Karst Values of Kosciuszko National Park
A Review of Values and of Recent Research

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There are seven areas of karst within Kosciuszko National Park ranging from the sub-alpine to montane forest conditions. Two, at least, Yarrangobilly and Cooleman Plains, are of national – perhaps international - significance. This paper amplifies earlier discussions of the heritage significance of the Kosciuszko karsts but does not greatly alter the earlier assessments. The highest levels of significance result from cultural values relating to use by indigenous people and to modern scientific research on karst processes.
Cooleman Plains, Yarrangobilly and perhaps Indi were used by indigenous people for dispositional burials, occupation, and perhaps parietal art, for over 10,000 years. The caves in the headwaters of Jounama Creek to the north of Black Perry Mountain have not been rigorously studied for their indigenous or other values because of their extreme inaccessibility within the Bogong Wilderness but their proximity to the Bogong bora rings and many Bogong Moth sites makes them a likely site.
Cooleman Plains and Yarrangobilly have been the subject of internationally published research in the fields of karst processes with publications of the late Joe Jennings being cited in texts more than four decades later. Micro-erosion meter sites established in 1984 are still being monitored and paper requests still being received. More recently, the world's first studies of the impacts of fire on karst processes in and above caves are being undertaken at Yarrangobilly (and on other NSW karsts) with several publications arising.

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INTRODUCTION

The significance and values of the karst resources of Kosciuszko National Park (KNP) have been previously summarised in Nicoll and Brush (1976), Spate and Houshold (1989), Good (1992), Spate (2004) and Spate and Gough (2016). Since those times little has changed in our knowledge of the karst systems except in relation to their karstic, biological and cultural values. Cave faunal surveys reported in Eberhard and Spate (1995), further work by Spate (unpublished) and reviews by Thurgate et al (2000, 2001a, 2001b) have greatly refined our knowledge in this regard most markedly in relation to Yarrangobilly and Cooleman Plains. Recent work at Yarrangobilly on various karst processes, including the impacts of fire on such processes, and on palaeontological and archaeological values as well as on the age of the limestones at Yarrangobilly and Cooleman Plains (Treble et al 2016, Rutledge 2018, this volume, Tadros et al. 2018) are discussed below. Ellis and Halbert's (2016 eds) excellent book, Caves and Karst of Yarrangobilly, provides much information on all aspects of Yarrangobilly.

Karsts are landscapes formed on rocks with a greater degree of natural solubility than is commonly found. In the case of Kosciuszko these are all limestone (although dolomite does occur at Cooleman). Karst areas are characterised by gorges, caves, deranged hydrological systems and many fascinating small-scale karst features such as various forms of

karren. Karst systems and processes are produced by a complex interplay of geology, soils, biology, climate and time (Kiernan 1988, Hamilton-Smith et al. 1998). Over the last three or four decades the importance of karst has been increasingly apparent as has the dimensions and importance of their non-geologic values. This is perhaps best and dramatically demonstrated, by the increasing world-wide acceptance of the IUCN Guidelines for the management of caves and karst, largely developed by Australians (Watson et al 1997). These guidelines are already in use by NPWS for steering plans of management in parks across the State. The management objectives and actions identified in the Kosciuszko Karst Area Management Plan (KAMP; OEH 2015) are consistent with these guidelines.

The 2006 Plan of Management for Kosciuszko National Park (NPWS, 2006) identifies seven management units within the park for special management prescriptions as they are considered "to contain places and values of exceptional significance". These include the Cooleman Plain and Yarrangobilly karst areas; the alpine landscapes of the Main Range; and the ski resort areas. At Kosciuszko the values and significance of karst are recognised in the KNP National Park Plan of Management 2006; KNP Geodiversity Action Plan 2012-17 and Kosciuszko Karst Area Management Plan 2015 (KAMP). The latter two are as yet unpublished. There is also a Speleological Reference Group consisting of park staff and community members experienced in cave and karst matters.

The seven karst areas within Kosciuszko have a wide range of geological, geomorphological, biological and recreational values in addition to their cultural significance to both indigenous people and to later arrivals. At least two of the areas, Cooinbil and Cowombat Flat, would appear not to have cave systems – at least enterable by humans – but they have much of interest. Carne and Jones (1919) reported additional limestone areas (notably on the Main Range) but these seem to be errors or misreporting of locations. These areas are not listed or are dismissed in Lishmund et al. (1986). The KAMP defines seven areas on the basis that limestone outcrops almost continuously from Cooleman Plain down Cave Creek to the Goodradigbee River. (e.g. Matthews, 1985; CSS, 2009). Some of the upper Goodradigbee limestones are of a different group (in the Pocket Formation) and have previously been recognised as different (for example, as the Wilkinson Limestone) below the waterfalls on Cooleman Creek (Pickett, 1982). Further geological research is required here.

