Cave and Karst Management in Australasia XX

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the triple bottom line

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Photo by Black Water Rafting guide - Steve Greed
Bottom photo: Marjorie Coggan in Peters Palace, Rumbling Gut Cave, Waitomo, New Zealand
Photo by John Brush

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What is special about Australian Caves and Karst?

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Abstract

Australia has 19 World Heritage Properties – many of these have karst-associated values. We had one UNESCO Global Geopark until it was torpedoed by stupid political ideologies. Australia has a program of recognising significant 'national' landscapes – again many of these have karst values and provide some recognition of karst.

There are other areas such as the Nullarbor limestone karst and wonderful sandstone karst and pseudokarst landscapes of northern Australia which are worthy of World Heritage or similar status which are again precluded from proper recognition by Australia's political and cultural systems.

This paper reviews the karst areas of Australia in regard to their international and national significance. In keeping with the conference themes of 'people, planet, profit' comment will be made on what Australia's karst resources offer the nation.

Introduction

In 1975 Joe Jennings published a paper titled *How well off is Australia for karst and caves? A brief geomorphic estimate* in which he suggested that the continent had a paucity of cave and karst features with only Tasmania approaching the situation in the rest of the world. Much has been added to our knowledge of Australian karst and caves since that time. Whilst Jennings' estimate is still fundamentally correct, what has changed dramatically is that the values of these resources have achieved international and national recognition through instruments such as World Heritage listing. There are other important areas that have received little recognition or are poorly sampled in reserves.

This paper will review various types and levels of recognition and see how inclusive they are in recognising Australia's karst and cave environments. Firstly what sorts of values can we now identify for our karst areas? Ken Grimes provides an overview with his map of Australian karst regions (Figure 1).

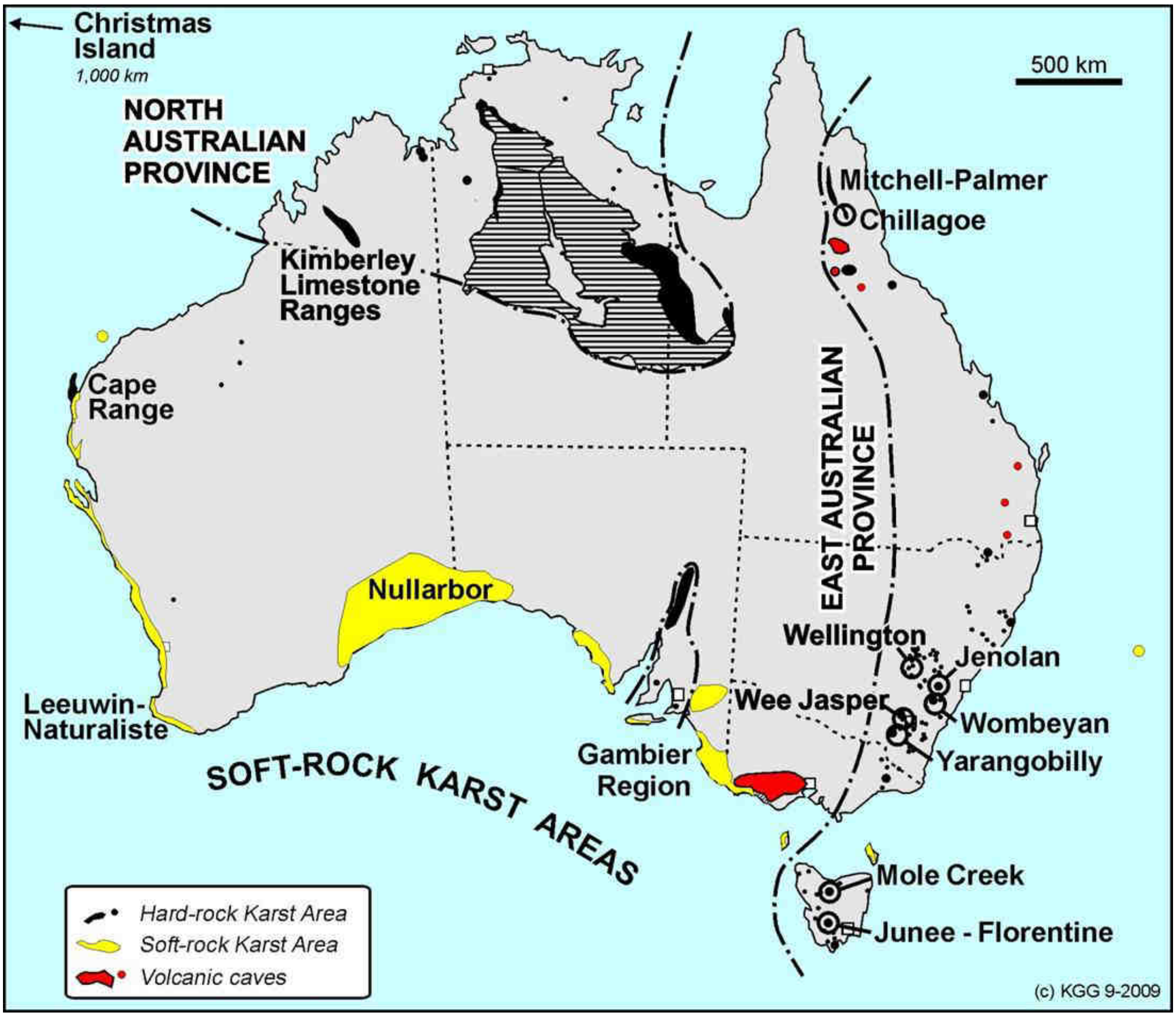

Figure 1. Australian karst regions (courtesy Ken Grimes).

Some of the values that can be ascribed to our karst, cave and pseudokarst resources include:

- Largest extent of young dune limestones in the world.
- Significant karst caves and landforms in many areas.
- Incredible antiquity of Jenolan and perhaps other caves.
- Significant rock art in both karst and pseudokarst caves.
- Remarkable palaeontological values.
- Largest semi-arid to arid limestone region in the world.
- Significant subterranean biodiversity.
- Significant pseudokarst caves and karst features in sandstone, granites and laterites.
- Spectacular and unusual scenery.
- Significant aquifer systems.
- Significant contribution to local economies through cave tourism and scenery-based tourism.
- Etc.

These values, in many cases, are within relatively well-protected and managed reserve systems although that coverage can be very patchy especially in karst regions such as those with the young dune limestones.

World Heritage properties

Australia has 19 properties inscribed on the World Heritage list in recognition of their "outstanding universal value". Some of these are serial sites. These are shown on Figure 2 and their values, dates of inscription and the presence/absence of karst values are shown in Table 1.

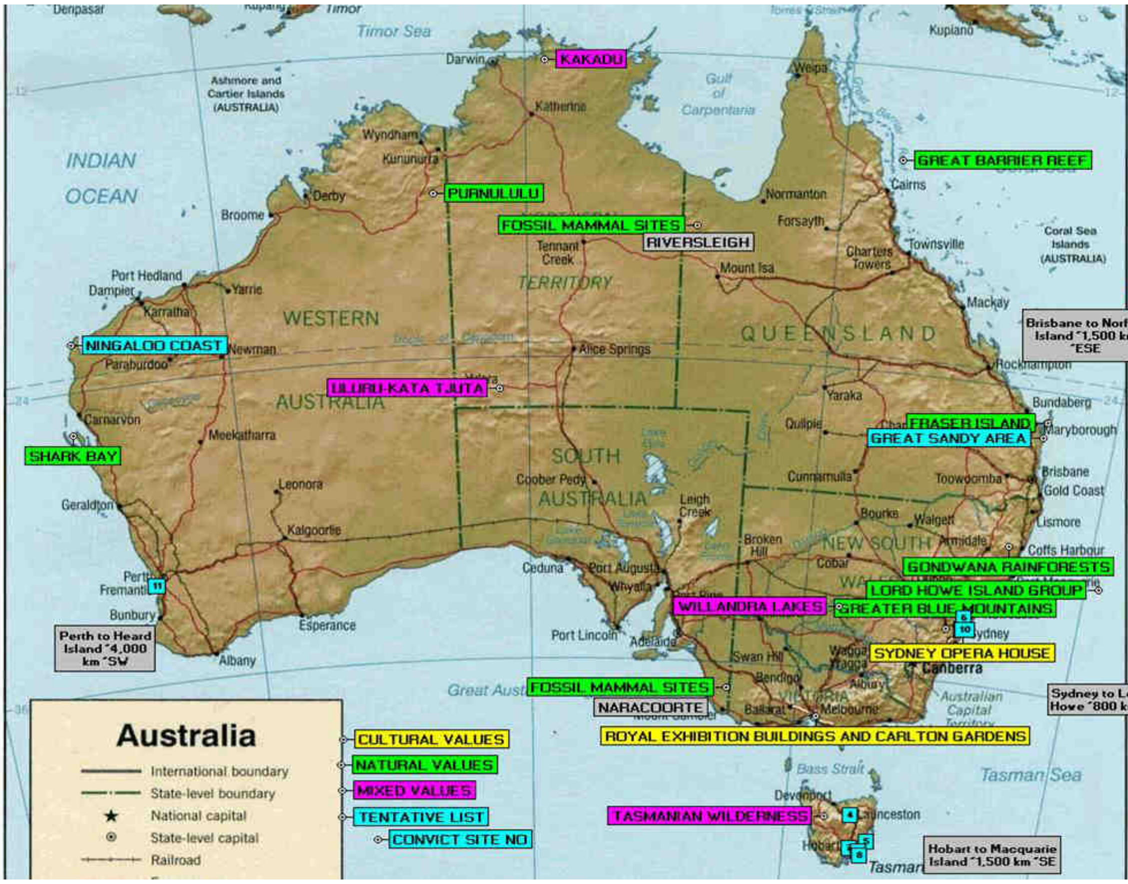

Figure 2. Australian World Heritage properties (note that the Ningaloo Coast and the Australian Convict Sites were in fact inscribed in 2010).

AUSTRALIAN WORLD HERITAGE PROPERTIES			
World Heritage Property [number of sites]	Inscription values	Date of inscription	Karst values
Great Barrier Reef	4 N	1981	Yes
Kakadu National Park	3 C 2 N	1981	Yes (P)
Willandra Lakes Region	1 C 1 N	1981	No
Tasmanian Wilderness	4 C 3 N (!)	1982	Yes
Lord Howe Island Group	2 N	1982	Yes
Uluru-Kata Tjuta National Park	2 C 2 N	1987	Yes (P)
Heard & McDonald Islands	2 N	1987	Yes (P?)
Wet Tropics of Queensland	4 N	1988	Yes (P)
Shark Bay	4 N	1991	Yes
Fraser Island	3N	1992	No
Australian Fossil Mammal Sites [2]	2 N	1994	Yes
Gondwana Rainforests of Australia [~50]	3 N	1996	Yes (?)
Macquarie Island	2 N	1997	Yes (P)
Greater Blue Mountains Area	2 N	2000	Yes
Purnululu National Park	2 N	2003	Yes (P)
Royal Exhibition Buildings & Carlton Gardens	1 C	2004	No
Sydney Opera House	1 C	2007	No
Ningaloo Coast	4 N	2010	Yes
Australian Convict Sites [11]	3 C	2010	?
Great Sandy Area (2010 Tentative List - Extensions to Fraser Island WHA)	3 N	-	No

Table 1. Australian World Heritage properties and their values. Notes: N = natural values; C = cultural values; P = pseudokarst.

From Table 1 for the 19 inscribed properties it can be seen that:

- Seven have karst values.
- Five have pseudokarst values.
- One or more of the 50 or more sites in the Gondwana Rainforests of Australia property probably has karst values.
- There are probably lava (pseudokarst) caves on Heard Island.
- Stretching the point maybe - the old Fremantle Gaol (Australian Convict sites) has conducted tours of an underground labyrinth of tunnels used to obtain groundwater for the gaol!

Thus 14, perhaps 15, of the 19 properties have some connection with karst or karst-like landforms. What are these connections?

- Great Barrier Reef – the "blue holes" of Cockatoo Reefs and elsewhere (Figure 3).
- Kakadu National Park – karstic scenery and caves and cultural values associated with them.
- Willandra Lakes Region – none
- Tasmanian Wilderness – very significant karst and cultural values associated with caves.
- Lord Howe Island Group – caves and coastal karst landforms in Quaternary dune limestones.
- Uluru-Kata Tjuta National Park – pseudokarst features with associated cultural values.
- Heard & McDonald Islands – probable lava caves.
- Wet Tropics of Queensland – pseudokarst features such as the Mt Hypipamee Crater (Figure 4).
- Shark Bay – large solution features (probable dolines) and minor caves on Dirk Hartog Island. Coastal karst landforms.
- Fraser Island – none
- Australian Fossil Mammal Sites [2] – caves, relict caves and other karst features.
- Gondwana Rainforests of Australia [~50] – limestone karsts exist in the Macleay Valley and elsewhere.
- Macquarie Island – lava caves.
- Greater Blue Mountains Area – Jenolan Caves and many sandstone pseudokarst features.
- Purnululu National Park – the striking "beehive" and other pseudokarst features.
- Royal Exhibition Buildings & Carlton Gardens – none.
- Sydney Opera House – none.
- Ningaloo Coast – large range of caves and other karst features and very significant subterranean biodiversity.
- Australian Convict Sites [11] – man-made tunnels under the Old Fremantle Goal.

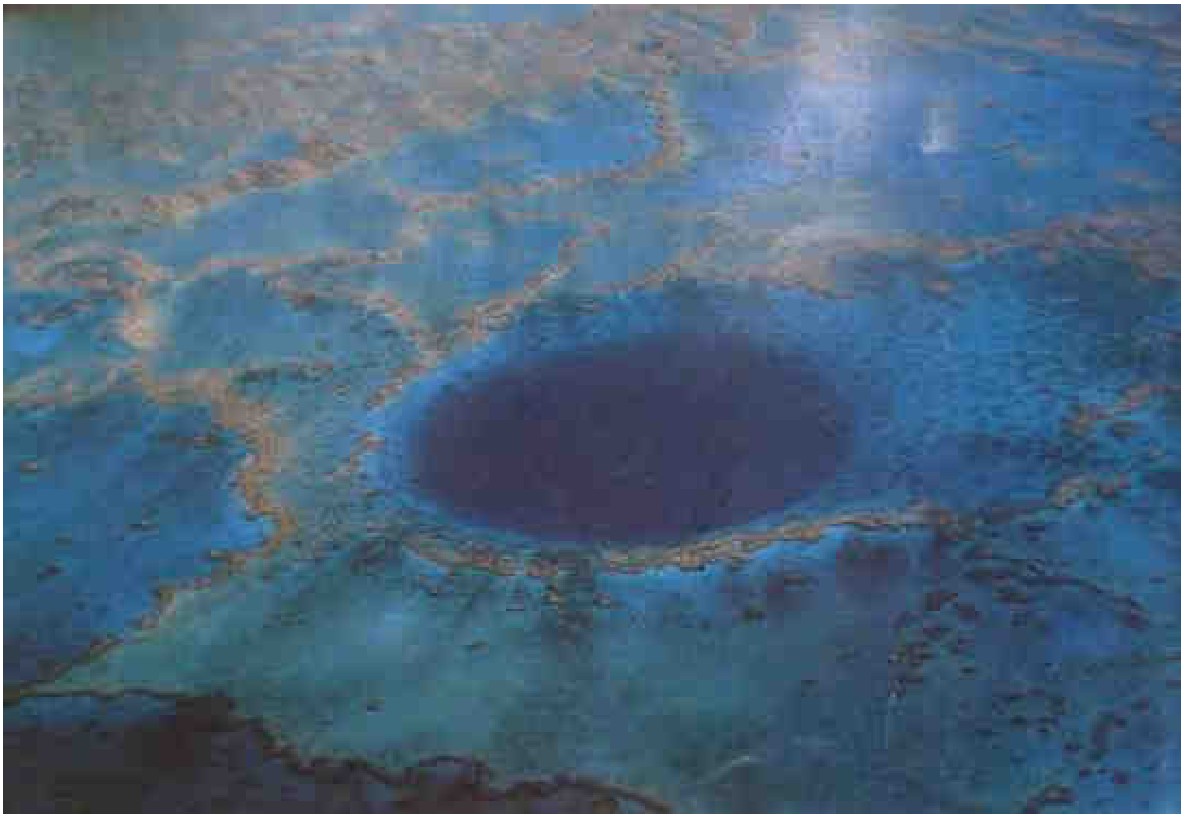

Figure 3. Blue Hole in Cockatoo Reef, Great Barrier Reef World Heritage Area.

Figure 4. Mt Hypipamee Crater, Wet Tropics of Queensland World Heritage Area.

Ramsar sites

Other than World Heritage, how else may Australia's karstic heritage be recognised? Of the 66 Ramsar Convention sites in Australia at least three have karst values. [*The Ramsar Convention on Wetlands of International Importance … is an international treaty for the conservation and sustainable utilisation of wetlands. It is named after the city of Ramsar in Iran, where the Convention was signed in 1971*]. Two of these are on Christmas Island (one may have been damaged by Howard's detention centre); the other is Picanninie Ponds in South Australia.

Hosnies Springs is of particular interest. These are freshwater springs at the contact between the underlying volcanics and the over-lying reefal limestones of this rapidly uplifting island as it drifts north to the Wharton Trench. Here there are mangroves 30-40 m tall in freshwater at 24-37 m ASL (Figure 5). The Dales at the western end of Christmas Island are largely constructional features in tufa more dramatic than similar features on the mainland. Picanninie Ponds are quite different – upwelling freshwater in Tertiary limestone producing deep shafts – perhaps under the influence of rising carbon dioxide rich waters of uncertain origins at depth (Webb et al., 2010).

Figure 5. Hosnies Springs Ramsar site, Christmas Island.

Geoparks

The Kanawinka Geopark was recognised internationally as a UNESCO Global Geopark. The Network of Global Geoparks is based on the following criteria:

- To encourage understanding of Earth Science.
- To enhance sustainable management of resources.
- To provide education opportunities.

However, the concept seems much misunderstood by federal bureaucrats. The global status was withdrawn following representations from the Federal Government. To their great credit, the seven local governments in South Australia and Victoria have continued to support the Kanawinka Geopark. The Geopark contains 58 separate geosites in five precincts (Figure 6). Many of the geosites are karst features in the Tertiary and Quaternary limestones of this area.

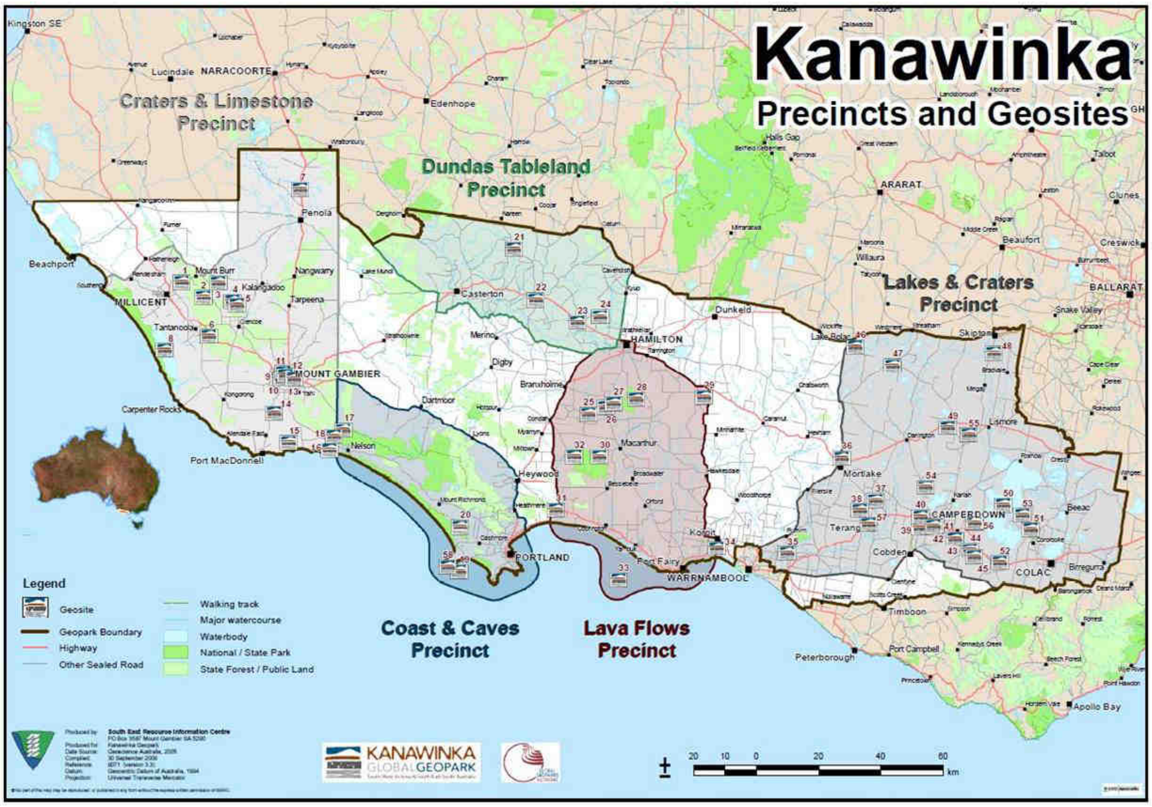

Figure 6. Kanawinka Geopark, South Australia and Victoria.

Other geopark proposals have been discussed in five states in addition to Victoria. It seems unlikely that these will proceed further at this time. A number of countries are currently establishing or have established national facilities (e.g. Brazil, Canada, Chile, China, Italy, South Korea) to develop geoparks and ultimately seek listing as UNESCO Global Geoparks.

Australian National Landscapes

Recently the concept of Australian National Landscapes has been developed largely by Tourism Australia and other interested parties. In the words of Bruce Leaver (pers. comm.) a national landscape "*is an offer of a nature/heritage experience to a tightly defined target market with a characteristic profile. The first stage in NL roll out is a destination branding process that identifies the distinctive experience*". Sixteen national landscapes have been identified (Figure 7). Most of them contain World Heritage areas. The boundaries are deliberately "*fuzzy" to define "an 'experience boundary' and a site pleading to be 'in' or 'out'* [is] *only relevant if* [it] *contributed to the branded experience*" (Leaver pers. comm.).

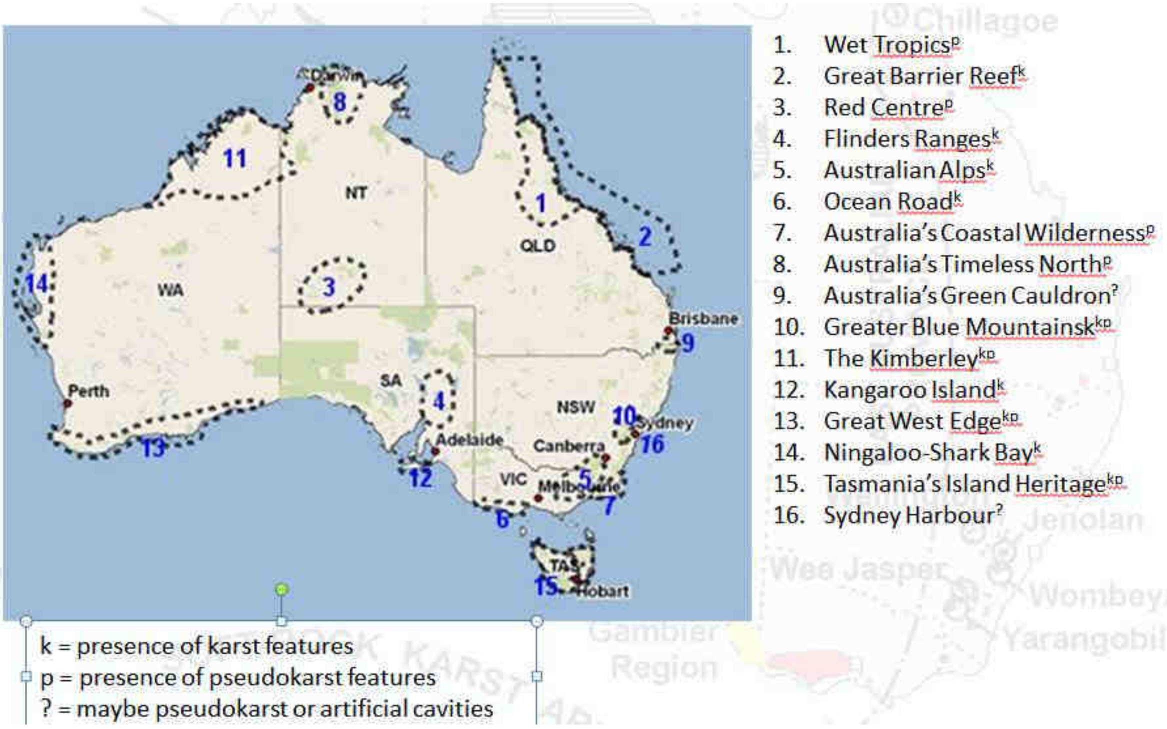

Figure 7. Australian National Landscapes (Tourism Australia website). Superscripts indicate the presence/absence of karst and pseudokarst.

Nation-wide assessment of Australia's karst and pseudokarst

In 2006, the Heritage Division, within the then Commonwealth Department of Environment, Water, Heritage and the Arts formed the view that a simple and effective framework for the comparative analysis of karst values across Australia had not been developed. Geological and geomorphological approaches to enable comparative analyses had been developed by various authors, however, karst sites have not generally been considered holistically, for example the significant biodiversity values that are known for many karst areas have often not been considered, or have been overlooked.

A decision was made to hold an expert workshop to allow assessment of karst sites around Australia by identifying the most significant karst sites, their outstanding values and why these sites are of higher significance than other examples. Many of Australia's karst scientists were invited to participate by preparing position papers on areas they considered important. These were discussed at a two-day workshop in Canberra and with remarkable unanimity 14 karsts were considered nationally significant (Figure 8). Many of these are within World Heritage areas, Australian National Landscapes or have Ramsar sites.

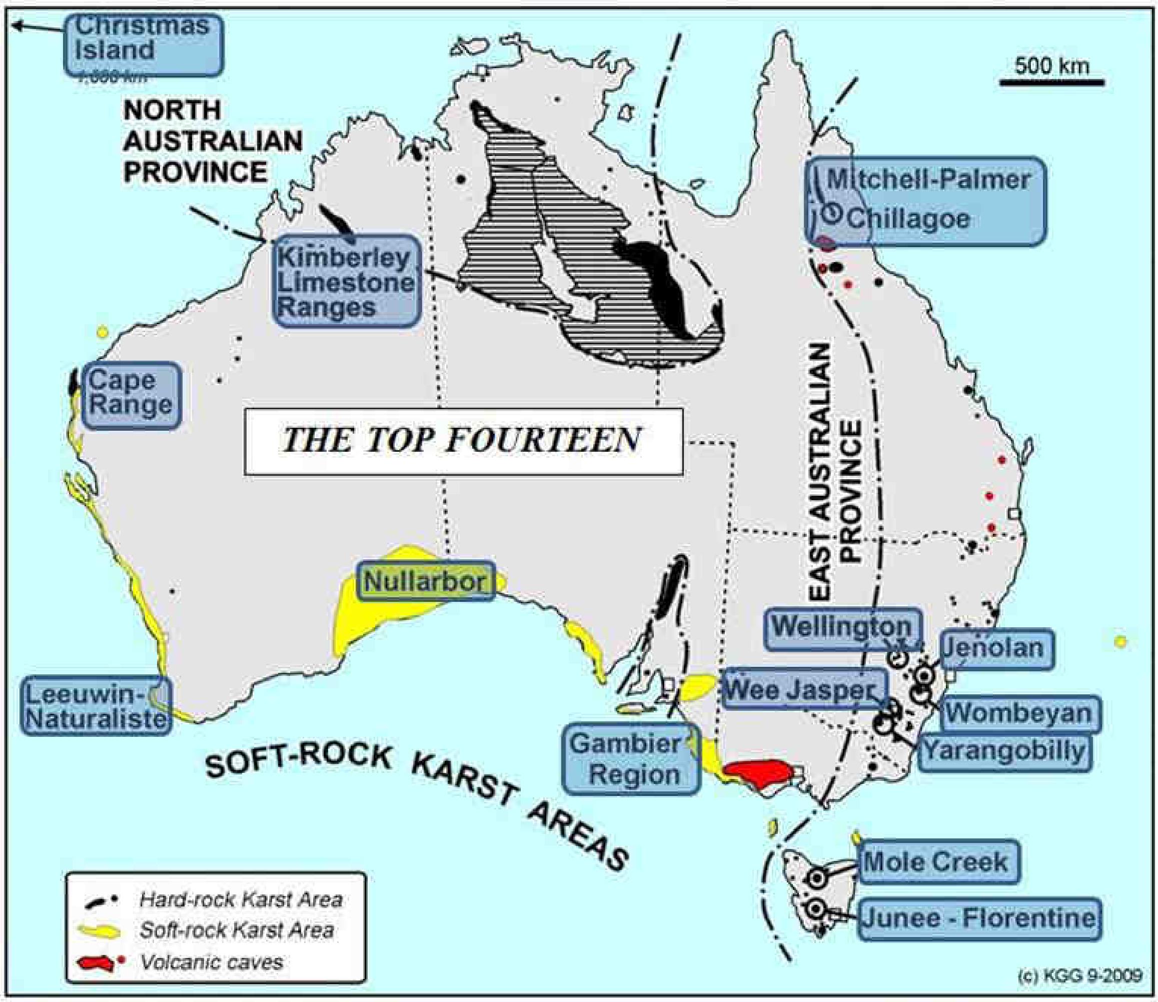

Figure 8. Fourteen karst areas identified as nationally significant by the Framework for Karst Values Workshop, Canberra, April 2006.

Discussion

It seems that Australian karst and caves are relatively well recognised by international and national instruments. However there are three aspects which arise.

Firstly, the Nullarbor karst has long been considered to be of "outstanding universal value" (e.g. Davey et al., 1992). Much of the Western Australian portion is leased for cattle grazing with a few areas of reserved land. Some of these reserves are quite extensive but important areas such as Mundrabilla Station are excluded. Due to the different land tenures and systems pertaining in South and Western Australia, it would seem that inscription of the Nullarbor as a World Heritage site is as long away as ever. It does not fit in with the concept of national landscapes.

Secondly, the Gregory karst should have been included in Karst Values Workshop considerations if only for the immense length of Bullita Cave with the thin Supplejack Dolostone (10-17 m, White and White, 2009). There probably would have been 15 nationally significant karst recognised if it had been discussed.

The third area for discussion is the remarkable range of sandstone karst and pseudokarst areas across northern Australia. Purnululu and Kakadu World Heritage Areas do not capture the full range and scale of the sandstone features. Many are "hidden" in Arnhem Land Aboriginal lands (Figure 9) but others such as the Abner Range (Northern Territory, Figure 9) and the Carnarvon Ranges (Queensland) could well make up an extended serial World Heritage nomination with Purnululu and Kakadu.

Figure 9. Ruined City, Arnhem Land (National Library of Australia).

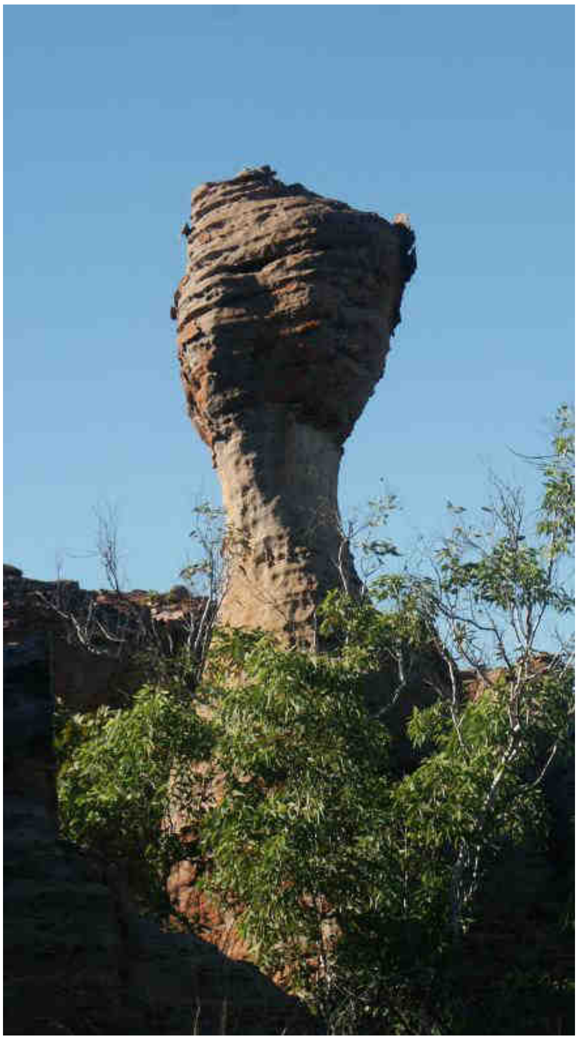

Figure 10. Sandstone pillar in the Abner Range of the Northern Territory.

Acknowledgements

I am grateful for the input of several delegates following the presentation at Waitomo particularly Dr Susan Q White.

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Beyond the Master Plan

Naracoorte Caves World Heritage Area 2013

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Abstract

Naracoorte Caves National Park (NCNP) is a renowned fossil mammal site, co-listed with Riversleigh, North Queensland as a UNESCO World Heritage Area.

Located in the southeast of South Australia it is one of four commercial sites operated under the jurisdiction of the Department of Environment, Water and Natural Resources (DEWNR). These sites operate businesses within distinctive natural settings and Master Planning is being conducted at each location, the recommendations of which will direct future investment.

In 2009 master planning began at Naracoorte.

In 2013 the planning will be completed.

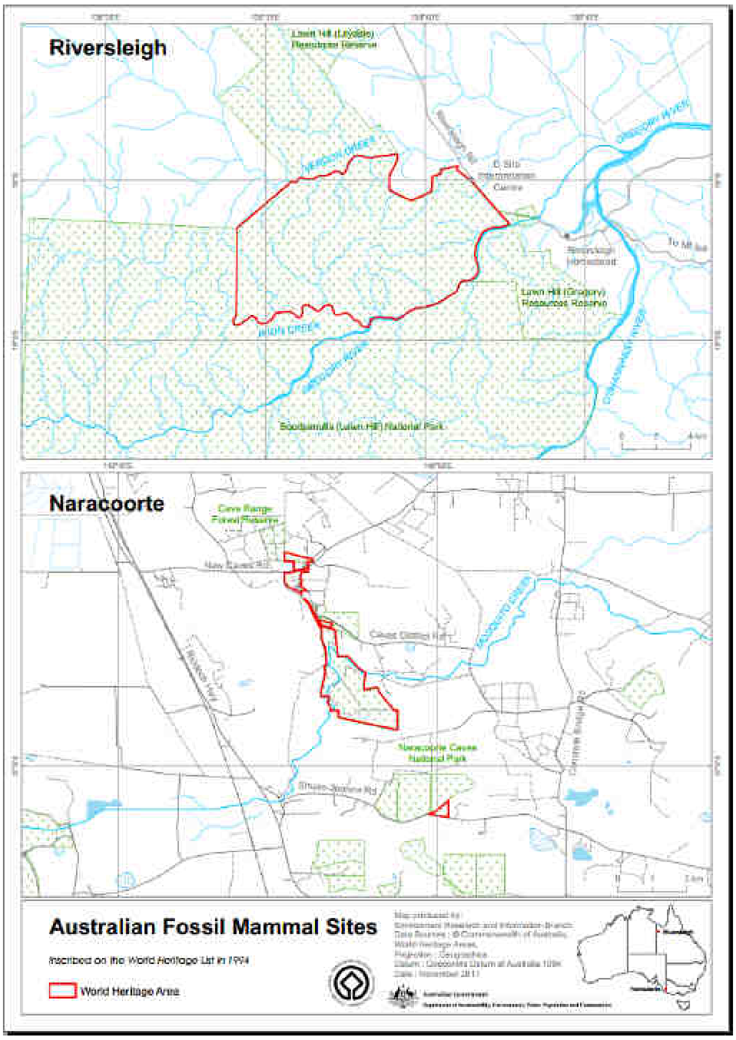
Beyond 2013 DEWNR will implement recommendations from the Plan.

- These will enhance what is currently offered.
- Help enhance the business model.
- Improve productivity.

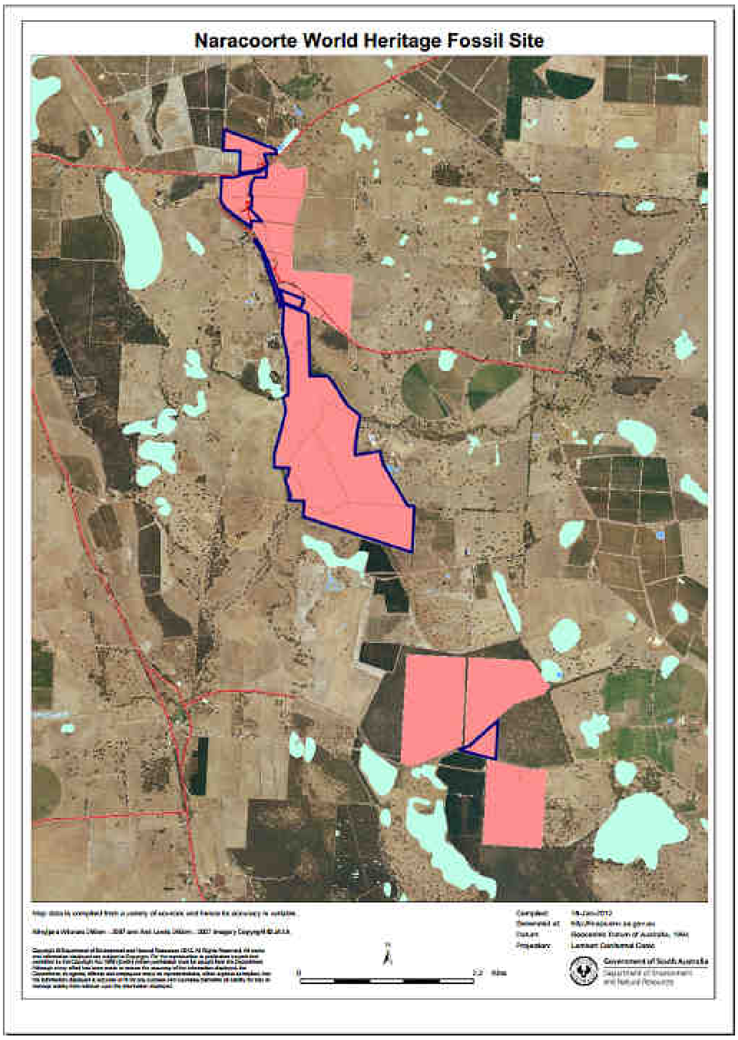
Australian Fossil Mammal Site, Naracoorte

In 1994 UNESCO determined Australia's Naracoorte and Riversleigh fossil sites as being worthy of World Heritage entitlement and co-listed them as the 'Australian Fossil Mammal Sites'. Riversleigh assemblages span the last 10 to 25 million years; Naracoorte's representativeness is younger, being from 500,000 to 17,000 years.

At the fossil bed, Victoria Fossil Cave (Smith) 2012



Map – Riversleigh and Naracoorte WH locations 2011



Naracoorte Caves National Park World Heritage Area 2012

Keeping the Outstanding Exceptional

Naracoorte's Master Plan aims to clarify future directions, help fulfil obligations under the World Heritage Convention and ensure the World Heritage Area remains an integral part of the tapestry of tourism attractions in the Limestone Coast of SA. It aims to be a market leader by providing exceptional and innovative experiences and advancing the financial performance of the site by appealing to a broader range of visitor markets. It is interested in identifying opportunities for other parties to deliver visitor experiences at NCNP WHA.

Before the Master Plan

Prior to establishing its Master Plan process, DEWNR had conducted a review of its education programme (2009) and completed a Visitor Strategy (2010). In 2012 a Branding Strategy & Interpretive Framework was completed, followed by an Interpretive Framework.

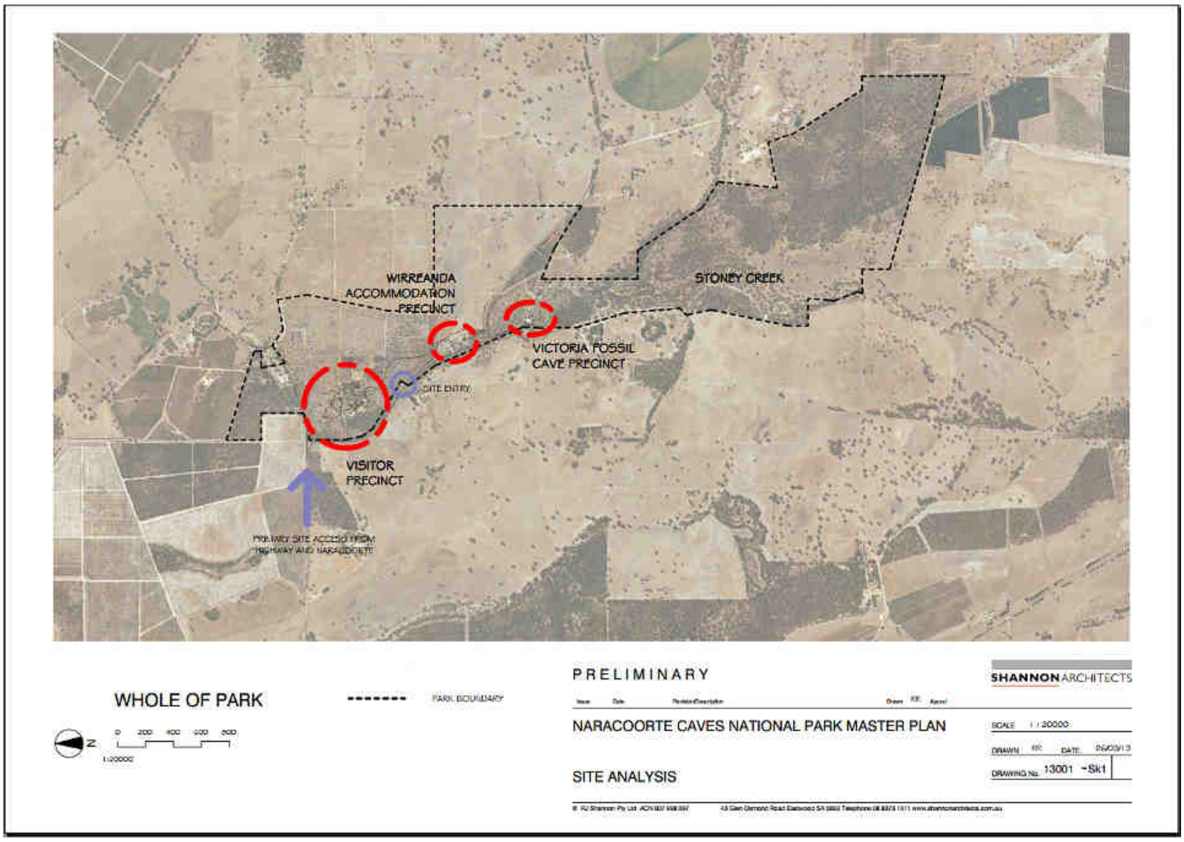
Master Plan Reference Group

The reference group was established to facilitate input from key stakeholder groups – federal, state and local government, state museum, state and regional tourism, local business and tourism, regional development, education and science and Friends of Naracoorte Caves. A range of DEWNR staff are involved, including the site's interpreters and café staff.

Consultants were appointed in 2012. The lead consultant was the designer of the Wonambi Fossil Centre and the Bat Teleview Centre and this history is invaluable.

Site development

For conceptual purposes the consultants divided the Park into four areas - the main Visitor Precinct, the Wirreanda campground & accommodation, the Victoria Fossil Cave Precinct and Stoney Point hiking area. Site development looks to improve the arrival experiences, upgrade car parks, enhance way-finding and improve linkages overall.



Shannon site development map 2012

Cave experiences

Naracoorte's show cave experiences celebrate natural and cultural heritage, comprising science and research around extinct and existing animals, interpretation of human history and geological development and the results of scientific research.

The planning looks to enhance visitor experiences by giving site interpreters additional tools to expand their presentations. DEWNR is planning cave lighting upgrades and some infrastructure improvements. Novice and extended adventure caving activities have been an important part of the offer for many years and are not under Master Plan scrutiny except that they will become more visible, exciting visitor interest and increasing participation.

