been destroyed by fire. The Potoroo *P. tridactylus* and *Burramys* type hair occur later, with more marked increase in shrub layer. The Dingo, *C. lupus*, is also present at this time.

The Mt Gingera Big Cave record does not record fauna during the entire core, with no record in Zone 1 or 3, and only one sample in Zone 2, which dates to around 900 years. In the cores from Bogong Peaks there is no appreciable decline in diversity with depth in BP1, as the younger nature of the core compared to BP2 does not put an upper limit to the preservative property of the site. BP2 itself does record faunal populations to over 350 years, while Mt Gingera 4 has some mammal hair in the bottom zone also dating from 300 years. Taphonomically it is difficult to set an upper ceiling of a maximum date for the preservation of faunal remains at aestivations sites.

The Gingera Big Cave site is the only site in this study able to be used for shelter and occupation. Human hair was discovered in Zone 4a, as well as Dingo, *C. lupus*, and
the Bent-wing Bat *M. schreibersii* in the sample above it, with both species able to co-exist in close proximity to human habitation.

It appears that taphonomic conditions may be limited by the human habitation at the site. The only hair discovered mid-zone was the Potoroo *P. tridactylus*, in association with rapidly decreasing charcoal and a rise in the representation of shrubs. Since both Potoroo species seem to be able to endure European land management at this site until recently, the discovery of hair at the site during a period of human habitation in prehistory is not unexpected, either as a local population or an extra-local population that was hunted and brought back to the site.

Bats would be expected around the rock pile environment given the food resource of aestivating moths. Interestingly the two taxa recorded in the Mt Gingera 4 deposit were the Bent-wing Bat, *M. schreibersii*, and Horseshoe Bat *Rhinolophus cf.*, as neither of these species was listed in the subalpine zone by Green and Osborne (1994), and both are cave species. In contrast in Gingera Big Cave the bat species were the Bent-wing Bat *M. schreibersii* and the lesser Long-eared Bat *N. geoffroyi* where the large rock shelter space allowed more woodland species, such as *N. geoffroyi* to forage at the site. Helman et al. (1988) recorded bat species *Tadarida australis, N. geoffroyi, Vespadelus regulus* and *Vespadelus sagittula* in the upper Cotter Catchment, but these species are open forest species.

The most dominant species in Gingera Big Cave is the Dingo, *C. lupus*, which goes some way to explaining the relative lack of introduced predators in the top zone.

There is evidence that the Dingos supresses populations of the red Fox *V. vulpes*, and may set an upper limit on the population, and that while Dingos co-exist with a wide range of small mammals the arrival of the Fox has caused extinctions and declines (Johnson and VanDerWal, 2009).

Even though the Gingera Big Cave deposit is the oldest in the study it does not have the resolution to span the arrival of the dingo or the question of older faunal extinctions such as the extinction of the Thylacine, *Thylacinus cynocephalus*, on the mainland. It is possible that older deposits at other aestivation sites could record significantly further back in the Holocene.

Aestivation sites are important for bird populations. Feathers were found in every profile and are readily recognizable under the microscope. Taxonomic resolution was limited to the recognition of Passerine feathers, and these were further identified into the crow family Corvidae, but a species level identification was not sought. An exhaustive list of fossil avian remains, including those spanning the Pleistocene, was
compiled by Rich and van Tets (1982). In the current study the sub-fossil remains are feathers, rather than bones or eggshells, so identification is based on the microscopic character of feathers rather than skeletal morphology.

Avian species exhibit a similar migratory pattern of springtime arrival as the moth to the sub-alpine and alpine areas, for instance the moths provide abundant food source for large flocks of Little Ravens, *Corvus mellori*, and when Bogong Moths begin leaving the mountains in late February Little Raven numbers also decline (Osborne and Green, 1992). Bennett gives an ethnographic account of Indigenous people catch and eating *C. mellori* at aestivation sites (Young et al., 2000). During the summer months large flocks of Little Ravens can be seen at aestivation sites, and may help to identify sites where Bogong Moths aestivate (Plate 7.3).