The seven areas are of local, regional, state or national significance – some would argue that some features are of international significance – predominantly from a cultural perspective in the field of scientific endeavour. Whether these areas would ever reach the level of the World Heritage criterion of "outstanding universal value' is very much open to discussion. However, we believe that Cooleman Plains and Yarrangobilly are of international significance because of their place in the scientific literature.

In addition to the karsts developed in soluble rocks, there a number of small-scale pseudokarst features, chiefly in granite, scattered across the Park including boulder caves along the Snowy and Ingeegoodbee Rivers (Finlayson 1981). The ephemeral caves in ice and snow should also be mentioned in passing (Halbert and Halbert 1972). These sometimes contain many forms analogous to 'traditional' karst caves – and attract the interest of an additional class of visitors to those who utilise other caves within the Park.

All of the karst and pseudokarst areas within the Park have very considerable value for interpretation especially in regard to landscape development and evolution, karst processes, palaeontology and archaeology. This is especially true of Yarrangobilly and Cooleman Plains (and perhaps Cooinbil because of its easy access).

GENERAL DISCUSSION

The seven karst areas (excluding the 'pseudokarst' granite and ice caves) within the Park (Fig. 1) are all developed within Silurian or Devonian limestones or their derivatives (Owen and Wyborn 1979, Wyborn et al. 1990), Spate (2003) and Spate and Gough (2016) (Map 1). Nicoll and Brush (1976) and Brush (2016) provide details on many of the significant caves especially at Yarrangobilly Spate and Gough, Treble et al. and Brush (chapters 5, 6 and 11, respectively, in Ellis and Halbert 2016) provide additional information on aspects of the Yarrangobilly karst area.

All the areas are within the Lachlan Fold Belt but there are significant differences from a geological perspective (see the introductory chapters in Lishmund et al 1986). These differences do not concern us from a karst perspective. A grouping of the areas is discussed below – and each area is discussed in detail. It is obvious that the areas are distinct from other NSW karst areas in that they lie near the crest of the Eastern Highlands – the so-called Great Dividing Range – and are in alpine, sub-alpine or montane environments (for further discussion of their geomorphic settings see Houshold et al. 1986). Cooleman and Yarrangobilly have outstanding above-ground