Alexandra Show Cave (Smith) 2012

Blackberry novice adventure (Bourne) 2006

Stick-Tomato novice adventure (DEWNR) 2012

Built development

The Park's 'visitor' buildings in the main precinct include a café, a teleview centre and a visitor centre (Caves Café, Bat Teleview, Wonambi Fossil Centre).

The Wirreanda camping and accommodation complex caters primarily to schools, but is available for other users.

The scope is to improve visibility and presentation and grow viability for the café, improve the interior of the bat centre and external connections between the centre and the rest of the site. Exhibitions and story telling in the Wonambi Fossil Centre will be revamped as little has changed since its inception.

Caves Cafe (DEWNR) 2012

Bat Teleview Centre (Bourne) 2002

Wonambi Fossil Centre (Bourne) 2002

Flinders Gallery (Bourne) 1999

Diprotodon WFC (Bourne) 2003

The Triple Bottom Line

As a government agency DEWNR operates under a public sector financial model governed by strict rules required for handling public money. The three 'Ps, 'people, profit and planet' are as essential to Naracoorte Caves' business success as to any business, private or public. As an environmental land manager DEWNR's role is to protect and conserve the natural and cultural resource under its administration, benefiting present and future generations. The philosophy of 'planet' is inherent in DEWNR's mandate. The principle of 'profit' is possibly the surprise, but being profitable or cost neutral means the job of protection and conservation is conducted with lesser pressure on the public purse.

'People' of course, are of prime importance whatever the business model.

People (social)

Internally the 'people' component strives for a climate of empowerment and a culture of openness and respect between staff at all levels. The key is to have motivated people with high level customer service skills, ability with social interaction and a willingness to use their initiative. Staff with these characteristics are sought, trained and retained. Good policies, processes and practices support staff endeavours.

As a publicly funded agency DEWNR has a community service obligation (CSO). Active and consistent engagement with its communities of interest is essential for building and sustaining strong external relationships and fulfilling the obligation. Key stakeholders comprise local, regional, national and international communities. Friends of Caves are active volunteers who put hours of time and effort into the Park. Tourism at all levels acknowledges the importance and relevance to economy of a World Heritage site. Science and education sectors utilise the site.

Profit (economic)

Presenting a first class site with high-level customer service and interesting and enjoyable activities that enchant visitors is the key to a profitable outcome. Behind the 'enchanting' of visitors is the serious business of needing to understand their motivations and spending drivers. DEWNR seeks to improve its cost structures, increase profitability and expand revenue opportunities. It must be aware that public agencies can be viewed as having an unfair competitive advantage and this need for neutrality means its entrepreneurship has constraints not felt by private enterprise.

Planet (environment)

As a public land manager the requirement to protect and conserve the Park's natural and cultural assets is a matter of course. Staff look to achieve consistent environmental management practices and should lead by example. Active engagement with key stakeholders meets the challenges of providing access to the National Park within the confines of protection, and meeting World Heritage obligations. The main tools are to educate, inform and build awareness of the resource values and why impact mitigation is essential. Strong partnerships such as with Friends of Caves engender pride in the assets and helps build a support system that filters into the wider community.

Live Attractions

A living attraction at NCNP WHA is *Miniopterus Schreibersii Bassanii,* the Southern Bentwing bat. An endangered species, they breed at NCNP WHA. For many years a South Australia Museum based expert has been providing advice and opinion on the bats. The Friends group is involved with monitoring the population. In 2012 an American Fulbright scholar spent the year at Naracoorte Caves undertaking what has become a baseline population monitoring record. A volunteer is continuing the monitoring in 2013 supported by FONC. All this is fed into site interpretation.

Pink Bat(t)s on the ceiling, Bat Cave, (Bourne) 2003

Miniopterus Schreibersii Bassanii, the Southern Bentwing bat (DEH) 1980

Science and research

Palaeontological involvement at the site has been undertaken in some shape or form since the discovery of the fossil deposits in1969. The most recent work investigated past climate change hoping to identify patterns of change and how these affect the resilience of ecological communities through time. The lessons learnt should help site management and interpret findings to a wide audience.

'Under the Ledge', Victoria Fossil Cave (Bourne) 2003

Third Blanche Cave excavation 'Caring for our Country' (Bourne) 2012

Threats – controls and mitigations

Threats come primarily from significant natural events and humans. Low resilience thresholds are characteristic of cave values and the fossils and the fossil deposits are similarly fragile. Management response against human impact is to control access, require DEWNR permits and EPBC referrals, have properly planned projects, maintain fencing and gates and have trained staff.

There is no formal buffer zone around NCNP WHA and to date this has not been an issue.

Adjacent landowners include forestry, farming and vineyards. In 2011 many small reserve areas adjacent to the NCNP WHA were incorporated into the Park, adding a further measure of protection.

Flooding from major rainfall events has affected the integrity of research excavations but also provided an understanding of how such events worked in times gone by.

Wildfire is a potential threat and DEWNR's regional Park staff have the responsibility for fire management systems. A recent practical response has been to reduce fuel load adjacent to the visitor precinct. Pest plants and animals are an issue. FONC assist DEWNR in control of pest plants while pest animal control is a DEWNR task.

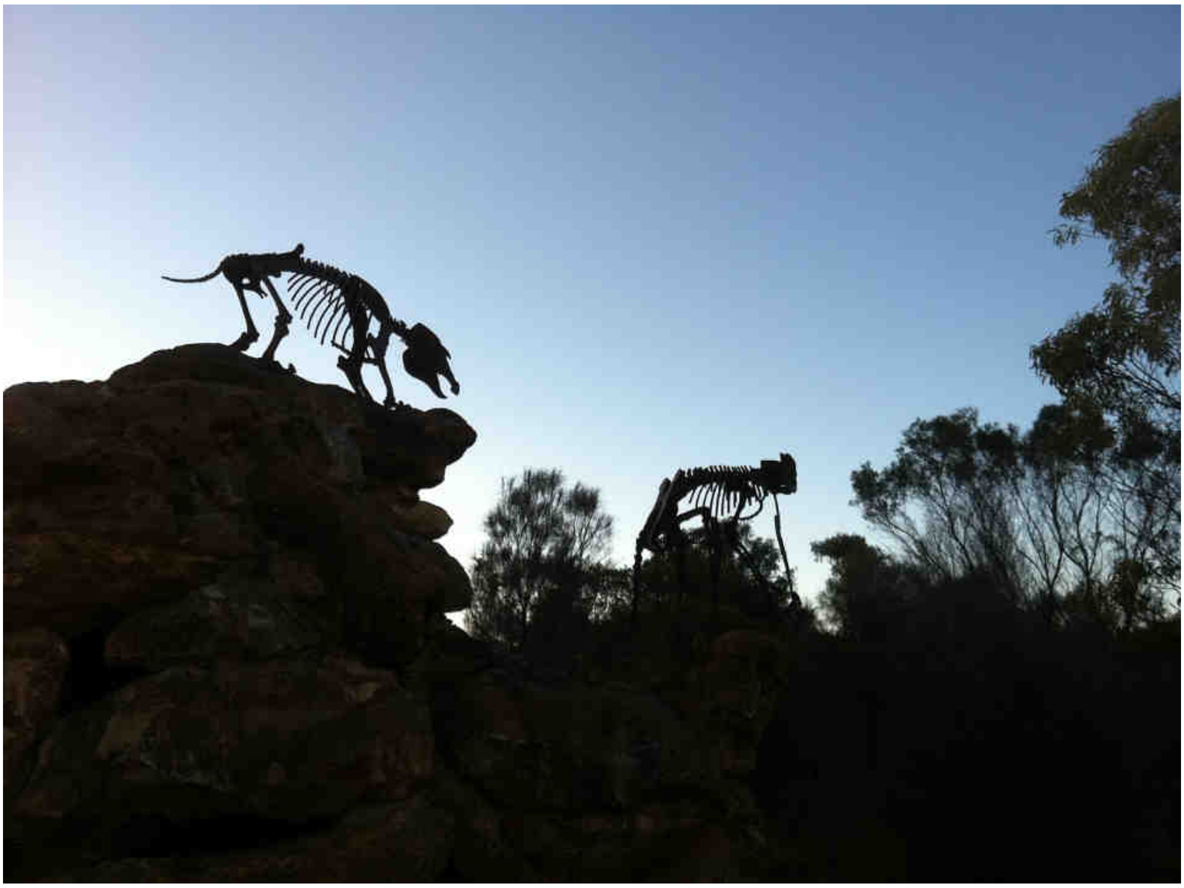
Flooding of the second Blanche Cave excavation (DEWNR) 2010

Conclusion

The Australian Fossil Mammal Sites Naracoorte and Riversleigh are outstanding representations of major stages of the earth's history, including the record of life. Both sites provide complimentary evidence of key stages in the evolution of the fauna on one of the world's most isolated continents.

To maintain the outstanding universal values at Naracoorte Caves National Park and World Heritage Area the 'triple bottom line' approach delivers real benefit.

It is the only true way a national park and/or a world heritage area can fulfil its protection and conservation obligations while sustaining staff capability and achieving the best value it can for taxpayers' money.



NCNP WHA Entrance (DEWNR) 2012

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"Ecotourism" in two karst areas in Madagascar

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Abstract

The two internationally renowned karst areas of Madagascar are both plateau massifs in Jurassic limestone and have the distinctive weathered landscape of pinnacle karst, known locally as tsingy. The park's magnificent landscapes together with their caves and exceptional biodiversity are ideal for ecotourism. However, the move to ecotourism in Madagascar in the 1990's was made not for the above reasons but as the only real solution to managing and protecting threatened natural areas. To do this ecotourism trails funded by government and various international agencies were developed in both parks. Innovative infrastructure design and the use of local materials on the trails allows them to blend into the landscape. The trails of variable difficulty allow the entire spectrum of tourists to view landscapes and flora and fauna with minimal damage to their environment. Trained Malagasy guides, knowledgeable about culture and biodiversity, accompany all groups, further ensuring the protection of the parks. The parks and their surrounding areas benefit financially from the ecotourism either directly from park entrance fees or by employment generated by catering for the needs of tourists.

Introduction

In keeping with the conference theme of the triple bottom line, herein is a discussion of the development of "ecotourism" in the Tsingy de Bemaraha National Park and the Ankarana National Park in Madagascar (Figure 1).

Figure 1: Location of the two National Parks in Madagascar (adapted from Grunewald and Wolozan, 2006).

There are many definitions of "ecotourism" the two presented below were obtained from McKay (1997).

Ecotourism is natured-based tourism that involves education and interpretation of the natural environment and is managed to be ecologically sustainable (Australian Department of Tourism, 1994).

The alternative and more fitting for this discussion is:

…low impact nature tourism which contributes to the maintenance of species and habitats either directly through a contribution to conservation and/or indirectly by providing revenue to the local community sufficient for local people to value, and therefore protect, their wildlife heritage area as a source of income (Goodwin, 1996).

A major attraction in both parks is a geomorphic feature known locally as tsingy (Figure 2). Tsingy is a karst surface covered with limestone pinnacles that in the tropical climate has fretted into razor sharp shards and spikes. There are four definitions of this Malagasy word: derived from the ringing sound the stone makes when struck (Middleton, 2004); derived from the Malagasy word for sharp (Bradt, 2011); a Sakalava guide claimed that the meaning was "walking on tiptoes"; another source claims the translation is "where one cannot walk". Despite the ambiguity of its translation, it is used for terrains with pinnacle karst throughout Madagascar.

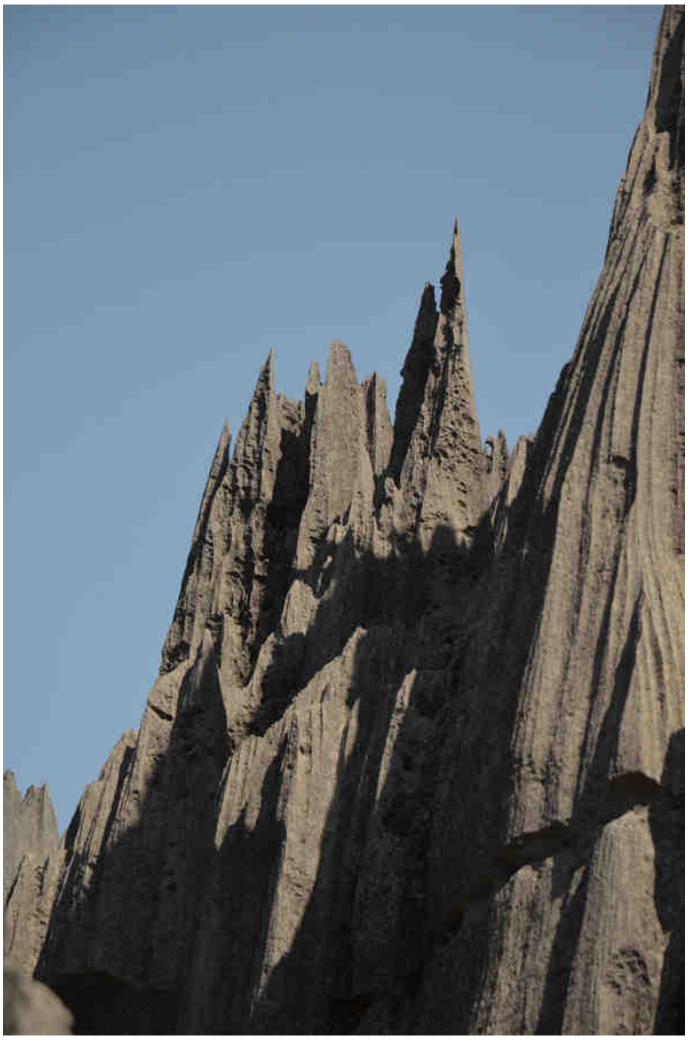

Figure 2: Tsingy.

Tsingy de Bemaraha National Park

In 1927, the entire Bemaraha Plateau, an area of 1520 km^2 (Figure 1), attained a special level of protection when it was declared as The Antsingy de Bemaraha Strict Nature Reserve. By the 1980s, the limestone massif was at risk of deforestation as the result of slash and burn agriculture on its perimeter and in the easily accessed sections of the reserve. This forced the

Malagasy government to undertake environmental action. Initiated in 1987, the heritage nomination process would see the Antsingy de Bemaraha inscribed as a UNESCO World Heritage site in1990, the first in Madagascar. As a result the area had a budget granted by government and various international agencies. A conservation program was commenced with the aim to protect the reserve while at the same time ensuring sustainable economic development of the surrounding areas. This was found to be insufficient because the Strict Nature Reserve status would not allow what was considered the only real solution for managing and protecting a threatened natural area, "ecotourism". Hence, in 1994, the Tsingy de Bemaraha National Park was created allowing 725 km^2 of the Strict Nature Reserve to become accessible to tourists. The new national park came under the direction of Madagascar's National Association for the Management of Protected Areas (ANGAP). In addition, the two parks are administered by Madagascar National Parks.

Tsingy de Bemaraha National Park is difficult and expensive to access. The popular tourist route starts some 180 km to the south at Morondava (Figure 1). It is largely on unsealed roads with two ferry crossings of major rivers. At the south end of the park is the village of Bekopaka where there are fully serviced camping sites and hotels, while the park's visitor center is located on the banks of the Manambolo River (Figure 1). The park offers eight developed ecotourism trails of varying levels of difficulty. All groups have to be accompanied by a local ranger/guide trained in ecotourism. Guides and tickets can be obtained at the parks visitor's center. Part of the ticket price goes directly to the local community. The community also benefits from employment in the park and servicing the needs of the tourists.

The limestone of the Bemaraha is Jurassic and is composed of two layers of high purity and low porosity of the limestone that are separated by a more solution-resistant middle band of marly limestone, which takes longer to erode. The limestone has been dissected by the opening of a perfect joint maze to produce both caves and canyons. The upper and lower limestones both weather in the tropical climate to pinnacles, rock needles and spires - tsingy.

The park offers eight ecotourism trails. The Petit Tsingy trail provides good exposure for those afraid of heights and prone to difficulty with rough terrain. The "Grand Tsingy" group of trails start l7 km north of Bekopaka. The Andamozavaky trail, a full days' excursion, is the cream of these. A journey through dense forests, canyons and caves, and up and down vertical walls is required to reach the top of the massif. On the top the trail wanders through spectacular tsingy, over forbidding precipices and onto stunning lookouts. The trail is a circuit and the descent from the top is equally stimulating. Safety is at a premium and climbing harnesses supplied by the park are required for this trail. It should probably be classed as adventure tourism. The Manambolo Trail starts as a canoe ride upriver to reach a Vvazirnba tomb and includes a decorated cave. Several of the trails close to the river can be combined, making a bivouac amongst the karst. There is only one developed trail in the north of the park, which caters for people entering Tsingy de Bemaraha from the village Antsalova, and has even less visitors.

The park's trails were explored and developed for tourism by Jean-Claude Dobrilla. The paths blend into the landscape, camouflaged by the use of local limestone and wood cunningly bolted into place (Figure 3); no concrete was observed on the park's circuits.

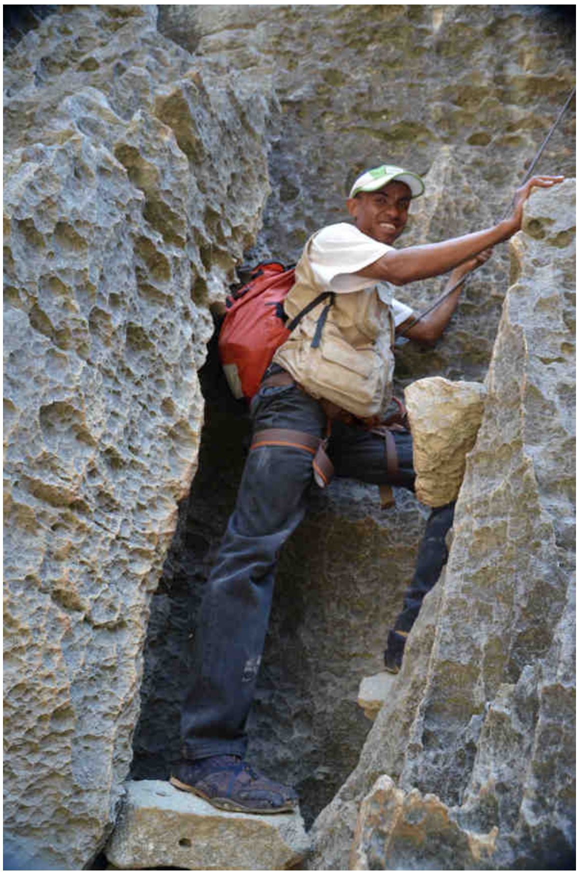

Figure 3: limestone blocks bolted into place as an aid to climbing

The park is closed to tourists for maintenance during the wet season from beginning of November to the end of April when approximately 1500 mm of rain falls and temperatures can reach 60°C. This frees some park employees to assist on family farms during the growing season.

Local guides speak a diverse range of languages, catering to the needs of most tourists. For example, one guide speaks English, French and also Japanese. The guides are exceptionally well informed about the local culture, competent with a discussion of biodiversity but are inadequately trained to discuss karst processes. Some guides have been trained in wilderness first aid. They diligently ensure that tourists do not deviate from the marked trails, so preserving the integrity of the fragile tsingy, and conserve the environment by picking up litter and preventing graffiti. The park is outstandingly clean.

Ankarana National Park

Unlike Tsingy de Bemaraha, that has an international reputation for its karst, Ankarana's reputation lies in its caves. The Ankarana Special Reserve (Figures 1 and 4) was created in 1956. Prior to this the rugged relief and the dense vegetation had helped protect the region from extensive human intrusion. In 1986, a British expedition (Wilson, 1987) realized that the area faced an uncertain future, particularly as local deforestation had the potential to increase siltation in the caves and reduce the food supply for the cave communities. Intervention was required if the Ankarana Massif was to be safeguarded for the future. The Malagasy government at that time had the will, but sadly lacked the resources. In 1987 a film was made featuring the major attractions: the Crocodile Cave, the tsingy and the lemurs. As a result, in the 1990s money was raised from international conservation organizations and the area was protected for the benefit of karst wildlife, the people of Madagascar, scientists and cavers alike.

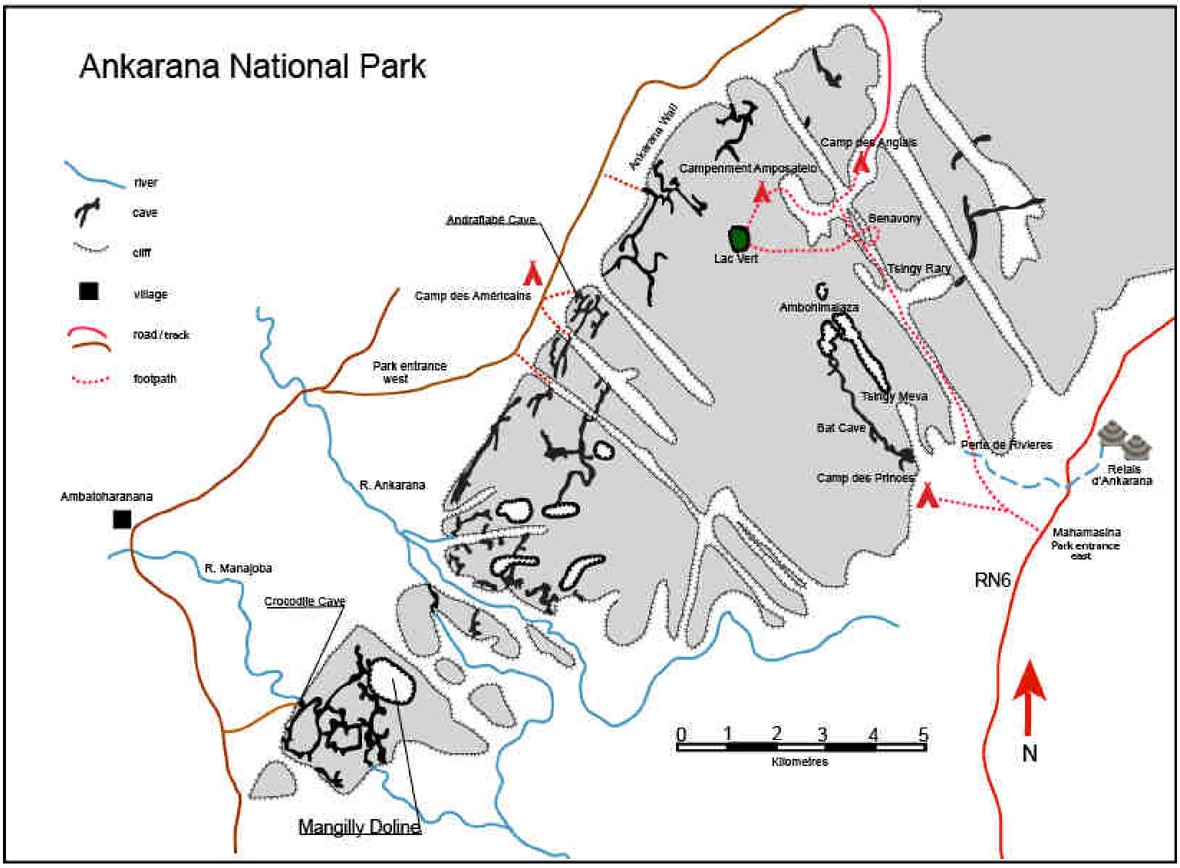

Figure 4: The Ankarana National Park (after Middleton, 2004).

As with the Tsingy de Bemaraha, ecotourism in the new National Park was able to produce additional funds for development and maintenance, and helped support the local community. The overthrow of the Malagasy government in 2009 saw the international conservation agencies depart, so currently the Ankarana National Park relies entirely on the revenue generated by ecotourism.

The Antakarana tribal group is predominant in Ankarana and its environmentally focused beliefs are beneficial to the conservation of the park. A third of the park entrance fee, together with donations given by tourists at sacred sites, are used to finance community development projects. A local committee administers the collective fund, with thirty-eight projects having been completed since 1992. Unfortunately, at present sections of the park are threatened by uncontrolled sapphire mining.

The Ankarana Special Reserve is 250 km^2 and is a partially vegetated plateau composed of 150-million-year-old middle Jurassic limestone. The plateau slopes gently to the east but on the west ends abruptly in the Ankarana Wall, a sheer cliff that extends 25 km (Figure 4) and rises as high as 280 m asl. The limestone on the plateau has been etched into tsingy by the 2000 mm average annual rainfall. To the south the limestone massif is broken up into karst towers. In the centre of the plateau tectonic activity associated with the eruption of Montagne d'Ambre has faulted the limestone forming deep gorges. Rivers flow through the caves and are home to Nile crocodiles.

The Ankarana National Park (Figure 1) is on an arterial road RN6, located such that it draws day visitors from Diego Suarez 70 km to the north and from Nosy Be, a tropical paradise known as the Perfumed Isle, to the west. Such tourists do not necessarily have an ecotourism focus. This is in contrast to the Tsingy de Bemaraha where careful planning and a minimum of three days are required for a visit. However, accommodation at Mahamasina is available for tourists who wish to stay longer at Ankarana.

The advertised trails all start from the eastern park entrance on RN6 (Figure 4). Four of the walking trails start 2.2 km from the main road along a drivable track. All initially follow the same path, with junctions leading to the Perte de Rivieres (a massive sink of three rivers), the Tsingy Rary, Benavony Cave and Lac Vert (Green Lake). The Green Lake can also be reached by a longer 9.2 km trail. Another set of trails departs from Camp des Princes (Figure 4) to the Perte de Rivieres, the Tsingy Meva, the Ambohimalaza forest and the Bat Cave. The Bat Cave is over 4 km long and features a lower level with a river and an upper level that is well decorated.

The Crocodile Cave, portrayed in the 1987 film, lies to the south in a block of limestone separate from the main massif, and tours can be arranged to this cave from the park headquarters.

The west entrance to the park (Figure 4) accesses spectacular caves, including Andrafiabé Cave and Skeleton Cave, and several camping areas, including the well-equipped Camp des Américains. It is utilized by specialist tour agencies offering a different experience for those interested in more demanding trails and caves. However, a park guide is still required.

A day excursion to the Andrafiabé Cave and Skeleton Cave (Figure 4) from the east side of the park entails a long and arduous drive, hence a visit to these magnificent caves has to be somewhat truncated. Due to the preferences of tour operators park guides are less familiar with the western sections of the park, making visitation difficult.

At Ankarana, the trails have been developed with local materials in the same manner as those at the Tsingy de Bemaraha, the exception being one stretch of 165 concrete stairs leading down into the Bat Cave doline. In the caves infrastructure is minimal. The park does not supply helmets and lights for cave visits. Again the local guides have excellent language skills and are knowledgeable about culture and biodiversity, but have only elementary knowledge of karst processes in the park. The park is clean and free from litter and graffiti.

Conclusion

There is no doubt that ecotourism as developed in the two karst parks is a success. The change of half the park from Strict Nature Reserve to National Park has enabled the Tsingy de Bemaraha to completely fulfil all requirements of ecotourism: it is low impact, contributes to the maintenance of species and habitats and provides employment and revenue for the local community. Therefore it is sustainable. Ankarana, located within a more populous area and being accessible to a greater variety of tourists, provides different management challenges, however the presence of ecotourism does provide a multitude of benefits similar to Tsingy de Bemaraha with regard to conservation and sustainability.

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Show Caves of Southern Spain

A comparative study of the applications and outcomes of three different approaches to the triple bottom line

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Abstract
This paper looks at the management and presentation of three show caves situated in the south of Spain: Cueva de Pileta, near Benaojan; Gruta de las Maravillas, in Aracena; and Cueva de Nerja, on the Costa del Sol. It examines how the managements' varying focuses on the triple bottom line affect both the caves themselves and the visitor experience. The Gruta de las Maravillas sits in the heart of the community and is valued as "Aracena's most cherished treasure", a source of local pride, employment opportunities and a significant tourist attraction. Here the three aspects of the triple bottom line seem to be all given due consideration. The Cueva de Pileta is a listed National Monument for its superb prehistoric cave art, but it remains a family concern. Fortunately for the cave and its visitors, the Bullon family is totally dedicated to the preservation of the cave and the education of visitors. Cueva de Nerja is also famous for its cultural worth as a prehistoric site. However, at Nerja the profit focus is detrimental to the natural features of the cave, which in turn impacts badly on the general visitor experience.

Introduction
In November 2012 the author visited three show caves in southern Spain with two seasoned cave tourists, one of whom is, like the author, a show cave guide. The caves were visited on consecutive days; as time was limited each cave was visited only once, and impressions from the earlier ones were still fresh as the later caves were experienced. At two of the caves, Gruta de las Maravillas and Cueva de la Pileta, informal discussions were held with the cave guides and manager. At Cueva de Nerja the staff declined the request for information, directing the author instead to their website. Each site clearly had a different focus regarding the triple bottom line. At Gruta de las Maravillas the focus was fairly balanced, though people and place were apparently of more primary concern. At Cueva de la Pileta the focus was strongly on place, with visitors also a priority. At Cueva de Nerja profit was, without doubt, the raison d'être. The resulting outcomes for the cave environments, the staff and the visitors at each site have implications for how cave managers in general should view and balance the triple bottom line.

Gruta de las Maravillas
The Gruta de las Maravillas is a highly decorated cave of great beauty, situated in the heart of the town of Aracena, directly underneath the medieval castle-fortress which crowns the town. Aracena itself is located in an agricultural area of Andalucia; a region known as the Sierra de Aracena y Picos de Aroche Nature Park. It is in the province of Huelva, about 50 km from the Portuguese border and off the main tourist circuit.

Gruta de las Maravillas is located beneath the castle ruins

The caverns are formed in 570 Myo Pre-Cambrian marble (Durán, 15 December 2012, pers. comm.). This rock originated in an ocean separating the super continents of Laurasia and Gondwana (Garcia, 2011, p 25). The length of the cave is about 2130 metres (Garcia, 2011, p 25).

The cave discovery related to intensive mining activity in the region during the nineteenth century. The first reference to it is in the Sevillian newspaper 'El Porvenir' in 1850 (Garcia, 2011, p11). However local tradition is that the caverns were discovered by a shepherd looking for a lost lamb (Garcia, 2011, p13). The free access that local people had to the cave in this early period led to the removal of many formations and damage to others (Durán, 15 December 2012, pers. comm.).

Due to the great tourism potential of the cave, the Marquis of Aracena, Francisco Javier Sanchez-Dalp, and the mayor of Aracena, Juan del Cid, initiated the development and lighting of the cave between 1912 and 1915; visits officially began in September 1914 (Garcia, 2011, pp15-16), making 2014 the centenary of the cave as a tourist attraction. As more sections of cave were discovered these were gradually developed and added to the tour (Durán, 15 December 2012, pers.comm.).

Royal visits from King Alfonso 13th and Queen Victoria Eugenia of Spain cemented the popularity of the caves domestically, and the rise of international tourism to Spain in the 1960s brought an influx of visitors from Europe and around the world (Durán, 15 December 2012, pers. comm.). The cave featured in several blockbuster movies, including 'Tarzan in King Soloman's Mine', 'Journey to the Centre of the Earth' and 'Clash of the Titans', bringing further attention to the site.

In the 1970s increased visitor numbers started to cause management issues and geologists from Malaga experimented with different lights, in order to reduce the incidence of lampenflora. It was found that the amount of time lights remained on had more impact than the type of lights used. Guides are now responsible for lighting maintenance and cleaning the cave with bleach, following strict maintenance guidelines (Durán, December 15 2012, pers. comm.).

Ongoing research and consultancy with the Department of Geology of the University of Granada began in the early 90s (Garcia, 2011, p21). As a result the number of daily visitors was restricted to 1000, with between 20-40 visitors per tour and a total of about 150,000 visitors per annum (Durán, 15 December 2012, pers. comm.). Tour times are flexible, with tours running when enough visitors arrive, and wait times of no more than an hour. Tours last between 45 minutes and one hour. Audio guide iPods are available with cave commentary in four languages – English, French, German and Portuguese.

Gruta de las Maravillas is managed by the local Town Hall. Sixteen people are employed at the cave:

- Six permanent guides
- Four casual guides
- Two tourist officers
- Two ticket sellers
- Two managers

Aracena town square features images of Gruta de las Maravillas on decorative seating

The town square features seating decorated with hand-painted tiles showing images from within the cave. From here the approach to the cave precinct is also very attractive, by foot up a cobbled street, with water feature, shade trees and restaurants. Adjacent to the visitor centre are a few souvenir shops. The visitor centre includes a ticket office, an information centre and an interpretation centre. The cave entrance, on the other side of a small square, looks like a large office entrance.

Aracena information centre and interpretation centre

The welcome from staff at the cave was warm and genuine. Our tour included a Spanish coach group, which is quite common at the site. Large tour groups in Spain are very boisterous, making the guide's job quite difficult. The guide used a small personal amplifier to assist voice projection, which worked well.

The entrance to Gruta de las Maravillas

The cave itself is richly decorated and in very good condition, though with occasional lampenflora in evidence. The tour is over two of the three known levels of the cave and includes a lake and large rimpools. The floors are cobbled in places and frequently wet and slippery. The few handrails are stainless steel. The cave is nicely illuminated, with water features lit particularly effectively. The overall presentation of the cave is of a very high standard. However the passages between chambers are narrow and platforms fairly small, making the guide's job more difficult, particularly in combination with noisy, sociable groups.

Painted image of Gruta de las Maravillas, Aracena town square

The tour proceeds through the Shell Chamber, with fossil deposits; the Diamond Chamber, featuring glittering crystals; the Shawl Chamber; the Grand Hall, about 50 metres high; up the Ascent to Heaven, where there are lovely views of the Great Lake, to the Cathedral; past the Sultana's Bath, a delicate rimpool; then the Chamber of God's Crystal, with aragonite and many helictites reflected in the Emerald Lake; through the Chickpea Chamber; and the aptly, if coyly, named Nude Chamber and, finally, the Lake Passage.

Gruta de las Maravillas cave manager, Eva Jiminez and cave guide, Amparo Durán with Richard and Sasa Kennedy

Our guide, Amparo Durán, was very knowledgeable about the cave's geology and history and very entertaining and lively in her presentation. She incorporated an English translation for her three English-speakers, alongside her Spanish commentary. Though her English was not fluent it was possible to follow the information easily. Safety and minimal impact was repeatedly emphasised, which was necessary due to the lack of engagement from the group as a whole. A strange divergence from the environmental emphasis otherwise in evidence on site was the proud displaying of a fern growing adjacent to a light towards the end of the tour.

The audio tour was a little less successful; the information was relevant and succinct, but the only indication when to turn on various segments was the name of the chamber, which was not always obvious in the cave, causing confusion and distracting from the cave itself. This could be remedied with simple numbered posts corresponding to information segments. There was low-level mood music running through the audio tour, which was irritating when trying to take in English commentary from the guide parallel to the audio guide commentary. Another problem with the audio tour was a lack of instructions as to how to use the iPod – probably obvious to most people these days, but not all people.

Photography is not allowed in the cave, which is understandable given the difficulty of managing the clients, even without cameras. It is, however, unfortunate, as there is so much to take in during the tour that it is impossible to retain a clear memory of the cave's many highlights. A photo is taken as you enter the cave, which is ready to purchase on departure from the tour, at extra cost. This in no way makes up for the lack of photographic opportunities during the tour, with the background of the shot not at all representative of the beauty of the cave.

Gruta de las Maravillas is a very special cave experience, with the outstanding level of decoration, high standard of presentation and quality interpretation all contributing to a great tourism experience.

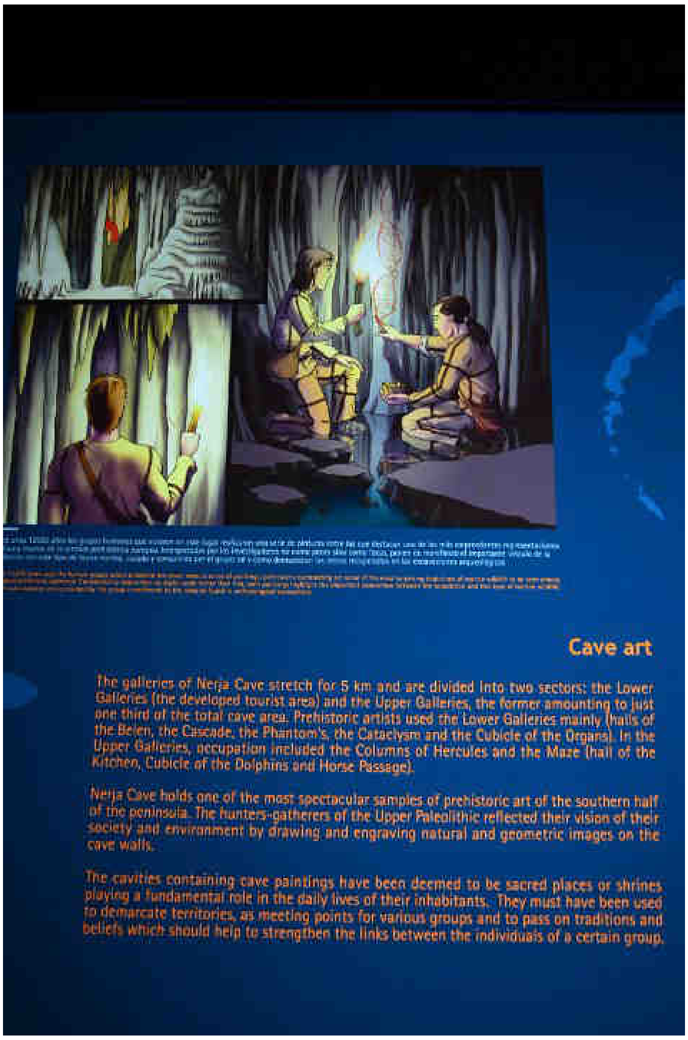
Cueva de Nerja

The Cueva de Nerja is situated a few kilometres outside the town of Nerja, in the province of Malaga. It is close to the coast, on the Costa del Sol, and located on the lower part of the Sierra Almijara. It was originally known as the Cave of Wonders. The name Nerja comes from an Arabic word meaning 'spring of water' (Hierro, 2012, p 4). The cave extends over 7,200 metres from North to South (Hierro, 2012, p 10). There are three known levels to the system, the Lower Galleries, the Upper Galleries and the New Galleries. Of these the Lower Galleries are open to the general public, with the other areas reserved for scientific study.

The caves are formed in marble from the Triassic period, 200 Mya, with the caverns believed to be formed about 5 million years ago during the Pliocene and Pleistocene periods. The warm period of the Quaternary is when scientists believe the formations were produced (Hierro, 2012, pp 6-11). A massive earthquake 800,000 years ago led to the devastation which gives the Cataclysm Chamber its name (Hierro, 2012, p 14) and in 4000 BP water deposited rocks and sediments into the cave entrance, blocking it until its discovery by modern humans (Hierro, 2012, p10).

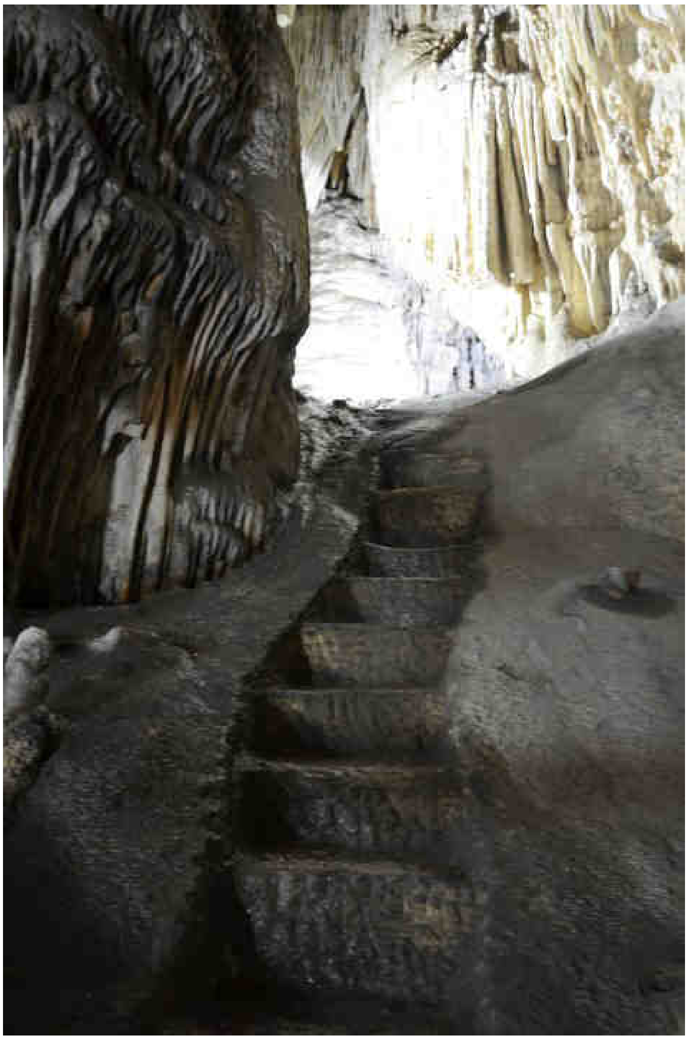
The cave was discovered by three local youths, 'catching bats for fun', in 1959 (Hierro, 2012, p4), who first entered the Cataclysm Chamber. The Upper Galleries were discovered later in the same year and the New Galleries in the 1970s.

In June 1961 the cave was declared an Artistic National Monument (Hierro, 2012, p6). Since its discovery the cave has been the subject of continuous excavations and detailed study relating to its geology, ecology and prehistoric significance (Hierro, 2012, p 6). It is known to have been occupied from the Upper Palaeolithic period until the Chalcolithic, or Copper Age. It is believed to have served as a living place, sanctuary and burial ground (Hierro, 2012, p 20). There are over 600 paintings and engravings on the cave walls, and remains include marble bracelets, underground stores, ceramics, bone fish hooks, painted stones, engraving tools, jewels, loom weights and group burials (Hierro, 2012, pp 20-24).



Cave art interpretation board, Christmas Crib Chamber, Cueva de Nerja

The Committee for Archaeological Excavation at Malaga was responsible for opening up a visitors' entrance to the cave and building infrastructure to facilitate visitation and scientific investigations (Hierro, 2012, p 6). The cave was officially opened on June 12, 1960. Being located in a popular tourist area, the cave has high visitation, with 527,096 in 2001 dropping to 376,518 visitors in 2011 (The Nerja Caves, 2013). It provides employment in a range of positions from ticket sellers, restaurant workers, retailers, photographers and photo developers, parking attendants, managers and cave guides. Neither the guide book nor the website names the managing body.



Early infrastructure (circa 1960) includes steps cut into crystal, Cueva de Nerja

The cave is a popular venue for artistic performances. Every summer the 'International Festival of the Cave at Nerja' is held, with performances of ballet, flamenco and music featuring, and up to 600 spectators attending in the Cascade Chamber (Hierro, 2012, p14). At other times visitors are free to view the cave unguided and at their own pace. Locals can visit the cave free of charge on Sunday mornings (The Nerja Caves, viewed 3 April, 2013).

The cave precinct is approached via the car park, where (on the occasion of our visit) a bored-looking attendant was in attendance for no apparent reason, and a collection of retail venues included a gift shop, a large restaurant and a photographic studio. A statue of the boys who discovered the cave is prominent near the cave entrance. There are also extensive gardens behind the commercial precinct.

The approach to Cueva de Nerja

The ticket office staff were very offhand and appeared uninterested in either visitors or the site. When a request was made to discuss the cave and its management they referred the author to their website, which was in contrast to the personal assistance provided at other cave venues visited. The ticket office has audio guides available (at extra cost), but these were not offered to us. The only rule we were given when collecting tickets was that no flash photography was allowed in the cave. Photos are available for downloading on the Nerja website, with most being very amateur shots (out of focus and badly framed), but their availability was not mentioned.

The approach to the actual cave is down a stairwell, past a currently blocked off section of the cave. As we stepped into the first chamber we were greeted by the flash of the professional photographer! On departure from the cave the print is proffered for purchase immediately. It would appear that only clients' flashes have an impact on the cave…

The first chamber in the cave, the Christmas Crib Chamber, contains displays of archaeological remains and interpretive material on both the geology and occupational history of the cave. The English translations, at least, are riddled with inaccuracies. However, the interpretive material is visually well presented and interesting, particularly in relation to the use of the cave by prehistoric peoples.