Plate 7.3- A large flock of Little Ravens, *C. mellori*, present at an aestivation site.

7.4) Human Hair in aestivation site sediments
The positive identification of human hair in the samples required a high level of certainty. This can usually be achieved by visible morphological characteristics, but absolute certainty in all cases, especially in the case of degraded, truncated or dirty samples, may not be possible even with DNA analysis. Samples may be contaminated
during excavation and analysis with modern hair, but the condition of modern hair and hair that has spent a prolonged time within the sedimentary matrix is visibly obvious. Hair that was identified as human was photographed and placed in an airtight vial.

The discovery of human hair from the samples required a change in the protocol for sample storage, analysis and ultimately repatriation. The possibility that some human hairs may be missed in the sample analysis might demand that the entire sample may have to be returned to the site, but this will depend on the wishes of the traditional owners of the respective areas. Protocols for sample management will be created following consultation with Traditional owner groups.

Although the incidental nature of human hair deposition at aestivation sites precludes burial, the Bogong Moth has great a social importance. The gatherings of large groups of people for harvesting the moth had definite cultural and spiritual protocols. Anthropological and anecdotal evidence suggests some variability in the social context of harvesting *A. infusa* by the Indigenous people through the Australian Alps. This includes the role of women, as well as variation in the ceremonies in the long term, and harvest season length. The impact of harvesting on the high mountain environment, plants and animals and the moth population itself is not a fixed one, but variable in time and space.

Human hair can be interpreted as definite human presence, and it provides a minimum timeframe for site usage, although an absence of human hair does not preclude site usage, continuity of usage at the site cannot be assumed, as much from moth aestivation stochasticity as environmental or social variability. Aside from the context of cultural sensitivity human hair must be interpreted in this study as with other hair, as a given species with ecological and environmental requirements that was present at or very near the point of deposition.

The BP2 record has Human hair present during the early settlement period, but dropping out of the record by the late 19th century. This period during settlement that the feasts still occurred in the Bogong Peaks Wilderness are described by anecdotal accounts of the Bogong feasts by settlers near Tumut, and they also describe their rapid collapse (Young et al., 2000). This collapse occurs during the time of greatest environmental changes wrought on the highlands by European settlement, where the ecology of these areas was changed from being favourable to Indigenous people to an ecology dominated by seasonal grazing of introduced grazing animals.

On both Mt Gingera sites Human hair is present only in the pre-contact times. At Mt
Gingera 4 hair is present until the very late 18th and early 19th century. This abrupt absence may represent the spread of disease reaching Indigenous populations before the arrival of the first settlers in the immediate vicinity. So that by the time of the arrival of the first explorers in the Brindabella Ranges there would already have been a massive upheaval to Indigenous society, where large gatherings at the more remote aestivation sites may possibly have already been abandoned.

7.5) Environmental change and aestivation
Climate directly affects the distribution and abundance of a species, and moths are particularly sensitive to microclimatic change. The high mountain environments that are favoured aestivation areas of A. infusa change quickly to lethality with colder autumn seasonal temperatures. Common (1954) recorded a high mortality of the Bogong after a sudden cold spell in early April at Mt Gingera. Both seasonal and longer-term climatic changes can increase or decrease the suitability of both regional areas and specific sites for aestivation, and this may be recorded in variation of depositional regimes at aestivation sites. The reaction of the population of a species to the effects of climate change must eventually decide the viability of that species in a given area. It is on this basis that patterns of behaviour, and over the longer term, physiological and genetic changes, may emerge within a species.