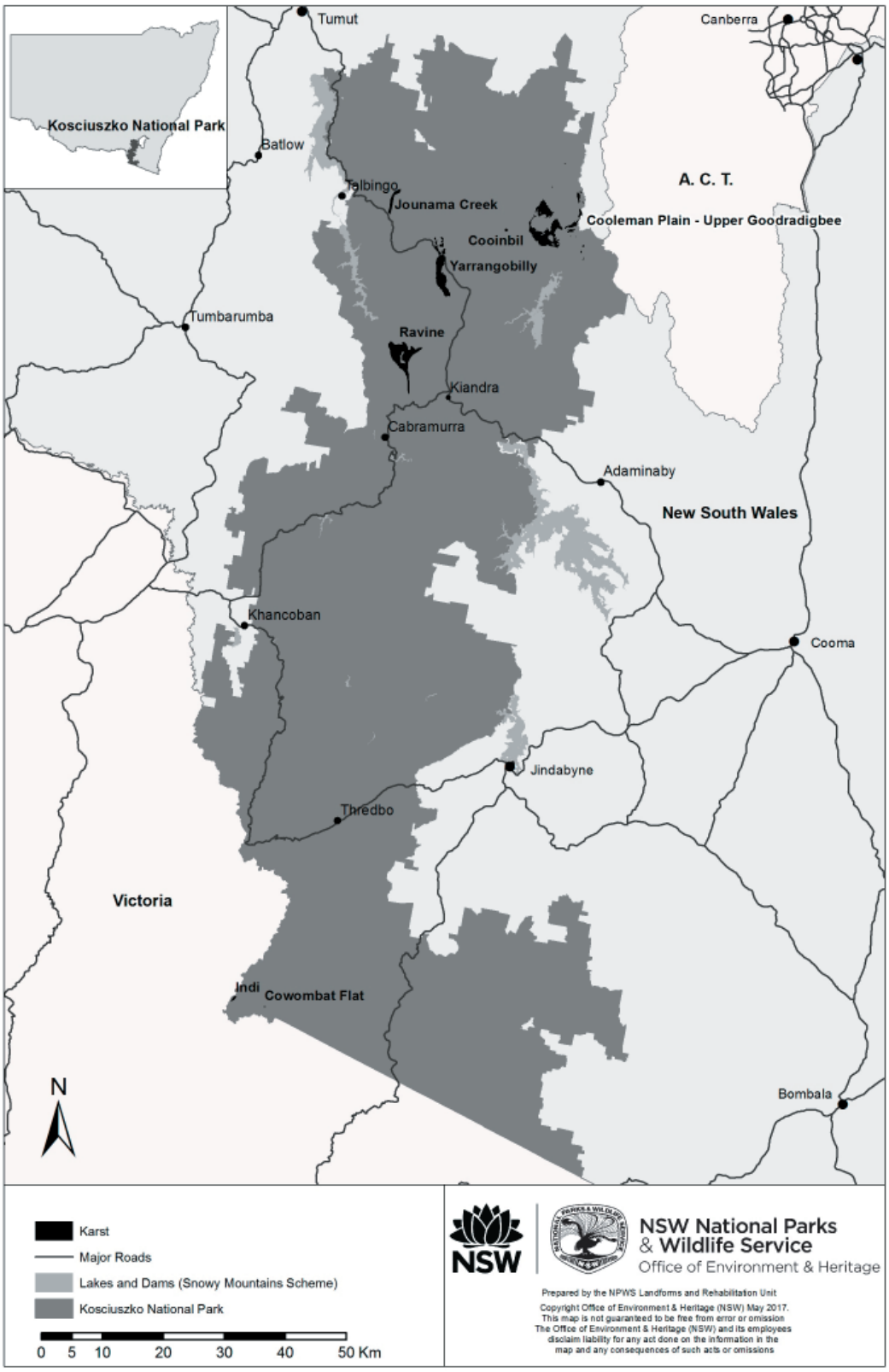

Figure 1. The seven karst areas in Kosciuszko National Park

Karst area	Period	Epoch	Unit Name
Cooleman Plains	Silurian	Wenlock-Pridoli	Cooleman Limestone
Upper Goodradigbee	Silurian	Ludlow-Llandovery	Pocket Formation
Cooinbil	Silurian	Ludlow-Llandovery	Peppercorn Formation
Yarrangobilly	Silurian	Wenlock Pridoli	Yarrangobilly Limestone
Jounama Creek	Silurian	Wenlock/Llandovery?	Ravine Beds
Indi	Silurian	Llandovery??	Cowombat Siltstone
Cowombat Flat	Silurian	Llandovery?	Cowombat Siltstone
Ravine	Devonian + Quaternary	Emsian + Quaternary	Lick Hole Formation + unnamed

Table 1. The geological setting of the Kosciuszko karst areas.

karst landscapes, particularly caves, gorges and rising streams.

The seven areas considered are shown in Table 1.

They all have varying proportions of sub-alpine grasslands and forests and montane forest communities. Ravine has been highly disturbed by grazing, fire and weed invasion and appears to be somewhat of a rain shadow area. Cooleman has been extensively disturbed by past grazing of cattle and by rabbits. Recently, wild horses have been having major impacts at Cooleman including on karst features, as well as swamps and other sensitive vegetation types, and physical damage to cultural heritage items (Office of Environment and Heritage 2016 – hereafter OEH)

Each of the areas has distinctive characteristics in terms of topographic setting, broad vegetation type and degree of karstification and degree of karst hydrological integration. Only two areas, Cooleman and Yarrangobilly, have been surveyed for their dependent cave invertebrate populations (Eberhard and Spate 1995) although only at a reconnaissance level. Both these areas have endemic plant species. Some sites, particularly Yarrangobilly and, to a lesser extent, Cooleman have significant subfossil deposits including such species as Smokey Mouse (*Pseudomys fumeus*) and the Thylacine (*Thylacinus cynocephalus*) (Spate, 2006).

As with many other karst areas under the management of the NSW National Parks and Wildlife Service all the seven karst areas are within Kosciuszko National Park or have their entire catchment areas within Service estate. This makes their management easier from the viewpoint of total catchment protection. However, the remoteness and ruggedness of some of the karst areas also presents management challenges.

The significance of the seven karst areas ranges from national to local. We argue that for Cooleman and Yarrangobilly that there are aspects that may be of international significance based on their scientific importance. Given that whole Park is internationally recognised as a UNESCO Man in the Biosphere Reserve and nationally as a result of its listing on the Register of the National Estate extensive discussion of significance may not be relevant here. The significance of individual areas is discussed below disregarding UNESCO and National Estate listings.

In general, the suite of karst areas have outstanding or representative at state to national scale, and maybe beyond, significance for their geomorphology, their landscapes above and below ground, and for their flora and fauna and indigenous connections.

Table 2 (updated from Spate and Houshold 1989) gives an assessment of the scientific and other significance of each of the seven karst areas.