Visitors absorbed by interpretation of early cave dwellers, Cueva de Nerja

The chamber is marred by many broken formations, unsympathetic infrastructure and lampenflora. Sadly, this is just a hint of what is to come in terms of cave damage.

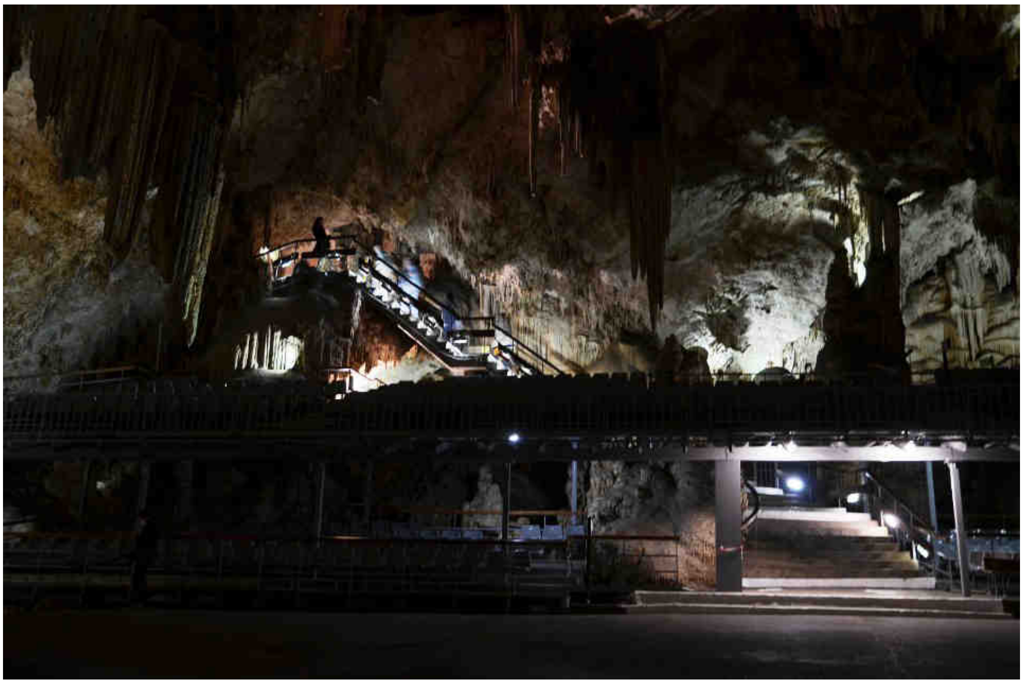
The cave is generally underlit, with the flat lighting dimming the sense of drama that the enormous caverns and potentially spectacular formations should provide. The stairs and platforms are cemented, with wooden and occasionally rope handrails. Large painted arrows point the way on. Signage is largely limited to named maps of the various sections of the cave, which, on a positive note, include audio guide segment numbers. The signs have been vandalised and remain unrepaired. At the time of our visit we did not see any visitors using audio guides and comments in TripAdvisor indicate that they are only infrequently offered to visitors (TripAdvisor, viewed 9 April 2012). Visitors are given a brochure to guide them through the cave, but it merely contains directions through the cave and names of features.

Cave signage, Cueva de Nerja

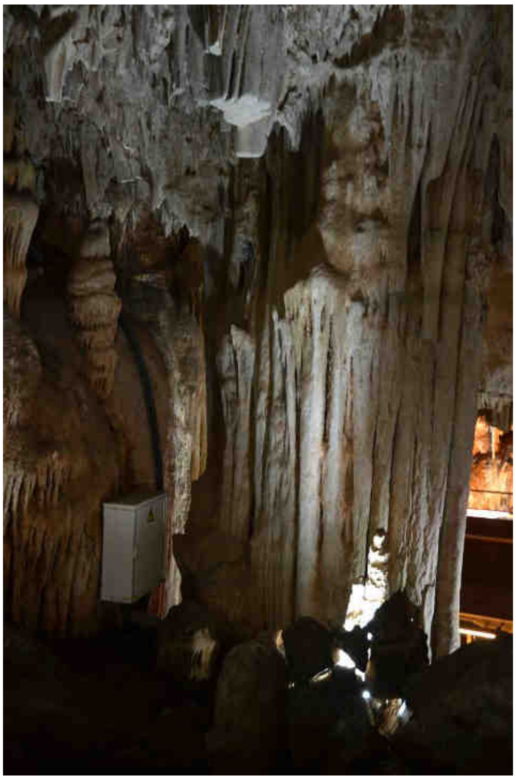
At the Cascade or Ballet Chamber is the first indication of minimal impact regulations; a large sign indicates that pets are not allowed in the cave, smoking and eating are not permitted, nor is flash photography or touching the formations. The sign also indicates that there are stairs in the cave, perhaps a little belatedly. This was the only obvious measure taken to protect the cave from visitor damage.

Apart from the initial chamber there was no guide or security presence in the cave and no indication of remote cameras to keep check on visitors. In the first chamber the guide was occupied in discussion with the photographer, showing no interest in the visitors or the cave. In the Cataclysm Chamber a female singer yowled, unrestricted, during our entire tour. She only ever completed one or two lines of each song before moving on to the next, showing absolutely no respect for the cave or other visitors. At no time did any member of staff try to restrict her, or even explain her presence – maybe she was practising for a cave performance, but we will never know (and I hope not, for the sake of visitors!).

The Cascade Chamber is dominated by an enormous, two-tiered bank of about 100 theatre seats, permanently fixed to the platform. Unprotected formations are within easy reach of the seating.



Theatre seating, Cueva de Nerja



Electrics box fixed to formation, Cueva de Nerja

Moss adjacent to lights, which are left on throughout the day, Cueva de Nerja

Throughout the cave infrastructure is poorly sited, often fixed to crystal formations. Formations are dull and dirty. Broken formations can be seen throughout.

The most dominant feature of the cave is the omnipresent lampenflora. The cave positively glows green. Nearly every light has a forest of moss nearby.

In the Cataclysm Chamber is the most dramatic feature of the cave, the Great Column, said to be the largest in the world at 32m high and measuring 13m x 7m at the base (Hierro, 2012, p 14). Whether or not it is the largest column known, there is no disputing the magnificence of this feature.

The Great Column, Cueva de Nerja

The tragedy of this cave is that it has all once been so very beautiful, with enormous crystal formations, rich and varied decorations and chambers of grand proportions. It should be a premier show cave, but instead is a terrible disappointment – uninspiring and largely uninterpreted.

Cueva de la Pileta

The Cueva de la Pileta is set in a rugged and majestic landscape, comprised of jagged limestone peaks and valley farms. It is located on the small Harillo Farm, not far from the village of Benaojan, in the province of Malaga. It was declared a National Monument by the Spanish government on 25th April 1924, in recognition of its archaeological significance (Bullón J, 2005, p39).

The approach road, Cueva de la Pileta

The cave is formed in Jurassic limestone and shows evidence of damage from the Lisbon earthquake of 1755 (Bullón T, 16 December 2012, pers. comm.). It contains over 3000 artworks from the Upper Palaeolithic through to the Bronze Age. There are figurative paintings in the French and Cantabrian styles, Palaeolithic engravings and schematic art from the Neolithic era (Bullón R, preface to Bullón J, 2005, p9). Inside the cave is what appears to be a Neolithic cemetery; when discovered it contained fifteen skeletons laid out in the foetal position (Bullón T, 16 December 2012, pers. comm.). There is also potential evidence of human sacrifice; at the bottom of a 72m hole lie the remains of three animals and one human (Bullón T, 16 December 2012, pers. comm.).

The cave was discovered by José Bullón Lobata in 1905. The cave 'Las Grajas' was known locally as the 'Cave of the Bats', due to the swarms of micro-bats heading out to feed of an evening, but the deep drop at its entrance had deterred locals from entering the cavern. José was motivated to enter by his need for fertiliser to use on his farmlands. His initial exploration led to the discovery of skeletal remains, pottery shards and markings on the walls and gradually he continued his solitary explorations of the cave, discovering more artefacts and a variety of pre-historic artworks in the new passages and chambers he traversed (Bullón J, 2005, pp12-24).

Rumours of hidden gold led to unending attempts to infiltrate the cave and plunder its treasures, and José's family began their quest to preserve the cave, learn more about the treasures it contained and share them with the public in a responsible and respectful manner (Bullón J, 2005, p25).

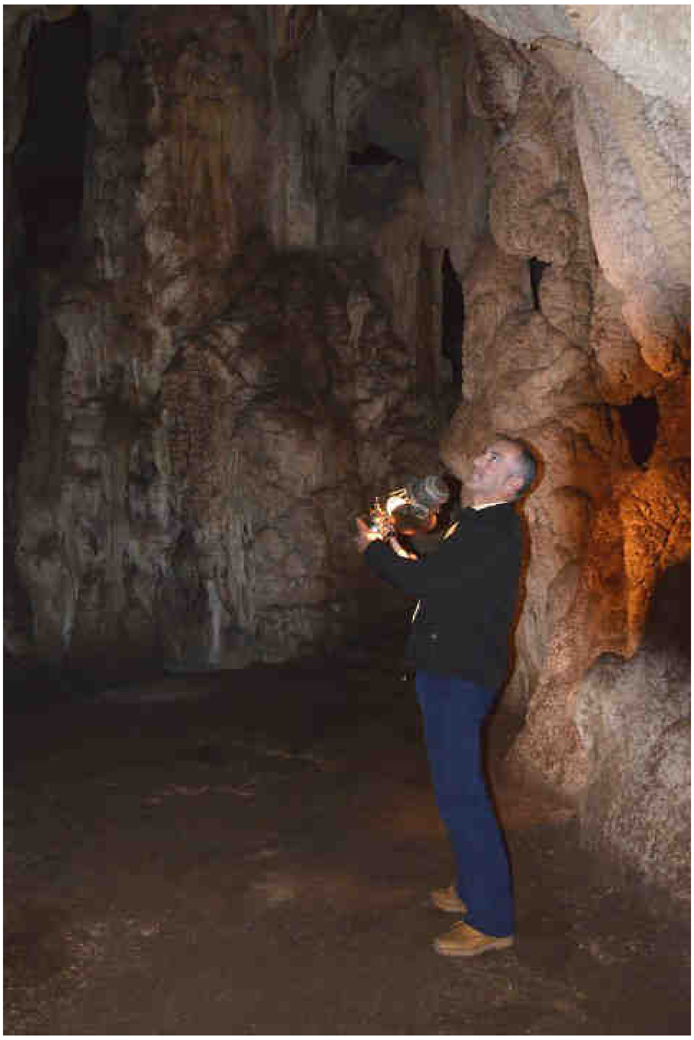
The cave has been the focus of sustained scientific study. Unfortunately, many of the specimens taken from the cave in earlier times have ended up in private collections, or disappeared without trace (Bullón J, 2005, pp28-29).

The Cueva de la Pileta is located in rugged country

Meanwhile José Bullón began to create some rudimentary steps in the cave in order to improve access to scientists and interested parties (Bullón J, 2005, p 23). Four generations of the Bullón family have continued in his work of protecting, preserving and promoting the cave, often at great personal expense (Bullón J, 2005, p 31, 34). Tomás Bullón García developed the current entrance in 1924 and in the same year the government declared him the official guardian of the cave, to facilitate its protection (Bullón J, 2005, p38). He also improved the internal stairs and constructed the stone approach steps and iron railings in this year. The family continued to make further discoveries in the cave up until 1993 (Bullón J, 2005, pp 40-41).

The approach to Cueva de la Pileta is up some rustic steps

The Cueva de la Pileta remains in the care of the Bullón family, who are proud of the fact that they are backed neither by big business nor major institutions (Bullón J, 2005, p26). The breath of visitors is considered to be the major threat to the artworks in the cave and visit times are strictly controlled (Bullón T, 16 December 2012, pers. comm.). Tours are conducted by paraffin lamp and torchlight, with a minimum of infrastructure to assist access; some cut steps, a few concrete stairs and a few galvanised handrails. Only a small portion of the cave is shown, in order to protect its integrity. Tour length is about 500m each way (Bullón T, 16 December 2012, pers. comm.).



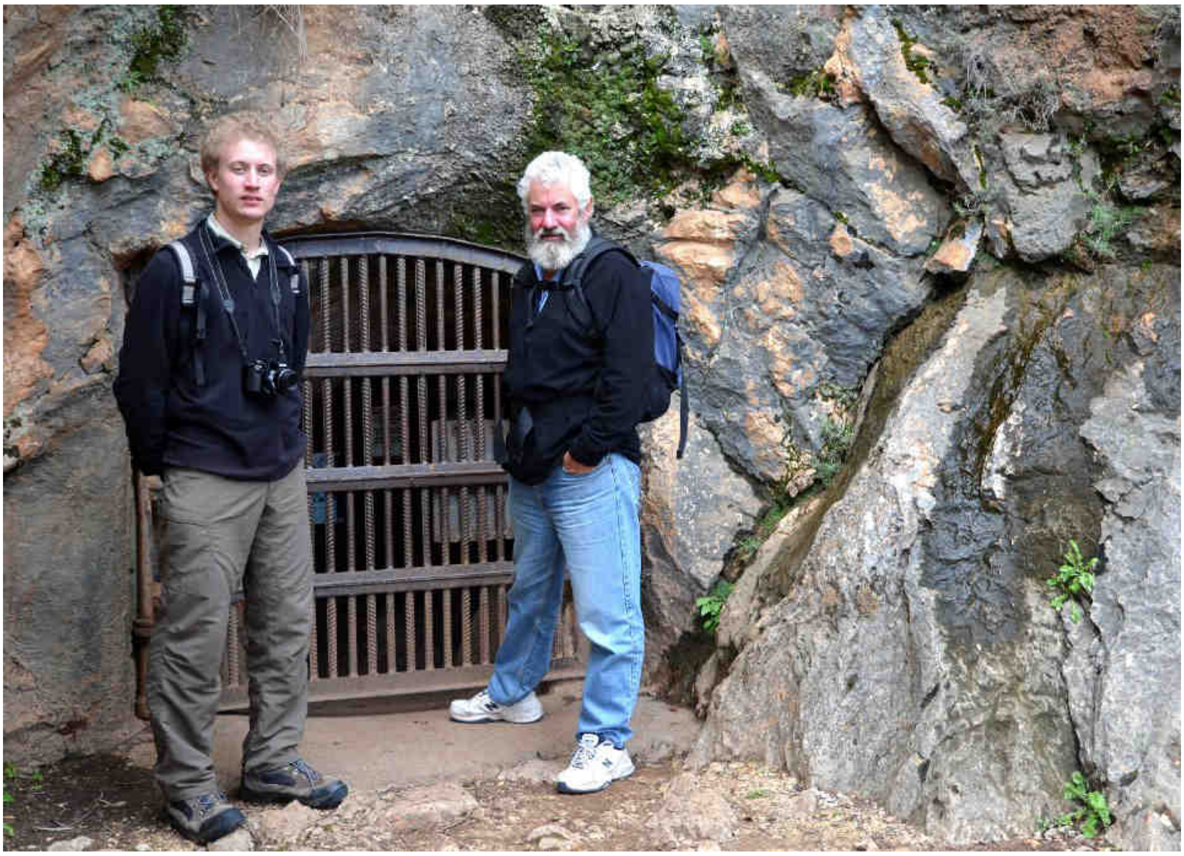
Tomás Bullón Almagro, guide, Cueva de la Pileta

About 9000 visitors experience Cueva de la Pileta each year. A maximum of 25 per hour visit in summer and holiday periods; in the low season the number is about 20-25 per day. It is open from 10am-1pm and 4pm-6pm daily (Bullón T, 16 December 2012, pers. comm.).

Four members of the Bullón family make up the staff of the cave, with other family members working in town in occupations such as teaching (Bullón T, 16 December 2012, pers. comm.). The guides are highly trained and dedicated.

Information board, Cueva de la Pileta

A sign leads to the small car park above the Bullón family farm, which must have the best views of any car park in Spain. At the car park is an information board with an excellent cave map and a short history and description of the cave. From here rustic stone steps climb the steep hillside to the simple waiting area. A wooden shelter shed incorporates the kiosk, open briefly as the guide arrives. A sign on the cave gate requests that visitors wait for the arrival of the guide, but it is not clear when this might be.



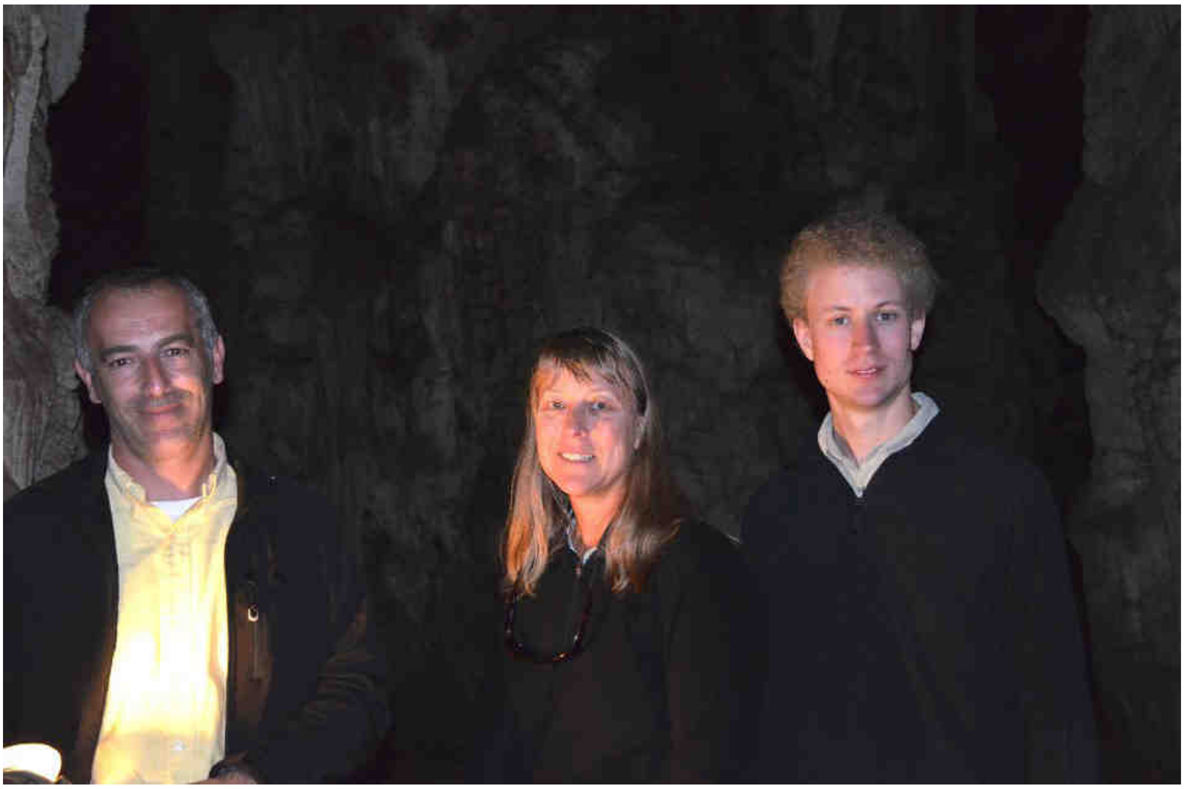
Richard and David Kennedy at the entrance to Cueva de la Pileta

On entry to the cave, through a small gateway, the first chamber serves as the ticket booth and souvenir stall. On the wall are certificates honouring the work of the Bullón family in developing and conserving Pileta Cave. This is also where the guide collects his paraffin lamp and visitors are given one battery-powered lantern between four to light their path.

With minimal infrastructure and slippery, uneven floors, moving through the cave with only one diffuse light between four visitors is quite difficult. For any visitors with mobility or sight issues this could provide major problems and safety issues. Though safety warnings are delivered little assistance is offered.

The paintings and engravings throughout the cave are in pristine condition, are varied in style and content and of high quality. The main themes are animals, including a beautifully executed pregnant mare, a large fish sketch and goats; and a series of symbolic line drawings, which are believed to be shamanic calendars (Bullón T, 16 December 2012, pers. comm.). The crystal formations in the cave are also in good condition, but are not outstanding examples, though minerals in the cave (including iron oxide, manganese and copper) provide a range of colour. Prehistoric fires have dulled the crystal in many areas (Bullón T, 16 December 2012, pers. comm.).

This is one of the best and most atmospheric guided tours ever experienced by the author, in a cave or anywhere else. Our guide, Tomás Bullón Almagro, was very knowledgeable about the cave's history and significance, being the great grandson of the discoverer, a co-owner of the site and an archaeology graduate. He delivered a completely bi-lingual tour, being very fluent in English as well as his native Spanish. The low light was sufficient to see the paintings easily and clearly but also contributed greatly to the atmosphere.



Tomás Bullón Almagro with Sasa and Richard Kennedy, Cueva de la Pileta

Though geology and cave fantasy comprise part of the tour, the focus is on the prehistoric artworks and the lives of the artists. The interpretation is delivered clearly, with authority and passion. The stories are fascinating and detailed, with the added intimacy implied by the guide's links to the site and the history of its exploration and development. In addition to interpretation of the artworks themselves, visitors are told of the human cemetery located in the cave, the possibility of human sacrifice having taken place here, the different family and tribal groups who occupied the cave at different periods, the pottery shards and other finds, including a hollowed out stalagmite used as a mortar for the grinding of pigments.

The protection of the cave and its artefacts is clearly the priority, with all aspects of cave and tour management stemming from this central concern. One of the seven people on our tour requested a private tour, where she could sit for longer and sketch the cave. Tomas explained that as the major risk to the artworks came from human breath a longer viewing was not an option.

Recognition for the dedication of the Bullon family in protecting Cueva de la Pileta

This tour is a unique experience. Though the sections of the cave included in tours do not contain particularly memorable formations, to be able to enter a cave with such high quality prehistoric artworks and have the cave and its prehistory interpreted with such passion and knowledge is a rare honour.

Visitor Impressions of the caves

To obtain a broader impression of the visitor experience at each of the cave sites a survey of TripAdvisor ratings and reviews was completed on April 9, 2013. This website covers tourist attractions and accommodation worldwide and, while it cannot guarantee a balanced view of visitor experience, it is at least a fairly reliable site, where operators can reply to visitor comments and complaints. In addition it applies the same ratings system across the cave sites, allowing a fair comparison. The overall ratings are listed as raw numbers in Table 1and as percentages in Table 2.

The figures show that Gruta de las Maravillas was rated highest of the three show caves, though the caves were all rated very highly and the results were quite close. At Gruta de las Maravillas 95.8% of visitors rated the experience as either excellent or very good, Cueva de Pileta rated 91.9% in these two bands and Cueva de Nerja 88.8%. The figures were also similar between the caves at the bottom end of the satisfaction scale.

TRIP ADVISOR – Ratings raw numbers			
Rating/Cave	**Aracena**	**Nerja**	**Pileta**
Excellent	63	285	37
Very Good	31	181	18
Average	2	47	5
Poor	1	7	1
Terrible	1	5	0
TOTAL	98	525	61

Table 1. Trip Advisor raw ratings figures

TRIP ADVISOR – Ratings by percentage			
Rating/Cave	**Aracena**	**Nerja**	**Pileta**
Excellent	64.2	54.3	60.6
Very Good	31.6	34.5	31.1
Average	2.0	8.9	8.2
Poor	1.2	1.3	1.6
Terrible	1.0	1.0	0.0
TOTAL	100%	100%	100%

Table 2. Trip Advisor ratings by percentage

Visitor reviews on TripAdvisor provide more detailed feedback on how the general public experiences the cave sites (TripAdvisor, viewed 9 April 2013). A brief overview of the major positives and negatives for each site is presented in Table 3.

TRIP ADVISOR FEEDBACK		
Cave	**Positives**	**Negatives**
Gruta de las Maravillas	Most beautiful cave	Slippery floors
	Friendly guides	Waiting for tour to fill
	Wonderful experience	Ban on photography
Cueva de Nerja	Sheer size and beauty of caverns	Ban on flash photos
	Nice restaurant with good views	Pushing of professional photos
	Alternative to heat/sun	Cost of tickets
		Cost of audio guide
Cueva de la Pileta	Non-commercial atmosphere	Ban of photos was lamented but understood
	Quality of artworks	Slippery floors
	Guide's knowledge	Waiting time for tours
	Custodian's devotion	

Table 3. Summary of the most common feedback on Trip Advisor

Many posts regarding Gruta de las Maravillas describe it as the most beautiful cave they have ever seen and many comment on the friendly guides. The complaints are about slippery floors, having to wait for tours to fill before departure and the ban on taking photographs. But all visitors agreed the glories of the cave made it a wonderful experience (TripAdvisor, Gruta de las Maravillas, viewed 9 April 2013).

Even with all the drawbacks cited above, most of the reviews describe the experience at Nerja in very positive terms; the ban on flash photography in combination with photo sales being pushed seemed to be the major irritant. Another regular complaint was the cost of tickets and additional cost for an audio guide. One visitor complained that the security guards throughout the cave (not in evidence on the occasion we visited) would not be engaged in conversation. However, it seems that the grandeur of the caverns and the sheer majesty of the formations were enough for most visitors. A major positive for visitors was the contrast to the heat and bright sun (or sometimes rain) to be found outside. While other sites drew comment on the quality of the guides, there was little comment on the lack of this at Nerja. It is likely that the demographic visiting this cave makes them a less discerning group of visitors than those at the caves in areas lacking highly developed mass tourism (TripAdvisor, Cueva de Nerja, viewed 9 April 2013). However, the complaints about cost of tickets indicate that visitors do not consider they are getting value for money. Given the price is a reasonable €8.50 per adult, the same as Gruta de las Maravillas and slightly higher than Cueva de la Pileta at €8, and that neither of these sites had complaints about their cost, it seems that there is something lacking in the experience, though visitors do not specify what it is.

Visitor, Cueva de Nerja

At Pileta visitors generally appreciated the non-commercial atmosphere of the caves and were impressed by the paintings and guide's knowledge. Negatives noted include the problem of slippery floors combined with low light levels, and the issue of having to wait for tour numbers to build prior to a tour departing. Visitors lamented the lack of photographic possibilities, but were understanding of the reasons for this (TripAdvisor. Cueva de la Pileta, viewed 9 April 2013). Many noted with approval the dedication shown to caring for the cave.

Kiosk and waiting area, Cueve da la Pileta

Overall, the visitor feedback for each site was as positive as the ratings would indicate. In light of this, further study would be required to clarify the factors leading to the large and steady downturn in visitor numbers at Nerja, which will have had a significant impact on the profit margin of the caves.

Conclusion

At each of these three cave systems the tourist experience and the caves themselves have been shaped by their location, the circumstances and timing of their discovery and the history which has led to the particular bottom line focus of each managing authority.

The Gruta de las Maravillas was discovered in the nineteenth century, a time of scientific discovery and fascination with the natural world. Located in the heart of the town, it is also close to the hearts of the local population, as demonstrated by its unofficial title of 'Aracena's Treasure'.

The bottom line focus becomes clear on reading the introductory section of *La Gruta de las Maravillas,* the tourist booklet available at the cave:

> *To work for the caves is a delight. Our daily challenge and responsibility is to conserve and take care of this jewel of nature so future generations can continue coming. Our other responsibilities are to offer the best high-quality service to all those who honour us with their visit, and to attract more visitors through frequent promotional campaigns...*
>
> *Generations of tour guides, managers, office staff, tourist agents, town councillors, investigators and conservationists have all treated Aracena's star attraction with care and affection for nearly one hundred years...*
>
> *... We cannot forget the local inhabitants of Aracena, who show off their rich patrimonial legacy with pride and modesty... We cannot forget our visitors either, who, through word of mouth, have recommended Aracena to others, and we would like to thank them for their fidelity over so many years.*
>
> *The purpose of this guide is to make your visit to the Maravillas cave a unique experience. It is also a way of showing our appreciation and gratitude to all those who, directly or indirectly, have been working for the Cave for nearly a century* (Garcia, 2011, p 5).

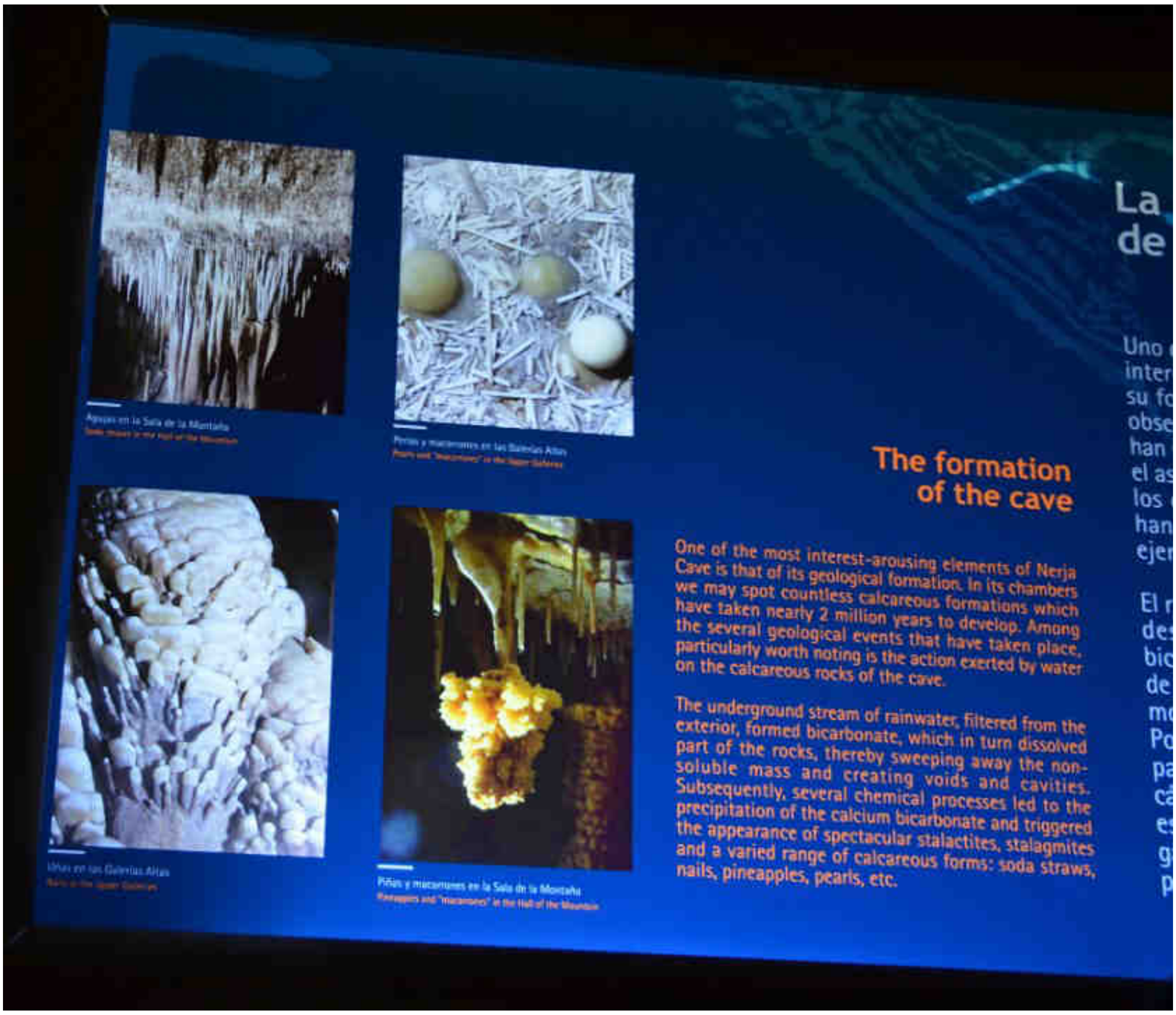
The priorities here are quite clear – environment, closely followed by people, including staff, visitors and the local population. From this profit will follow.

This ethos was also quite clear at Aracena – from the guide's commentary, through to the warm welcome and generous assistance which the author was offered. The passion felt for the caves was evident; cave protection was emphasised, but in an easygoing manner; a range of interpretive strategies were in place, from guides and tour translations to an interpretation centre. Locals are obviously proud of their 'star attraction', as evidenced in the attractive seating in the main square of the town, which features tiles painted with images of the cave formations.

The cave is protected by regular, monitored maintenance, considered infrastructure and watchful guides. Though visitation is high, and groups may not all be environmentally focussed, the cave, open for nearly a century, is in remarkably good condition. The only negatives to the experience were the lack of photographic opportunity and the occasional lampenflora in difficult to access places.

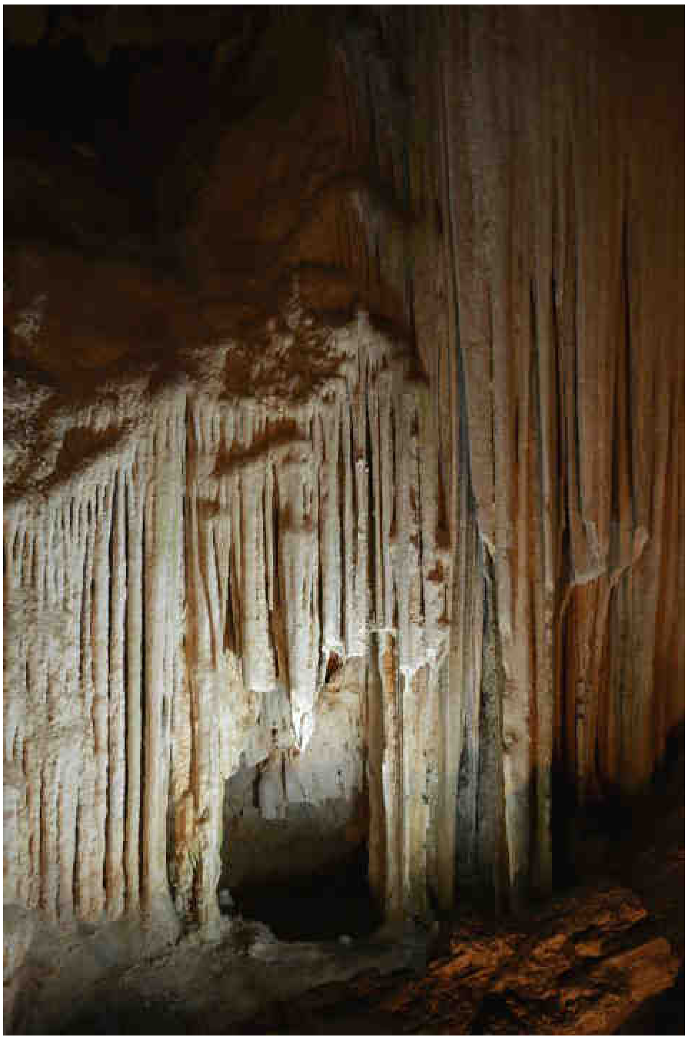
All of this contributed greatly to the extremely positive visitor experience, which is reflected in the reviews and ratings seen on TripAdvisor, the most widely viewed tourism ratings site on the web. These, in turn, contribute to word of mouth, assisting the bottom line aspect of profit.

Cueva de Nerja was discovered at a time when tourism was about to boom in Spain, and the Costa del Sol, where it is located, was to play quite a part in that boom. The mass resort and beach tourism which dominates the economy of the area was bound to influence the development of the cave as a tourist site. The typical visitor is less likely to appreciate the environmental and archaeological intricacies of a cave and more likely to look at it in a superficial manner.



Inaccurate signage, Cueva de Nerja

The cave is managed and presented accordingly, seemingly as a cash cow and certainly with little care for the environment, apart from the pre-historic paintings and artefacts, which are out of bounds to the average visitor.



Broken formations, Cueva de Nerja

As the guidebook to Cueva de Nerja states:

> *The cave at Nerja is an important element in the promotion of this coastal zone of the Axarquia as a tourist destination* (Hierro, 2012, p4).

The first impression on arrival at Cueva de Nerja is of a small retail centre and this illustrates the bottom line focus at this site; profit is paramount. While the majority of visitors to the site seem to cope well with this and, indeed, many enjoy their visit to a high degree, the cave is suffering gross neglect and environmental degradation as a result. The decision to allow untimed, unguided access to the cave means that lights are on constantly, creating an extreme degree of lampenflora to flourish throughout the cave. The unsympathetic placement of infrastructure has also contributed a degree of damage.

Moss in Cueva de Nerja

The author's experience at this cave was one of extreme disappointment in the presentation of the cave and anger at the level of environmental damage and disregard. Though generally the reviews for this cave on TripAdvisor were positive it seems possible that, with a steady drop in visitation of 28.6% over ten years, and the lowest satisfaction rating of the three caves on TripAdvisor (especially notable in the excellent category), perhaps other visitors are not entirely satisfied either.

If Nerja is to turn its fortunes around, a rethink of its bottom line priorities may be in order.

Cueva de Pileta was fortunate to be discovered by, and on the farm of, Jóse Bullón Lobato. Though a simple farmer he quickly understood the importance of the cave and its artworks. He worked tirelessly to protect it and instilled in his family the importance of their ongoing custodianship of the site.

The location of the cave in a more remote and wild area, along with low-key publicity, also helps protect the cave from undue visitor pressure.

Again, the bottom line focus is evident in the guidebook available at the cave:

> *Despite the deterioration caused by the activity of prehistoric man, the beauty of the rock formations found in the cave is almost boundless. There are still virginal areas which astound even the most experienced geologists…*
>
> *After a century in the custody of the Bullón family, the rock paintings in the Pileta are amongst the best preserved in the world. The scientific community testifies to this and it can be appreciated by any visitor who cares to compare it with other, similar caves. The microclimate found inside the cave has been undisturbed by the strictly controlled regime of visits. Evidence of this are the colonies of bats which still inhabit its interior, something that is rarely seen in other caves open to the public.* (Bullón R, 2008, pp 9-10)

The booklet concludes:

> *When you leave this cave, dear reader, it is with the assurance that when next you return you will find it still the same.*

Visitors are welcome, but not at the expense of the cave. It might seem that visitors would be put out by their clear relegation to second place in the list of priorities, but from comments in TripAdvisor it would appear that, on the contrary, they appreciate the devotion shown to the cave by its custodians and are happy to co-operate.

Due to the minimal infrastructure in the cave, minimal maintenance is required, and with the small-scale operation, restrictions on numbers and the low-key nature of the site few staff are required. Profit does not appear to be a major consideration; 9000 visitors per annum are enough to keep four people employed. The impression is that if less were required this would be fine by the family; they would find employment elsewhere.

The clear focus on the environment actually enhances the visitor experience and certainly benefits the cave, its biota and the important archaeological artefacts it contains. Positive visitor word of mouth will help ensure that profit continues to flow.

The evidence from these caves suggests that if the bottom line focus is primarily on the environment and people, then, with reasonable planning and management, the third aspect of the triple bottom line, profit, will follow (see Table 4). However, if the focus is primarily on profit, this will potentially have detrimental effects on the cave environment, staff and visitors. This, in turn, may well lead to declining profit.

TRIPLE BOTTOM LINE OUTCOMES			
CAVE	**Gruta de las Maravillas**	**Cueva de Nerja**	**Cueva de la Pileta**
Bottom line, with apparent focus	**Planet, people,** profit	**Profit,** people, planet	**Planet,** people, profit
Cave condition	Very good	Very poor	Excellent
My experience rating	Very good/excellent	Poor	Excellent
TripAdvisor rating - very good/excellent	95.7%	88.7%	91.7%
Bottom line result	Success	28% drop in visitation over 10 years…	Success

Table 4. Triple bottom line outcomes

Acknowledgements

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World-wide show cave visitor numbers over the recent past

A preliminary survey

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Abstract

This paper provides a very preliminary investigation of the changes in visitor numbers in show caves world-wide over the last decade with some longer datasets available. There were problems in the way in which data was sought and in the way in which very many generous people provided data. Thus the data we discuss here is limited geographically and temporarily.

It is intended to make this a first step in developing a far better understanding of show cave visitation world-wide.

Introduction

The Australasian Cave Tourism and Management Conference Proceedings provided annual visitor numbers for Australian show caves for a number of years. Unfortunately in recent decades this has not happened for a variety of reasons. To the best of our knowledge there has never been a review of these annual series to examine trends, peaks and troughs. Nor has there ever been an attempt to review such figures in the light of local events such as floods and earthquakes or international happenings such as the SARS "epidemic", the GFC or the current European economic woes.

In discussions with Greg Martin we were advised of dramatic changes in the Waitomo Glowworm Cave visitor numbers over a few decades, so we thought we should look further afield and see what is happening in Australia, New Zealand and at as many show cave sites in Britain, Europe, Asia, Africa and South and North America as we could obtain responses from given the short time frame leading up to the Waitomo Conference.

This paper will present a very preliminary view of what is happening world-wide. Little analysis of the data is presented primarily due to the poor temporal and geographic spread of the data – although we have been provided with some excellent datasets as shown below. This paper is intended to be a precursor to further work.

However, as Brian Clarke has pointed out to us recently absolute visitor numbers do not tell us much – it is the experiences we offer, what value adding we do and what the visitors contribute to the local economy and our business which are the important factors.

The survey

Once the idea had been generated by the contact between Greg Martin and Andy the idea of looking around the world arose. After data started arriving it was obvious that a professional data analyst was needed. Thus came the involvement of Dr Jess Spate.

Initially we asked for visitor numbers for the past decade. We said that we were happy to receive percentage changes if the various site had "commercial in confidence" issues. However, it became obvious that our requests in both the detail we wanted and the length of record were inadequate.

Visitor numbers for the last decade were sought in waves from:

- All Australian show cave operators
- Three New Zealand operators
- Personal contacts in Brazil, USA, United Kingdom, Europe, Asia, Bermuda and South Africa
- The National Caves Association (USA)
- The International Show Caves Association (ISCA)

Realising our mistake we contacted our respondents and requested additional information which was forthcoming in many cases.

Some 57 positive responses were received – many with comments pertinent to local events (fires, floods, road construction etc.) and or international happenings (9/11, SARS, GFC etc.). In most cases annual visitor numbers were supplied however some were on a "financial year" basis. These differ around the world.

In a very few cases (perhaps for 'commercial-in-confidence' reasons) only percentage changes were supplied. Data was supplied for periods for two to 105 years. We also had estimates of visitor numbers for some of the smaller sites.

Limitations of the survey

- We should have asked for at least 15 years – preferably all available years. Ten years misses out the 9/11 tragedy.
- We should have asked more firmly for comments on impacts of local and international events.
- A mix of periods supplied i.e. data ranges from between 2 to 105 years.
- A mix of calendar and financial years arrived. These vary from country to country and through the long runs of years in some cases.
- The very uneven geographical spread of requests (and responses).
- Only Slovakia and the Czech Republic provided data on all show caves.

Figure 1. Location of the responding sites as shown by the red dots. Note that one dot may represent a number of separate cave sites (e.g. in South Korea) due to limitations of scale. Note also the very poor geographical spread world-wide.

	SITE	COUNTRY	# OF CAVES	YEARS	TYPE		SITE	COUNTRY	# OF CAVES	YEARS	TYPE
1	Buchan	Aus	3	94	Actual	28	di Toirano	Italy	1	12	Actual
2	Ngilgi	Aus	1	7	Actual	29	del Vento	Italy	1	10	Actual
3	Kelly Hill	Aus	1	10	Actual	30	Seongryugul	Korea	1	37	Actual
4	Wombeyan	Aus	5	28	Actual	31	Gosugul	Korea	1	35	Actual
5	Jenolan	Aus	8	11	Actual	32	Hwaamgul	Korea	1	8	Actual
6	Capricorn	Aus	1	24	Actual	33	Daegeumgul	Korea	1	5	Actual
7	Chillagoe	Aus	3	22	Actual	34	Hwanseongul	Korea	1	15	Actual
8	Mole Creek	Aus	2	15	Actual	35	Yongyeongul	Korea	1	15	Actual
9	Yanchep	Aus	1	7	Actual	36	Ondalgul	Korea	1	4	Actual
10	Naracoorte	Aus	3	8	Actual	37	Gossigul	Korea	1	9	Actual
11	Tantanoola	Aus	1	7	Actual	38	Baekyonggul	Korea	1	3	Actual
12	Calgardup/Giants	Aus	2	13	Actual	39	Cheongokgul	Korea	1	16	Actual
13	PMRose	Aus	1	2	Estimate	40	Mulu	Malaysia	3	27	Actual
14	Engelbrecht	Aus	1	2	Estimate	41	Spellbound	NZ	2	6	Actual
15	Cutta Cutta	Aus	1	5	Actual	42	Te Anau	NZ	1	4	%ages
16	Careys	Aus	1	6	Estimate	43	Slovakia	Slovakia	12	42	Actual
17	Nixhohle	Austria	1	10	%ages	44	Skocjan	Slovenia	1	10	Actual
18	Eisreisenwelt	Austria	1	93	Actual	45	Postojna	Slovenia	3	13	Actual
19	Hundalm	Austria	1	46	Actual	46	Cango	Sth Africa	1	13	Actual
20	Otscher	Austria	1	10	Actual	47	Kents	UK	1	13	Actual
21	Crystal	Bermuda	2	26	Actual	48	Talking Rock	USA	1	14	Actual
22	Lago Azul	Brasil	1	7	Actual	49	Natural Bridge	USA	1	10	%ages
23	Santana	Brasil	5	5	Actual	50	Cumberland	USA	1	7	Actual
24	Czech Republic	Czech Reb	14	10	Actual	51	Marengo	USA	1	7	Actual
25	Aillwee	Ireland	1	6	Actual	52	Diamond	USA	1	7	Actual
26	Grotta Gigante	Italy	1	105	Actual	53	Luray	USA	1	6	%ages
27	Frasassi	Italy	1	21	Actual	54	Ohio	USA	1	63	Actual

Table 1. Respondents, the number of caves represented, years of record and type of data supplied.