The phenomenon of aestivation is difficult to define precisely, because behavioural, genetic and hormonal changes as well as population variability and climatic change alter the nature and the manifestation of aestivation. White et al. (1998) proposed three reasons why the alpine cutworm moth, Euxoa auxiliaris aestivated in alpine talus slopes in Montana, they were, protection, thermoregulation, and for the exploitation of the large summer flowering in alpine environments. A simple evolutionary view of aestivation of A. infusa is that the colder conditions present at permanent aestivation sites in boulder piles reduces the metabolic rate of the ectothermic A. infusa, aiding the entrance into a dormant state. This mechanism, and the shelter provided by aestivation sites, would enable the evolution from a seasonal breeding migration to aestivation proper by increasing the survival of aestivating moths.

The antiquity of aestivation of the Bogong Moth is an interesting question. The current pattern of migration and aestivation of the Bogong Moth must have begun sometime after the LGM. Larkins (1980) theorised that during the LGM A. infusa summered at a lower altitude and as the country warmed, they sought higher altitudes
for aestivation, and today rarely aestivate below 1400 m. The distribution of late-Pleistocene fossil *B. parvus* does lend some support to this line of reasoning. Common (1954) thought that aestivation began during the late-Pleistocene in response to increased heat and aridity of the breeding grounds. Flood (1973) felt that the present pattern of aestivation most likely began either at 15 ka BP, during a warming period at the end of the Pleistocene, or around 1.5 ka BP, during a possible period of climatic amelioration. Jones (2001) suggested that aestivation must have evolved over thousands of years, and that the population fluctuates naturally with ENSO phenomena, but the largest historic migrations of the Bogong Moth recorded do not coincide with recognised ENSO events (Gergis and Fowler, 2006). It is possible that the largest population numbers of adult *A. infusa* occur in wetter seasons, with higher rates of larval survival, and that the evolutionary pressure for aestivation is more intense during the periods of lower recruitment of arid seasons. Moy *et al.* (2002) interpreted proxy records and postulated that peak ENSO amplitude occurred between 1–2 ka BP, with the evolutionary and ecological drive for the current temporal and spatial migratory population dynamics of *A. infusa* greatest in the late-Holocene.

The response of the *A. infusa* to past environmental change supplies some insight into the response of the species to predicted climate change. However, the speed and range of human induced climate change is far greater than during the mid to late Holocene.

Regional predictions for South-eastern Australia by CSIRO for seasonal climatic warming vary in range and by time, with an average annual temperature increase of up to 2.0 °C by 2030 and to almost 6.0 °C by 2099 (Climatechangeinaustralia.gov.au, undated). These climatic changes will potentially alter the biota in both the breeding grounds of *A. infusa*, as well as the sub-alpine environment that the species aestivates in. In the breeding grounds it is likely C4 grasses will increase in dominance and, coupled with a shorter growing season before the browning back of broad leaved pasture plants, will increase the pressure on the larval stages of the moth for both nutrients and developmental speed.

The changing climate will have both a temporal and spatial effect on aestivation, that is the timing of migration and the geographic distribution of aestivation. As well as changing the context of aestivation such as its size and factors such as length of snow-lie or more frequent fires. Snow cover and duration have been declining in the Snowy Mountains (Hughes, 2003).
Interestingly Green (2010) theorised that moths would come later in the year possibly arriving after the hibernation of the Mountain Pygmy-possum, *B. parvus*, and leading to a food shortage for the possum in spring. He took extensive field notes over a number of years and found that the Bogong Moth has been arriving at the Snowy Mountains significantly later over the years with no apparent explanatory climatic cause, and highlighted that *A. infusa* are not responding to earlier snow melt for migration timing, but for insectivorous predators such as *B. parvus* it is vital. The amount of possible error in this study limits the possible conclusions that may be drawn, but it does illustrate the importance of keeping field notes. A later migration of the Bogong due to increased temperatures globally would seem unlikely, with the higher temperatures in the breeding grounds earlier in spring reducing the window for broad leaved pasture plant growth, and higher temperatures increasing the need for early migration of the moth. More heat would also be expected to speed the developmental stages of pupae. The study by Parmesan (2007) found that butterfly emergence and migratory arrival had three times stronger advancement than the first flowering of herbs, making it much more sensitive to warmer temperatures. As such there may be more asynchrony in insect–plant interactions than in mammal-insect ones coming from rapid climate change.