The karst areas are sites that are within the Park and are thus dependent on the Park in all ways including their geographic location. They are all, in the proper sense of the word, “unique”. But, they have a range of values from local to international. However, the holistic nature of karst systems, being part of complex biophysical processes (and time), means that proper management of karst requires that environmental conditions remain essentially unchanged through time – within the bounds of natural environmental variability. However, definition of the time scale over which natural variability is to be considered is can be very problematic – even conditions in, and thus management operations of, two closely related caves such as Jersey and Jillabenan at Yarrangobilly relate to very different time scales ranging from 100 to 106 years. Such time scales are markedly different to most natural area management regimes and certainly much longer than political cycles or theoretical enthusiasms.

Work by Osborne (2001a, b) has brought into question whether the fundamental tenet of karst management – that of whole catchment management as an

Karst area	Geology	Geomorphology	Hydrology	Sedimentology	Palaeontology	Archaeology	Botany	Zoology	History
Cooleman Plains									
Representativeness	2	2	1	3	3	2	3	2	3
Outstandingness	2	2	2	3	3	3	4	2	3
Cooinbil									
Representativeness	3	4	4	4	*	*	*	*	*
Outstandingness	4	4	4	4	*	*	*	*	*
Yarrangobilly									
Representativeness	2	2	2	3	2	2	3	3	2
Outstandingness	2	2	2	3	3	3	3	2	2
Jounama Creek									
Representativeness	2	4	4	4	*	*	*	*	*
Outstandingness	4	4	4	4	*	*	*	*	*
Indi									
Representativeness	3	3	4	3	4	4	*	4	4
Outstandingness	4	4	4	4	4	4	*	4	4
Cowombat									
Representativeness	4	4	4	4	*	*	*	*	*
Outstandingness	4	4	4	4	*	*	*	*	*
Ravine									
Representativeness	3	3	4	3	4	*	*	*	*
Outstandingness	3	3	4	4	4	*	*	*	*

1 = international; 2 = national; 3 = regional; 4 = local; * = data deficient

Table 2. Degree of scientific and cultural significance of the eight karst areas within Kosciuszko National Park (after Spate and Houshold 1989 and Spate 2004).

appropriate management response – given that many Eastern Australian karst areas may have developed from rising groundwater rather than sinking surface waters. His finding may not relate to any of the karst areas within Kosciuszko; however. it is worth remembering that simple, and long-held management paradigms, must be questioned from time to time. Osborne (1996) has also pointed out the important role of sulfide mineralisation in the development of caves at Yarrangobilly and perhaps Cooleman. Both these concepts reinforce the comments above about timescales and environmental variability.

Cooleman and Yarrangobilly have had considerable research emphasis largely concentrating on cave documentation, karst geomorphology and hydrology, terrestrial vegetation and cave-dependent fauna and more lately on the impacts of fire on karst processes. There is much more survey and documentation work that could be done in these – and the other areas. Particular issues include terrestrial flora, subterranean fauna, hydrological relationships and landscape evolution. Recent work at Yarrangobilly has also evidenced the important of karst sites for palaeontology and archaeology (Aplin et al. 2010, Ford and Aplin 2010).

The Kosciusko National Park Fire Management Strategy 2008 – 2013 acknowledges the potentially adverse impacts of fire on the natural, cultural and

recreational values of the Park, including its karst environments. It specifically addresses karst management in relation to prescribed burning and wildfire suppression. Further management guidelines and policies are set out in the various documents referred to above.

Cooleman Plains

The Cooleman Plains Management Unit consists of the Cave Creek catchment in its entirety as well parts of the Upper Goodradigbee River and of the Peppercorn and Tinpot Creeks. Part of the area lies within the Bimberi Nature Reserve and the Bimberi Wilderness Area. It contains broad open plains, significant gorges and caves as well as many other karst forms such as dolines, stream sinks and risings and karren features.

A good general description of the area is found in the Cooleman Plains Karst Area Management Plan adopted in July 1987 as a supplementary plan to the Kosciusko National Park Plan of Management and formalised in the 1988 Amendments to that Plan and in the KNP Karst Area Management Plan.

The area includes the very popular car-based attraction of Blue Waterholes (the largest karst spring in the mainland part of the Eastern Highlands), a number of spectacular gorges, many caves and other karst features. It is a popular walking and horse-riding area and includes a number of sites of significance to both Aboriginal and European cultural heritage. Perhaps the most important of these is the Coolamine Homestead complex. Grazing continued on part of the area until 1977.