Methodology of the analysis

We are only skimming the surface of what is possible with datasets like these. Our results are largely visual and narrative rather than statistical at this stage. We will not be providing much interpretation of events influencing visitor numbers in this paper.

The data preparation process for an individual series went as follows:

- Some data was only provided as yearly percentage changes. In these cases the last year of complete data was given the value 1 (this can be thought of as 100% if you prefer) and the rest of the series calculated back to the best of our ability – it was not always clear whether the percentage changes given were calculated forwards or backwards, year by year or over the full period of record.
- Where 2012 numerical data existed, we normalised all previous data by this, resulting in a value of 1 for the 2012 year. In this way we intended to show rising and falling trends most clearly and allow comparison with percentage-change-only datasets.
- Datasets were then grouped by location for best illustration of national and regional responses.

Where 2012 data was not available, we normalised by the last year in the series. This does make trends slightly harder to see, but we felt this data was still valuable enough to include. Extrapolation would be the alternative and possibly dangerous.

As mentioned previously, this is a preliminary analysis only. There are a number of significant issues of which we are aware, but which have not yet been addressed. The most serious are:

- The aforementioned cases where no 2012 data exists.
- Some series were supplied with metadata noting that the years used was not calendar but financial. However, in most cases just the figures were supplied. It is not known how many series relate to financial years and which are standard calendar years. In effect this means that some series are offset by six months or other periods.
- Most of the series given relate to individual caves, but some cover entire resorts or multi-cave tours/passes.
- At present the dataset, although certainly rich enough to be interesting, is small. Most

countries/regions are distinctly under-represented.

- Problems in comparing sites where visitor numbers may differ in many orders of magnitude.
- The impacts of openings and events (e.g. relighting with attendant publicity) which greatly influence visitor numbers but without specific data from operators will just appear as "noise".

What might affect visitor numbers?

Clearly there are a huge variety of factors that influence the numbers of visitors visiting show caves. These range from international (e.g. oil prices, exchange rate variations between countries, disease outbreaks), national (e.g. the Gentle Revolution in Slovakia (known as the Velvet Revolution in the Czech Republic) – see Figure 8 below) and local such as weather events and roadworks (e.g. Diamond Caverns, USA). What may be a disaster in one country may benefit another. Regina Roach (pers. comm.) suggests that the SARS epidemic in Asia which spread to 37 countries globally in 9 months in 2002-03 lifted visitor numbers at Yarrangobilly with visitors visiting more caves and buying higher priced goods in the gift shop!

Table 2 provides a listing of some of the major world-wide events for the decade prior to the end of 2012.

Year	Stock markets	Oil Price (USD/US Barrel	Events
2001	Wall St ↓ after 9/11	30	Iraq invasion
2002	Wall St ↓	30	Bali bombings
2003		34	SARS
2004		44	Athens Olympics
2005		60	Hurricane Katrina
2006		69	Nth Korea Nuclear test
2007	China ↓ Wall St ↓	75	US mortgage crisis
2008	GFC	97	Obama elected/Beijing Olympics
2009	Dubai ↓	62	Swine flu/Victorian bushfires
2010	Greece ↓ Wall St ↓	68	Gulf of Mexico oil spill
2011	Wall St ↓	92	Bin Laden killed/Christchurch earthquake
2012		100	London Olympics/Nth Korea rocket test

Table 2. Major events world-wide in the past decade.

A listing of local events that might impact on show cave visitation is probably limitless! Some are outlined below:

- Bushfires/wildfire e.g. Western Australia and Victoria
- Floods e.g. Jenolan, Gunns Plains, Capricorn Caverns and Careys Cave floods
- Christchurch earthquake (bad for South Island, good for North?)
- Roadworks at Diamond Caverns, USA
- Snow
- The "Wet" in Australia
- National and State awards
- Grants
- Campaign launches
- Accreditation
- Major events (e.g. sporting events)
- New management
- And many etceteras!

The results

We received datasets from 54 respondents as shown in Table 1 above. The data covers about 110 separate caves and just over a thousand years of data.

The data is presented as a series of graphs firstly of the global data we acquired and secondly by region. These are normalised to either 2011 or 2012. Cango Caves and Brazilian caves are also included although the datasets are limited in length or do not show much variation. We also provide very few long run datasets of actual numbers. The long run datasets show as much as anything the difficulty of comparing actual numbers.

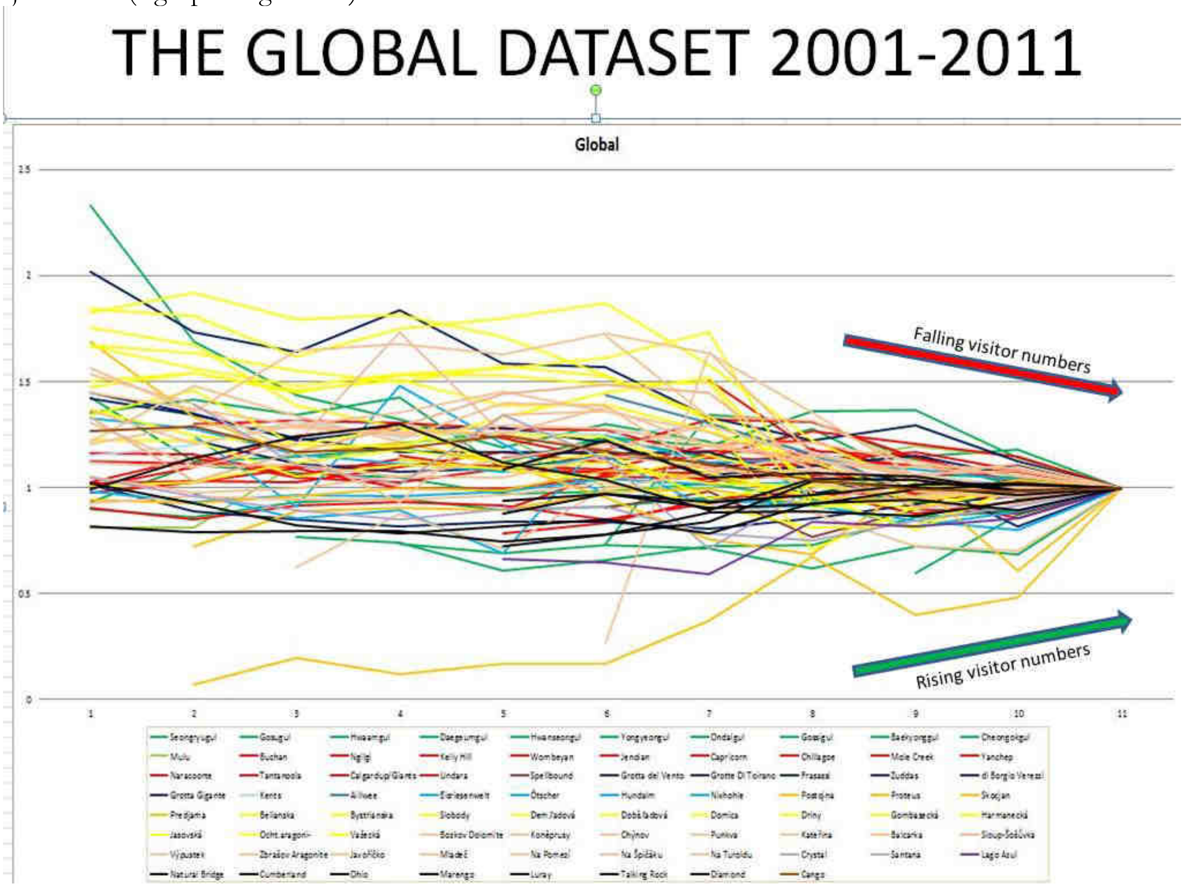
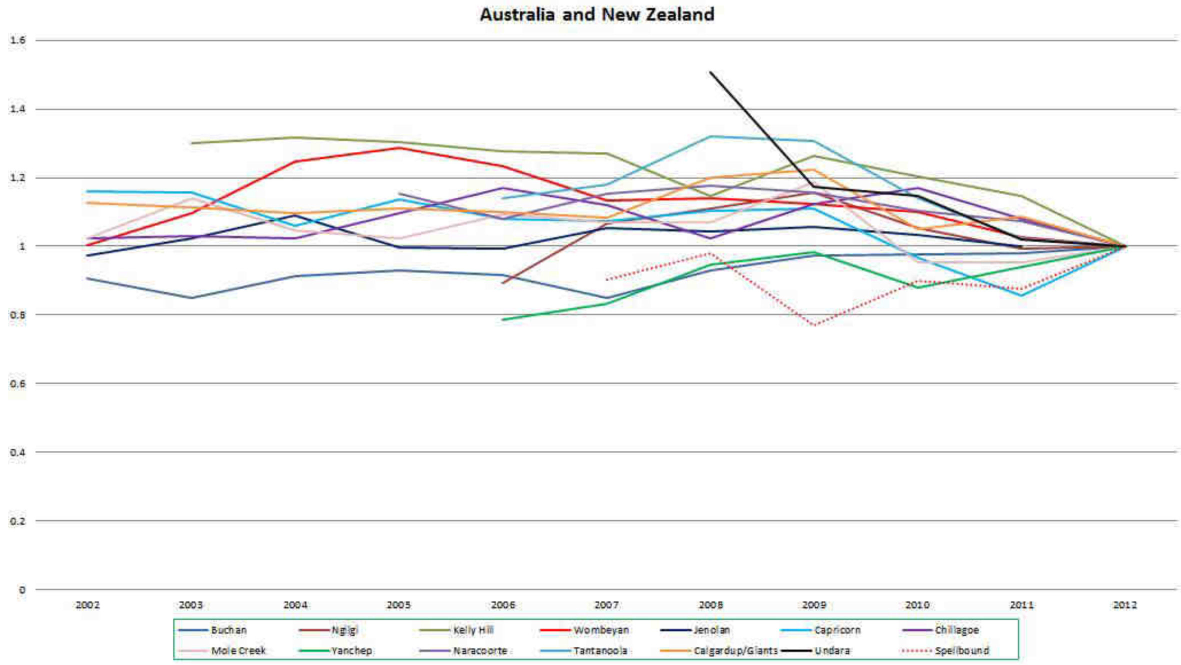
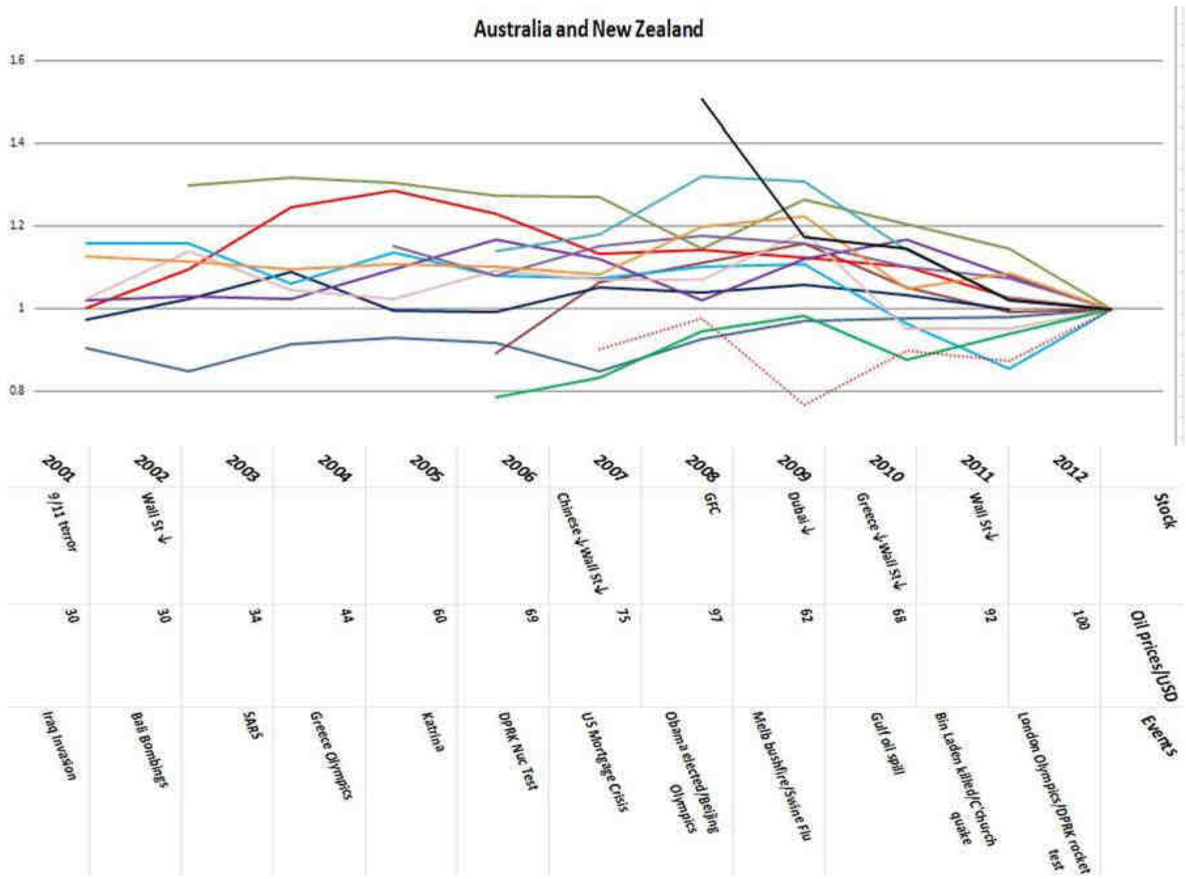


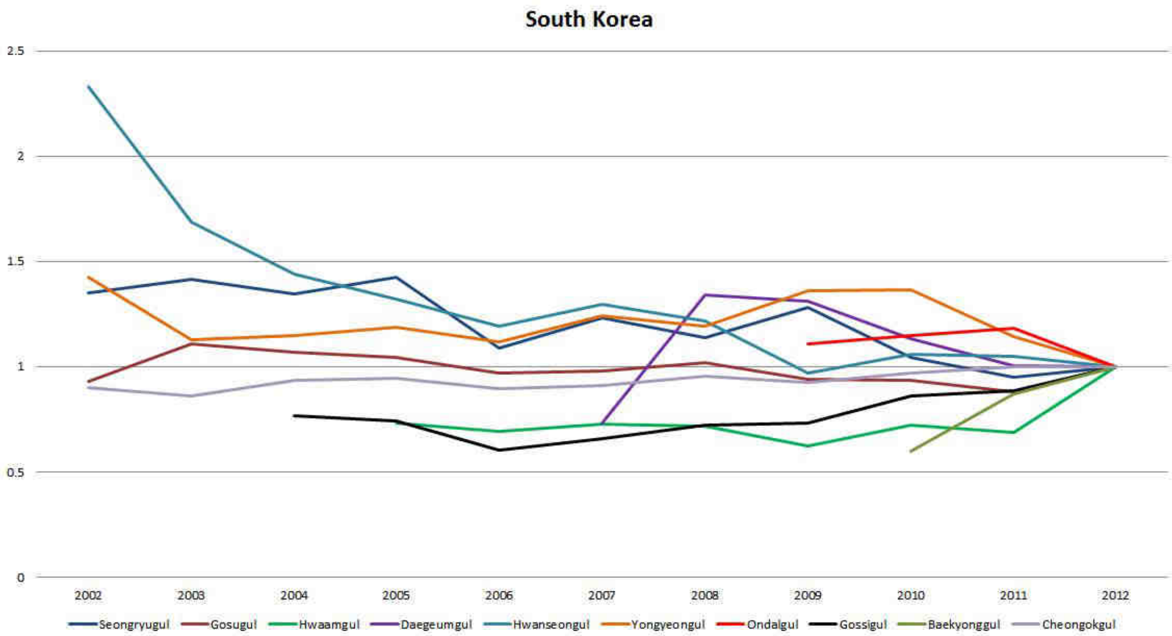
Figure 4. The entire dataset. Note the arrows showing increasing/decreasing visitor numbers. This applies to all except the long-run graphs. It is also interesting that the increasing number trends show less variability than declining trends. This is a matter to be further investigated.



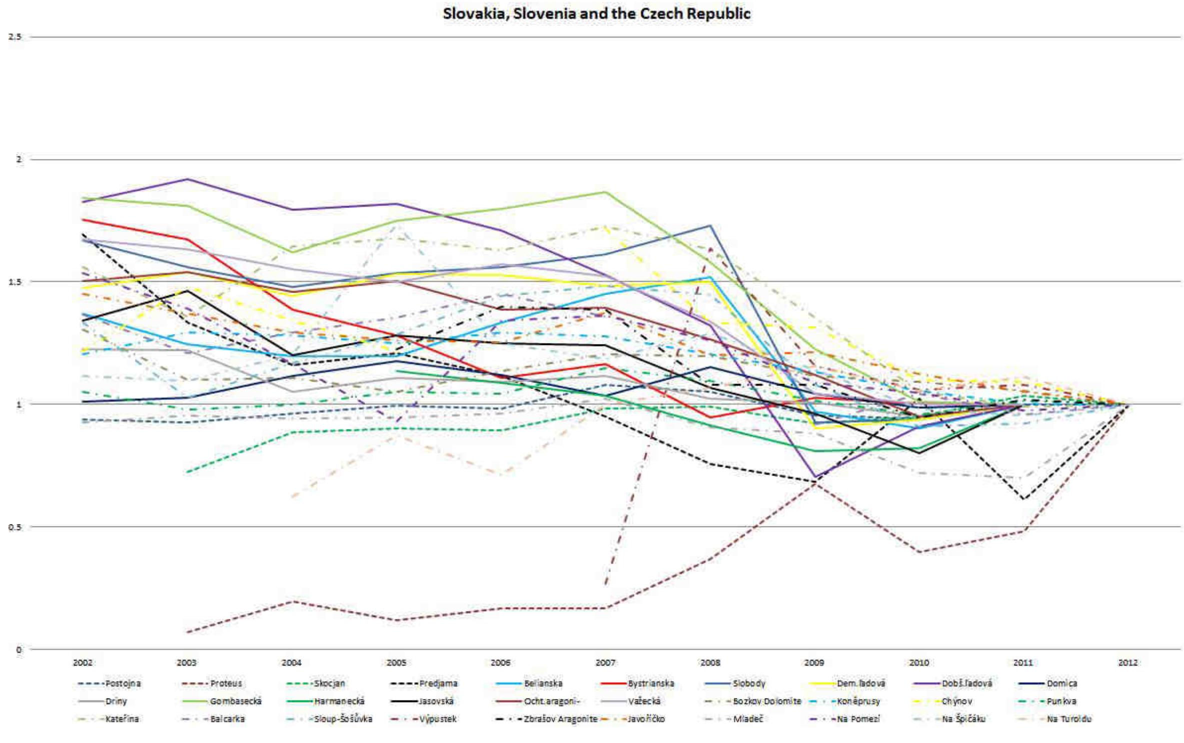
Australia and New Zealand dataset. This includes data from only 13 of Australia's 24 show cave operations – and only one from New Zealand. In most cases the numbers have not fluctuated wildly.



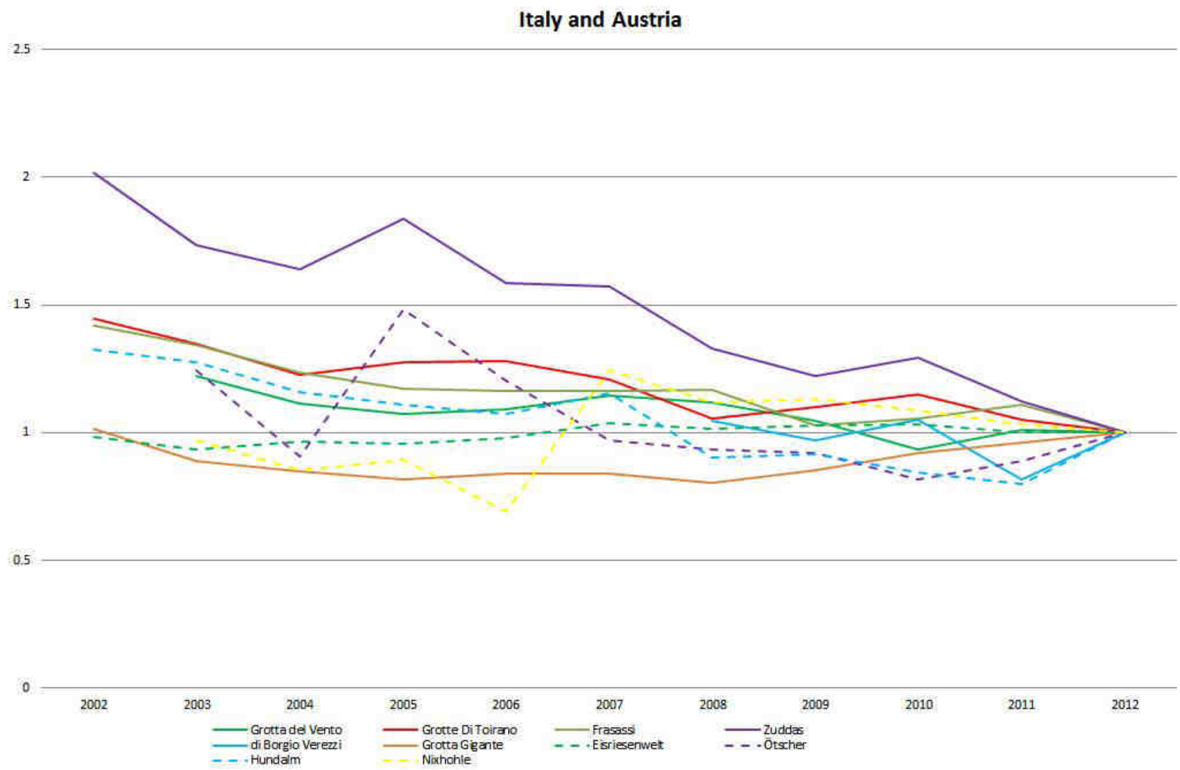
Australia and New Zealand dataset with world-wide events superimposed. Antipodean caves do not seem to be greatly influenced by world events.



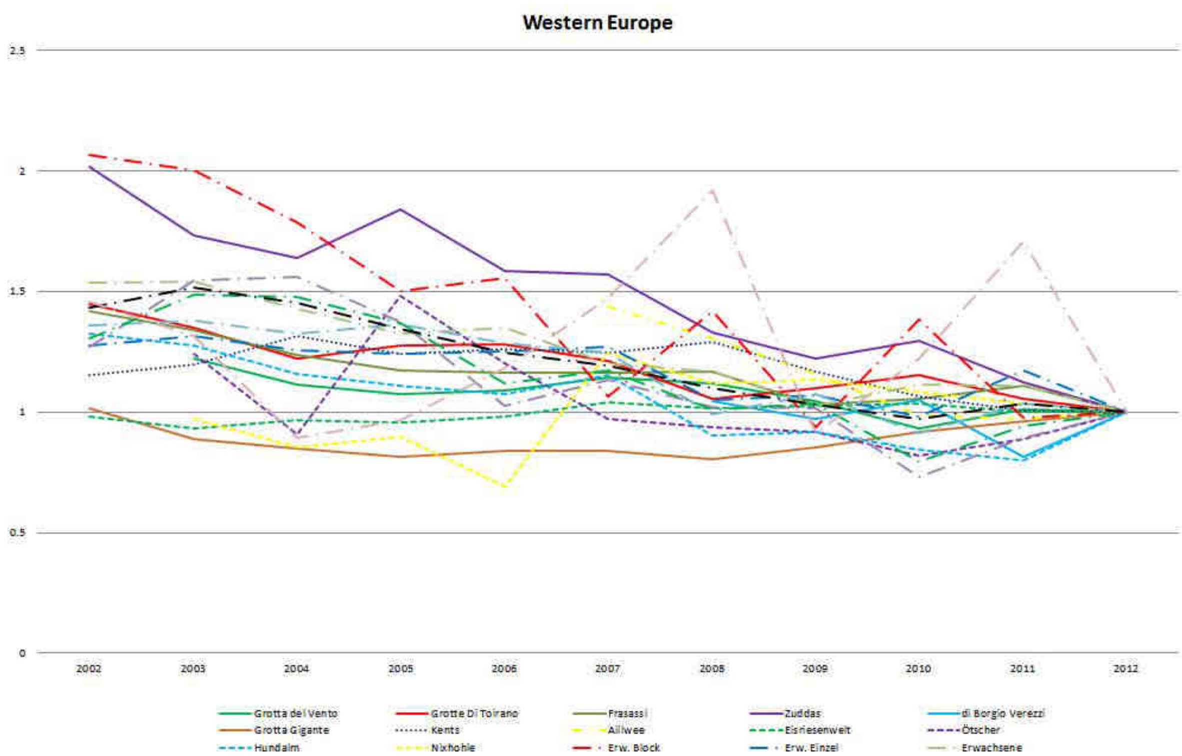
South Korea dataset. Note the very large decline in visitor numbers at Hwanseongul – the other caves are relatively static.



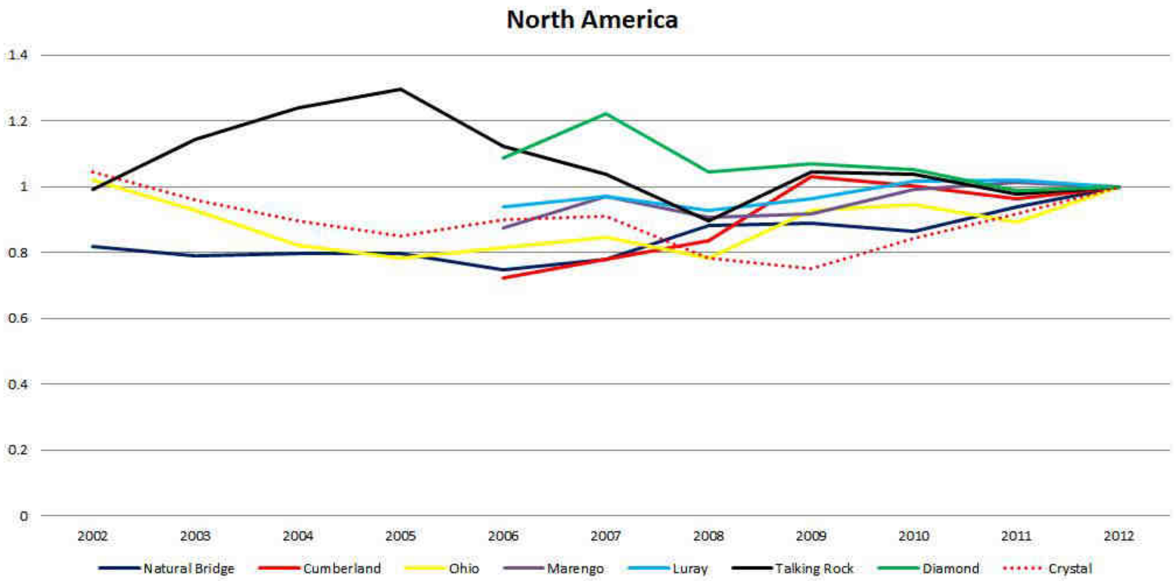
Slovakia, Slovenia and the Czech Republic dataset. Perhaps the most wildly varying data set – note the influence of the Green (Velvet) Revolution in Slovakia producing very sharp declines.



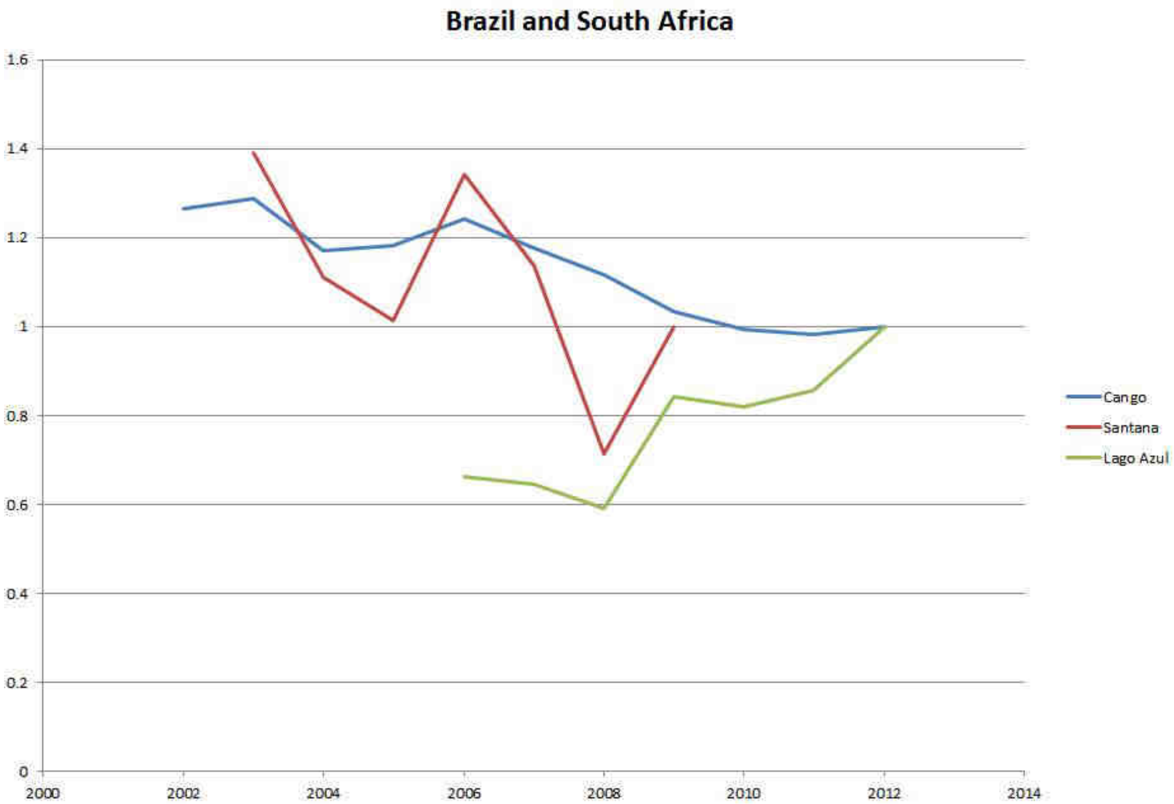
Italy and Austria dataset. Mostly a general decline here or relatively static.



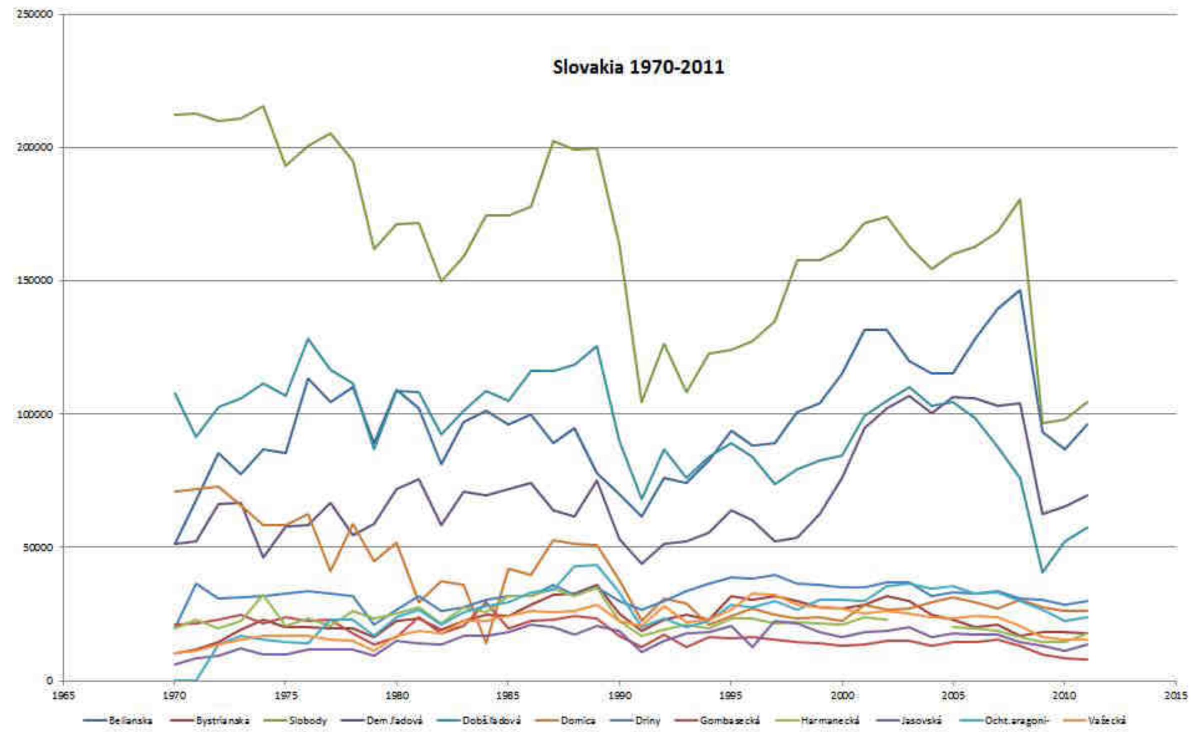
Western Europe dataset. Figure 9 above is a subset of this dataset. A similar comment applies. The brown dot-dash line should be ignored – problem with that data set.



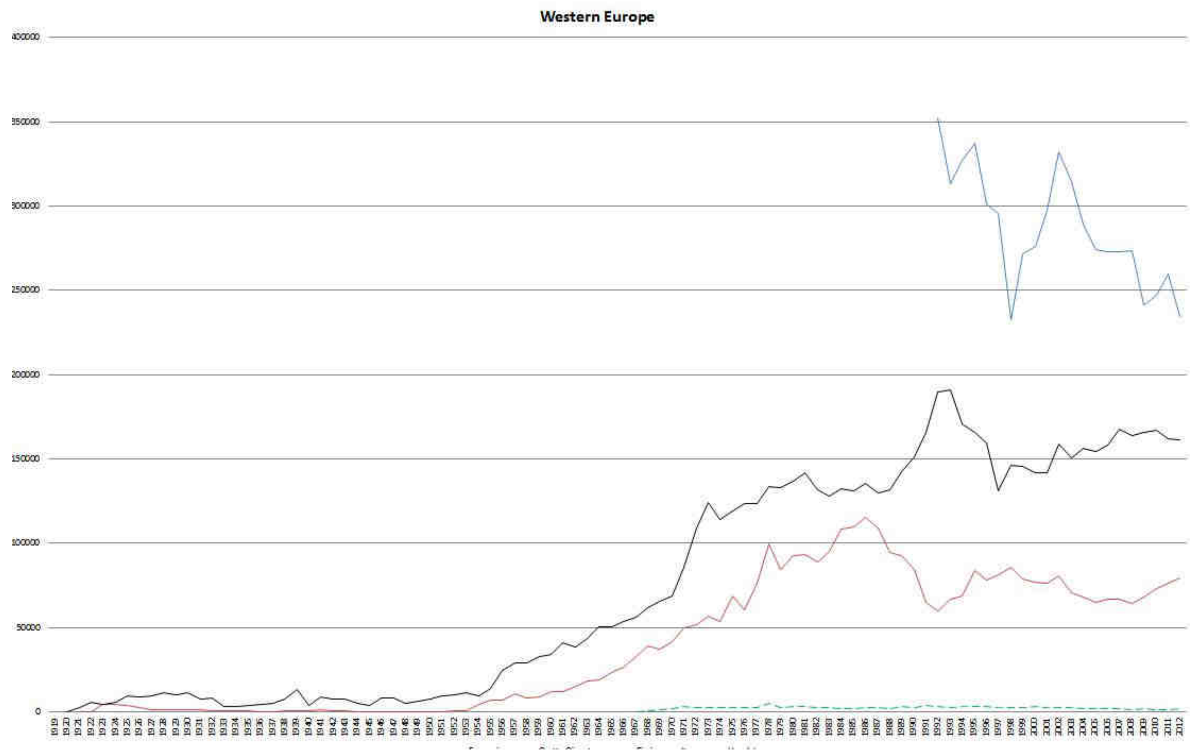
USA and Bermuda dataset. Grouped together as Bermuda's tourism industry is dependent on the USA. Unfortunately we have only a very few caves from the US and short runs of data. However the variability is relatively low – perhaps as a result of the heavy use of ancillary operations in the USA – e.g. gift shops, zip-lining etc.



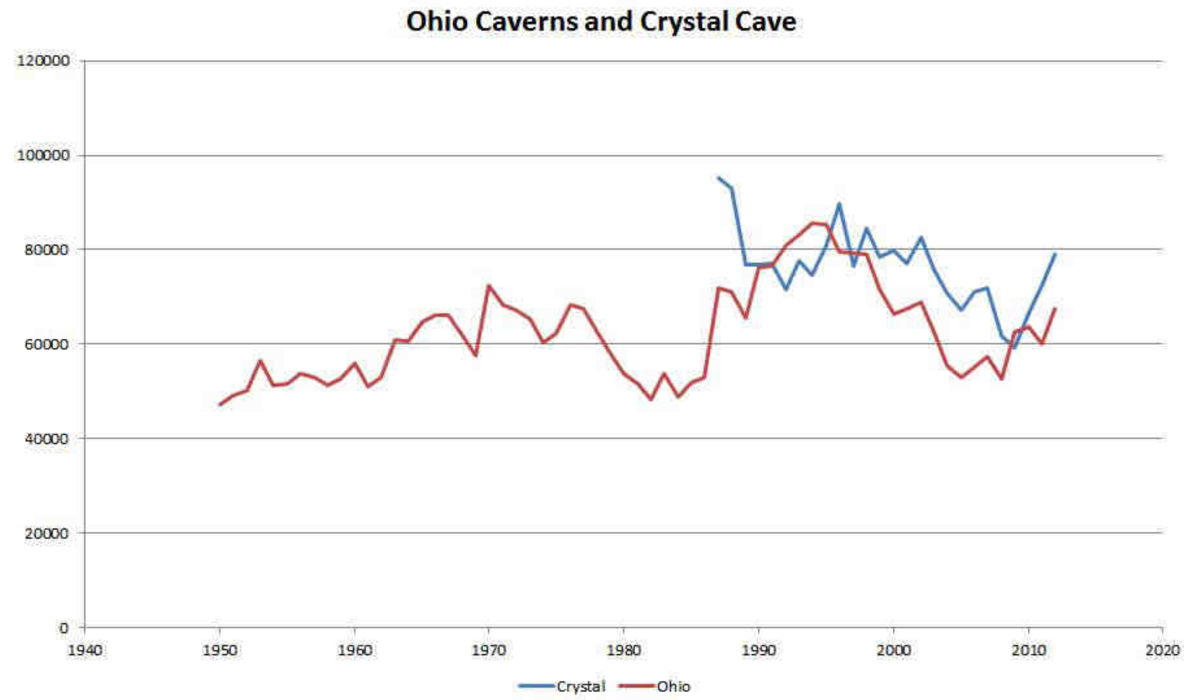
Brazil and South Africa dataset. Very limited data from Brazil and a long-term decline at Cango.



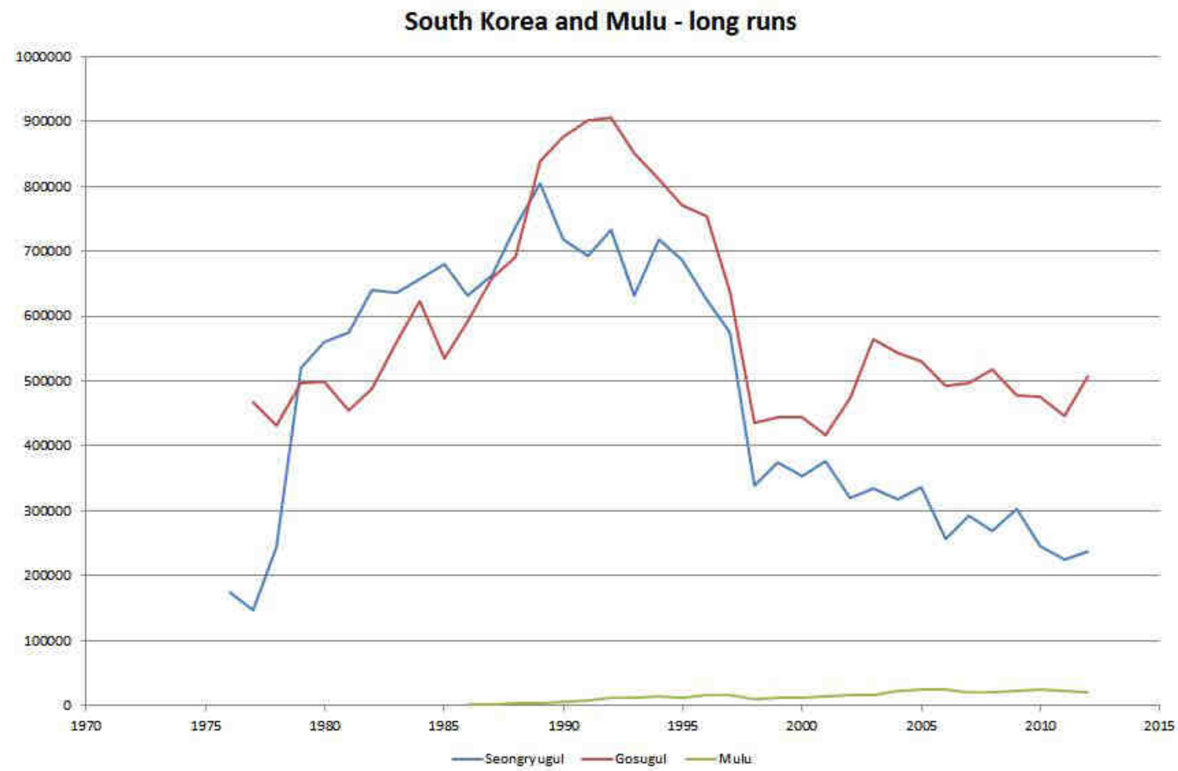
Slovakia long runs. Here we see again the strong falls as a result of the Green (Velvet) Revolution and again in about 2008 – for what reason? Why did some of Slovakia's show caves not react strongly?



Western Europe long runs. This graph shows dramatically the issues in comparing absolute visitor numbers. Interesting that both Hundalm (Austria) and Grotta Gigante (Italy) had a spike in 1978 but opposite directions in about 1981.



Ohio and Crystal long runs. This graph illustrates relatively well the relationship between the USA and Bermuda. The influence of 9/11 is clear.



Korea and Mulu long runs. Again this shows the problems in comparing absolute numbers. The reasons for the rapid and continuous increase and subsequent decline in South Korea requires further investigation.

Discussion

According to the website http://www.showcaves.com/ there are about 1500 show caves around the world. The indications are that there are around 300 in each of the USA and China. The 54 operations reported here clearly do not represent the situation world-wide as they represent only about 4% of the total. Asian show caves in particular have enormous visitor numbers relative to the rest of the world. Apart from South Korea they are not seen in this survey.

Butler (1980) developed a theoretical model of the evolution of tourist areas. We do not see much evidence that his model actually fits the changes and trends in visitor numbers that we see in our admittedly limited dataset.