Shi *et al.* (2015) highlighted the value of boulder-piles as thermal refuges for small mammals in light of habitat loss and climate change. The boulder-microhabitat can allow species persistence because they are partially decoupled from the regional climatic conditions, and serve as thermal refuge, but there is large spatial variability in the boulder-pile environment itself (Shi *et al.*, 2014). Shi *et al.* (2015b) found that a number of factors, such as slope gradient and elevation interacting with vegetation cover, the number of rock layers and rock cavity size, lead to thermal variability at each site, and therefore capacity to thermally buffer high summer temperatures or low winter temperatures. At a regional level different sites will be more or less able to cope with climate change.

The effects of climate change on the geographic range of aestivation sites would depend, in part on the context, extent and length of the climate change, where the effects of short-term climate change are dampened by population and site variability, while larger and longer changes may be compounded by the creation of environmental feedback loops. For example, the hotter the climate becomes the higher the evaporation, and the higher the evaporation the greater the potential water deficit. A high water deficit at an aestivation site can make the site much less...
effective at dampening high temperatures, and therefore may reduce a site’s suitability for aestivation.

It is not clear how sensitive the altitudinal range of aestivation sites is to environmental change. It is predicted that trends in the pressures of selection for lower altitude permanent aestivation sites would be greater with colder environmental conditions, while selection pressure at higher sites would be greater with warmer climatic change.

Keaney (2006) approximated distributional changes to the altitude of aestivation sites by predicted global warming using the method of Cawood and Cechet (1996) for the estimation of altitudinal change to treeline from global warming by assuming that the distribution of many permanent aestivation sites is located at approximately the treeline and the tree line moves 100 m for every degree increase or decrease to average temperatures. Following Keaney (2006), a predicted climate change of between 2 °C and 6 °C by 2100 could render most of the current aestivation sites unsuitable. The speed of this change makes population adaptation of other species such as B. parvus or the two mermithid nematode species, A. bogongae (Welch) and H. cunicola (Welch) which parasitise A. infusa at aestivation sites at risk of extinction.

The variability in the relative abundance of arboreal pollen taxa at aestivation sites cannot be used to imply change in tree-line level during the late-Holocene, as studies indicate the stability of species on the higher mountain peaks in the Australian Alps well beyond the environmental records of Bogong Moth aestivation deposits (Macphail (1981); Hope (1974); Martin (1986a); Martin (1986b)). Tree-line movement is more complex than a given altitudinal rise or fall, as the determination of the tree-line is an interaction of summer temperatures, exposure, desiccation of soils, snow depths and the frequencies of out of season glazing storms or frosts (Macphail, 1975).

Forest structural change is a more useful and explanatory concept than tree-line change for land-managers, where the response of the overstorey to environmental change is not an altitudinal limit change but rather a structural one, that is forest spacing, species dominance, stand ages and stand type. These are traits that are greatly affected by the interaction of both climate and fire. Drought is a major factor affecting the composition and distribution of communities of sub-alpine plant species (Morgan, 2005), both in terms of water stress and susceptibility to major conflagration. With the predicted climate change affecting the frequency and severity of both drought and fires a larger amount of the subalpine woodland may be
transformed into a regenerative form, where more sensitive regrowth would be more marginal or susceptible to structural change.