Spate and Houshold (1989) argued that aspects of Cooleman Plains had levels of significance ranging from international to local in a number of fields of scientific endeavour. Others argued, in discussion at the First Fenner Conference, for example, that the grounds for international significance were overstated. Spate and Houshold argued that the quality and range (and citations) of the geomorphological and hydrological research conducted by the late Joe Jennings and others gave credence a view supporting international significance. The gorges, blind valleys, springs, caves and other karst features, including the probable exhumed Devonian karst features around "Bung Harris Dam", are an important part of the suite of Australian karst landscapes.

Thus, this aspect of the significance of Cooleman Plains rises from regional to national. Table 2 above gives an overall assessment of scientific significance of Cooleman.

Since 1989, work conducted by Eberhard and Spate (1995) and reviewed in Thurgate et al. 2001a, 2001b, has demonstrated the presence of a number of aquatic crustaceans of considerable significance. These aid in our understanding of the evolution of the fauna of continental Australia (George [Buz] Wilson, Australian Museum, personal communication).

There is a rich archaeological significance at Cooleman with many artefact scatters, several burial sites; parietal art has been reported in the past (Spate 1997).

There is much more to Cooleman Plains than scientific values as is evidenced by the number of visitors – including many who have come back frequently over many decades. It is important for recreation – active and passive, as a destination, for its indigenous and European heritage of occupation, grazing, use of caves and as a gateway to other parts of the Park notably the Bimberi Wilderness and Namadgi National Park. Its significance for these sorts of values is at a least a regional level.

Its values are dependent on the maintenance of its natural values on one hand and on the various cultural features on the other. It provides both a significant destination and access route – features which render it susceptible to both "being loved to death" and to being over-managed. Keeping the Blue Waterholes area in a natural condition but allowing heavy use is a particular challenge.

Cooinbil

The tiny Cooinbil karst (<2 ha) is an interesting site, containing solutional features such as karren, have formed on a small limestone outcrop. Although located very near the intensely used Cooinbil Hut horse use area it is not disturbed by current park use. It is of local significance.

Yarrangobilly

The Yarrangobilly Management Unit covers an area of 18,211 ha and includes the large Yarrangobilly karst area. It is delineated by the catchment of the Yarrangobilly River above Little Glory Hole Creek. Parts of the Management Unit lie within the Bogong and Goobarragandra wilderness areas. It also includes the Jounama Pine Plantation (currently being harvested and returned to native species) which partially overlies the karst. An enigmatic area, to the west of the Jounama Pine Plantation, is of uncertain hydrological affinities and lies in the Jounama Creek catchment (rather than that of the Yarrangobilly River).

The Yarrangobilly karst area can be arbitrarily split into three broad zones based largely on the degree of disturbance, visitor use and management intensity. From south to north these are:

1. The Visitor Services Zone (Yarrangobilly Show Caves Precinct; up to the north side of Harriewood Gorge and including Grotto and Castle Caves).

This area contains a range of recreational opportunities range from guided cave tours, swimming in the thermal pool and caving, to sightseeing, picnicking camping, walking and fishing.

2. The so-called Yarrangobilly "plateau" (from Harrie Wood Gorge to the north side of Wombat Creek (the creek-line along which Yans Crossing Fire Trail runs) – including all drainage to Coppermine Cave). Cave access is tightly controlled; the area is subject to little disturbance (other than the presence of the Snowy Mountains Highway). The area including the former Yarrangobilly racecourse, Garnet Hill, Yarrangobilly Village, Jounama Pine Plantation and a small area in the headwaters of Jounama Creek around GR 305 567 (Yarrangobilly 1:25,000) outside of the Yarrangobilly Management Unit.. Much is intensely disturbed, heavily used for recreation and for pine harvesting and subsequent rehabilitation.

However, the area is considered in one block in the discussion below.

There are several hundred caves in the area as well as a large number of other karst features (such as blind valleys and pinnacle fields like "The Tombstones"), endemic plants and animals (including rare and endangered species, Downing and Oldfield (2002) and a considerable number of European cultural features. The number of Aboriginal sites and cultural features appears to be limited although this is probably an artefact of lack of knowledge rather than actual situation. This is changing through better communication with the Local Aboriginal Land Council and with identification of whole-of-landscape values as well as specific sites.

Sir Terence Murray reported finding numerous Aboriginal bones and removed a skull from a cave in 1839 (Mowle, 1891; Spate, 1997). Aboveground, the presence of numerous stone flakes in Rules Creek Valley is indicative of an aboriginal campsite (NPWS, 2000). More recently, excavations in Drummond Cave (Y259) unearthed burnt bones and stone artefacts, which indicate people visited the site on several occasions over the time interval of 9700-9120 years before present. This more than doubled the previously known 4500 year history of occupation above 1000 m ASL in the Australian Alps (Aplin et al., 2010; Ford and Aplin, 2010).