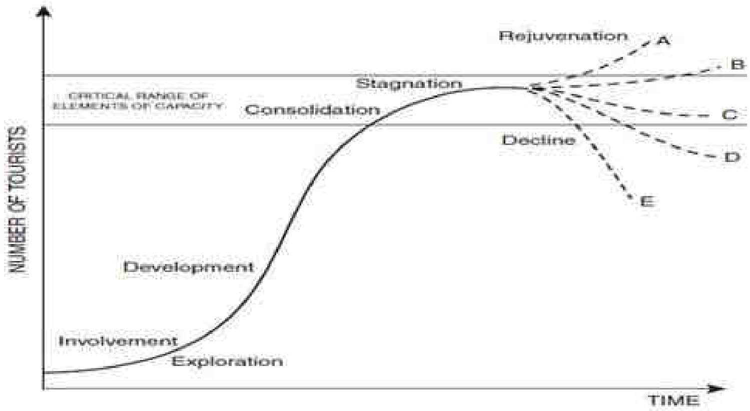


Figure 1.1 Hypothetical evolution of a tourist area. (For explanation of A– E see 'Implications.')

A= **Growth and expansion**
B = **Conservative growth**
C= **Stability**
D= **Decline**
E= **Terminal decline**

Butler's (1980) theoretical model of the evolution of tourist areas.

The only analysis of show cave visitor numbers that we can find is that of Bao (2006) and we quote him at length:

> *The life cycle model was first introduced to China by 1993. Since then, various scholars have used it as a descriptive tool in several specific case studies. For example, Bao (1994, 1995) analysed the development of large-scale theme parks and karst caves. He found that caves had no obvious exploration and involvement stages, and that \development stage, visitation to such a cave will decline. (p107)*

> *According to many cases studies (Bao, 1995), the life cycle of a karst cave is very special. They usually have no exploration and involvement stages, and their first stage is usually the development stage. Normally, caves isolated from other tourist destinations go directly to the development stage after they are open. They then will experience a short consolidation and stagnation stage, and subsequently come to a close soon afterwards. If a cave is close to a famous tourist destination, the situation will be different.*

> *Because it is dark and dangerous in the karst cave before it is open, only a few local residents would go to it after its initial discovery. When it is better known, tourists tend to flood in. Because there are so many karst caves in China, they can only attract tourists from nearby. The number of tourists normally falls quickly after the initial influx, as shown in the cases in Guangdong and Yunnan Provinces (Bao, 1995). However, if the cave were close to a famous tourist destination, such as Ludi Cave in Guilin city, tourists to such caves would fluctuate in numbers with going to the famous tourist destination. (pp 109-110)*

To us this seems so far from the reality of the situation in the rest of the world that we need to explore the subject of cave visitor numbers and their fluctuations further.

To this end we wish to:

- Extend the datasets geographically and temporarily.
- Extend the events calendar to world-wide, regional, national and local events to identify happenings that affect visits to show caves.
- Develop better methodologies for analysis.
- Investigate the differences in the variability signals between rising and falling visitor trends.

We will be seeking, via ISCA and other contacts, better datasets for longer periods and comments on what makes your visitor numbers go up and down. Especially from the show cave 'capitals of the world' – China and the USA. We intend, with your collective help, to expand a much extended and more thorough analysis of show cave visitor trends for the ISCA Congress at Jenolan in November next year!

Hopefully better understanding what influences visitor numbers visiting show caves will allow us to plan to avoid the inevitable pressures that affect show cave operations. To this end we seek your assistance in generating better data.

Acknowledgements

Greg Martin provided the original impetus for this paper. Many others have provided information or commentary. We thank all those below and apologise to any we may have missed. Many of the respondents provided very valuable comments which we would have liked to reproduce. However we had not asked permission to reproduce their verbatim comments so we have chosen not to include them.

Albin Tauber	Eric Evans	Kirsty Dixon
Alessio Fabbricatore	Friedrich Oedl	Lana Little
Alison Moos	Gabriella Barozzi	Mario Verole-Bozello
Ann Augusteyn	Geoff Kell	Mark Delane
Anne Wood	Gordon Smith	Mona Schaufuss
Bob Holt	Grant Commins	Neil Collinson
Brad Wuest	Greg Martin	Nick Heath
Brian Clark	Grotta di Toirano	Nick Powe
Brian Vauter	Hein Gerstner	Nicky Johnson
Dale Calnin	Heros Lobos	Paul Flood
Dan Cove	Hundalm Ice Cave	Pete Chandler
Dave Smith	Grotte is Zuddas	Peter Gazik
David & Julie Holdsworth	Jody Gersten	Peter Stefin
David Summers	Johann Wahl	Renata Marinelli
Deb Cardin	John & Sue Douglas	Rod & Isabel Graves
Deb Mara	Julia Coggins	Rosana Cerkvenik
Dusan Milka	Katja Dolenc Batagelj	Sara Bonacucina
	Kim Lyoun	Tanya Stiff

Hermannshöhle provided data which arrived too late to be included in this paper. However we thank them for their input.

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Bao, J and Zhang, C. (2006). *The TALC in China's Tourism Planning: Case Study of Danxia Mountain, Guangdong Province, PRC,* Chapter 7 (pp 107-116) in Butler RW (ed) *The Tourism Area Life Cycle, Vol. 1: Applications and Modifications,* Channel View Publications, Clevedon, Buffalo, Toronto

Butler, RW. (1980). *The Concept of a Tourist Area Cycle of Evolution: Implications for Management of Resources*, Canadian Geographer, 24(1)5-12

A preliminary survey of the invertebrate fauna of the Gunung Mulu World Heritage karst area, Sarawak, Malaysia

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Abstract

The Gunung Mulu World Heritage Area (Mulu) is situated in the north eastern corner of Sarawak, Malaysia on the Island of Borneo, adjacent to the South China Sea. The area was prescribed as a national park in 1974 and is the largest national park in Sarawak covering an area of 528 km^2 . The area contains significant karstic limestone, with some of the world's largest caves by volume known from the area including Deer Cave and the Clearwater System.

In 2012 a team of Australian speleologists undertook a preliminary survey of the invertebrate biodiversity of eight caves within Mulu. The caves were a mix of tourist, adventure and wild caves within the park. Invertebrates were recorded from a mixture of different microhabitats found within the caves and reference specimens from each cave were collected and preserved for future study.

The aims of the study were to document the biodiversity of the caves; provide a photo inventory of species recorded; compare the invertebrate diversity and abundance between different cave zones and microhabitats; compare the invertebrate diversity and abundance between caves used for different tourism purposes.

The survey recorded over 19,000 specimens using a combination of collection and observation of species that presently represents 100 different morpho-species, from 28 orders and 9 classes. The number of morpho-species is expected to increase with additional sampling and further identification of the specimens already collected. Forty different species have been photo-inventoried thus far.

Preliminary analysis of data has shown no discernible differences in invertebrate diversity or abundance between tourist caves and wild caves. Observed differences in invertebrate populations are related to microhabitat variability and availability within sampled caves, with greater invertebrate abundance related to bird and bat guano deposits. This study represents the first stage of invertebrate research at Mulu, and future efforts will focus on increasing the photo inventory to provide a useful resource to the Mulu Park and Sarawak Forestry staff to identify cave invertebrates in the field. Ultimately increasing the local knowledge of cave invertebrate fauna will provide the best protection for these important ecosystems.

Introduction

The Gunung Mulu World Heritage Area (Mulu) is situated in the north eastern corner of Sarawak , Malaysia on the Island of Borneo, adjacent to the South China Sea (Figure 1). The area was prescribed as a national park in 1974 and is the largest national park in Sarawak covering an area of 528 km^2. Mulu contains the second highest peak in Borneo, Gunung Mulu, a sandstone mountain situated to the east of the Melinau Limestone that contains the extensive caves that are the subject of the current study.

Gunung Mulu World Heritage Area (GMWHA) contains significant karst and associated subterranean fauna. Although substantial research was undertaken on the bio-speleological values, this was more than 30 years ago and much has changed in regard to our knowledge of such fauna especially within tropical settings.

Dr G E Wilford was the first individual to visit the Mulu caves with the objective to explore the caves in the early 1960s. Wilford worked with the Geological Survey of the Borneo region and completed surveys of Deer cave, parts of Wind cave and Terikan cave. He indicated in his book of the caves of Sabah and Sarawak that large and spectacular caves are most likely to be discovered in the Melinau area.

Prior to the 15 month scientific expedition by the Royal Geographical Society in 1977 - 78, the Mulu caves had first been reported in 1858, however, little work had been done on the biospeleological values of the area.

Aims and Objectives of Preliminary Survey

The current preliminary survey aims to provide a basis for future biological surveys in Mulu by building upon the only other substantial biospeleological survey undertaken in the area by Chapman (1982). The current preliminary survey aims to provide an initial overview of the invertebrate fauna in the cave systems near the Park Headquarters and predominately in those used as tourist caves and adventure caves.

The primary survey aims were to:

1. Preliminary overview of the biodiversity and initial insights into the cave ecosystems as a baseline and starting-point for future ecosystem studies of the cave systems.
2. Provide a photo inventory of species recorded.
3. Compare the invertebrate diversity and abundance between different cave zones and microhabitats.
4. Compare the invertebrate diversity and abundance between caves used for different tourism purposes.
5. Provide management strategies to facilitate fauna survival and mitigate threats.
6. Provide recommendations for future works to compliment the findings of the current study.
7. Preparation of recommendations for further cave biodiversity studies, potentially focusing on sustainable cave management and adequate tourism development

The caves chosen were a mixture of tourist caves, adventure use caves and wild caves and included a range of habitats and use levels. The caves examined are shown in Table 1.

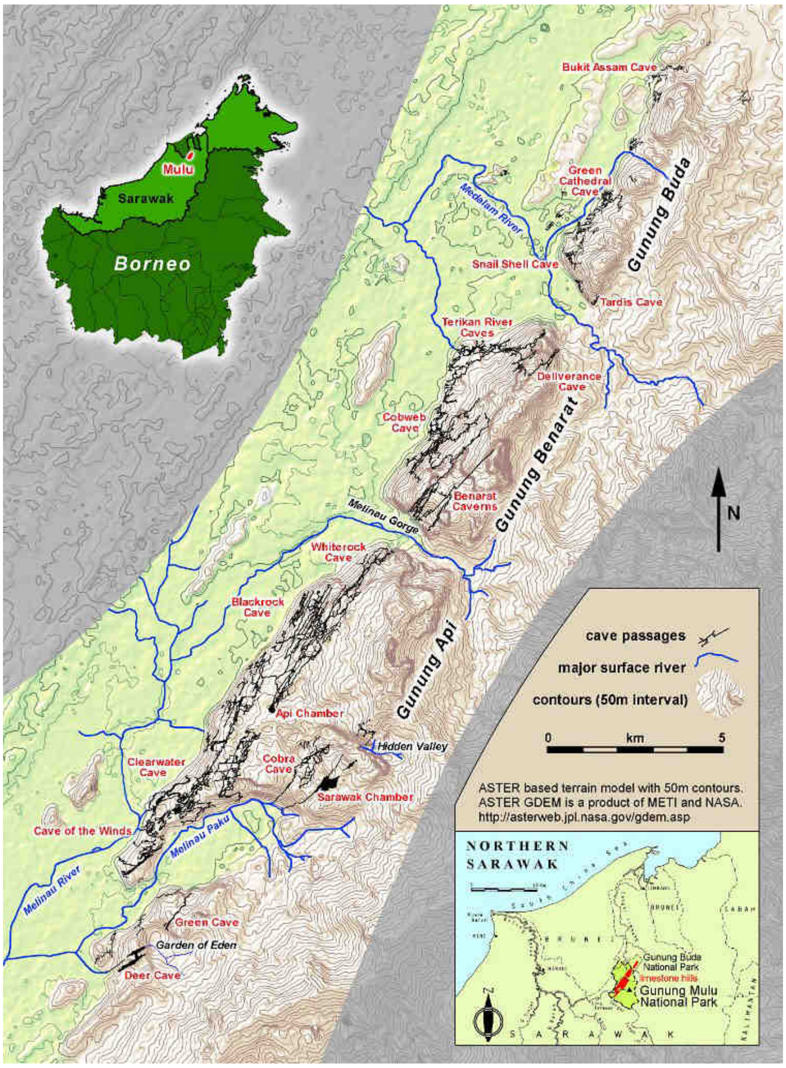

Figure 1 Map of all Mulu Cave systems (after www.mulucaves.org)

Cave Name	Primary Use	Limestone Section	Visitation
Deer Cave	Tourism	Deer/Green Section	High
Deer Water Cave	Wild	Deer/Green Section	Low
Green Cave	Wild	Deer/Green Section	Low
Stonehorse Cave	Adventure	Deer/Green Section	Low
Fruit Bat Cave	Adventure	Kenyalang/Fruit Bat	Low
Kenyalang Cave	Adventure	Kenyalang/Fruit Bat	Low
Lagang Cave	Tourism/Adventure	Gunung Api	Moderate
Racer Cave	Adventure	Gunung Api	Moderate
Clearwater Cave	Tourism/Adventure	Gunung Api	Moderate

Table 1 Cave usage and location within Mulu

Survey Timing and Participants

The survey was undertaken between the 29th April – 12th May 2012. The survey was undertaken by a specialist cave biologist, Dr Timothy Moulds (Australia), and assisted by a team of Australian speleologists who have experience in cave interpretation, guiding and speleology. An additional field visit was undertaken by Dr Timothy Moulds and a smaller speleological team from the Western Australian Speleological Group (WASG) in December 2012 (12th – 17th December) to revisit some of the primary caves examined previously. The Australian biospeleological team were Dr Timothy Moulds, Jay Anderson, Ross Anderson, Patrick Nykiel, Rob Susac, Barbara Zakrzewska, Dr Stephen Swabey, Toni Lowe, Sharon Thwaites, Ian Thwaites, Jane Pulford, Tony Veness, Dr Bert De Waale, Gregoriy Tsaplin, Christine Best, Andrew Thomas, and Sandi Cheema.

Mulu park administration provided assistance to the project through the provision of accommodation, staff for field work and guiding, and numerous other forms.

Further field assistance was provided by Mulu Park staff including, Bian Rumei, Syria Lenjau, Jeffry Simun, Brian Clark, Sue Clark, Jeremy Clark and Sarawak Forestry Staff led by Anne Malissa King.

Introduction to Subterranean Biology

Caves form a very stable and generally homogenous environment in which to conduct various ecological and evolutionary experiments, such as on competition between species, resource partitioning, and the processes of speciation (Poulson and White, (1969)). The total absence of light severely alters or completely removes many circadian cycles affecting ecosystem function (Lamprecht and Weber, (1992), Langecker, (2000)). Temperatures are usually constant, varying only slightly between seasons. Humidity is commonly high, providing an ideal habitat for many invertebrate species susceptible to desiccation. The lack of photosynthetic plants changes the trophic structure of cave ecosystems, with energy sources usually being transported from the surface (Poulson and Lavoie, (2000), Poulson, (2005)). Caves are defined as human-sized subterranean voids, although cave adapted animals are known to occur in the smaller spaces between large voids called micro- and meso caverns (Howarth, (2003)).

Caves are divided into several distinct biological zones to aid interpretation (Figure 2). These correspond to the amount of available light and varying environmental conditions (Humphreys, (2000)). The *Entrance Zone* is the area directly around the cave entrance; it is generally well lit, often supports photosynthetic plants, and undergoes daily temperature and humidity fluctuations. The *Twilight Zone* is just beyond the entrance zone and is often dominated by lichen and algae that require low light conditions. The temperature and humidity are still variable but fluctuations are dampened compared with epigean variation.

Deeper into a cave, light is reduced to zero and the *Dark Zone* is entered, which is subdivided into three zones, the transition, deep cave and stale air zones. The *Transition Zone* is perpetually dark, but still fluctuates in temperature and humidity determined by epigean conditions. The *Deep Cave Zone* is almost constant in temperature and humidity conditions.

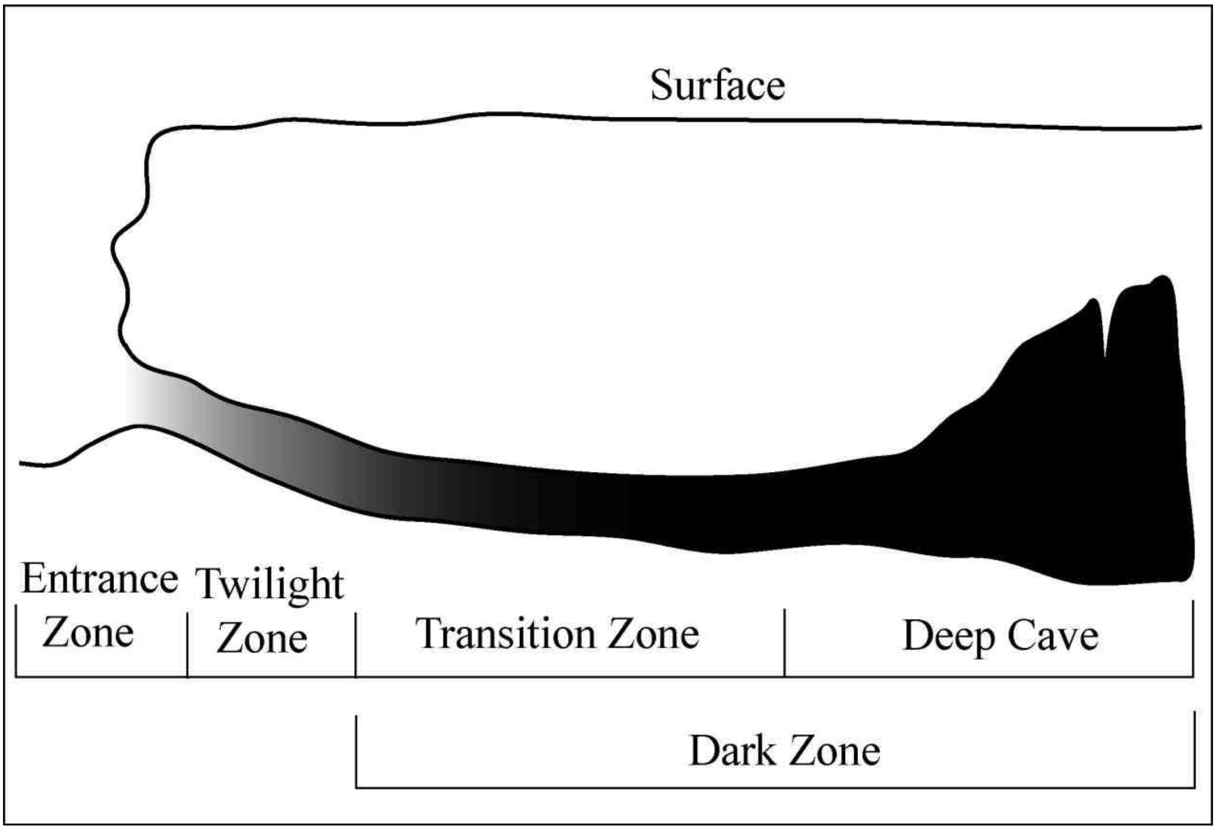

Figure 2 The environmental zones of a cave shown in cross section. (Figure after Moulds, 2006).

Classifications of cave dependence

Cave invertebrates are generally classified according to their degree of cave dependence using a modified version of the Schiner - Racovitza system (Schiner, (1854), Racovitza, (1907)). This system originally relied upon organisms ecological association with subterranean environments, requiring detailed ecological knowledge of animals that is commonly lacking for most species. In order to circumvent this lack of knowledge, the concept of troglomorphy (Christiansen, (1962)), specific morphological adaptations to the subterranean environment, is used to define obligate subterranean species. The term troglomorphy, initially confined to morphology has since been used to describe both morphological or behavioural adaptations (Howarth, (1973)). The most currently accepted term for obligate subterranean fauna is that summarised by Sket (2010).

This combination provides a practical system, easily applied in the field and with minimum of detailed ecological study required. The level of subterranean dependency for different ecological groupings is described below:

- *Troglobionts* are obligate animals that rely on the hypogean (subterranean) environment for survival (Sket, (2010)) These species rely solely on the cave environment for food and reproduction. They are generally restricted to the deep cave zone where conditions are the most stable and are rarely found closer to entrances in the twilight zone.
- *Troglophiles* are animals that can complete their entire lifecycle within a cave but possess no specific adaptations to the cave environment. These species are capable of living outside caves in suitably sheltered and moist epigean habitats. This corresponds to the eutroglophile classification of Sket (2010).
- *Trogloxenes* are animals that regularly use caves for part of their lifecycle or for shelter, but must leave the cave to feed. Common examples of these are bats and cave swiftlets.

- *Accidentals* are animals that do not use caves on a regular basis and cannot survive in hypogean environments.

Aquatic hypogean animals are classified using a similar system to terrestrial hypogean animals except the prefix 'stygo' is used instead of 'troglo' (Humphreys, (2000)).

The Trophic Basis of Cave Ecosystems

Cavernicolous populations are dependant for their survival upon energy inputs into cave systems. These inputs can vary widely, with availability of food usually being the primary limiting factor (Peck, (1976)). Many cave ecosystems revolve around periodic flooding (Hawes, (1939), Humphreys, (1991), Culver *et al.,* (1995)) that carries organic material and accidental epigean animals into cave systems. Tree roots penetrating the roofs and walls are another energy source found commonly in tropical caves and lava tubes (Hoch, (1988), Hoch and Howarth, (1999)). Guano from bats, birds and Orthoptera is an important energy source (Harris, (1970), Poulson, (1972), Decu, (1986), Blyth *et al.,* (2002), Moulds, (2004), Moulds, (2006)) with large, varied and unique ecosystems existing around such deposits. Dead animals can be a source of food for scavengers near cave entrances (Richards, (1971)). Accidentals wandering in from cave entrances also provide a food source, although this is generally periodic in nature and inconsistent in quantity, except in caves with large active rivers that are capable of carrying in large volumes of epigean animals, especially during high water flow periods.

For the most part, cave environments are generally depauperate in food and consequently are sparsely populated by cavernicolous animals. However, caves containing guano deposits differ fundamentally because there is a virtually unlimited food supply, commonly resulting in large populations of guano dependant arthropods known as guanobites. Guanobites possess no specific behavioural or morphological adaptations, presumably because of the lack of selection pressure to minimise energy expenditure that dominates the evolution of troglobites. The colonisation and establishment of guano dependent communities in caves is poorly understood. Mechanisms for the dispersal of guano dependent arthropods are potentially numerous, but most are poorly investigated at best (Moulds, (2004)).

Sources and diversity of cave guano

Cave guano deposits from specific sources can each possess a unique assemblage of taxa (Horst, (1972), Poulson, (1972)). Throughout the world's biogeographic provinces different taxa are responsible for being the most important guano producers.

The most widespread and common guano is that produced by bats and these deposits are generally the largest in volume. The spatial and temporal deposition of bat guano differs from tropical to temperate caves. Cave-dwelling bats in temperate regions show an annual cycle of occupancy over summer months when pups are born, before colonies disperse to cooler, wintering caves where they enter torpor. This annual cycle results in large amounts of guano deposited over summer months and then a cessation of guano input for at least half the year. In contrast, tropical caves generally show constant bat occupancy rather than an annual cycle, and less aggregation of individuals due to warmer ambient temperatures (Trajano, (1996), Gnaspini and Trajano, (2000)). Gnaspini and Trajano (2000) note that many bat populations in tropical Brazil are, however, commonly nomadic, resulting in roaming colonies varying their location in an irregular and non-seasonal fashion. This results in non-continuous guano deposition in a single locality over several years. The diet of bats (either haematophagous, insectivorous, frugivorous, or nectarivorous) also influences the composition of guano piles and, hence, the associated guanophilic communities (Gnaspini, (1992), Ferreira and Martins, (1998), Ferreira and Martins, (1999)).

Birds are common guano producers in the northern parts of South America, the Caribbean and tropical caves of south-east Asia. Cave-dwelling birds nest in the dark zone, providing an important energy resource for many cavernicolous animals.

Swiftlets (*Aerodramus* spp.) nest in the entrance and dark zones of tropical caves in south-east Asia, northern Australia and the Pacific, and are insectivorous (Medway, (1962), Humphreys and Eberhard, (2001), Koon and Cranbrook, (2002)). The volumes of bird guano deposited are comparable to similar sized bat populations.

Previous biospeleological literature relating to Mulu Karst

Royal Geographic Society 1977/1978 Expedition

The Royal Geographical Society (RGS) expedition did not place karst and caves as the foremost objective of the 15 month expedition. In fact only six speleologists were present among the 130 scientists. However, the speleologists present determined that the potential was of such magnitude that follow up expeditions were required and subsequent UK led speleological expeditions occurred. Thus, the 1980 expedition was initiated.

Chapman, 1982

The primary published reference relating to biospeleological investigations at Mulu is Chapman's 1982 study, based upon field investigations undertaken in 1978 and 1980 as part of the RGS expedition and the subsequent Mulu 1980 Speleological Expedition (Eavis *et al.*, 1981). This paper reports the biospeleological investigation of 14 caves divided into four geographical groups. The paper serves primarily as a species inventory of cave invertebrates, and makes commentary on the biogeographical significance of the Mulu cave fauna, including its potential evolutionary explanation.

Chapman (1982) reports a total of at least 136 species, from 129 genera, 104 Families, 34 Orders, nine Classes and four Phyla. The species inventory does not generally distinguish the individual distribution of species between the 14 caves examined. This is the first reference that identifies a significant diversity of troglobiont fauna in a lowland cave in southeast Asia (Deharveng and Bedos, (2000)).

Deharveng and Bedos 2000

This paper provides an overview of subterranean diversity and distribution across South East Asia as a whole and makes specific comment regarding four karst areas studied by the authors over numerous biospeleological expeditions. The karst areas examined and compared are Tham Chiang Do (northern Thailand), Ngalau Surat (central Sumatra, Indonesia), Gua Salukkan Kallang/Towakkalak System (southern Sulawesi, Indonesia), and Batu Lubang (Halmahera Island, Moluccas, Indonesia). All these systems were comprehensively sampled including parallel sampling of outside habitats and soil so as to allow reasonable assignment of troglobiont status to species examined. Much of the detailed comparisons are based on collembolan species which are the taxonomic speciality of the authors. The comparison draws upon the research by Chapman in Mulu caves regarding the relationship between habitat stability, predictability and substrate heterogeneity, rate of food input and proneness to flooding with species richness.

Volshenck and Prendini 2008

This review of subterranean scorpions from around the world characterises *Chaerilus chapmani* (Lourenço and Franke, (1985)) as a true troglobitic scorpion, making it one of only 20 such species in the world. It is the only Malaysian troglobitic scorpion. The remainder of Asia contains four other troglobitic species; *Chaerilus sabinae* (Matampa Caves, India) (Lourenço, (1995)), *Liocheles polisorum* (Christmas Island, Australia) (Volschenk *et al.*, 2001), and two species from the Phong Nha – Ke Bang karst in north central Vietnam, *Vietbocap cahni* and *V. thienduongensis* (Moulds *et al.*, (2010), Lourenço and Pham, (2010), Lourenço and Pham, (2012)).

McFarlane et al. 2011

The paper summarises the knowledge of crab diversity in Borneo with a focus on the subterranean species and especially those species occurring at Mulu. The paper provides records of the six species known from Mulu and the known subterranean distribution of the two obligate species. The paper also provides a field key and photographs of several species.

Report Limitations and Exclusions

The current report was produced from data collected during a 14 day visit and a subsequent 5 day visit to Mulu in May and December 2012. The survey was intended as a preliminary investigation into the subterranean biodiversity of eight caves examined within the park. Identification of specimens collected were undertaken with limited reference material and equipment and are considered to be preliminary identification for the purposes of the report.

Due to the limitations in both time and available local resources in Mulu, the level of identification of the material collected during the current survey is preliminary and considerable further work is required to determine the number of species new to science collected. This collection can then form the basis for any future surveys to be conducted on the cave fauna of Mulu.

Survey Methodology

Surveys for subterranean fauna may use many different techniques according to the type of fauna being targeted and the amount of time available for the survey. These methods can include:

- pitfall traps (baited and unbaited).
- hand foraging (using forceps and paintbrushes to actively collect observed fauna).
- litter traps left in situ for days or weeks and then fauna extracted in a tullgren funnel.
- net hauling of water for aquatic fauna.
- nets left in situ in narrow streams to sieve water flows for discrete time periods.

Due to the very limited amount of time available for the current preliminary survey it was decided to use active hand searching (hand foraging) to enable a wide variety of different habitats, and caves to be surveyed quickly and detect the majority of species present within. In order to undertake a more comprehensive survey of the subterranean fauna (vertebrate and invertebrate) a combination of multiple techniques in each cave over longer time periods would be required. This was beyond the scope of the current project.

The majority of caves sampled during the current biospeleological survey were not sampled as part of Chapman's survey, with much of his sampling concentrating on the Clearwater System and other associated caves, as well as more remote caves further to the north (Chapman, (1982)). Green Cave, Deer Cave and Deer Water Cave were common to both surveys, albeit in differing sampling intensities.

Microhabitat Sampling

Each cave investigated for invertebrate biodiversity was sampled using a standardised method to enable results between caves to be comparable and also repeatable during any subsequent surveys. Caves were selected for sampling on advice from the Mulu Park Manager, Brian Clarke to provide a mixture of tourist, adventure and wild caves for comparison.

Each cave was sampled in the Entrance Zone, Twilight Zone and Dark Zone (Figure 2), with a selection of the main microhabitats sampled from each zone. The following microhabitats were identified as occurring within the Mulu caves

- Fresh guano
- Old guano
- Massive guano
- Damp sediment
- Dry Sediment
- Walls/Speleothem
- Streamway/Water pools

In each light zone of a cave the overall site was photographed and the location on existing cave maps was recorded to facilitate repeat sampling in the future. Each sampling site was then assessed for the presence of microhabitats, with each microhabitat identified in the site sampled for 20 minutes each. The abundance of each species was recorded using a combination of collection of voucher specimens (maximum of five specimens per morpho-species per cave) for future identification and observation of total species abundance within each microhabitat. The location of

any cave infrastructure, such as paths or lighting was also recorded.
The intensity of sampling varied between caves, as a function of accessibility, diversity of microhabitats, time available for the survey, availability of guides to facilitate access to some caves and other stochastic factors. The level of sampling within each cave is summarised in Table 2.

Cave	Number of Sites Sampled	Notes
Deer Cave	**4**	Collection only in Massive Guano microhabitat, no abundance observations
Deer Water Cave	**1**	
Green Cave	**2**	
Stonehorse Cave	**18**	Visited in May and December 2012, sites resampled
Fruit Bat Cave	**8**	Visited in May and December 2012, sites resampled
Kenyalang Cave	**4**	
Lagang Cave	**19**	Visited in May and December 2012, additional sites sampled in December 2012
Racer Cave	**10**	
Clearwater Cave	**5**	Collection only, no abundance observations

Table 2 Sampling intensity of Mulu Caves

Several other specialised microhabitats that were identified by Chapman (1982) that were encountered very occasionally were bog or mush guano, where guano is deposited into small water pools creating a liquid guano environment. This microhabitat was only seen during the current survey within sections of Clearwater Cave and limited opportunistic sampling was undertaken within it.

Material collected was placed in 70% ethanol for preservation, and sorted using a Premiere (20x - 40x) stereomicroscope. Specimens were identified to lowest practical taxonomic level using the resources available at the time of the survey in Mulu. Preliminary identification of material was identified by Dr Timothy Moulds. All material collected remains the property of the Republic of Malaysia, and has been kept by the Sarawak Department of Forestry office in Mulu NP.

Sample Locations

Sampling locations are shown in Appendix C and includes a photo of each specific area where available.

The location of specific caves sampled is shown in Figure 3.

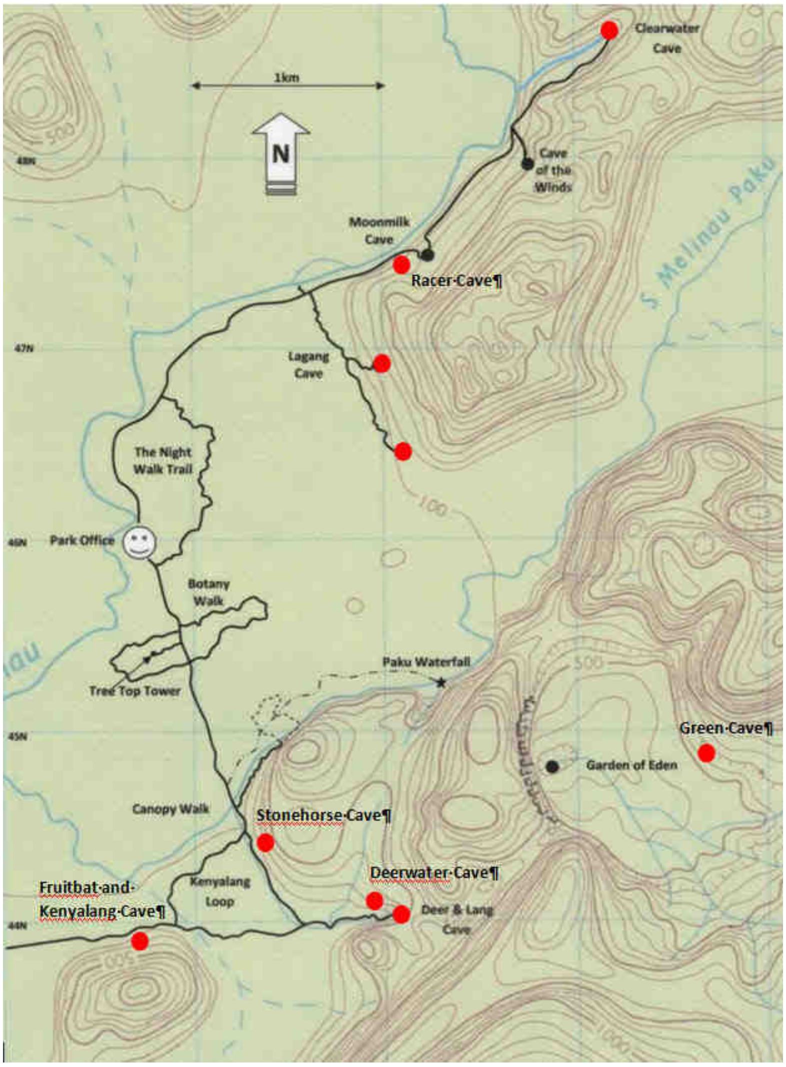

Figure 3 Locations of caves surveyed for invertebrates during the current survey

Survey Results

The survey recorded over 19,000 specimens using a combination of collection and observation of species abundance that presently represents 93 different morpho-species, from 25 orders and 8 classes. The number of morpho-species is expected to increase with additional sampling and further identification effort. Forty different species have been photo-inventoried thus far and are shown in Appendix B.

The spider *Heteropoda* sp. (Sparassidae) was the most widespread species found in all caves sampled, followed by the millipede sp. A, Opilione Phalangodidae? sp.A, Lepidoptera: *Tinea*? sp. and Araneae: Pholcidae sp. A that were recorded in six of the seven caves comprehensively surveyed (excluding Clearwater Cave and Deer Water Caves). The majority of species (44.6%) were recorded from a single cave, with very few species recorded from five or more of the caves surveyed (Figure 4).

The most diverse order was Coleoptera with 13 species recorded, followed by Araneae (10 spp.), Isopoda (10 spp.), Diptera and Hemiptera (9 spp. each) and Diplopoda (8 spp.). Eleven orders are represented by single species (Figure 5).

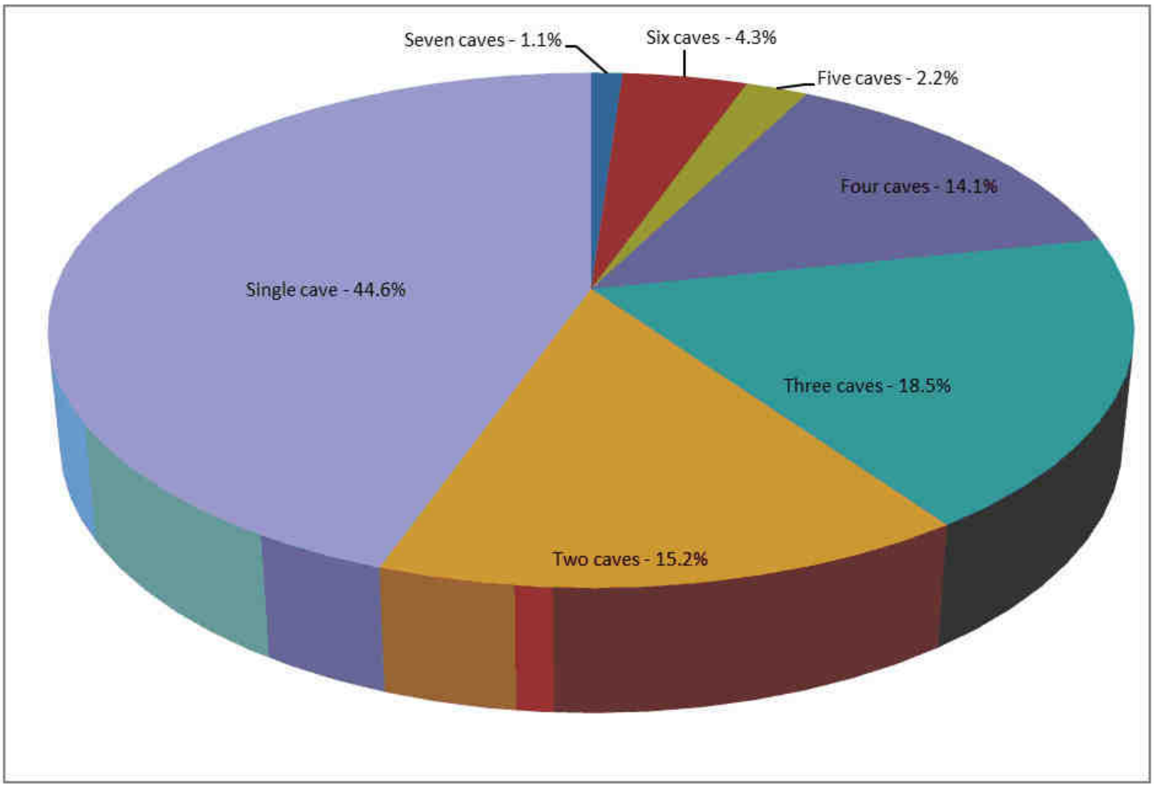

Figure 4 Percentage of species recorded from multiple caves.

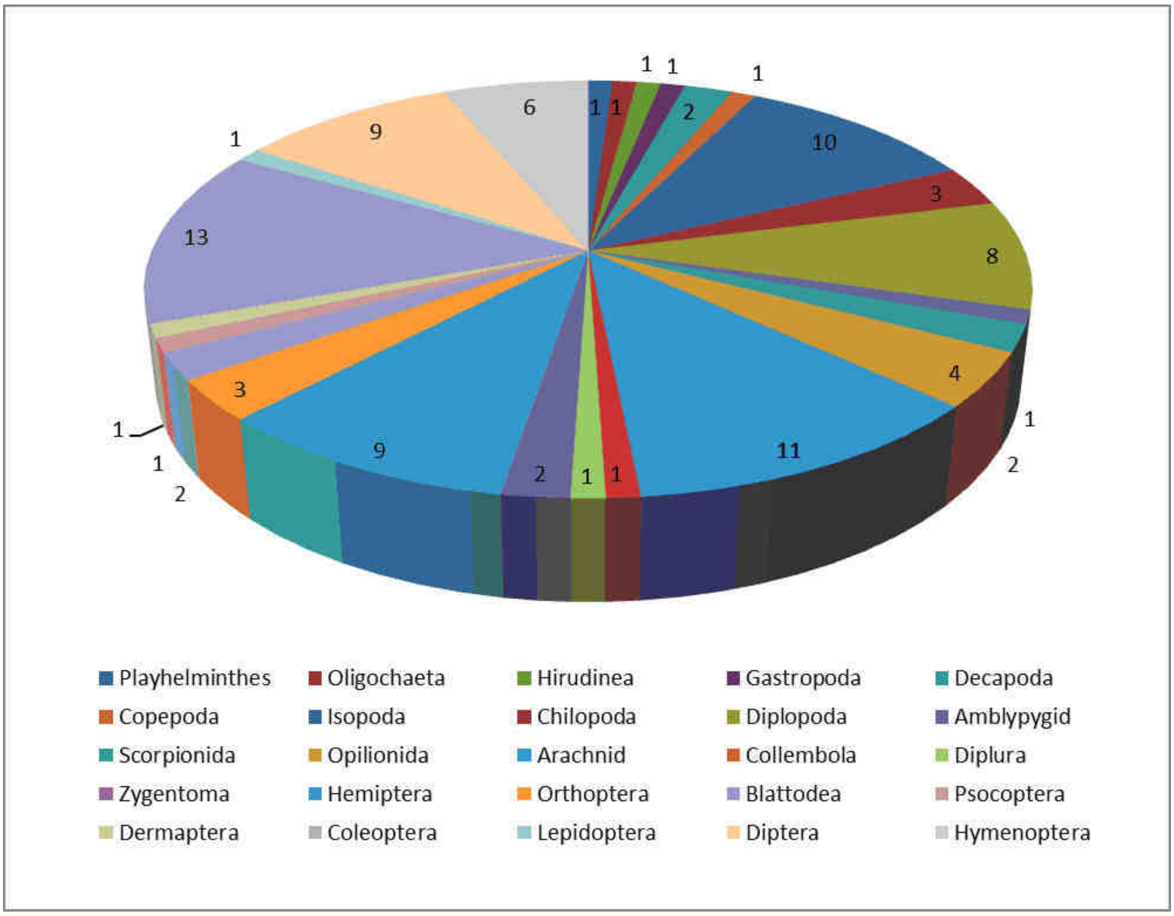

Figure 5 Diversity of species recorded by Order across nine caves.

The key results are presented individually for each cave surveyed, and detailed abundance data is presented as an appendix in Appendix A.

Deer Cave

Deer cave was sampled in three primary areas, the main entrance, Antler passage and the massive guano piles located near the Garden of Eden Track. The massive guano areas were not sampled extensively, and abundance of species was not recorded due to a lack of available time and the immensity of the task due to the extremely high abundance present. These are certainly the habitat for the largest arthropod diversity within the cave.

Antler passage, which is located above the main passage was found to be quite dry, and largely free of guano, providing very different microhabitats to those in the main passage.

Figure 6 Deer cave guide rail with a Naked Bat and numerous symbiotic hairy earwigs. Photo Jane Pulford.

Deer Water Cave

This is the outflow for the river that enters Deer Cave from the Garden of Eden entrance and sampling was limited to a single visit and a single microhabitat of damp sediment. The invertebrates present consisted of several highly abundant dipteran species, including chironomids and phorids. Several beetle species were also present in high abundance including a species of staphylinidae.

Green Cave

Green Cave was sampled in the Entrance zone and in the Dark Zone (lower River Area). The Entrance area contained several species of isopod and also Hemiptera: Vellidae? within a small gour pool, and Rhyparochromid bugs. The area sampled, although a substantial distance from the entrance still received light for much of the day due to the large entrance size and these species are most likely accidentals to the cave environment.

The dark zone area associated with the small river passage contained a very high abundance of Anobiid beetles, clustering in groups of five to twenty individuals. Two species of cave cricket were also present here, the large *Rhaphidopora oophaga* and the smaller *Diestrammena mjobergi*.

Fruit Bat Cave

The entrance area of Fruit Bat Cave consists of a large chamber with an almost continuous cover of dry guano, with small patches of fresh guano under roof bell holes. This dry guano microhabitat supports an abundant population of the small cockroach *Pyenoscelus indicus*, the cricket *Diestrammena sarawakana* and several species of reduviid bugs. The emesine species is likely to be Baguada? sp. cf. *cavernicola* which was identified by Chapman within Deer Cave and also collected were two species of harpactocoid reduviids, which were unrecorded by Chapman (1982).

The deeper sections of Fruit Bat Cave are dominated by scattered fresh guano throughout, resulting in a series of the more common and widespread species such as *Diestrammena mjobergi* and the widespread millipede sp. A. Some of the small water pools located within formations contained aquatic isopods *Cyathura* sp. nov.

The alternate entrance area of Fruit Bat Cave is a roosting area for Fruit Bats (*Balionycteris maculata*) which gives the cave its name and contains numerous discarded seeds within the associated guano. This area was not sampled for invertebrates.