Structural change of the vegetation due to human induced climate change is a real threat to sub-alpine ecology. Pryor (1939) described the possible extent of high country degradation from burning as two extremes, that is a slightly damaged forest that is more or less undisturbed, to a barren waste of eroded mountains with a sparse cover of plants. This is poignant as a prediction for the natural land managers under the effects of anthropogenic climate change, where the flammability of the forest can drive ecological change of vegetation away from a forest form into a scrub form, a point that should be taken to account in the prescription of fuel reduction burns. Predictions of the effect of climate change on the ACT include fires with higher intensities, with reduced inter- fire intervals and that are more prone to spread (Cary, 2002). The spatial patterns of average inter-fire interval for the Australian Capital Territory was modelled by Clarke et al. (2002), and under the scenario of large climate change the majority of the ACT had a fire interval of less than ten years, including much of the sub-alpine, and the Mt Gingera area. The same trend could be expected in the Bogong Peaks area, and possibly exacerbated in the drier Tinderry Ranges. Increasing fires intensity and frequency would place large stress on the *E. pauciflora* overstorey transforming it into a scrubby layer, possibly to the exclusion of *P. lawrencei* from much of its current range. Such a forest structure would limit tree hollow habitat for fauna including many types of mammal and avian faunal species, including migratory birds, bats, possums and gliders, quolls, Potoroos and Phascogales, and also impact on species that use *P. lawrencei* as a food plant, including the Smoky Mouse *P. fumeus*, the Bush Rat *R. fuscipes*, the Estern Pygmy-possum *C. nanus*, and Mountain Pygmy-possum *B. parvus*. Both increased fire frequency, and early snowmelt from climate change can have major impacts on small mammal populations (Green et al., 2008) This level of disturbance would be greater than the impact of the arrival and settlement of the area by Europeans, as the system is already in a disturbed state and is sensitive to changes in the fire regime’s frequency and intensity. Rapid and large climatic change from human use of fossil fuels needs to be addressed as a matter of urgency, to slow the rate at which that change occurs and to reduce the size of that change, and to allow any chance of conservation of the ecology of sub-alpine areas as we know of them today, lest Pryor’s vision of a barren landscape is realised.
8) Conclusions

‘O overcome me, Power and Truth;
Transmute my ignorance, burn it bare;
So that against your flame, not I
But all that is not You, may die.’
From ‘Moth’ by Judith Wright

The methods detailed in this dissertation for the discovery and analysis of assemblages of both plant and faunal remains, preserved in the accumulating sediments at aestivation sites of the Bogong Moth, in the crevices of granite tors in the northern Australian Alps, were described as pioneering by Macphail & Hope (2011).

Aestivation caves sites are sensitive terrestrial archives of the sub-alpine, and provide opportunity for multi-proxy ecological studies with independent lines of evidence; where preserved pollen provides a signature of local vegetation; hair gives a signature of mammalian populations, and charcoal a signature of the occurrence of fire.

Charcoal, and chitinous samples from these deposits provide ample material for dating and the construction of age depth models.

In this study fieldwork focused on the sampling of deposits at aestivation sites to ascertain the pollen, mammalian hair and charcoal concentrations of the profiles of these montane deposits, as well as the depositional rates of the sediments. From this information a narrative of ecological change in these areas can be constructed, especially the ecological impact of European settlement. The aestivation sites of Bogong Moth, *A. infusa*, show particular promise as a terrestrial archive. The micro-remains of these moths are abundant and, in sheltered locations, they are a key source of deposited sediments. Their capacity to provide a pioneering archive for understanding the floral, faunal and Indigenous history of the northern Australian Alps is the key focus of this thesis.

Data from aestivation site deposits will provide valuable context to long term environmental change and therefore our understanding of the environmental context of human occupation in the ACT and surrounding areas, especially during the late Holocene, as well as the effect of post-European land management practices. The extraction of pollen and other environmental proxies from aestivation site deposits is a novel source, limited to the sites of gregarious seasonal dormancy of insect species with adequate preservative properties for sediment accumulation. For example, it is
possible that these techniques could be used to analyse the roosting sites the monarch Butterfly, both in Australia and overseas, or areas of the hibernation of *E. auxiliaris* in the United States of America.