The scientific significance of the Yarrangobilly karst area is summarised in Table 2. The levels range from local to national. The cultural significance is unquestioned with similar levels of significance. These assessments have been reinforced most recently by NPWS (2000). There are a suite of rare and endangered plant and animal species here as well as limestone-endemic species such as the recently confirmed blackthorn species, Bursaria calcicola and B. spinosa var. lasiophylla. The presence of this latter variety is of considerable interests as it is the host for the Bathurst Copper Butterfly, Paralucia spinifera, and its associated ant, Anonychomyrna itinerans. If the Butterfly is confirmed at Yarrangobilly it will be a very large extension of range for this rare and endangered species. There are significant subfossil deposits within some of the caves and, as stated above, there are significant archaeological and palaeontological sites.

The area has very considerable aesthetic and recreational significance. The gorges, blind valleys, springs, caves and other karst features are an important part of the suite of Australian karst landscapes. A very large number of recreational activities are undertaken within the Management Unit. The area is recognised nationally as a site of very great recreational value (Davey 1984).

Jounama Creek/Black Perry Mountain

The area consists of a north-westerly extension of the Silurian Yarrangobilly Limestone in the valley of Jounama Creek and its tributary Cave (or Clive) Creek. Most of the carbonate rocks are a highly metamorphosed and mineralised ridge which forms Black Perry Mountain. A single small, and unusual, cave is found high up on the eastern flank of the ridge and 15 small caves are found in the Cave Creek valley to the north of Black Perry. Other areas of limestone may exist on Jounama Creek below the Cave Creek junction at Pether's Lode. The area is within the Bogong Wilderness and is accessed by foot from the Snowy Mountains Highway.

The significance of the karst and caves is probably little more than local although the cave on Black Perry may rank more highly than this. The karst and associated adjoining skarn deposit is uncommon in NSW and is of state to national significance. At least one mineral present here (babingtonite) is only known from two other localities in Australia (Gole 1981, Mindat, 2014). The caves in caves along Cave Creek may have Indigenous values.

Indi

This small area consists of two small limestone lenses north of McHardies Flat on the upper Murray River. There is one limestone outcrop further north with one high level, albeit small cave. They are accessed via 4WD tracks from Victoria (with little prospect of these being closed) and is essentially isolated in winter. Indi is within the Pilot Wilderness

The area is unusual in that the 13 small caves are perched on a small terrace 10-15 m above river level. It is not known if this bench is structural or a river ter-

race cut in the limestone. The caves appear to be hydrologically isolated by thick clayey, possibly glacial outwash sediments in the lower parts of the caves and thus small ephemeral lakes exist in wetter periods.

The significance of the Indi karst is local to regional (Table 2). Although some research on the geomorphology of the karst and its regional setting has been conducted nothing has been published.

The regional level of significance here arises from the perched watertable, the possible palaeoclimatic significance of the clay sediments and from the associations with Aboriginal prehistory (Spate 1997). The area has not been adequately surveyed for its biospeleological attributes – especially aquatic invertebrates.

Cowombat Flat

Cowombat Flat, precisely on the border between Victoria and New South Wales, possesses a few small dolines demonstrating that there are both soluble rocks and a subterranean drainage system. A karst system must be present albeit in an area of only a hectare or so. The New South Wales part is within the Pilot Wilderness and is only of local significance.

Ravine (O'Hares Creek/Lobs Hole)

Although there is a great deal of limestone at Ravine most is very thinly bedded, flaggy or impure and thus karst features are absent although there are persistent rumours of caves – and one photograph of a cave entrance alleged to be in O'Hares Creek has been seen. Searching over many years has not revealed any caves in the Devonian limestones (which are one of the two areas within the Park separately entered on the former Register of the National Estate for the geological values – for their fossils in Ravine's case). The Lick Hole Formation is an exemplary example of Early Devonian limestone rich in fossils and displaying changes in depositional environments (Flood 1969, Pedder 1971, Percival 1979).

However, groundwater has dissolved calcium carbonate from the Devonian limestones. This has been re-deposited in a number of places where the waters of the ephemeral streams tumbles over the cliffs of the Milk Shanty Walls. In these sites there are large tufa banks containing some caves of construction, massive stalactites and other karst forms. These may be the largest deposits of tufa south of Far North Queensland. They probably have been deposited very recently – probably through the Quaternary Period.

Ravine has been highly disturbed by grazing, mining, timber cutting, fire and weed invasion. It appears to be somewhat of a rain shadow area and soils are generally infertile

WHAT IS NEW?