Figure 7 Seeds and sprouting bodies in Fruit Bat Cave alternate entrance – Photo Tony Veness

Kenyalang Cave

Kenyalang Cave is located in the same limestone block as Fruit Bat Cave and the entrance is located vertically above. The invertebrate assemblage recorded was similar to that of Fruit Bat but due to the lower amounts of guano was slightly different in composition. The cave contained a high abundance of collembolan, not observed in any other cave examined during the current survey. A possible copepod was observed in a small pool of water which may have been washed out of the epiphreatic zone. It was unable to be collected with the tools available, but if further collections are made in this cave the potential presence of stygofauna within drip pools should be examined.

Stonehorse Cave

This was one of the two most intensely sampled caves undertaken by the expedition, along with Lagang Cave. The cave was sampled throughout the Entrance and main passage to the large pit section where considerable guano is present. The cave showed a very similar assemblage of species as Lagang and Racer cave, with guano areas dominated by Tineidae moths and their larvae, and associated Braconid wasp parasitoids. Schizomid arachnids are also common in guano deposits. Numerous cave crickets are present throughout, as well as amblypygids and scutigerid centipedes. Pools of water associated with speleothem development contained aquatic isopods.

Stonehorse Cave is currently being developed as a tourist cave with a staircase built from the main boardwalk to the cave entrance. No development has thus far been undertaken within the cave, apart from fixed ropes as part of the adventure cave tour infrastructure.

Figure 8 Philosciid? isopod in Stonehorse Cave. Photo Ross Anderson.

Lagang Cave

This cave had the most intense sampling of all caves examined as it shows a wide variety of habitats, with both tourism and wild caving usage. Six separate areas within the cave were surveyed, including the two entrances that form part of the tourist route, one site on the boardwalk, an area of Fast Lane, and two sites away from cave infrastructure including on top of the large blocks near the intersection with the main passage and one sampling site within the extension passage. The ability to sample the newly discovered extension provided an excellent opportunity to record completely undisturbed invertebrate assemblages with no obvious potential impacts from cave infrastructure.

Figure 9 Anobiid? beetles on a piece of fresh guano in Fast Lane, Lagang Cave. Photo Ross Anderson.

The diversity is dominated by the abundant Millipede Polydesmid? sp. A which was associated with both old and fresh guano deposits at both entrance areas, Fast Lane and the extension. Other abundant species include the schizomid, sparassid spider, two species of opiliones, amblypygdid and the cave cricket *Diestrammena sarawakana*. Interestingly the large cave cricket *Rhaphidophora oophaga* was only observed within the extension area.

One of the most notable species recorded from Lagang Cave was collected from the Fast Lane and was a linyphiid spider recorded near fresh guano that upon detailed inspection was found to be blind, depigmented and possessing an elongate process from the centre of the cephalothorax.

Racer Cave

Racer Cave is used for adventure tours and receives moderate visitation. It was found to contain a very similar diversity to Lagang and Stonehorse caves with a few exceptions. The Barychelid trapdoor spider *Idiommata* sp. was relatively abundant in the deeper parts of the cave associated with damp sediments and guano deposits (Figure 10). Isolated drip fed pools associated with speleothems were found to contain two different species of aquatic isopods, Asellidae: *Stenasellus* sp. and Anthuridae: *Cyathura* sp. These species were previously recorded from similar habitats by Chapman (1982) from Water Polo Cave, and the later species from other karst areas in southern Sarawak.

Figure 10 Location of burrows of the Barychelid trapdoor spider Idiommata sp. near the end of Racer Cave. Photo Ross Anderson.

The current survey recorded the scorpion *Chaerilus chapmani* from this cave (Figure 11), a new distribution record, but not unsurprising as it was previously known from the Clearwater system (Chapman, (1982)). Two specimens were collected from the deep cave zone, near the end of the main adventure route, associated with fresh guano and damp sediment. A further two smaller scorpion individuals were also collected and may represent an additional undescribed species or potentially juveniles of *Chaerilus chapmani*. Detailed assessment by a scorpion taxonomist will be required to determine this.

Figure 11 Troglobitic scorpion Chaerilus chapmani from Racer Cave. Photo Ross Anderson.

Clearwater Cave

Invertebrate surveying within the Clearwater system was opportunistic only, and primarily only species that had not been observed by the survey previously in other caves were collected. Several different microhabitats were also observed in this cave and opportunistically sampled including bog (mush) guano and streamway (Figure 12).

Figure 12 Clearwater river streamway in Clearwater System. Photo Ross Anderson.

PATN Analysis

The data were analysed used for similarity using PATN (version 3.12, Blatant Fabrications Pty. Ltd. 2009). Data were analysed using Bray and Curtis association, and nearest neighbour fusion algorithm. Data for two caves which were not comprehensively sampled were removed from the analysis to increase clarity of results. The caves not included in the analysis were Deer Water Cave and Clearwater Cave.

The PATN analysis by total diversity and abundance for each cave shows Racer, Lagang and Stonehorse Caves to contain very similar invertebrate assemblages and are also similar to both Kenyalang and Fruit Bat Caves. Green Cave and Deer Cave are the most dissimilar in their invertebrates assemblages.

The PATN analysis by microhabitat showed strong similarity between invertebrate assemblages within microhabitat, especially fresh guano, with most of the specialised habitats being dissimilar to all others, such as the massive guano in Deer Cave and the streamway sections of Clearwater Cave.

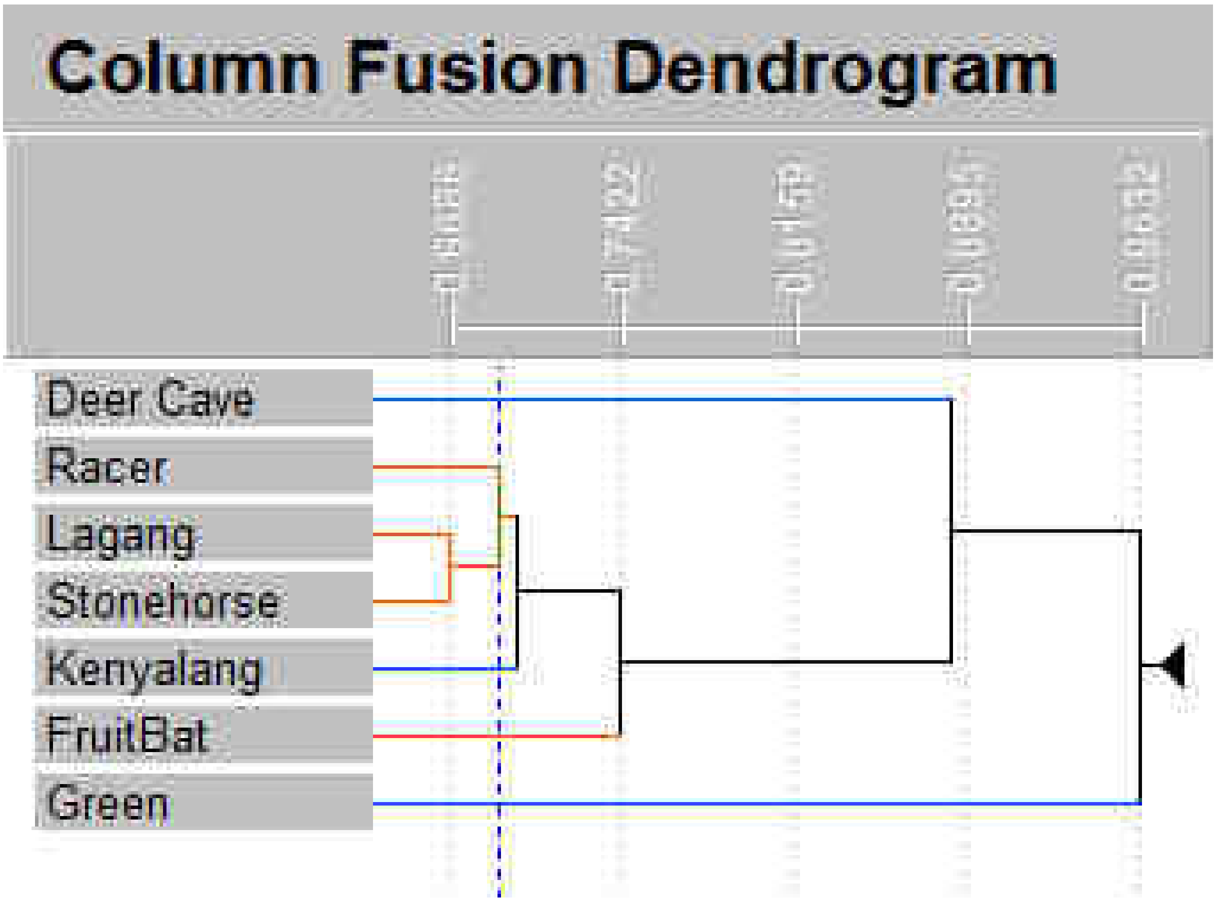

Figure 13 Column Fusion dendogram Nearest neighbour analysis – by cave

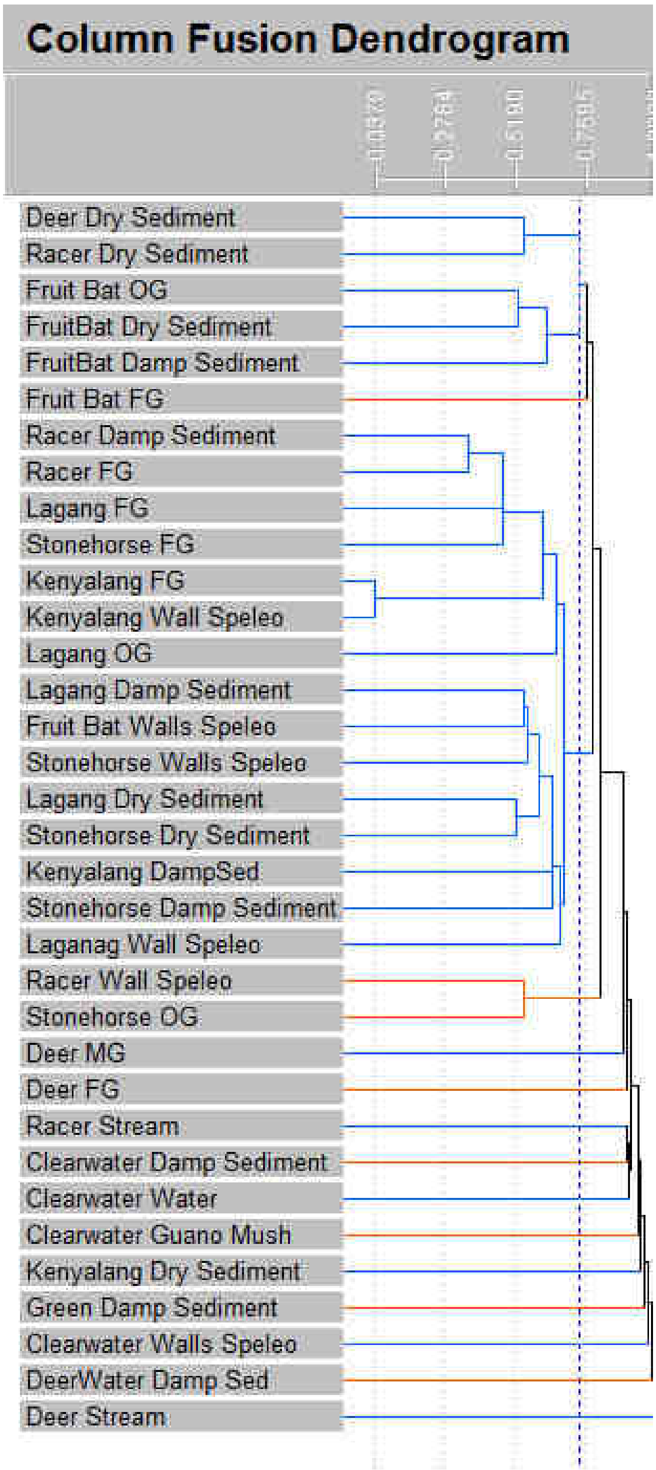

Figure 14 Column Fusion dendogram Nearest Neighbour analysis by microhabitat. FG – Fresh Guano, OG – Old Guano, MG – Massive Guano

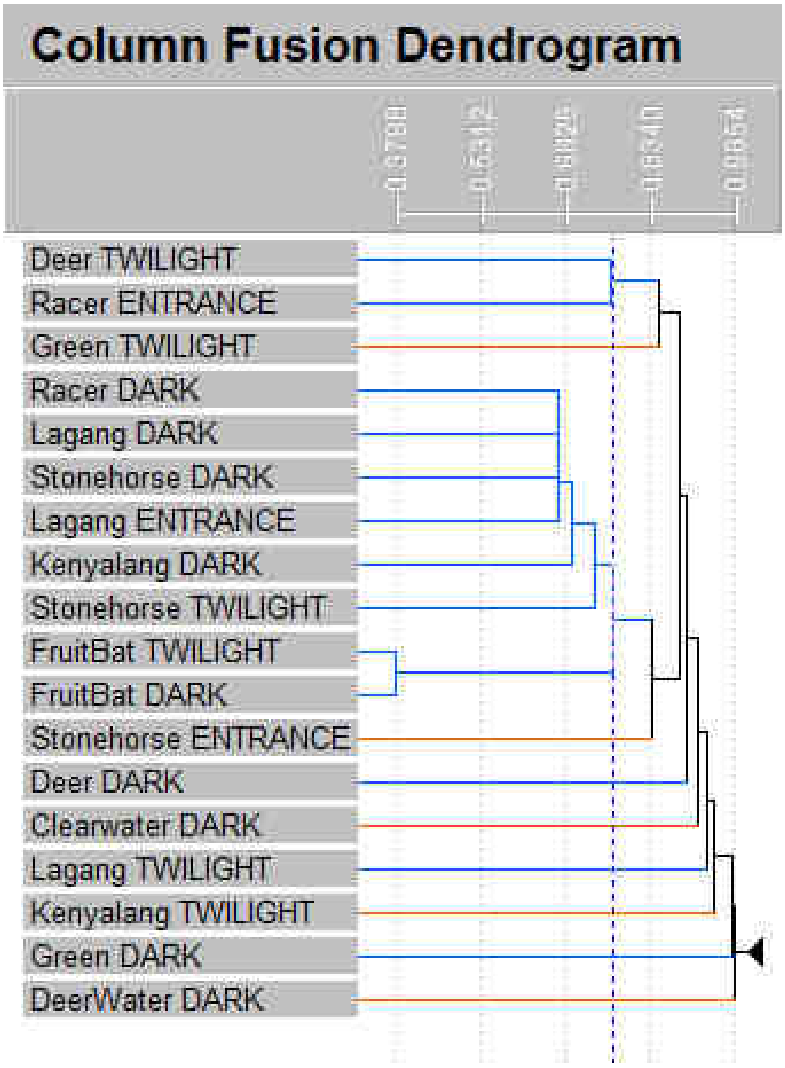

Figure 15 Column Fusion dendogram Nearest Neighbour analysis – Cave Zone

Cave Biodiversity Discussion

Cave Biodiversity in Gunung Mulu World Heritage Area

The diversity of the Mulu karst area is very high and contains numerous obligate subterranean species, although the exact number is still currently unknown. The majority of species collected during the current survey appear to match those recorded by Chapman (1982), however, several previously unknown species were recorded. Further, more detailed identification will be required prior to confirmation.

The patterns of diversity between the caves examined is complex with no obvious patterns evident from similarity analysis (Section PATN Analysis), although it would appear that caves are showing similarity based upon presence of similar micro-habitat rather than similarity of light zones. The Deer Cave, due to its complete dominance by massive guano piles appears to make it distinctly different in invertebrate composition to caves with far less guano such as Stonehorse or Lagang Cave. It is currently unknown whether there exists any difference in invertebrate composition between the different limestone blocks such as Fruit Bat/Kenyalang to Deer Cave/Green Cave to Lagang/Clearwater local areas of Mulu. The caves do show some level of association (Figure 15) but the strength of the current analysis is weak and further data, and identification of existing collected specimens may alter the results significantly. The determination of this will require far greater knowledge of both specific cave diversity and will invariably be linked to the geological history and karst geomorphology of Mulu.

Endemicity

The Mulu karst most certainly contains endemic species, although the exact number is currently hard to determine as many of the invertebrate identifications are still incomplete, for both Mulu and other karst areas in Borneo and South East Asia.

Some of the invertebrate diversity found in Deer Cave could possibly be endemic, including the 'Hairy earwig' *Arixenia esau* that is associated with the naked bat species *Cheiromeles torquatus,* although this is more likely associated with the endemicity of the bat host rather than the cave itself. Much of the other specialised invertebrate fauna recorded by Chapman (1982) was found to occur in other karst areas in Borneo, Java and Sulawesi.

Regional Significance

The results of the current preliminary study allow a cursory comparison with other karst areas, in Borneo or the remainder of Asia. This is primarily due to the often incomplete identification of many of the specimens, both in Mulu and the rest of the vast majority of the South East Asian karst. Comparison of species richness and taxonomic diversity is also difficult due to the highly variable nature of invertebrate collections from tropical caves. Very few surveys are comprehensive in nature, with many focussing on troglobiont species only or a specific taxonomic group or specific habitat such as guano. This leads to inherent bias in collecting focus and methods giving a misleading impression of diversity of richness when considering that most of the species richness in tropical caves is composed of guano associated species and non-troglobiont species (Deharveng and Bedos, (2000)).

As the specimens collected are identified further and additional surveys are undertaken a greater understanding of Mulu's subterranean biodiversity will become apparent, especially within a regional context. The preliminary results do, however, make it abundantly clear that the diversity and biogeographical significance of these species is very high and further work is required to truly appreciate the scientific values of this unique and important karst area.

Management Implications

The currently available data provides an insight into the diversity of subterranean fauna in the Mulu caves. In the future this will provide a greater understanding of localised distribution within the karst system and eventually at a localised cave scale.
The current data does not enable a meaningful interpretation of cave invertebrate biodiversity as it relates to specific cave use for tourism, adventure caving or wild caving, however, it is readily apparent to the authors that existing cave usage is not impacting upon the subterranean fauna observed in Mulu.

The authors note that the cave infrastructure within Mulu is of a very high world standard and promotes minimal impacts to both cave habitats and cave invertebrates generally. The Mulu Park staff provide excellent visitor education and supervision prior to and during cave tours eliminating predicable and avoidable impacts to the caves. The issues of rubbish and floor preservation were the only areas that management should consider some future actions with regard to the specific instances outlined.

Rubbish

Rubbish within caves is almost exclusively associated with illegal bird nester activity. Much of the rubbish was located in the far reaches of wild caves. It appeared historical in nature and was removed by the authors. Due to the complete removal of bird nests in most of these areas, the future accumulation of rubbish is unlikely to occur.

Floor preservation

The compaction of floor sediments is potentially one of the most significant impacts to cave invertebrates. It is most important in high use caves, and due to the excellent pathways and elevated boardwalks throughout the majority of Mulu tourist caves compaction is largely absent. In some adventure caves, while track marking is present to some degree some sections of caves may require additional/ more obvious track marking to reduce potential future impacts. This is evident especially for some aquatic habitats within Stonehorse and Fruit Bat Caves where aquatic fauna may be impacted as the path crosses directly over water pools. While it may not be practical to divert paths in some instances, these habitats should be noted to cave visitors to help minimise impacts.

Recommendations for Future Work

The current study provides a very preliminary assessment of the general subterranean invertebrate diversity of Mulu since it was initially studied 30 years previously by Chapman (1982). The current study allows the site to be interpreted within a modern biospeleological context. This initial assessment has allowed the authors to gain a substantial understanding of the order of magnitude of the invertebrate diversity of Mulu, and the level of complexity of the biodiversity patterns likely to be present.

Key recommendations and focus for future cave biodiversity studies are:

1. Further photo inventory be undertaken for remaining specimens collected.
2. Further species identification and cross checking of species collected between different caves to further define morpho-species distribution within the various karst blocks in Mulu.
3. Focussed studies on particular microhabitats such as guano or aquatic systems.
4. Undertake species inventories for all major caves in Mulu NP to enable a better comparison of invertebrate diversity both within the Mulu and also with other karst areas in Sarawak, Borneo and the remainder of South East Asia.
5. Dedicated sampling of stygofauna, as only opportunistic specimens collected to date and true diversity is unknown.
6. The specimens collected during the current survey should be held by an appropriate research institute with suitable laboratory space and access to specialised library resources such as the Sarawak Museum to enable their continued identification and study by taxonomic experts.
7. Training of local staff about cave fauna and local invertebrate diversity so they can recognise common species and identify habitats.

Conclusions

The present study has provided a preliminary investigation of the invertebrate diversity across nine different caves within the Gunung Mulu World Heritage Area. This study compliments and builds upon the only other broad scale cave invertebrate diversity study of Mulu by Chapman (1982) and provides a modern context for future research in Mulu. The patterns of diversity are complex in Mulu, invariably due to the very high diversity of species, the large number of microhabitats present within caves, the multitude of energy inputs and the systems and the geomorphological history of the area. It will take considerable further effort to start to unravel these complexities but it should prove very rewarding as Mulu is undoubtedly a premier site of world cave tropical cave invertebrate diversity and provides a superb opportunity to investigate evolutionary processes in such a setting.

Acknowledgements

The authors would like to acknowledge the Republic of Malaysia for the opportunity to visit their beautiful country and the very warm welcome received. This preliminary survey would not have been possible without the co-operation of the Forestry Department of Sarawak and the Gunung Mulu World Heritage Area. The authors wish to thank the entire staff from the Mulu office of Sarawak Forestry and Mulu Park staff for their tireless efforts to make this survey possible and make us all feel extremely welcome.

The authors also wish to acknowledge the following taxonomists for assistance in providing preliminary identifications from photos of specimens: Dr Mark Harvey (Western Australian Museum), Julianne Waldock (Western Australian Museum), Dr Cathy Car (Western Australian Museum), Dr Lisa Kirkendale (Western Australian Museum), Dr Lorenzo Prendini (American Museum of Natural History), and Dr David Merritt (University of Queensland).

Figure 16 The Australian Mulu 2012 Biospeleology Expedition Team. left to right: Ross Anderson, Patrick Nykiel, Tony Veness, Jane Pulford, Rob Susac, Barbara Zakrzewska, Tim Moulds, Jay Anderson, Sandi Cheema, Stephen Swabey, Toni Lowe, Ian Thwaites and Sharon Thwaites. (Photo Ross Anderson).

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Appendix A

Diversity and Abundance of Mulu Cave Invertebrates

Table 3 Species diversity and abundance from seven caves in the Gunung Mulu World Heritage Area, Sarawak, Malaysia

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage	Dark Zone - track	Dark Zone	Dark Zone	Dark Zone	Twilight	Twilight	Twilight	Twilight	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone
			Twilight	Massive Guano compacted	Fresh Guano	Streamway	Damp Sediment	Old Guano	Dry Sediment	Walls/Speleothem	Fresh Guano	Damp Sediment	old Guano	Walls/Speleothem	Fresh Guano	Mushy Guano	Damp Sed. A	Damp Sediment	Water Pool	Speleothem
	Platyhelminthes																			
Observed	Planariidae?	*Mitchellia sarawakana?*																	12	
Collected																			1	
	Annelida																			
Observed	Oligoceate																		3	
Collected																			1	
Observed	Hirudinea:	Gnathobdellida?																		
Collected																				
	Gastropoda																			
Observed	Subulinidae	*Lamellaxis clavulinus?*																		
Collected		Small conical Snail	2																	
	Crustaceans																			
Observed	Decapoda	*Cerebusa tipula*					2													
Collected		Orange/yellow																		
Observed	Decapoda	*Cerebusa caeca*																		
Collected		white																		
Observed	Decapoda					25	2													
Collected		Shrimp																		
Observed	Isopoda	*Cyathura* sp. nov.										35								
Collected		White aquatic										5								
Observed	Isopoda	*Stenasellus* sp. nov.																		
Collected		Pink aquatic																		
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																		
Collected					2															
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																		
Collected		pretty pattern			2															
Observed	Isopoda	slater (spiky)																		
Collected																				
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov																		
Collected																		8		
Observed	Isopoda	*Nagarus lavis*																		
Collected					2															
Observed	Isopoda	*Setaphora parvicaputa*																		
Collected		tiny yellow philosid																		
Observed	Isopoda	*Paraperiscyphis platyperaeon*																		
Collected		grey to white																1			
	Myriapoda																			
Observed	Chilopoda	*Geophilida* sp.		2																
Collected				1																
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*	1											1						
Collected																				
Observed	Diplopoda	Spirostreptida? sp.										3			21					
Collected		common yellow										1	2							
Observed	Diplopoda	white little																		
Collected																				
Observed	Diplopoda	Doratodesmidae?										3								
Collected		rough dorsal processes										1								
Observed	Diplopoda																			
Collected		Smooth deeply segmented																		
Observed	Diplopoda	brown																		
Collected																				
Observed	Diplopoda	Trichopolydesmidae sp.?																		
Collected		Recurved points to back plates																		
Observed	Diplopoda	*Pseudodesmus sp.?*																		
Collected		Lateral wings curved																		

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage	Dark Zone - track	Dark Zone	Dark Zone	Dark Zone	Twilight	Twilight	Twilight	Twilight	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone	Dark Zone
			Twilight	Massive Guano compacted	Fresh Guano	Streamway	Damp Sediment	Old Guano	Dry Sediment	Walls/Speleothem	Fresh Guano	Damp Sediment	old Guano	Walls/Speleothem	Fresh Guano	Mushy Guano	Damp Sed. A	Damp Sediment	Water Pool	Speleothem
Observed	Diplopoda																			
Collected		Lateral wings square															1			
	Arachnids																			
Observed	Amblypygid	*Charius?/Sarax? sp.*							1	2		1			1					
Collected																				
Observed	Opilione	Stylocellidae? sp.																		
Collected		black one																		
Observed	Opilione	Phalangodidae? sp.												2						
Collected		Orange long legs															1			
Observed	Opilione																			
Collected		Grey																		
Observed	Schizomid	Hubbardiidae sp.							2			1			7					
Collected			2		2				1				2			2				
Observed	Scorpion	*Chaerilus chapmani*																		
Collected																				
Observed	Laelapidae	*Hypoaspis?*					20													
Collected							1						1							
	Araneae																			
Observed	Sparassid	*Heteropoda sp.*	7						5	11										
Collected																				
Observed	Linyphiidae?																			
Collected		no eyes, depigmented, head process																		
Observed	Amaurobiidae?	sp. A																		
Collected		big palps																		
Observed	Zoderiidae?	sp. A																		
Collected		Red Spider																		
Observed	Theridiidae	sp. A																		
Collected		Medium black																		
Observed	Theridiidae	Theridon? sp. B									4									
Collected								1												
Observed	Theridiidae	sp. C																		
Collected		Black																		
Observed	Theriidae	sp. D																		
Collected																				
Observed	Pholcidae	*Spermophora? sp.*		5					3	2			1							
Collected		4 eyes		3								1				1				
Observed	Pholcidae	Pholcid sp. B																		
Collected		2 eyes																		
Observed	Barychelidae	*Idiommata* sp.							2		10									
Collected																				
	Hexapoda																			
Observed	Collembola																			
Collected																				
Observed	Dipluran Campodeidae	*Lepidocampa sp.*													1					
Collected																				
	Insects																			
Observed	Zygentoma	Silverfish Other								1										
Collected																				
Observed	Zygentoma	Silverfish Spotty																		
Collected																				
Observed	Hemiptera: Reduviid																			
Collected																				
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*							1	2	1									
Collected								3												
Observed	Hemiptera: Reduviid	Emesinae																		
Collected		small																		
Observed	Hemiptera: Reduviid	Harpacticoid sp.A		1																
Collected		White with red eyes		1				2												

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage Twilight	Dark Zone - track Massive Guano compacted	Dark Zone Fresh Guano	Dark Zone Streamway	Dark Zone Damp Sediment	Twilight Old Guano	Twilight Dry Sediment	Twilight Walls/Speleothem	Twilight Fresh Guano	Dark Zone Damp Sediment	Dark Zone old Guano	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano	Dark Zone Mushy Guano	Dark Zone Damp Sed. A	Dark Zone Damp Sediment	Dark Zone Water Pool	Dark Zone Speleothem
Observed	Hemiptera: Reduviid	Harpacticoid sp.B								1										
Collected		White and black stripe																		
Observed	Hemiptera: Heteroptera	Cimicid																		
Collected																				
Observed	Hemiptera: Heteroptera	Veliidae? sp.																		
Collected																				
Observed	Hemiptera: Heteroptera	Rhyparochrominae?																		
Collected																				
Observed	Homoptera	Plant Hopper, Large with orange stripes																		
Collected																				
Observed	Orthoptera	*Raphidophora oophaga*																		
Collected																				
Observed	Orthoptera	*Diestrammena mjobergi*	4	10				2	13			3	31							
Collected																				
Observed	Orthoptera	*Diestrammenasarawakana*							6	12	13	25		22	32					
Collected		Stripy legs and body							1											
Observed	Blattodea	*Pyenoscelus indicus*						9	30		250	40	38		187					1?
Collected								1	1											
Observed	Blattodea	*Blattela cavernicola*							24			7	1							
Collected		Golden							1											
Observed																				
Collected	Blattodea	Forest							1											
Observed	Psocoptera																			
Collected																				
Observed	Dermaptera	Hairy			2															
Collected																				
Observed	Dermaptera	other					200													
Collected							3													
Observed	Coleoptera	Grey 1mm																		
Collected																				
Observed	Coleoptera	Carabid?																		
Collected		larvae large																		
Observed	Coleoptera	Dermestid larvae						1												
Collected								1												
Observed	Coleoptera	Black round 1mm																		
Collected																				
Observed	Coleoptera	Grey 1mm																		
Collected																				
Observed	Coleoptera	Histeridae: *Hister* sp																		
Collected					1		200													
Observed	Coleoptera	Histerid larvae																		
Collected																				
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*	1																	
Collected		tiny small																		
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																		
Collected																				
Observed	Coleoptera	Pselaphidae																		
Collected																				
Observed	Coleoptera	staphylinidae																		
Collected																				
Observed	Coleoptera	small staphylinidid					200													
Collected																				
Observed	Coleoptera	medium staphylinid		100																
Collected				1																
Observed	Coleoptera	Jacobsonnidae?																		
Collected																				
Observed	Lepidoptera	*Tinea sp.*					100		1		1	2	1	2						
Collected		Tineid Moth																		
Observed	Lepidoptera	*Tinea sp.*										20			17					
Collected		Tineid Larvae																		

			May-12	May-12	May-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	Dec-12	Dec-12
			Deer Cave	**Deer Cave**			**Deer Water Cave**	**Fruit Bat Cave**								**Clearwater Cave**				
			Antler Passage Twilight	Dark Zone - track Massive Guano compacted	Dark Zone Fresh Guano	Dark Zone Streamway	Dark Zone Damp Sediment	Twilight Old Guano	Twilight Dry Sediment	Twilight Walls/Speleothem	Twilight Fresh Guano	Dark Zone Damp Sediment	Dark Zone old Guano	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano	Dark Zone Mushy Guano	Dark Zone Damp Sed. A	Dark Zone Damp Sediment	Dark Zone Water Pool	Dark Zone Speleothem
Observed	Diptera	*Chetoneura cavernae*								11										
Collected																				
Observed	Diptera	Tipulidae sp. A																		
Collected		short legged																		
Observed	Diptera	Tipulidae sp. B		300																
Collected				5																
Observed	Diptera	larvae					20													
Collected							1													
Observed	Diptera	sp. A					3000													
Collected		Large					2													
Observed	Diptera	Phoridae					4000													
Collected							3													
Observed	Diptera	Bar fly																		
Collected																				
Observed	Diptera	Midgie					3000													
Collected							1													
Observed	Diptera	Nycteribiidae																		
Collected																				
Observed	Hymenoptera: Formicidae	sp. A										2								
Collected		Tiny																		
Observed	Hymenoptera: Formicidae	sp. B																		
Collected		Ant small brown					1													
Observed	Hymenoptera: Formicidae	sp. C	2									80	16		5					
Collected		ant-small black											1							
Observed	Hymenoptera: Formicidae	sp. D																		
Collected		Ant medium elongate																		
Observed	Hymenoptera: Formicidae	sp. E																		
Collected		Large ant (wasp minic)																		
Observed	Hymenoptera	Braconidae?										4								
Collected								1												

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
	Platyhelminthes																				
Observed	Planariidae?	*Mitchellia sarawakana?*																			
Collected																					
	Annelida																				
Observed	Oligoceate																				
Collected																					
Observed	Hirudinea:	Gnathobdellida?																		55	
Collected																				1	
	Gastropoda																				
Observed	Subulinidae	*Lamellaxis clavulinus?*																			
Collected		Small conical Snail																			
	Crustaceans																				
Observed	Decapoda	*Cerebusa tipula*																			
Collected		Orange/yellow																			
Observed	Decapoda	*Cerebusa caeca*																			
Collected		white																			
Observed	Decapoda																				
Collected		Shrimp																			
Observed	Isopoda	*Cyathura* sp. nov.																			
Collected		White aquatic																			
Observed	Isopoda	*Stenasellus* sp. nov.																			
Collected		Pink aquatic																			
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																			
Collected																					
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																			
Collected		pretty pattern																			
Observed	Isopoda	slater (spiky)															4				
Collected																	1				
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov																			
Collected																					
Observed	Isopoda	*Nagarus lavis*																			
Collected			1																		
Observed	Isopoda	*Setaphora parvicaputa*	4																		
Collected		tiny yellow philosid	1																		
Observed	Isopoda	*Paraperiscyphis platyperaeon*																			
Collected		grey to white																			
	Myriapoda																				
Observed	Chilopoda	*Geophilida* sp.																			
Collected																					
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*																			
Collected																					
Observed	Diplopoda	Spirostreptida? sp.		32					5	1		26	32	2				57			
Collected		common yellow		1								1		1							
Observed	Diplopoda	white little																			1
Collected																					1
Observed	Diplopoda	Doratodesmidae?													2						1
Collected		rough dorsal processes																			
Observed	Diplopoda																				
Collected		Smooth deeply segmented																			
Observed	Diplopoda	brown																			
Collected																					
Observed	Diplopoda	Trichopolydesmidae sp.?																			
Collected		Recurved points to back plates										1									
Observed	Diplopoda	*Pseudodesmus sp.?*																			
Collected		Lateral wings curved																			

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
Observed	Diplopoda																				
Collected		Lateral wings square																			
	Arachnids																				
Observed	Amblypygdid	*Charius?/Sarax? sp.*	1				4			1	1	1	1	1	1						
Collected																					
Observed	Opilione	Stylocellidae? sp.				3		7			5	6	8	13							
Collected		black one					1					1									
Observed	Opilione	Phalangodidae? sp.	2			1		4									2				
Collected		Orange long legs	1																		
Observed	Opilione																				
Collected		Grey																			
Observed	Schizomid	Hubbardiidae sp.		4	2			2		3		17	9		1						
Collected				2	1							1									
Observed	Scorpion	*Chaerilus chapmani*																			
Collected																					
Observed	Laelapidae	*Hypoaspis?*																			
Collected																					
	Araneae																				
Observed	Sparassid	*Heteropoda sp.*	3		1			1	1		2	1		3							
Collected																					
Observed	Linyphiidae?											1									
Collected		no eyes, depigmented, head process																			
Observed	Amaurobiidae?	sp. A																			
Collected		big palps	1																		
Observed	Zoderiidae?	sp. A																			
Collected		Red Spider																			
Observed	Theridiidae	sp. A																			
Collected		Medium black																			
Observed	Theridiidae	Theridon? sp. B																			
Collected																					
Observed	Theridiidae	sp. C																			
Collected		Black																			
Observed	Theriidae	sp. D															12			1	
Collected																	2				
Observed	Pholcidae	*Spermophora? sp.*	4					4	1	1	4		6	2							
Collected		4 eyes												1							
Observed	Pholcidae	Pholcid sp. B																			
Collected		2 eyes																			
Observed	Barychelidae	*Idiommata* sp.																			
Collected																					
	Hexapoda																				
Observed	Collembola																	1			
Collected																					
Observed	Dipluran Campodeidae	*Lepidocampa sp.*																			
Collected			1																		
	Insects																				
Observed	Zygentoma	Silverfish Other																			
Collected																					
Observed	Zygentoma	Silverfish Spotty																			
Collected																					
Observed	Hemiptera: Reduviid																				
Collected																					
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*																			
Collected																					
Observed	Hemiptera: Reduviid	Emesinae																			
Collected		small															1				
Observed	Hemiptera: Reduviid	Harpacticoid sp.A																			
Collected		White with red eyes																			

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
Observed	Hemiptera: Reduviid	Harpacticoid sp.B																			
Collected		White and black stripe																			
Observed	Hemiptera: Heteroptera	Cimicid																			
Collected																					
Observed	Hemiptera: Heteroptera	Veliidae? sp.																			
Collected																					
Observed	Hemiptera: Heteroptera	Rhyparochrominae?																			
Collected																					
Observed	Homoptera	Plant Hopper, Large with orange stripes																	2		
Collected																			1		
Observed	Orthoptera	*Raphidophora oophaga*									3										
Collected																					
Observed	Orthoptera	*Diestrammena mjobergi*																			
Collected																					
Observed	Orthoptera	*Diestrammenasarawakana*	15	12			4	3	10	6	46	18	24	16		8	11				
Collected		Stripy legs and body																			
Observed	Blattodea	*Pyenoscelus indicus*			1																
Collected																					
Observed	Blattodea	*Blattela cavernicola*																			
Collected		Golden																			
Observed																					
Collected	Blattodea	Forest																			
Observed	Psocoptera			100	10					1											
Collected																					
Observed	Dermaptera	Hairy																			
Collected																					
Observed	Dermaptera	other																			
Collected																					
Observed	Coleoptera	Grey 1mm						3													
Collected														1							
Observed	Coleoptera	Carabid?							1												
Collected		larvae large							1												
Observed	Coleoptera	Dermestid larvae		2																	
Collected				1																	
Observed	Coleoptera	Black round 1mm																			
Collected																	1				
Observed	Coleoptera	Grey 1mm																			
Collected																					
Observed	Coleoptera	Histeridae: *Hister* sp	4																		
Collected				1																	
Observed	Coleoptera	Histerid larvae										2									
Collected				1																	
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*				30			180									30			5
Collected		tiny small				1			3												
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae				40															
Collected						1															
Observed	Coleoptera	Pselaphidae																			
Collected																	2				
Observed	Coleoptera	staphylinidae																4			
Collected																					
Observed	Coleoptera	small staphylinidid																			
Collected																					
Observed	Coleoptera	medium staphylinid			4	40			2												
Collected					1																
Observed	Coleoptera	Jacobsonnidae?							1												
Collected																					
Observed	Lepidoptera	*Tinea sp.*		1					1								1			1	
Collected		Tineid Moth							1												
Observed	Lepidoptera	*Tinea sp.*							1												
Collected		Tineid Larvae																			

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	Dec-12
			LAGANG CAVE			Path	Path	Block Rockpile	Extension	Extension	Extension	Fast Lane	Fast Lane	Fast Lane	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance	Dream Pool Entrance
			Entrance #1 Dry Sediment	Entrance #1 Old Guano	Entrance #1 Fresh Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Dark Zone Fresh Guano	Dark Zone Old Guano	Dark Zone Damp Sediment	Entrance Dry Sediment	Entrance Damp Sediment	Entrance Spelothem	Entrance Fresh Guano	Entrance Damp Sediment (Roots)	Twilight Spelothem	Twilight Dry Sediment
Observed	Diptera	*Chetoneura cavernae*	50											6			25				
Collected			1																		
Observed	Diptera	Tipulidae sp. A																			
Collected		short legged																			
Observed	Diptera	Tipulidae sp. B	4								2			1			15			9	
Collected																					
Observed	Diptera	larvae																			
Collected																					
Observed	Diptera	sp. A																			
Collected		Large																			
Observed	Diptera	Phoridae						10	1			1								3	
Collected													2							4	
Observed	Diptera	Bar fly																			
Collected																				1	
Observed	Diptera	Midgie																			
Collected																					
Observed	Diptera	Nycteribiidae																			
Collected																					
Observed	Hymenoptera: Formicidae	sp. A		7	20																
Collected		Tiny		1																	
Observed	Hymenoptera: Formicidae	sp. B																			
Collected		Ant small brown																			
Observed	Hymenoptera: Formicidae	sp. C		2								2									
Collected		ant-small black																			
Observed	Hymenoptera: Formicidae	sp. D																			
Collected		Ant medium elongate																			
Observed	Hymenoptera: Formicidae	sp. E											1								
Collected		Large ant (wasp minic)																			
Observed	Hymenoptera	Braconidae?																			
Collected								1													

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
	Platyhelminthes																	
Observed	Planariidae?	*Mitchellia sarawakana?*	1															
Collected																		
	Annelida																	
Observed	Oligoceate																	
Collected																		
Observed	Hirudinea:	Gnathobdellida?																
Collected																		
	Gastropoda																	
Observed	Subulinidae	*Lamellaxis clavulinus?*		4									4					
Collected		Small conical Snail																
	Crustaceans																	
Observed	Decapoda	*Cerebusa tipula*																
Collected		Orange/yellow																
Observed	Decapoda	*Cerebusa caeca*					1						1	4				
Collected		white																
Observed	Decapoda																	
Collected		Shrimp																
Observed	Isopoda	*Cyathura* sp. nov.				15												
Collected		White aquatic				3												
Observed	Isopoda	*Stenasellus* sp. nov.																
Collected		Pink aquatic				1												
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																
Collected																		
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																
Collected		pretty pattern																
Observed	Isopoda	slater (spiky)																
Collected																		
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov															9	
Collected																	3	
Observed	Isopoda	*Nagarus lavis*											9					
Collected				1									1					
Observed	Isopoda	*Setaphora parvicaputa*											14					
Collected		tiny yellow philosid											4					
Observed	Isopoda	*Paraperiscyphis platyperaeon*				2		7		2		1		1				
Collected		grey to white					1				2	1	1	1				
	Myriapoda																	
Observed	Chilopoda	*Geophilida* sp.																
Collected								1	1									
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*															1	5
Collected																		
Observed	Diplopoda	Spirostreptida? sp.			1	3	3	1	5	19		2		3		8	100	
Collected		common yellow							1					1		2	1	
Observed	Diplopoda	white little																
Collected										1								
Observed	Diplopoda	Doratodesmidae?															5	
Collected		rough dorsal processes															2	
Observed	Diplopoda						5											
Collected		Smooth deeply segmented					2											
Observed	Diplopoda	brown																
Collected																		
Observed	Diplopoda	Trichopolydesmidae sp.?																
Collected		Recurved points to back plates					1											
Observed	Diplopoda	*Pseudodesmus sp.?*																
Collected		Lateral wings curved	1															

			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	Green Cave		Kenyalang Cave			
			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
Observed	Diplopoda		1															
Collected		Lateral wings square	1										1					
	Arachnids																	
Observed	Amblypygdid	*Charius?/Sarax? sp.*			3	1	2	2		3		10						
Collected																		
Observed	Opilione	Stylocellidae? sp.			1			4	12					5				
Collected		black one						1						1				
Observed	Opilione	Phalangodidae? sp.				1	1									1		
Collected		Orange long legs																
Observed	Opilione																	
Collected		Grey																
Observed	Schizomid	Hubbardiidae sp.																
Collected							2											
Observed	Scorpion	*Chaerilus chapmani*																
Collected								3	1									
Observed	Laelapidae	*Hypoaspis?*																
Collected								1										
	Araneae																	
Observed	Sparassid	*Heteropoda sp.*				1		3		2	8		1	3	1			
Collected																		
Observed	Linyphiidae?																	
Collected		no eyes, depigmented, head process																
Observed	Amaurobiidae?	sp. A																
Collected		big palps																
Observed	Zoderiidae?	sp. A																
Collected		Red Spider	1															
Observed	Theridiidae	sp. A																
Collected		Medium black																
Observed	Theridiidae	Theridon? sp. B																
Collected																		
Observed	Theridiidae	sp. C																
Collected		Black											1					
Observed	Theriidae	sp. D																
Collected																		
Observed	Pholcidae	*Spermophora? sp.*				4	14	16		5		10						
Collected		4 eyes						1		1		1						
Observed	Pholcidae	Pholcid sp. B									8							
Collected		2 eyes									2							
Observed	Barychelidae	*Idiommata* sp.					1	1		1								
Collected							1		1									
	Hexapoda																	
Observed	Collembola													1			100s	
Collected														1			2	
Observed	Dipluran Campodeidae	*Lepidocampa sp.*																
Collected																		
	Insects																	
Observed	Zygentoma	Silverfish Other																
Collected																		
Observed	Zygentoma	Silverfish Spotty																
Collected																		
Observed	Hemiptera: Reduviid																	
Collected				2														
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*																
Collected																		
Observed	Hemiptera: Reduviid	Emesinae																
Collected		small																
Observed	Hemiptera: Reduviid	Harpacticoid sp.A																
Collected		White with red eyes																