It is likely that many of the mountain peaks named after the Bogong Moth have aestivation sites, the Bogong Peaks in Northern Kosciusko, Mt Bogong in Victoria, or Mt Coree on the NSW and ACT border. The etymology of these places may be attached to the harvesting of moths where explorers or early settlers were informed of the presence of the moth or harvesting. This etymology is useful for researchers studying *A. infusa*, to harvest the rich sources of ecological data present at aestivation sites.

The terrestrial archive of deposits at aestivation sites are a useful source of information about past floral and faunal change, and their response to fire. In light of changing management strategies in terms of fuel reduction burns, or the effect of climate change on the frequency and intensity of bushfires, the proxy record contained in aestivation sites is invaluable as reference for land managers on the response of the sub-alpine and alpine ecological communities to disturbance.

Other types of scientific exploration directed towards aestivation sites are also very promising, including biochemical, genetic and archaeological. Direct archaeological investigation at aestivation sites is a potentially useful and rich source of discovery into the material culture of rich Indigenous culture in the South-eastern Highlands and its interaction with the landscape. Aestivation sites are a likely archaeological prospect as they are a very specific site type that was able to seasonally greatly increase the carrying capacity of the entire landscape, which promoted cultural exchange between groups spanning a large section of South-eastern Australia.

The aestivation sites of the Bogong Moth provide a unique terrestrial archive of environmental change in the mountainous areas of the South-eastern Highlands of Australia during the late Holocene. It is the unique position of aestivation sites in the environment, and their nature, that has allowed these sites to capture the period of greatest ecological change in the late Holocene, that is the contact period between Indigenous culture and the invading Europeans.

With the arrival of European invaders, environmental change was used by the colonising culture to attack the Indigenous one. This was not just a matter of negligence, rather a concerted effort to manipulate the landscape into one that would exclude the hunter gatherer. This can be seen in the widespread landscape destabilisation which occurred after European settlement in the form of very frequent
burning which homogenised large areas for grazing, the introduction of new species, land subdivision and fencing, and the use of bounties and poison on native species, the impact of these being manifest in the collapse of the large inter-tribal gatherings to harvest the Bogong Moth in areas like the Bogong Peaks. The sensitivity of the landscape of the high mountain regions of South-eastern Australia to fire and introduced species greatly affected Indigenous culture present at that transitory time. The documentation of the ecological changes that the invaders wrought is important, firstly as a testament to the invasion and genocide of the Indigenous populations, but also as a reference for current and future land management practices. The carrying capacity of a terminal successional subalpine forest comprised of large overstorey trees is high for indigenous people, while a heavily burnt post-disturbance vegetation has a higher carrying capacity for Europeans and livestock, and would exclude the traditional hunter-gatherer lifestyle. The impact of increased fire frequency and introduced species was catastrophic to the Indigenous culture, and even in colonial times this was a predictable outcome. A possible interpretation then is not that settlers were negligent, on the contrary, that these land management practices were systematically and purposely used against Indigenous populations to dispossess them of their ancestral lands, to give the settlers unchallenged land tenure. In the same way it would be beyond negligent to consider the effects of global warming on these high mountain ecosystems as slow or too distant, or in the worst case to deny them.
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### 10) Appendices

#### Appendix 1 - Regional Aestivation Site Climate Envelope

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<th>Precipitation Seasonality (C of V)</th>
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Appendix 2- Modelled local climate data for sampled aestivation sites.

ANUCLIM surface estimates of climatic parameters using long climate record estimates of conditions proximate to Bogong aestivation sites. Record based on longitude, latitude and elevation and provided by John Stein at The Fenner School of Environment and Society.

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Appendix 3 - Table of dates.

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<th>Depth (mm)</th>
<th>AMS date (years BP)</th>
<th>CALIB*</th>
<th>CALIBomb*</th>
<th>Median year BP (CALIB/CALIBomb)</th>
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*Calibration for single dates using southern hemisphere correction.
'Come then, my love, my lovely one, come.
For see, winter is past, the rains are over and gone.'

The Song of Songs 2:10