Since earlier assessments (e.g. Spate 2003, 2006) of the values of the Kosciuszko karsts little has changed in our knowledge of the seven areas except at Yarrangobilly where there have been considerable advances on two fronts. Firstly, we have the work of Dr Pauline Treble, Prof Andy Baker and their colleagues from ANSTO, the University of New South Wales and elsewhere looking at karst processes especially in relationship to fire. Secondly, there is the work of Fred Aplin and Fred Ford in regarding the vertebrate palaeontology and the occupation of the high country by Indigenous people.

Yarrangobilly Caves has hosted, and continues to work with, researchers from world-class institutions studying the above and belowground environment. Yarrangobilly has the only long-term sub-alpine cave monitoring program in Australia and the first experiment designed to investigate impacts of fire on cave drip water. The research has resulted in seven peer-reviewed journal publications with others to come. A summary of the research projects by Treble et al. (2016) was published in Caves and karst of Yarrangobilly by the Sydney Speleological Society. Here, we summarise the main themes of the research, the methods used and consider the significance of the findings at a national and international level.

Understanding the hydrological processes that affect speleothem development is a central research theme at Yarrangobilly. Campbell et al. (2017) characterised the hydrological influences on one speleothem in Jersey Cave to determine its suitability as a proxy record, whereas Markowska et al. (2015) used a network of drip sites in Harriewood Cave to understand drip water evolution in the epikarst. Both studies demonstrated that it is necessary to consider hydrological processes affecting individual sites for paleoclimate interpretation. Coleborn et al. (2016a) observed a different mechanism affecting cave hydrological processes: the intermittent daily water abstraction by vegetation. They found that transpiration from the overlying vegetation caused daily oscillations in drip discharge. Coleborn et al. (2016b) identified vegetation as a potential variable affecting karst processes. Soil CO2 concentration was lower at burnt sites five years post-fire because there was less vegetation. Lower soil CO2 concentrations can decrease calcite precipitation resulting in reduced speleothem growth (Coleborn et al. 2016b). These findings support a growing research area examining the impact of vegetation on karst processes and speleothem paleoclimate proxies.

Research at Yarrangobilly has also focussed on investigating the relationship between climate and surface conditions and speleothem formation. Tadros et al. (2016) demonstrated a relationship between El Niño Southern Oscillation (ENSO) and drip water trace element concentration. This informs the interpretation of palaeo-rainfall conditions in speleothem records. The impact of fire on drip water geochemistry was investigated using an experimental prescribed fire above South Glory Cave. There was a significant geochemical response to fire that could be used to identify fire events in speleothem records.

A flowstone sample from Jersey Cave was used to assess climate during the period 99-37 ka (Webb et al. 2014). They found that aridity peaked before a growth hiatus from 84 and 47 ka and the recommencement of growth was associated with greater moisture availability. This speleothem record is important because it covers a period that includes the megafauna extinction and the arrival of humans in Australia.

Cave drip discharge monitoring is a common research technique used at Yarrangobilly. The use of 'Stalagmate' commercial drip loggers makes it possible to generate long-term, high temporal resolution drip hydrographs. These data are used to study the cave discharge response to rainfall and build cave hydrological models. Markowska et al. (2015) used a combined conceptual and box hydrological model to explain five drip regime types at Harriewood Cave. Campbell et al. (2017) used drip monitoring and geophysical data to develop a conceptual model that would inform a simple drip model. The two studies independently showed that both caves can be represented by a two-store model (soil and epikarst).

Drip water geochemical properties such as trace metal concentration and stable water isotope (δ18O and δ2H) composition are monitored at Yarrangobilly Caves. Drip water samples were collected on a bi-monthly basis for two years from 18 sites in South Glory Cave to investigate the short-term impact of fire on drip water geochemistry. While, Tadros et al. (2016) used a longer dataset collected from three sites fortnightly from 2007-2013 to investigate the potential of using trace element and stable oxygen-isotope (δ18O) variations as palaeorainfall proxies. Drip water geochemical data is important to identify short-term responses to surface conditions and long-term trends in climate.

Surface monitoring provides an essential context to in-cave monitoring programs and is an important aspect of Yarrangobilly research. Tadros et al. (2018) collected aerosol samples from 2013-2017 and found that the aerosol sources at Yarrangobilly included automobiles, fires, coal fired power plants, windblown soil and sea salt from the Southern Ocean. Data from a weather station installed in 2011 above Harrie Wood Cave has also provided valuable long-term data including soil moisture, soil temperature, air temperature and wind direction which has been used in numerous research projects (Coleborn et al., 2016a, Tadros et al., 2016; Markowska et al., 2015).