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
Observed	Hemiptera: Reduviid	Harpacticoid sp.B																
Collected		White and black stripe																
Observed	Hemiptera: Heteroptera	Cimicid																
Collected							2											
Observed	Hemiptera: Heteroptera	Veliidae? sp.											8					
Collected													3					
Observed	Hemiptera: Heteroptera	Rhyparochrominae?											3					
Collected													2					
Observed	Homoptera	Plant Hopper, Large with orange stripes																
Collected																		
Observed	Orthoptera	*Raphidophora oophaga*										1		3				
Collected																		
Observed	Orthoptera	*Diestrammena mjobergi*			19	3	4	10	10	7	10	15		5				
Collected																		
Observed	Orthoptera	*Diestrammenasarawakana*														50	100s	
Collected		Stripy legs and body														1		
Observed	Blattodea	*Pyenoscelus indicus*														3	1	
Collected																1		
Observed	Blattodea	*Blattela cavernicola*																
Collected		Golden									1							
Observed																		
Collected	Blattodea	Forest																
Observed	Psocoptera																	
Collected																		
Observed	Dermaptera	Hairy																
Collected																		
Observed	Dermaptera	other																
Collected																		
Observed	Coleoptera	Grey 1mm																
Collected													?1					
Observed	Coleoptera	Carabid?																
Collected		larvae large																
Observed	Coleoptera	Dermestid larvae																
Collected								1	1									
Observed	Coleoptera	Black round 1mm																
Collected																		
Observed	Coleoptera	Grey 1mm																
Collected																		
Observed	Coleoptera	Histeridae: *Hister* sp																
Collected																		
Observed	Coleoptera	Histerid larvae																
Collected																		
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*						300	250					850		1000s		1000s
Collected		tiny small						2	2					3		2		2
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																
Collected																		
Observed	Coleoptera	Pselaphidae																
Collected																		
Observed	Coleoptera	staphylinidae												1				
Collected																		
Observed	Coleoptera	small staphylinidid											6					
Collected													1					
Observed	Coleoptera	medium staphylinid											1					
Collected													1					
Observed	Coleoptera	Jacobsonnidae?																
Collected																		
Observed	Lepidoptera	*Tinea sp.*														1		
Collected		Tineid Moth																
Observed	Lepidoptera	*Tinea sp.*								70		300				2		
Collected		Tineid Larvae										1				2		

			May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12	May-12
			Racer Cave		Site 1	Site 1	Site 1	Site 2	Site 3	Site 4	Site 4	Site 4	**Green Cave**		**Kenyalang Cave**			
			Entrance Active Streamway	Entrance Dry Sediment	Dark Zone Habitat Dry Sediment #1	DZH:2 Speleothem	DZH:3 Damp Sediment #1	DZH:4 Damp#2	DZH:5 Fresh Guano #1	DZH:6 Damp#3	DZH:7 Dry Sediment #2	DZH:8 Fresh G#2	Twilight Damp Sediment	Dark Zone Damp Sediment	Twilight Dry Sediment	Dark Fresh Guano	Dark Damp Sediment	Dark Speleothem/pools
Observed	Diptera	*Chetoneura cavernae*																
Collected																		
Observed	Diptera	Tipulidae sp. A																
Collected		short legged																
Observed	Diptera	Tipulidae sp. B																
Collected																		
Observed	Diptera	larvae																
Collected																		
Observed	Diptera	sp. A													20			
Collected		Large																
Observed	Diptera	Phoridae											1					
Collected													1					
Observed	Diptera	Bar fly																
Collected																		
Observed	Diptera	Midgie	1															
Collected																		
Observed	Diptera	Nycteribiidae																
Collected																		
Observed	Hymenoptera: Formicidae	sp. A								3								
Collected		Tiny																
Observed	Hymenoptera: Formicidae	sp. B																
Collected		Ant small brown																
Observed	Hymenoptera: Formicidae	sp. C		3								1						
Collected		ant-small black																
Observed	Hymenoptera: Formicidae	sp. D																
Collected		Ant medium elongate																
Observed	Hymenoptera: Formicidae	sp. E						1		4						1		
Collected		Large ant (wasp minic)														1		
Observed	Hymenoptera	Braconidae?																
Collected																		

			Dec-12 Stonehorse Cave Entrance Zone Walls/Speleothem	Dec-12 Entrance Zone Damp Sediment	Dec-12 Twilight Damp Sediment	Dec-12 Twilight Walls/Speleothem	Dec-12 Twilight Old Guano	May-12 Twilight Damp Sediment	May-12 Twilight Dry Sediment	Dec-12 Site 1 Dark Zone Fresh Guano	Dec-12 Site 1 Dark Zone Wall / Speleothem	May-12 Site 1 Dark Zone Fresh Guano	May-12 Site 1 Dark Zone Speleothem	May-12 Site 2 Dark Zone Speleothem #2	May-12 Site 3 Dark Zone Old Guano	Dec-12 Pits Dark Zone Fresh Guano	Dec-12 Pits Dark Zone Damp Sediment	Dec-12 Pits Dark Zone Walls/Speleothem	May-12 Pits Dark Zone Fresh Guano #2	May-12 Pits Dark Zone Damp Sediment
	Platyhelminthes																			
Observed	Planariidae?	*Mitchellia sarawakana?*																		
Collected																				
	Annelida																			
Observed	Oligoceate																			
Collected																				
Observed	Hirudinea:	Gnathobdellida?																		
Collected																				
	Gastropoda																			
Observed	Subulinidae	*Lamellaxis clavulinus?*						1												
Collected		Small conical Snail						1												
	Crustaceans																			
Observed	Decapoda	*Cerebusa tipula*												1						
Collected		Orange/yellow																		
Observed	Decapoda	*Cerebusa caeca*												1						
Collected		white																		
Observed	Decapoda																			
Collected		Shrimp																		
Observed	Isopoda	*Cyathura* sp. nov.											7		10					
Collected		White aquatic											3		1					
Observed	Isopoda	*Stenasellus* sp. nov.																		
Collected		Pink aquatic																		
Observed	Isopoda	Armadillidae: *Triadillo annandalei*																		
Collected																				
Observed	Isopoda	Armadillidae: *Tuberillo sarawakensis*																		
Collected		pretty pattern																		
Observed	Isopoda	slater (spiky)																		
Collected																				
Observed	Isopoda	Armadillidae: Gen.indet.,sp.nov											1							
Collected																				
Observed	Isopoda	*Nagarus lavis*						3							1					
Collected								1							1					
Observed	Isopoda	*Setaphora parvicaputa*											4	5						1
Collected		tiny yellow philosid																		
Observed	Isopoda	*Paraperiscyphis platyperaeon*																		
Collected		grey to white																		
	Myriapoda																			
Observed	Chilopoda	*Geophilida* sp.																		
Collected																				
Observed	Chilopoda: Scutigerid	*Thereupoda longicornis?*		1	1				1	2				1		1	1			3
Collected																				
Observed	Diplopoda	Spirostreptida? sp.		1				7					1							
Collected		common yellow						1												
Observed	Diplopoda	white little					3													
Collected																				
Observed	Diplopoda	Doratodesmidae?						3					1							
Collected		rough dorsal processes						1					1							
Observed	Diplopoda																			
Collected		Smooth deeply segmented																		
Observed	Diplopoda	brown						2												
Collected								1												
Observed	Diplopoda	Trichopolydesmidae sp.?																		
Collected		Recurved points to back plates																		
Observed	Diplopoda	*Pseudodesmus sp.?*																		
Collected		Lateral wings curved																		

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
Observed	Diplopoda																			
Collected		Lateral wings square																		
	Arachnids																			
Observed	Amblypygdid	*Charius?/Sarax? sp.*						1		3	9	2			2			5		5
Collected																				
Observed	Opilione	Stylocellidae? sp.									5	3	3	1			3	2		1
Collected		black one																		
Observed	Opilione	Phalangodidae? sp.	8					1			4							3		
Collected		Orange long legs	2																	
Observed	Opilione																			
Collected		Grey		2																
Observed	Schizomid	Hubbardiidae sp.		2				3		2		7		1	1	1	1		1	
Collected								2				1		1						
Observed	Scorpion	*Chaerilus chapmani*																		
Collected																				
Observed	Laelapidae	*Hypoaspis?*																		
Collected																				
	Araneae																			
Observed	Sparassid	*Heteropoda sp.*	2		1	3	1		4		1		2					2	1	6
Collected																				
Observed	Linyphiidae?																			
Collected		no eyes, depigmented, head process																		
Observed	Amaurobiidae?	sp. A																		
Collected		big palps																		
Observed	Zoderiidae?	sp. A																		
Collected		Red Spider																		
Observed	Theridiidae	sp. A		1																
Collected		Medium black		1																
Observed	Theridiidae	Theridon? sp. B	5			13	5													
Collected			1																	
Observed	Theridiidae	sp. C																		
Collected		Black																		
Observed	Theriidae	sp. D																		
Collected																				
Observed	Pholcidae	*Spermophora? sp.*						1					2		1		2		1	
Collected		4 eyes													1				1	
Observed	Pholcidae	Pholcid sp. B																		
Collected		2 eyes																		
Observed	Barychelidae	*Idiommata* sp.																		
Collected															1					
	Hexapoda																			
Observed	Collembola						1													
Collected																				
Observed	Dipluran Campodeidae	*Lepidocampa sp.*								5		6			1					
Collected												3			1					
	Insects																			
Observed	Zygentoma	Silverfish Other						1												
Collected																				
Observed	Zygentoma	Silverfish Spotty																		
Collected				1																
Observed	Hemiptera: Reduviid																			
Collected																				
Observed	Reduviid - Emesinae large	*Baguada?* sp. cf. *cavernicola*																		
Collected																				
Observed	Hemiptera: Reduviid	Emesinae																		
Collected		small																		
Observed	Hemiptera: Reduviid	Harpacticoid sp.A																		
Collected		White with red eyes																		

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
Observed	Hemiptera: Reduviid	Harpacticoid sp.B																		
Collected		White and black stripe																		
Observed	Hemiptera: Heteroptera	Cimicid																		
Collected																				
Observed	Hemiptera: Heteroptera	Veliidae? sp.																		
Collected																				
Observed	Hemiptera: Heteroptera	Rhyparochrominae?																		
Collected																				
Observed	Homoptera	Plant Hopper, Large with orange stripes																		
Collected																				
Observed	Orthoptera	*Raphidophora oophaga*		1						1	1	1		1						1
Collected																				
Observed	Orthoptera	*Diestrammena mjobergi*																		
Collected																				
Observed	Orthoptera	*Diestrammenasarawakana*	3	1	4	18	1		11	9	30	6	65			8	17	44	20	10
Collected		Stripy legs and body																		
Observed	Blattodea	*Pyenoscelus indicus*		1																
Collected																				
Observed	Blattodea	*Blattela cavernicola*																		
Collected		Golden																		
Observed																				
Collected	Blattodea	Forest																		
Observed	Psocoptera																			
Collected																				
Observed	Dermaptera	Hairy																		
Collected																				
Observed	Dermaptera	other																		
Collected																				
Observed	Coleoptera	Grey 1mm																		
Collected																				
Observed	Coleoptera	Carabid?																		
Collected		larvae large																		
Observed	Coleoptera	Dermestid larvae																		
Collected																				
Observed	Coleoptera	Black round 1mm																		
Collected																				
Observed	Coleoptera	Grey 1mm														1	1			
Collected																				
Observed	Coleoptera	Histeridae: *Hister* sp												50						
Collected												2								
Observed	Coleoptera	Histerid larvae																		
Collected																				
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani*										1							1	
Collected		tiny small																		
Observed	Coleoptera	Anobiidae: *Ptomaphaginus chapmani* Larvae																		
Collected																				
Observed	Coleoptera	Pselaphidae																		
Collected																				
Observed	Coleoptera	staphylinidae																		
Collected																				
Observed	Coleoptera	small staphylinidid																		
Collected																				
Observed	Coleoptera	medium staphylinid																		
Collected																				
Observed	Coleoptera	Jacobsonnidae?																		
Collected																				
Observed	Lepidoptera	*Tinea sp.*									5	4				20				
Collected		Tineid Moth																		
Observed	Lepidoptera	*Tinea sp.*										5			1	200				
Collected		Tineid Larvae										1							37	

			Dec-12	Dec-12	Dec-12	Dec-12	Dec-12	May-12	May-12	Dec-12	Dec-12	May-12	May-12	May-12	May-12	Dec-12	Dec-12	Dec-12	May-12	May-12
			Stonehorse Cave							Site 1	Site 1	Site 1	Site 1	Site 2	Site 3	Pits	Pits	Pits	Pits	Pits
			Entrance Zone Walls/Speleothem	Entrance Zone Damp Sediment	Twilight Damp Sediment	Twilight Walls/Speleothem	Twilight Old Guano	Twilight Damp Sediment	Twilight Dry Sediment	Dark Zone Fresh Guano	Dark Zone Wall / Speleothem	Dark Zone Fresh Guano	Dark Zone Speleothem	Dark Zone Speleothem #2	Dark Zone Old Guano	Dark Zone Fresh Guano	Dark Zone Damp Sediment	Dark Zone Walls/Speleothem	Dark Zone Fresh Guano #2	Dark Zone Damp Sediment
Observed	Diptera	*Chetoneura cavernae*	3						31		2							6		
Collected																				
Observed	Diptera	Tipulidae sp. A		15																
Collected		short legged		3																
Observed	Diptera	Tipulidae sp. B							1		1		10	30					1	
Collected																				
Observed	Diptera	larvae																		
Collected																				
Observed	Diptera	sp. A																		
Collected		Large																		
Observed	Diptera	Phoridae														1				
Collected																				
Observed	Diptera	Bar fly																		
Collected																				
Observed	Diptera	Midgie												1	1					
Collected																				
Observed	Diptera	Nycteribiidae							40											
Collected																				
Observed	Hymenoptera: Formicidae	sp. A																		
Collected		Tiny																		
Observed	Hymenoptera: Formicidae	sp. B		1																
Collected		Ant small brown																		
Observed	Hymenoptera: Formicidae	sp. C																		
Collected		ant-small black																		
Observed	Hymenoptera: Formicidae	sp. D		3																
Collected		Ant medium elongate		1																
Observed	Hymenoptera: Formicidae	sp. E																		
Collected		Large ant (wasp minic)																		
Observed	Hymenoptera	Braconidae?										7								
Collected																				

Appendix B

Photo Inventory of Mulu Cave Invertebrates

Mollusca: Gastropoda: ?Stylommatophora: Subulinidae: *Lamellaxis clavulinus* (Deer Cave) Photo Ross Anderson	
Crustacea: Isopoda: Anthuridae: ?*Cycthura* sp. nov. TB (Fruit Bat Cave) Photo Ross Anderson	

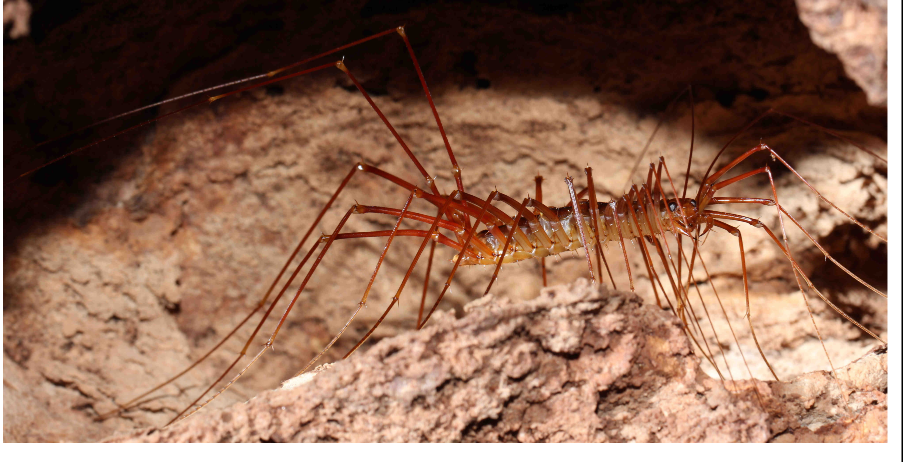
Crustacea: Isopoda: Armadillidae: ?*Tuberillo sarawakensis* (Deer Cave) Photo Ross Anderson	
Crustacea: Isopoda: (Deer Cave) Photo Ross Anderson	

Crustacea: Isopoda: Philloscidae: *?Setaphora parvicaputa* (Stonehorse Cave) Photo Ross Anderson	
Crustacea: Isopoda: Aramadillidae: *Triadillo annandalei* (Unknown Cave) Photo Ross Anderson	

Crustacea: Isopoda: sp. (Green Cave) Photo Jane Pullford	
Crustacea: Decapoda: Potamidae: *Cerebusa tipula* (Fruit Bat Cave) Photo Ross Anderson	

Crustacea: Decapoda: Potamidae: *Cerebusa caeca* (Green Cave) Photo Jane Pullford	
Crustacea: Diplopoda: Polydesmoidea? (Fruit Bat Cave) Photo Ross Anderson	

Crustacea: Diplopoda: Doratodesmidae? (Fruit Bat Cave) Photo Ross Anderson	
Diplopoda: Spirastreptida? sp. A (Lagang Cave) Photo Ross Anderson	

Diplopoda: recurved plates? sp.A() Photo Jane Pulford	
Chilopoda: Scutigeridae: *Thereuopoda longicornis*? (Stonehorse Cave) Photo Ross Anderson	

Chilopoda: Scolopendromorpha: sp. (Unknown Cave) Photo Jane Pullford	
Chilopoda: Geophilomorpha: ?Geophilidae: *Orphnaeus brevilabiatus* (Deer Cave) Photo Ross Anderson • Emits luminous green fluid when disturbed	

Arachnida: Amblypygid: *Charinus*? or *Sarax*? sp. (Stonehorse Cave) Photo Ross Anderson	
Arachnida: Shizomida Hubbardiidae sp. (Deer Cave) Photo Ross Anderson	

Arachnida: Scorpione: Buthidae: *Chaerilus chapmani* (Racer Cave) Photo Ross Anderson	
Arachnida: Opilione: Stylocellidae sp. (Lagang Cave) Photo Ross Anderson	

Arachnida: Opilione: Phalangodidae? sp. A (Stonehorse Cave) Photo Ross Anderson	
Arachnida: Araneomorphae: Sparassidae: Heteropoda sp. (Lagang Cave) Photo Ross Anderson	

Arachnida: Araneae: ?Amaurobiidae (Lagang Cave) Photo Ross Anderson	
Arachnida: Araneae: Pholcidae: ?*Spermophora* sp. (Lagang Cave) Photo Ross Anderson	

Hexapoda: Diplura: Campodeidae: *Lepidocampa ?weberi* (Stonehorse Cave) Photo Ross Anderson	
Insecta: Blattodea: *Blattella cavernicola* (Deer Cave) Photo Ross Anderson	

Insecta: Orthoptera: Rhaphidophoridae: *Rhaphidophora oophaga* (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Orthoptera: *Diestrammena sarawakana* (Fruit Bat Cave) Photo Ross Anderson • Banded legs • close to entrances • associated with guano when *D. mjobergi* is absent	

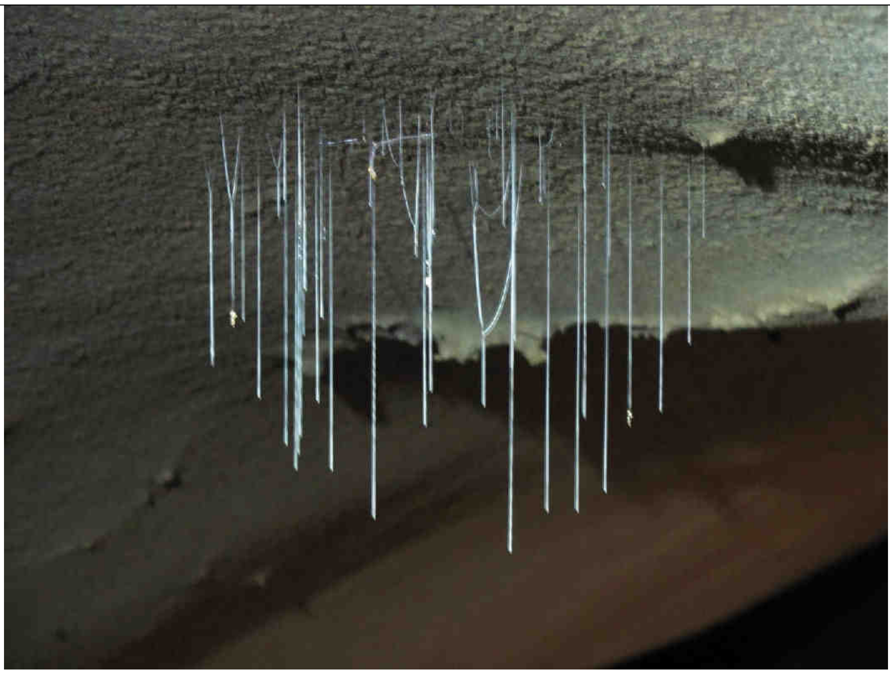
Insecta: Orthoptera: *Diestrammena mjobergi* (Lagang Cave) Photo Ross Anderson • Light brown • Deeper high humidity cave environment • associated with guano	
Insecta: Dermaptera: Arixeniidae: *Arixenia esau* (Deer Cave) Photo Ross Anderson	

Insecta: Hemiptera: Reduviidae: Harpactocoid? (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Hemiptera: Reduviidae: (Fruit Bat Cave) Photo Ross Anderson	

Insecta: Hemiptera: Reduviidae: Emesinae: ?*Baguada cf. cavernicola* (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Lepidoptera: Tineidae: Tinea? sp. (Fruit Bat Cave) Photo Ross Anderson (*Crypsithyrodes concolorella* / *Tinea porphyropa* / *Tinea antricola*)	

Insecta: Lepidoptera: Tineidae sp. larvae (Lagang Cave) Photo Ross Anderson (*Crypsithyrodes concolorella* / *Tinea porphyropa* / *Tinea antricola*)	
Insecta: Coleoptera: Trogidae: *Trox costatus* (Deer Cave) Photo Ross Anderson	

Insecta: Coleoptera: Leiodidae: *Ptomaphaginus chapmani* (Lagang Cave) Photo Ross Anderson	
Insecta: Diptera: (Deer Cave) Photo Ross Anderson	

Insecta: Diptera: (Fruit Bat Cave) Photo Ross Anderson	
Insecta: Diptera: Keroplatidae *Chetoneura ?cavernae.* (Fruit Bat Cave) Photo Tony Veness • non-glowing family similar in habit to glowworms	

Insecta: Hymenoptera: Ichnuemonoidea? (Fruit Bat Cave?) Photo Ross Anderson	
Insecta: Hymenoptera: Formicidae: *Pachycondyla tridentata* (Lagang Cave) Photo Ross Anderson	

Appendix C

Cave Sample Locations

Fruit Bat Cave – Dark Zone sample site Photo Ross Anderson	
Fruit Bat Cave – Entrance and Twilight sample area Photo Ross Anderson	

Green Cave – Dark Zone near lower river area Photo Ross Anderson	
Green Cave – Entrance Area near gour pool and formation Photo Ross Anderson	

Lagang Cave – Entrance and Twilight sampling area Photo Ross Anderson	
Lagang Cave – Dark zone Fast Lane area Photo Ross Anderson	

Lagang Cave – Dark zone, block area at end of Fast Lane. Photo Ross Anderson	
Lagang Cave – Dark zone Extension passage Photo Ross Anderson	

Stonehorse Cave – Entrance and Twilight Photo Ross Anderson	
Stonehorse Cave – Dark Zone site 1 Photo Ross Anderson	

<table>
<tr><td>Stonehorse Cave – Dark Zone
Site 2
Photo Ross Anderson</td><td></td></tr>
<tr><td>Stonehorse Cave – Dark Zone
Site 3
Photo Ross Anderson</td><td></td></tr>
</table>

Lagang – Dark Zone path guano pile May 2012 Photo Stephen Swabey	
Racer Cave – Entrance area Photo Jane Pulford	

Racer Cave – Dark Zone Site 4? Photo Tony Veness	
Kenyalang cave – Dark zone Photo Tony Veness	

Deerwater Cave – Dark zone Photo Jane Pulford	
Deer Cave – Dark Zone Photo Ross Anderson	

Glowworms are more diverse than we thought: cave and forest-adapted species in Australia

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Abstract

Glowworms emit light to attract prey into their webs. They are found in suitable wet caves as well as in forests. In wild caves of Tasmania and New Zealand, glowworm populations (*Arachnocampa tasmaniensis* and *Arachnocampa luminosa*, respectively) maintain synchronised rhythmic light output, waxing and waning together in a 24 hour cycle. Here I show how the Tasmanian species (and also probably the New Zealand species) is capable of synchronizing the bioluminescence cycle. In laboratory experiments we exposed a single larva to three others that were on a different cycle. The single larva shifted its time of glowing to match the others over about eight days. This synchronisation capability probably allows the glowworm colonies in caves to glow most brightly all at the same time as a way of attracting more flying insects into their webs. In comparison, the south-eastern Queensland glowworm species can't synchronise. It seems that the synchronisation ability is present only in the species that have large cave populations.

Introduction

In this paper, I point out the substantial behavioural differences among species of *Arachnocampa*, the glowworms of Australia and New Zealand. The main finding is that cave-adapted species such as *Arachnocampa tasmaniensis* synchronise their bioluminescence in caves, a form of cooperation that appears to give the participants an advantage in being able to attract prey more efficiently. In essence, it is an approach known as group foraging.

First, I'll present some background on glowworms. They are members of the genus *Arachnocampa*. They produce light to attract prey into their sticky snares. Light (bioluminescence) is produced in cells located at the tips of internal tubular structures branching from the gut, known as Malpighian tubules. In most insects they function solely as excretory structures, but in glowworms they have taken on a dual function; excretion and light production. *Arachnocampa* glowworms are the only insects that produce light in this way. The light-producing cells are located internally at the posterior end of the larva. The cuticle is transparent to allow the transmission of light. In addition, an internal reflector composed of a mass of air-filled respiration tubes is present around the light-producing cells (Figure 1). In this case, they function both as a respiratory system and a light reflector.

Figure 1: The posterior end of a glowworm larva showing the silvery-white reflector surrounding the light organ.

The distribution and relationships of glowworms are keys to understanding the behavioural and evolutionary differences between species. Claire Baker's research compared the traits of the New Zealand and one Australian glowworm (Baker and Merritt, 2003) and the morphology and DNA sequence of all known glowworm groups in Australia and New Zealand (Baker et al., 2008). She named a number of new species and – most importantly for this paper – provided a phylogenetic tree: a reconstruction of the most likely relationships among the present-day species, with estimated times (millions of years ago) when the major divergences took place. A few key points are that (1) as expected, the most ancient divergence is between the New Zealand species and all of the Australian species. (2) The Australian species can be divided into two main groups or subgenera: subgenus *Campara* and subgenus *Lucifera* (Figure 2). The subgenus *Lucifera* has only two member species: *Arachnocampa tasmaniensis* and *Arachnocampa buffaloensis*. They share the traits of inhabiting cooler regions and having significant cave populations. The subgenus *Campara* includes the remaining six Australian species, distributed from the wet tropics region of northern Queensland to the cooler temperate forests of the Otway Ranges in Victoria. They are predominately found in forest settings where the habitat is cool, shaded and damp, but some populations of these species are found in caves.

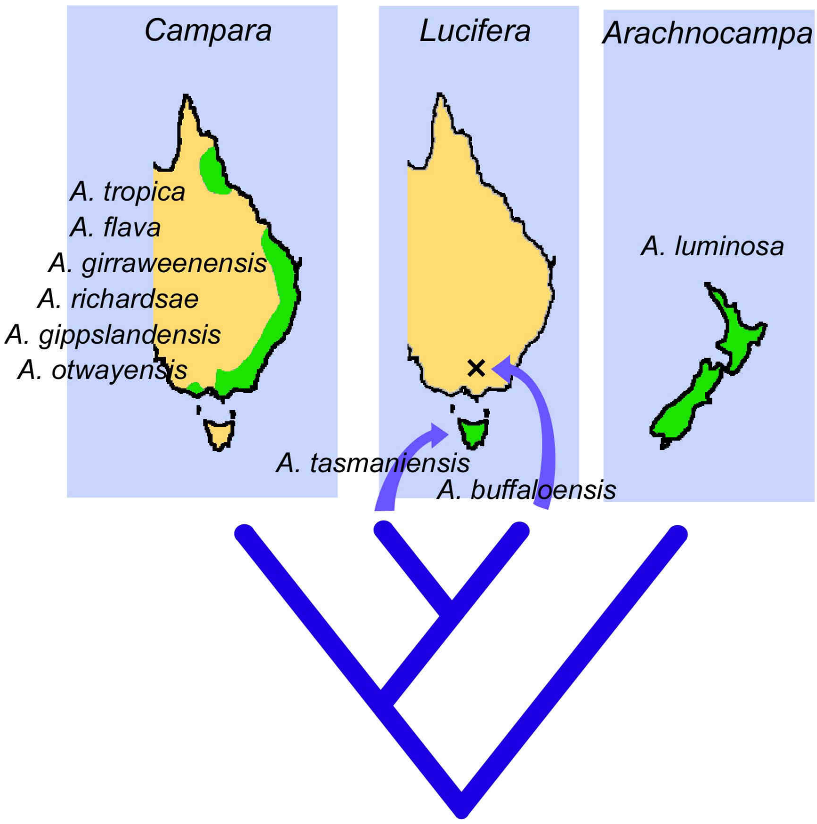

Figure 2: A phylogenetic tree showing the relationships and distributions of the Australian and New Zealand species of glowworms.

Students at the University of Queensland, School of Biological Sciences have been researching bioluminescence regulatory mechanisms. It has been known for some time that extraneous light causes larvae to cease glowing, as noted by some of the pioneering researchers on glowworms (Richards, 1960). This reflex is understandable; there is no advantage in expending energy producing biological light when it is barely visible and cannot compete with non-biological sources. The larvae have eyes so they can see light, although we don't know how sensitive they are. Larvae in forest habitats will glow throughout the night, modulating the intensity so that it is brightest after dusk and dims toward dawn. A number of factors other than light will cause an increase or decrease in bioluminescence intensity, including vibration and loud sounds. Rainfall causes a large increase in light output.

Because glowworms react to natural light, they have no obvious need for a circadian clock that controls their bioluminescence, but because so many animals show biological rhythms that control behaviours such as sleep-wake cycles, we tested for clock control of bioluminescence in the local forest species, *Arachnocampa flava*. We found that bioluminescence does come under the control of a biological clock (Merritt and Aotani, 2008). When larvae were placed in constant darkness in the laboratory they continue to cycle their light intensity. After a week or so, the amplitude of the daily cycles had damped, but a persistent rhythm was apparent. The rhythm is known as a circadian rhythm because it doesn't keep an exact 24 hour periodicity, rather individuals showed different periodicities, usually greater than 24h hours, just as humans do.

In a forest-adapted species such as *Arachnocampa flava*, the regular waxing and waning of solar light through each 24 h period entrains the clock every night and the presence of the clock control is only obvious under controlled experimental conditions. You may ask why have an endogenous control of an activity such as light production when a reflex-like response to the daily day-night cycles is sufficient to regulate the behaviour? This question is difficult to answer; however, many circadian biologists propose that the endogenous rhythm allows animals' metabolism to prepare for lights-on or lights-off and buffers them from initiating immediate but inappropriate responses to darker than normal or brighter than normal conditions.

The demonstration of a biological clock that controls the bioluminescence made us curious about what happens in cave populations. Glowworms in the deeper zones of caves never see daylight so it was possible that they would be glowing at a consistent level all the time because their clock – if they have one – has never been entrained by daylight. Alternatively, individuals might keep their internal rhythm of glowing but individuals in a colony would be out of phase with each other because each has its own personal periodicity.

The way to test this was to apply long-exposure, time-lapse photographic methods that would operate in a cave environment. Affordable digital SLR cameras were combined with time-lapse controllers and battery power allowing us to set up a system that would take a photo every 10 minutes while unattended for several days. Afterwards, the images are converted to grey scale and the image analysis software, ImageJ, used to count the number of larvae visibly glowing in each frame, to measure the intensity of each individual and the total intensity of larvae in the field of view over time.

The initial results from Marakoopa Cave in northern Tasmania – since confirmed in other Tasmanian caves – were unexpected. Individuals show precise 24 h cycles in their intensity of glowing. Within a colony individuals are synchronised, i.e. they showed the same time of peak and trough in their intensity curves. Consequently, the intensity of light produced by any single colony oscillates in the form of a sine wave. Some individuals never turn off completely; others dim to the extent that they are no longer detectable by the camera, but they all maintain the same periodicity. Another surprising outcome was that the time of the peak bioluminescence of colonies located well within caves tended to occur in the late afternoon. Colonies in different caves show different times of peak intensity and there seemed to be some plasticity, i.e. it might be earlier or later from one year to the next. Understandably, it is hard to be definite about this because the recording method gives a snapshot of periodicity over a few days at a particular location.

One explanation for the colony-wide cycling is that larvae synchronise to each other's bioluminescence. If proved, this would be significant because no such bioluminescence synchronisation had been shown in any organism. One comparison is the synchronously flashing fireflies of south-eastern Asia. The male beetles congregate in large numbers in a few trees and synchronise their flashes at about 1 – 2 Hz to attract females. The substantial difference is the fact that glowworm synchronisation is on the scale of 24 hours and involves the circadian system, whereas firefly synchronisation is a higher frequency. We could not eliminate other possibilities, such as the rhythms being entrained by detection of small daily temperature oscillations within the cave. After light, temperature variations are the next most effective entrainment stimuli for the rhythms of many animals.

An in-cave experiment was carried out that pointed to synchronisation but did not prove it. Mystery Creek Cave in Tasmania was chosen because it has a large colony of glowworms and is relatively easy to access. Colonies are present in the cave mouth and deeper. The idea was to focus a light beam on a subset of the main ceiling population to expose them to light for several hours a day for several days (Maynard and Merritt, 2013). The light should shift the phase of their glowing rhythm and, once the artificial light pulses ceased, they should resynchronise to the surrounding colony. A 12 V 20 white LED lamp was focussed with Fresnel lenses to create a 1.6 m diameter spot encompassing 78 larvae on the main ceiling colony in Mystery Creek Cave. A 12 V timer was used to expose larvae in the spot to 3 hours of light per day for 5 days. Over the five days of daily light pulses, the spot-lit cluster of larvae progressively shifted their peak glowing time to match the time of light exposure. Once the light exposures ceased, the larvae then progressively resynchronised to the surrounding population. After nine days when the experimental observations had to be terminated, the treated group had almost re-synchronised to the untreated, surrounding population.

We needed to carry out experiments in the laboratory where environmental conditions could be tightly regulated to prove that behavioural synchronisation was taking place and confirm that *A. tasmaniensis* has circadian regulation of bioluminescence. With permission from Tasmania's DPIPWE and assistance from Mike Driessen who has been monitoring the cave glowworms (Driessen, 2010), we collected larvae from the cave and set them up in the laboratory in Brisbane where we can maintain them in incubators at a cool 8°C; the mean annual temperature of Mystery Creek Cave.

First, we established that *Arachnocampa tasmaniensis* – like their mainland cousins, *Arachnocampa flava* – have a circadian control of their bioluminescence. Second, we showed that light entrains the rhythm, just as it does in *Arachnocampa flava*, but it entrains the rhythm to the opposite periodicity (Merritt and Clarke, 2009, 2011; Merritt et al., 2013). Light exposures of several hours per day, over several days, in otherwise dark conditions, caused the larvae to adjust their bioluminescence rhythm to peak when they anticipate the lights to come on. This seems counter-intuitive; however, our explanation is that the species is primarily cave-adapted and the ability to synchronise is an important adaptation. The ability of periodic light cycles to entrain them would cause a dark-zone colony to synchronise; an example of mutual social entrainment. But what happens among the many forest populations of this species? They switch on only at night. We took larvae from the mouth of a nearby cave and showed in the laboratory that indeed their endogenous rhythm tells them to glow most brightly during daylight hours, but the daylight itself over-rides the rhythm and causes them to switch off. At dark, the inhibition is lifted and they switch on their bioluminescence. It is as though the biology of *Arachnocampa tasmaniensis* is centred on cave habitats where synchronisation is a priority and forest habitats are an afterthought. On the other hand, the rainforest-adapted *Arachnocampa flava* that doesn't have cave populations (as far as we know) acts like a typical nocturnal animal; its endogenous rhythms tell it to glow most brightly at night.

These experiments told us that light could entrain the rhythms but we did not yet have proof that individuals can synchronise to each other's glows. Honours student Andrew Maynard designed laboratory experiments that proved synchronisation does take place. Larvae from Mystery Creek Cave were pre-set to different periodicities by exposing them to light for several hours per day over a number of days: one group's bioluminescence peaked at around 01:00 h and the other at 13:00 h. Then three larvae from one group were exposed to one larva from the other, placed 7 to 10 cm apart (Figure 3). The single larva changed its periodicity over several nights until its period and phase both matched the other three (Figure 4). As predicted, *Arachnocampa flava* under identical experimental conditions did not show any signs of phase matching. So these experiments proved that the simultaneous waxing and waning of glowworm light within caves is due to a visually-mediated synchronization of bioluminescence intensity.

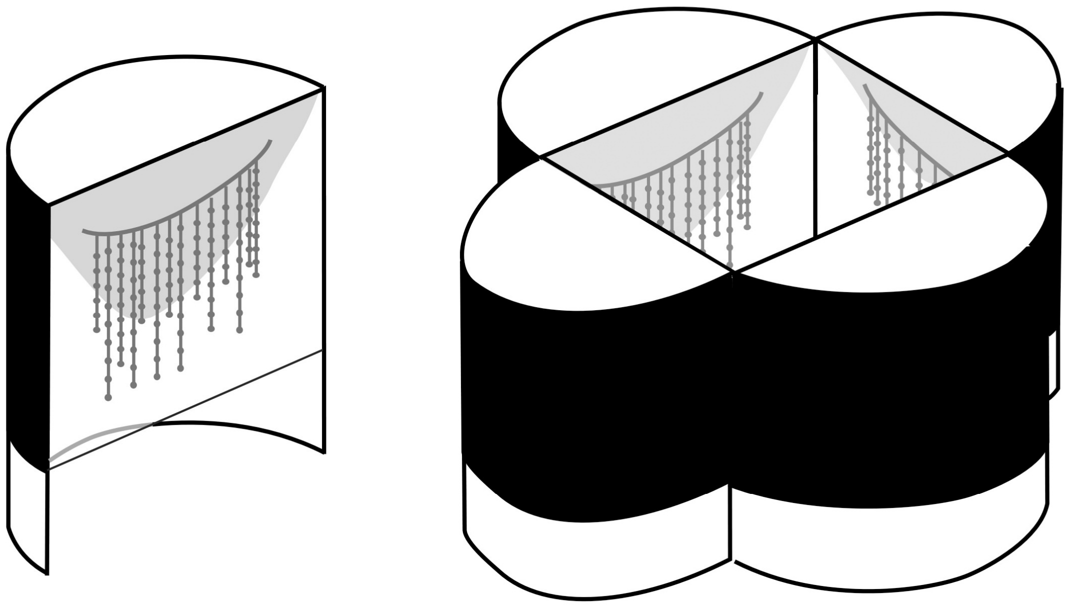

Figure 3: The arrangement of glowworms in individual habitats when they were exposed to each other's lights.

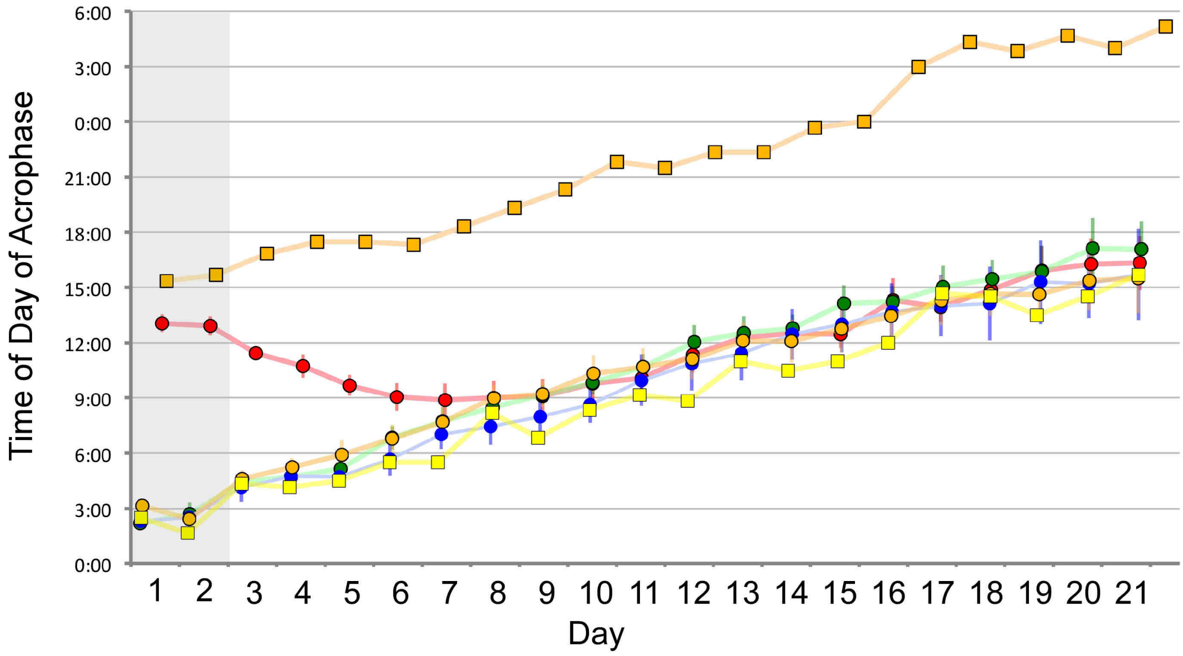

Figure 4: Synchronisation of a single larva (red symbols) to match the glowing cycle of three larvae that were initially synchronised to each other. The orange line is a control larva that was visually isolated from all others.

A second interesting outcome was that under constant darkness the larvae remained synchronised but they did not show the precise 24-hour periodicity that we see in cave populations; rather, they show a period of >24 hours. They entrain to each other but in the absence of any environmental cues the rhythm "free-runs" i.e. the group's periodicity is the average of each individual's periodicity and individuals do not have very accurate clocks (remember the definition of circadian means *approximately* daily). That is why the peak occurred slightly later each day in the laboratory experiments even after all four larvae were synchronised (Figure 4). We suspect that a consistent timing of the availability of prey from day to day could entrain the rhythm in caves, but we haven't yet done the experiments to test this idea.

Another outcome of the comprehensive photographic sampling was the observation that, while all colonies show the same 24-hour periodicity, they do not all show the same phase. The main ceiling colony in Mystery Creek Cave is composed of many thousands of individuals: it has shown a consistent phase over many years of sampling with the peak intensity occurring at 14:35 h (Merritt and Clarke, 2011). However, another more isolated colony has changed phase between sampling years. Another colony shows even more interesting characteristics. It is located on an outcrop several metres high and wide, encompassing a vertical rock face that transitions to an overhang. The subsection of the colony on the vertical face peaks at 11pm while the adjacent population located on the overhang peaks at 4 am. To explain the different phases we suspect that the subpopulations of the colony can't see each other due to their location and therefore cannot synchronise. Perhaps the subpopulations attract prey from different locations as well, explaining their different phases. In the future, such explanations can be tested by setting up insect traps inside caves to tell us when the prey insects are most likely to be active. The benefit of our combined approach – controlled laboratory experiments backed up by manipulations and recording in caves – allows us to create a model of how individuals should visually interact and then testing the model inside caves.