The research at Yarrangobilly is significant for Australia as it includes the longest cave monitoring program in the only sub-alpine cave site monitored in Australia (Harrie Wood Cave). The long-term monitoring provides information about the cave response to changing climate and recurring events such as ENSO (Tadros et al., 2016). The paleoclimate record from stalagmite YB-F1 has increased knowledge about past climates in southeast Australia during the period 99-37 ka (Webb et al., 2014). The hydrology of individual caves has been well-characterised, resulting in a comprehensive understanding of the Yarrangobilly Caves system (Markowska et al., 2015; Coleborn et al., 2016a; Campbell et al., 2017). Moreover, this cave system has been placed in an international context by the inclusion of data in meta-datasets (Baker et al., 2016).

The research findings from Yarrangobilly are internationally significant. New protocols have been developed for assessing the fidelity of a speleothem (Campbell et al., 2017) and for determining the relative importance of drip hydrological trends (Coleborn et al., 2016a). Surface processes such as tree water use and bushfires have been identified as potential causes of erroneous paleoclimate record interpretation (Coleborn et al. 2016a, other papers in preparation).

Yarrangobilly research is high quality and has been published in high-ranking journals. The research has primarily focussed on karst hydrological processes and climate processes affecting speleothem proxy paleoclimate records. Additionally, there are long-term monitoring campaigns for cave drip discharge, drip geochemistry, surface conditions. The research has significant findings for Australia and the wider speleothem proxy paleoclimate record community.

The second significant study arises from work carried out by Ken Aplin and Fred Ford, formerly of CSIRO, who investigated many caves at Yarrangobilly, Cooleman and Ravine looking for bone materials to provide evidence of both old and new faunal elements. Eleven sites were investigated with ages from the present back as far as an estimated age of one to four million years (Ford and Aplin, unpublished CSIRO Sustainable Ecosystems report, 2010).

The findings ranged from surficial deposits, layered unconsolidated and consolidated deposits, to an-

cient fossiliferous breccia. Some megafaunal species are represented. Serendipitously, one site, Drummond Cave (Y259), proved to be an Early Holocene human occupation site dating to 9700 calibrated years before present (Aplin et al. 2010). This is highest known occupation site within the region. The presence of stone artefacts and burnt bone indicated the site was used between 9700 and 9120 years before present but infrequently thereafter.

Examination of the Drummond Cave bone material has led to some insights into the coming and going of various mammalian species through the last 10,000 years indicating the regional extinction of such species as Gymnobelideus leadbeateri and Pseudomys higginsi. The fossiliferous breccia possibly predates the arrival of the genus Rattus and thus may shine a light on the pre-Rattus rodents.

CONCLUSIONS

The conclusions of this brief survey of the karst resources and their significance in Kosciuszko National Park are that the Park has international, national, regional and local significance in respect of its karst values. Recent research at Yarrangobilly has contributed significantly to our knowledge and recognition of the karst values. But, this has shown that we need more understanding on Yarrangobilly and the other areas. Studies in karst environments have much to offer us in terms of understanding climate change, the role of fire in geological and biological systems in karst processes and in unravelling archaeological and palaeontological histories. The biospeleological aspects also need further elucidation.

Threats to the karst largely arise from fire, visitor pressures, spread of weeds and of the impacts of wild horses. Fire can affect karst landforms directly by the spalling and calcining of bedrock outcrops destroying surficial karren features (Holland 1984, Spate 2003a, b, c), and by affecting karst processes as described above.

Visitor pressures can be high, but localised, at Yarrangobilly and Cooleman whilst the other areas receive very few visitors largely because of their remote locations and lack of knowledge of the sites. Five are in or partially within designated wilderness areas.

Blackberry (Rubus fruticosus) is found in varying densities in a number of the parks karst environments including Jounama Creek, Indi, Ravine and Yarrangobilly, where it forms dense thickets especially along gullies, creeks and rivers. At Ravine, blackberry infestations pose a major threat to the natural development of tufa terraces, since the type and nature of organic debris present, as well as hydrological regimes and microclimate are key factors that influence tufa deposition. Recent funding has enabled significant weed control programs to be implemented at Cooleman (targeting sweet briar and willow) and Yarrangobilly (targeting blackberry and elms) and have been highly successful in the areas treated.

Feral animals, particularly wild horses, are an issue in many of the karst areas and have caused considerable damage at Cooleman and Cowombat Flat to streams and swamps. Bedrock features such as the very fragile A-tents at Cooleman appear to have been directly destroyed by horse hooves.

Aside from horses, at present the impacts of introduced fauna on the values of the parks karst are relatively minor and limited to localised rooting of the ground by pigs and burrowing and grazing by rabbits. These pests are controlled in accordance with the Southern Ranges Regional Pest Strategy (OEH, 2013).

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