Conclusion

It is likely that the New Zealand glowworm, *Arachnocampa luminosa*, is a synchronising species, based on recording in Hollow Hill Cave and long-term time-lapse imaging at Waitomo Glowworm Cave, but the required laboratory experiments are yet to be carried out. *Arachnocampa flava* does not synchronise, and preliminary experiments indicate that the other Australian mainland species, *Arachnocampa richardsae* and *Arachnocampa girraweenensis*, like *Arachnocampa flava* cannot synchronise. An aim of future work is to find out which species groups show which behaviour and, if possible, examine the genetic machinery of the biological clock to see if there is any genetic signature associated with the evolution of this substantial change in behaviour among what was thought to be a homogeneous group of related species.

Acknowledgements

I would like to thank Arthur Clarke and Cathie Plowman for their help over the many years we have been working on Tasmanian glowworms. I'd also like to thank Mike Driessen of Tasmania's DPIPWE for assistance and permissions in working in Tasmania's world heritage areas. The many students who have worked on the *Arachnocampa* bioluminescence system at the University of Queensland – Claire Baker, Saki Aotani, Julie-Anne Popple, Rebecca Morley, Robyn Wills, Lisa Rigby, Essie Rodgers, Ami Amir Abdul Nasir, Andrew Maynard – have kept the project running and have all made useful contributions.

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Glowworm Photomonitoring in the Waitomo Glowworm Caves, New Zealand

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Abstract

The Waitomo Glowworm Caves have the most visited glowworm display in the world. Prior to 2009, the glowworm monitoring program had been based on intermittent quadrat counts at two sites. Data from these quadrats was limited, not statistically robust, and difficult to interpret. One of the characteristics of the quality of the display is the extent of the colony's coverage of the cave ceiling and walls so effective monitoring should encompass as large a proportion of the colony as possible.
Experimental long-exposure photomonitoring was developed in late 2008 and its design reported at the 2009 ACKMA conference. Data from the ensuing two years showed that monthly photomonitoring provided useful population counts, but a less labour intensive method with better resolution data was required to gain a proper understanding of glowworm population and biological cycles. Consequently, time-lapse glowworm photomonitoring was trialed in early 2011 and a permanent time-lapse photomonitoring system installed in July 2011. Photographs are taken at 30 minute intervals to match the frequency of temperature and humidity data collection by the automated climate monitoring systems. Despite some reliability issues, the glowworm time-lapse photomonitoring system has collected some interesting and useful data that has revealed previously unknown information about the glowworm population in the Glowworm Grotto.

Introduction

Tourists have been coming to see glowworms (*Arachnocampa luminosa*) at the Waitomo Glowworm Caves since 1889. In the following years, the caves became a popular tourist attraction, hosting 500,000 visitors per year during peak. For this reason, the glowworm population and the Waitomo Glowworm Caves are very important to the local Waitomo economy and region.
Glowworms are viewed at two main areas by tourists, the Demonstration Chamber where feeding lines are viewed and the Glowworm Grotto where glowworm lights are viewed from a boat (Figure 1). These displays are situated on the cave ceiling above the Waitomo Stream, which is a source of aquatic prey insects for the glowworms.

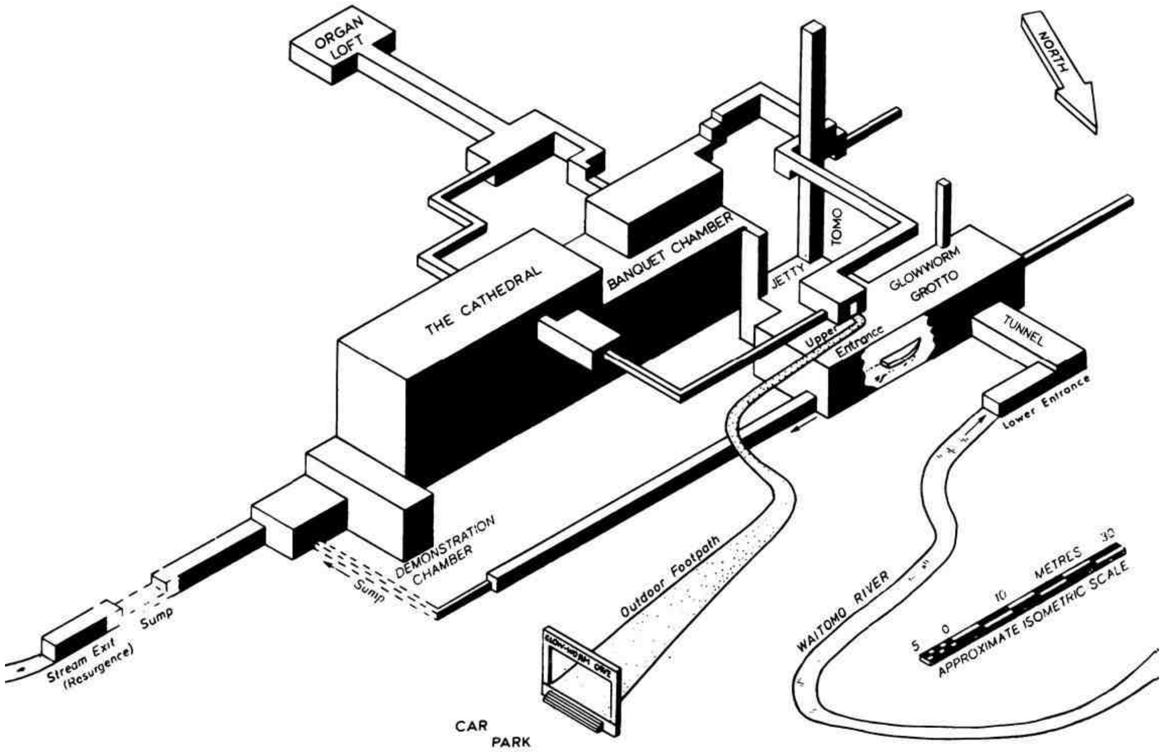

Figure 1. Isometric representation of the Waitomo Glowworm Cave with the Demonstration Chamber and Glowworm Grotto shown. (after de Freitas et al., 1982)

In 1979 glowworm numbers had declined so dramatically the cave had to be closed between April and July 1979. The decline was attributed to the replacement of the upper entrance door with an open grill door that allowed a free airflow through the cave in a process described by de Freitas et al., (1982). This caused glowworm desiccation and increased temperatures, which in turn increased occurrences of the glowworm-killing fungus *Tolypocladium extinguens*. Glowworms were transplanted from other caves to restock the population before the cave could reopen.

Between 1977 and 1980, C. Pugsley carried out photographic monitoring and quadrat counts at two-week intervals as part of his research on glowworm ecology (Pugsley, 1980, 1984). Quadrats counts were continued by Tourist Hotel Corporation staff (later Tourism Holdings Limited) but at intermittent intervals (D. Smith pers. comm. 2013). Until 2009, no regular, long-term monitoring of this important population was conducted, despite the installation of climate monitoring systems in the cave, primarily because of the difficulty of monitoring the glowworm population located on the high cave ceiling.

With the advent of affordable digital photography, glowworm photomonitoring was initiated during 2009 with several specific aims: 1) to determine annual changes in glowworm numbers; 2) to determine seasonal variation; 3) to provide early warning of any adverse effects of tourism or issues within the catchment. Monthly photomonitoring was done for a little over 2 years until it was decided a better method was needed and a method for continuous time-lapse photomonitoring was developed.

Monthly Photomonitoring

Photographic monitoring was done on a monthly basis starting from July 2009 by taking overlapping digital photographs of the main display in the Glowworm Grotto. A camera was attached to an extendable boom mounted on the cave wall (Figure 2). The boom was extended the same length each time, and then levelled to point straight up using a bullseye level placed on the lens. Then a series of 5 upward facing photographs taken through a plane parallel to the length of the Grotto at ~ 20º interval i.e. -40º, -20º, 0º (straight up), 20º & 40º with overlap between photographs. A Pentax E500 SLR camera with a 17.5-45mm lens was used with the focus set to infinity, ISO 800, F 3.5 and a 60 seconds exposure with the flash off. A wireless shutter release remote control was used to trigger each photograph.

Figure 2. Monthly photomonitoring set up showing the camera attached to the boom and adjustable camera mount.

The resulting overlapping photographs were digitally stitched together resulting in a single photograph of the main Grotto glowworm population (Figure 3). This photograph was then analysed using the image analysis program, ImageJ to give the total number of glowing glowworms. Counts of up to ~ 3300 larvae were recorded using this method. Monthly data was collected for a little over 2 years and results graphed. Results were variable and showed a broad trend of declining glowworm numbers over time (Figure 4).

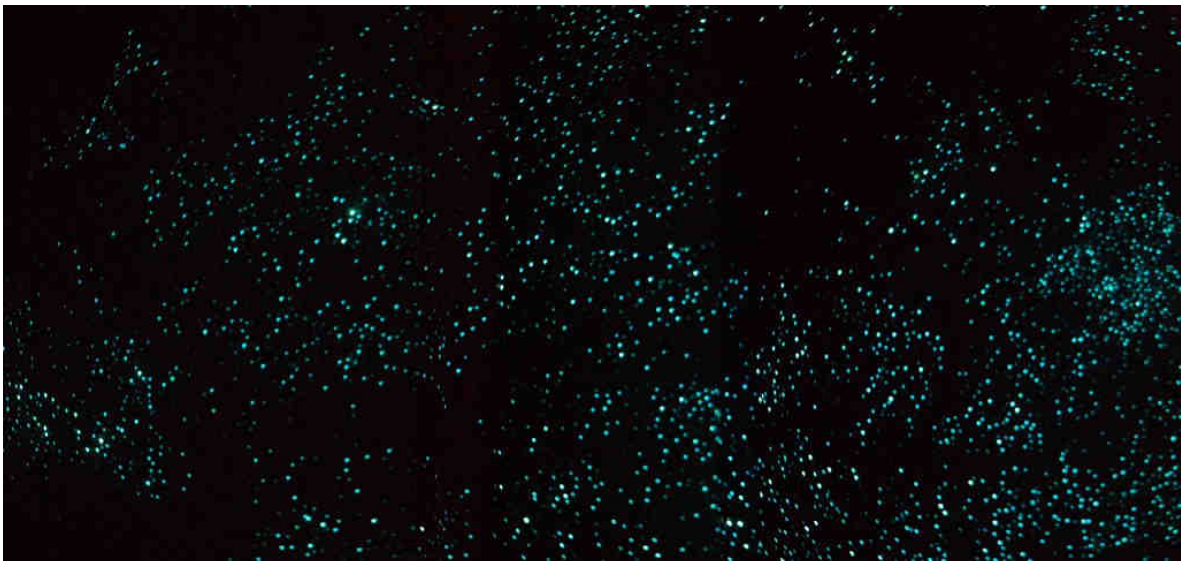

Figure 3. An example of a stitched monthly photograph showing the Glowworm Grotto glowworm display.

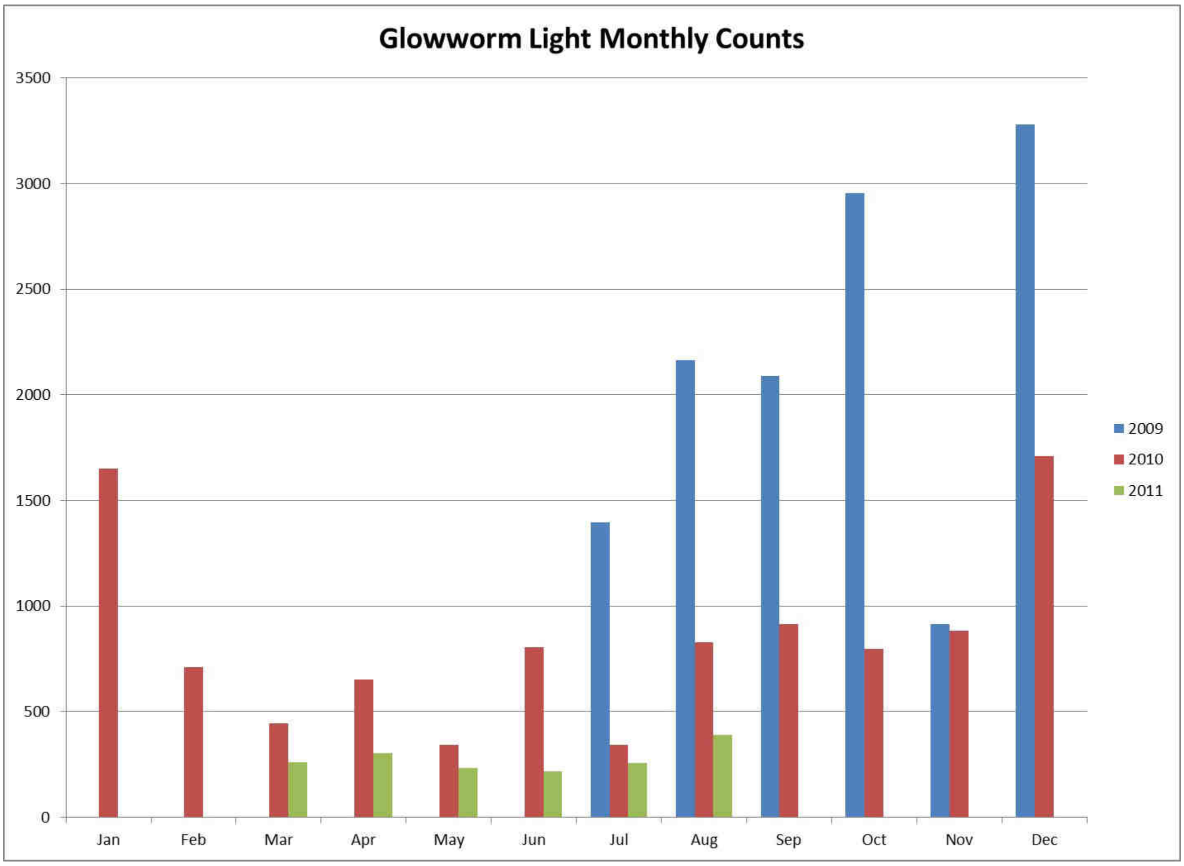

Figure 4. Monthly glowworm numbers plotted showing variable results and a broad trend of declining glowworm numbers over time.

In later times, two sets of monthly photographs were taken per session. The second set always yielded higher counts, possibly due to the glowworm population settling down after the light and sound disturbance of the equipment setting up. After a little over two years it was decided that results were of too low resolution to draw any real conclusions and a better method was required.

Time-lapse Photomonitoring

Time-lapse photography was first trialled in the Glowworm Grotto by Dave Merritt using equipment that had been tested in Mystery Creek Cave, Tasmania, for studies of *Arachnocampa tasmaniensis* bioluminescence rhythmicity. Following this successful trial, an off-the-shelf Habortronics time-lapse package was purchased and permanently installed above flood level on the true left, mid-way along the Grotto wall (Figure 5 & 6). Figure 6 shows the approximate time-lapse camera field of view. The system was based on a Canon Rebel T3 camera, powered by an 11.1 volt, 9 amp hour lithium ion polymer rechargeable battery that are exchanged monthly. At the same time the flash card with stored images was replaced.

Figure 5. The Harbortronics time-lapse monitoring package installed in the Glowworm Grotto

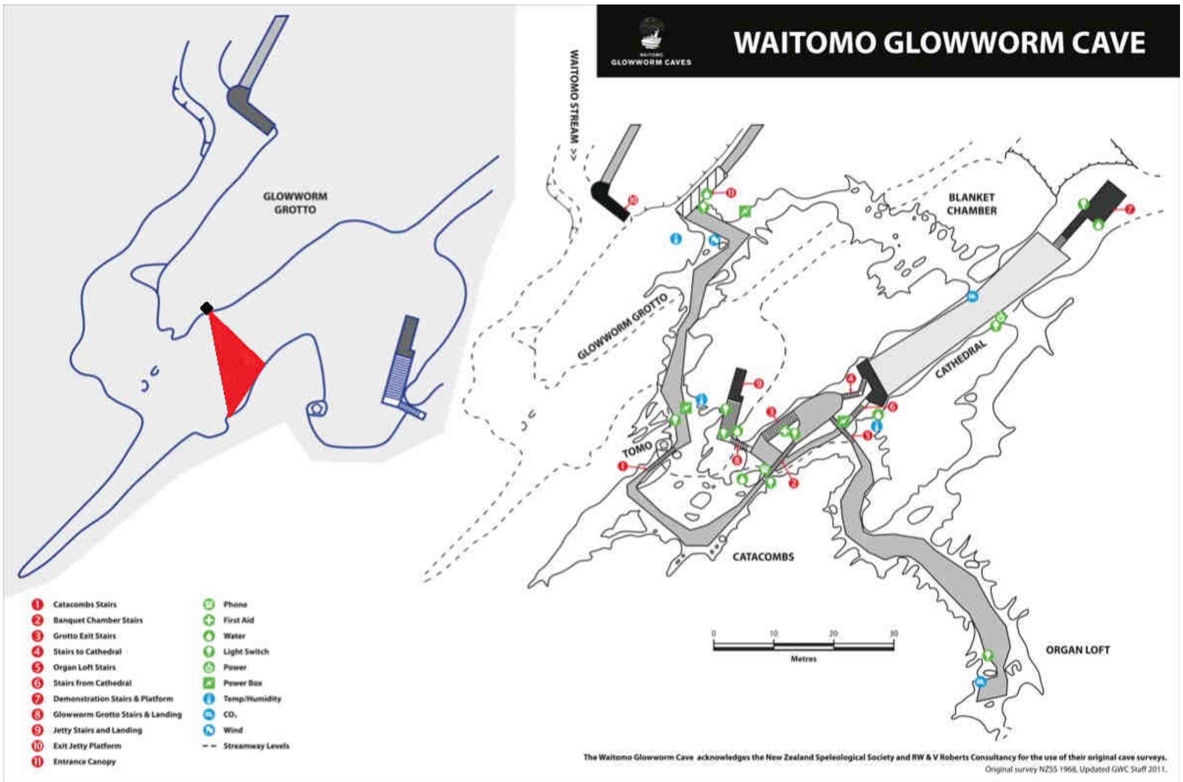

Figure 6. The Habortronics time-lapse camera location and approximate field of view shown in red on the enlarged section of the Waitomo Glowworm Cave map.

The time-lapse photomonitoring system took 20 second exposure photographs at 30 minute intervals to match the sampling rate of the automated climate monitoring system temperature and humidity readings (for automated climate monitoring system description see Cross, 2009). The sampling rate would allow correlations between glowworm light output and any potential environmental influences and would reveal any daily fluctuations in intensity. Although preliminary, the time-lapse glowworm photomonitoring system has yielded interesting information.

Results

The time-lapse photomonitoring system worked reliably for the first year of operation but developed ongoing battery and charging issues from late 2011, possibly due to the challenging conditions of high humidity and low temperatures. For this reason, the longest uninterrupted dataset is from January through to October 2011; thus, most of the data presented is derived from this time period.

A daily amplitude variation in overall intensity was present throughout the year. The amplitude of the daily cycle was much greater in summer than in winter (Figure 7). Removal of the daily cycle by calculating the mean daily light intensity showed a large reduction in mean light intensity from summer into winter (Figure 7). A correlation between mean daily Glowworm Grotto temperature and mean daily glowworm light output was also seen, with glowworm light output declining as temperature fell (Figure 8); however the annual change in temperature within the Grotto is relatively small (11 to 16 degrees C) compared to external daily and annual changes. In addition, a light intensity reduction appears to correlate with many, but not all catchment flood events (Figure 9).

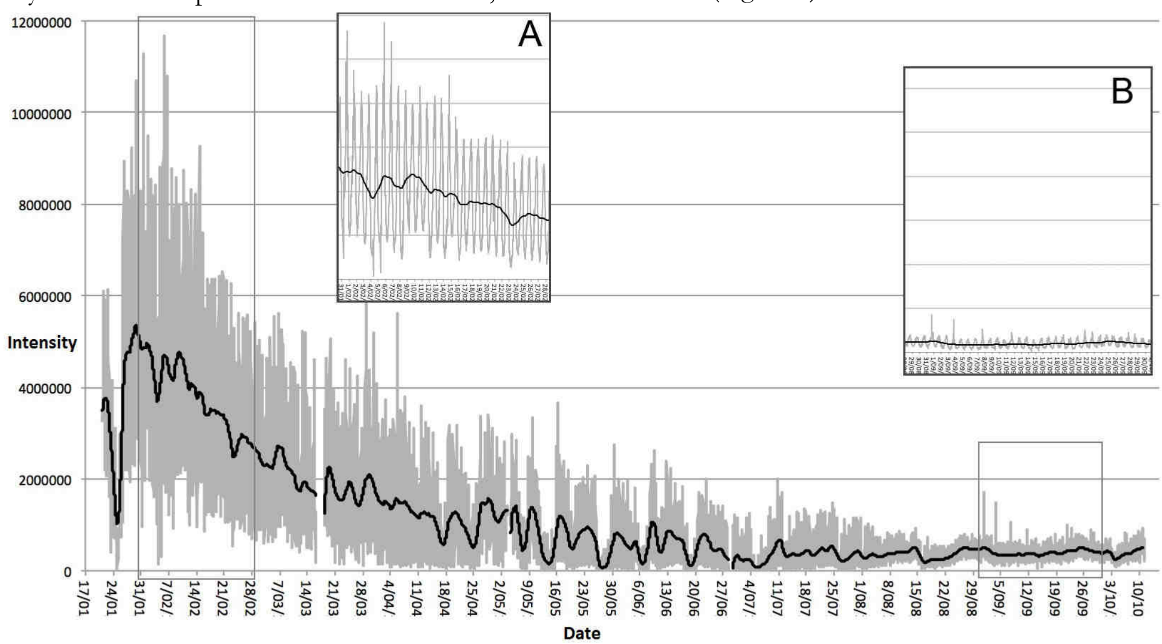

Figure 7 A large daily amplitude variation (grey) is seen between (A) “summer” (February) and (B) “winter” (September) and a reduction in mean intensity (black). The Y axis intensity unit is created by Image J and is the sum of the light of pixels in the photograph

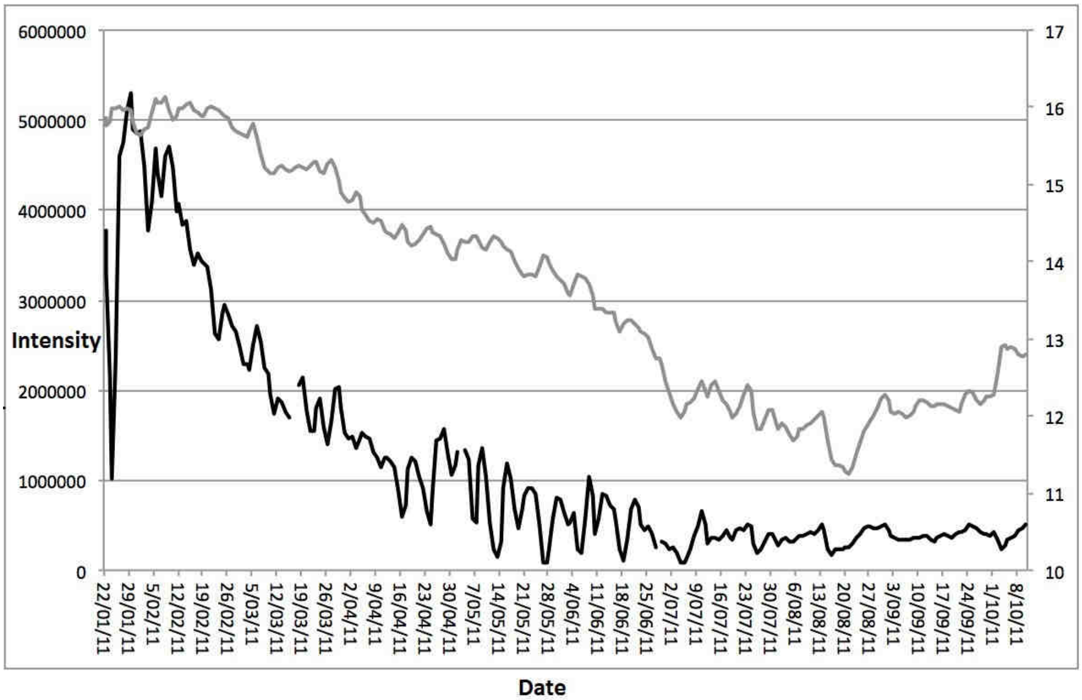

Figure 8. Continuous time-lapse data showing a correlation between mean glowworm light intensity (black) and mean Glowworm Grotto temperature (grey).

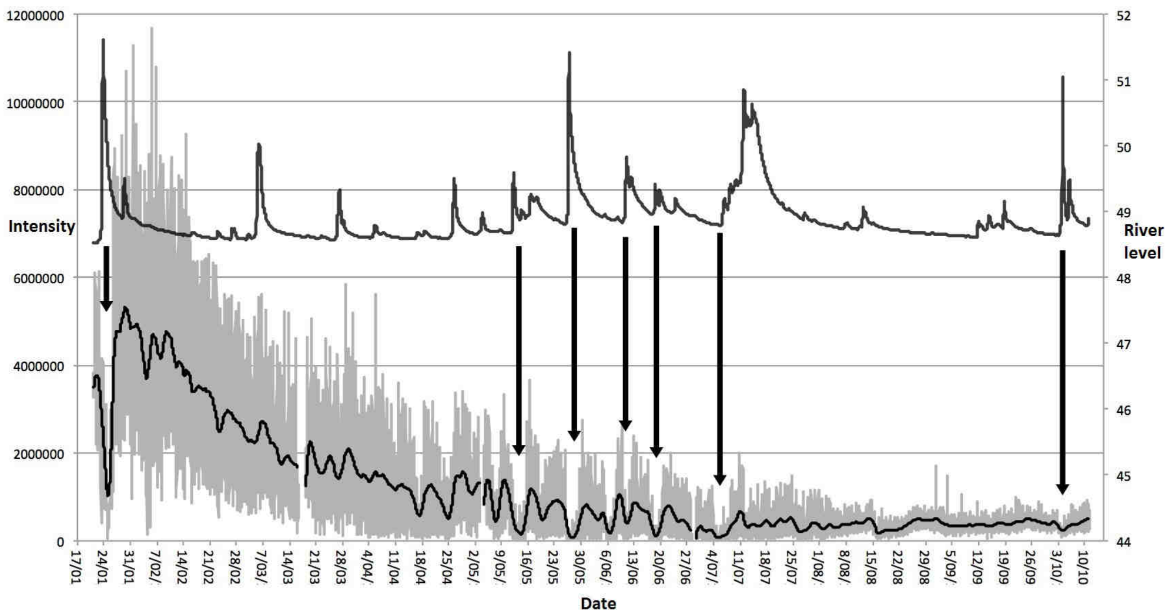

Figure 9. A comparison between time-lapse glowworm data and Waitomo Stream river level data (several kilometres upstream from cave) showing reduced glowworm light output in many but not all flood events.

Occasional unexplained sudden increases in light intensity and numbers glowing were seen in some cases, usually between 4 – 5 pm (Figure 10). This was thought to be due to disturbances in the cave. A consistent linear relationship was seen between number glowing and intensity apart from outlier disturbances mentioned above (Figure 11). The peak light output time of day appeared consistent between 4 and 6 pm from January to October 2011 whereas more variability was seen during 2012 (Figure 12).

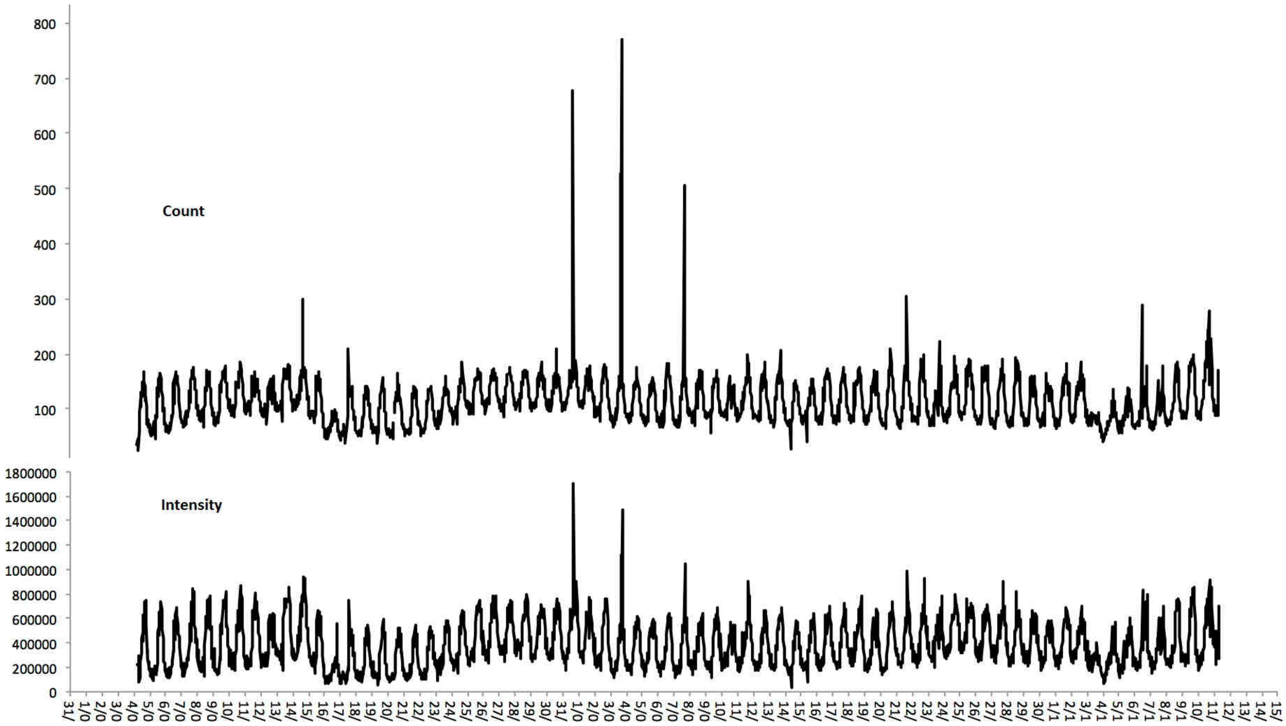

Figure 10. Sudden unexplained increases in light intensity and number glowing, usually between 4 and 5 pm.

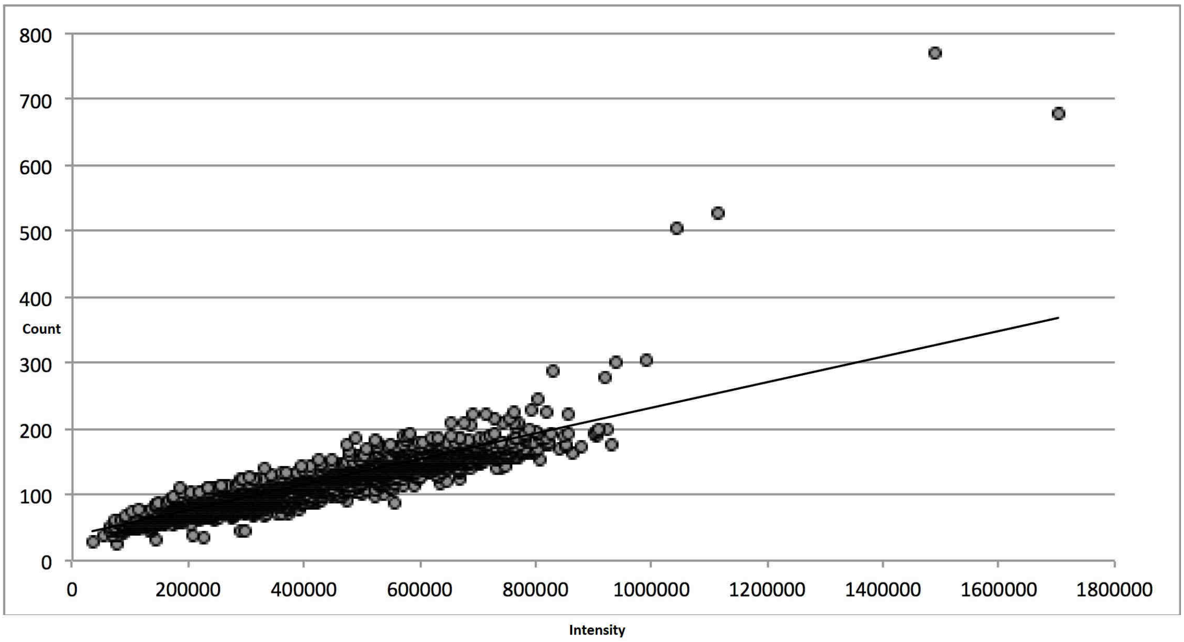

Figure 11. Time-lapse glowworm data shows a linear relationship between light intensity and number glowing.

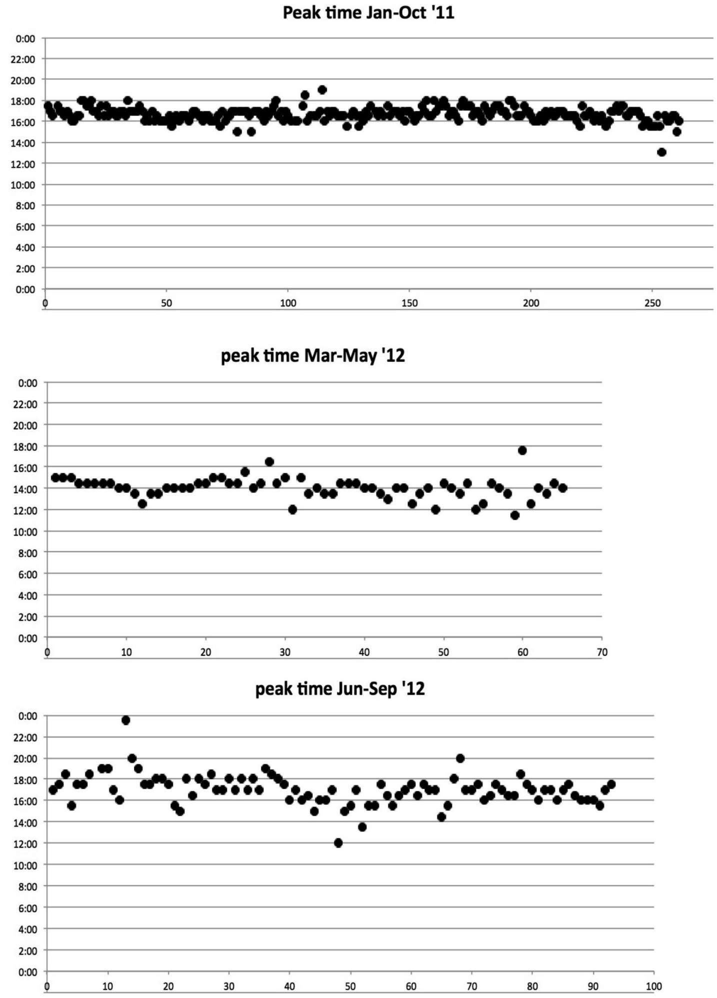

Figure 12. Time-lapse glowworm data shows relatively consistent peak light output time of day during 2011 but showed more variability during 2012.

Discussion

The pros and cons of monthly photomonitoring and continuous time-lapse photographic glowworm monitoring methods have become evident after using each for several years. Monthly monitoring captures the bulk of the Glowworm Grotto glowworm display but has coarse data resolution and is labour intensive. Time-lapse monitoring is automated and collects far higher frequency data that matches the capture of data from automated climate monitoring. Both methods require a similar labour component per month but the time-lapse camera provides much more fine-grained temporal data. This has allowed us to discover that the glowworms regulate their intensity on a 24 hour cycle, with the peak intensity in the late afternoon. On the down side, time-lapse monitoring currently only captures part of the Glowworm Grotto glowworm population and has proven to be subject to equipment malfunction in the tough cave environment. Also, data management and analysis has proven to be a challenge. Time-lapse imaging produces around 35 gigabytes of data per year, posing data storage and backup issues. The impact of the harsh cave environment on the time-lapse equipment became evident after many months in the cave. If the time-lapse system could be made more reliable, for example by heating the camera enclosure, or redundant systems could be installed, it would provide an informative monitoring system.

From the viewpoint of understanding the population dynamics of glowworms, light photomonitoring has a drawback in that it captures data on glowing larvae only, not the actual numbers present. Chris Pugsley showed in his study that under sub-optimal conditions, many larvae switch off completely and may switch on again when conditions improve. For a deeper understanding of annual cycles or long-term population density trends, the number of glowing larvae could be compared with counts of the number of larvae within quadrats. On the other hand, the photomonitoring provides information on the quality of the display, which is what visitors come to see, and allows us to measure the impacts of environmental variables such as flooding. It also allows us to assess the effect of changing any management practices.

Preliminary results suggest a correlation between temperature and glowworm light output. Whether temperature is directly influencing glowworm light output or indirectly by influencing prey insects or another unidentified factor is yet to be determined. River flood levels appear to cause a reduction in glowworm light output in many but not all cases so a better correlation is required before any conclusions can be drawn. The cause of sudden increases in glowworm light output and numbers glowing needs to be investigated. A cause could be a sudden noise created during guiding activities but is yet to be observed. The cause of a consistent peak time of day light output during 2011 but greater variably seen during 2012 has not yet been determined but could be influenced by many parameters that require further consideration.

Future Work

Given the dynamic changes in the intensity of the display that occur at daily, seasonal and annual scales, it is obvious that continuous and ongoing monitoring is required to understand environmental influences on the Waitomo Glowworm Cave population. Most pressingly, improvements in the reliability of the time-lapse camera are required. This could possibly be achieved by warming the enclosures and/or using an external power source rather than batteries. Photographic coverage of the whole Grotto is also desirable but would involve increasing the number of photomonitoring units. In the long term, it may be possible to predict the negative or positive impacts of environmental variables such as flood, rainfall and drought on the population by carrying out scientific studies that tease apart the direct affects of these variables on the glowworms from the indirect impacts on the glowworms' prey. Our photomonitoring data will be a valuable resource for such studies. The most obvious requirement is to relate prey availability to glowworm population size. From the viewpoint of ensuring that cave tourism and cave management practices are not affecting the glowworm population, it would be informative to photomonitor the population in a wild, unvisited cave in the same catchment area.

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Environmental Management of the Waitomo Glowworm Cave

Effects of Visitors and Ventilation on Carbon Dioxide Concentrations

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Abstract

Environmental management of the Waitomo Glowworm Cave aims to mitigate the potential conflict between presenting the cave to visitors and protecting it. In the case of the cave's microclimatic environment, it aims, firstly, to control rise in carbon dioxide (CO_2) levels above a certain threshold, and secondly, to keep evaporation rates low so that cave drying is minimised. Reduced ventilation combined with CO_2 from visitor respiration can lead to elevated CO_2 levels in the cave. The CO_2 combines with moisture in the cave to form carbonic acid that corrodes calcite features of the cave. This damage is essentially irreversible. High ventilation rates during cool external conditions can lead to cave drying. Managing visitor numbers and airflow through the cave can regulate both of these. Earlier work has shown that three ventilation regimes exist; namely, downflow, upflow, and neutral, which are determined by cave-to-outside air temperature gradient (T_d). Cave ventilation can be regulated by a door at the cave's upper entrance which, when closed, seals the entrance and restricts airflow though the cave. Ineffective management of cave ventilation and visitor numbers can affect cave microclimate thereby compromising the glowworms' habitat. This study examines the extent to which cave management effectively minimises both cave drying and rising cave air CO_2 concentrations in the cave. Four detailed monitoring experiments were carried out inside the cave over a 10-month period. The results of these experiments together with a statistical analysis of a five-year data archive show the extent to which visitor numbers and cave ventilation affect CO_2 concentration in the cave. Overall, the results show: cave air CO_2 levels are moderately related to visitor numbers; cave air CO_2 levels are not related to T_d; and cave drying is not related to T_d. From this it may be concluded that cave management practices through ventilation and visitor control is effective.

Introduction

The cave that is the focus of this research is the Waitomo Glowworm Cave, an icon of New Zealand's North Island tourist experience and one of the most heavily used tourist caves in the world in which cave fauna is the main attraction. Experience has shown that exceptional environments such as the Glowworm Cave must be carefully managed when used for tourism or recreational purposes. If the stability of the natural cave system is disturbed, deterioration of the cave can occur. Cave microclimate plays an important role in sustainable management of the cave because of its small size, the presence of speleothem features and climate sensitive fauna on which tourism relies (de Freitas, 2010). The cave's microclimate is a complex function of many variables, such as cave rock temperature, moisture availability and air exchange with the outside. Airflow, however, is the main control.

The opposing pressures of presenting and protecting the cave require a balance to be met. In order to establish an acceptable equilibrium between the two demands, a sound understanding of the cave environment and processes operating within it is necessary. The tension between these two interests, namely financial and environmental, has been described by O'Brien and Watson (1977) as the 'paradox of conservation'.

Description of the Glowworm Cave

The Glowworm Cave is located in the village of Waitomo near the centre of the North Island of New Zealand, about 160 km southeast of New Zealand's largest city Auckland. The cave is positioned in a ridge of Oligocene limestone underlain by a Mesozoic greywacke basement. Its two entrances are separated about 14 m vertically apart and linked by approximately 1300 m of interconnected chambers and passageways (Figure 1). The cave can be separated into two distinct levels; the upper level, comprised of the Main Passage, the Blanket Chamber and the Organ Loft; and the lower level, comprised of the Banquet Chamber, the Cathedral, the Demonstration Chamber, and the Glowworm Grotto. The Waitomo Stream flows through the lower entrance into the Grotto, sumps for a short distance, and then emerges in the Demonstration Chamber.

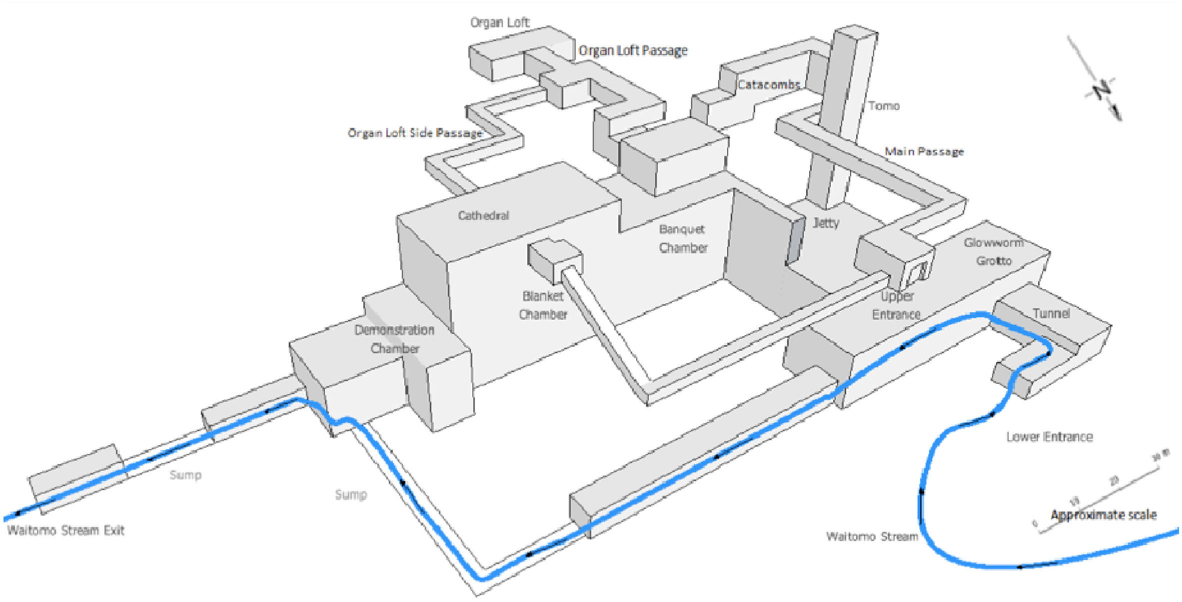

Figure 1: Schematic diagram of the Glowworm Cave at Waitomo, indicating the location of monitoring sites (after de Freitas et al., 1982: 384).

The stream sumps again near the end of the Demonstration Chamber before resurging outside the cave (de Freitas et al., 1982).

Since the Glowworm Cave is a two-entranced cave, air exchange with the outside takes place via efficient 'chimney effect' airflow downward and upward through the cave (Figure 2). Downflow occurs when outside air temperature is higher than that in the cave, as the relatively cool, dense cave air drains out. Upflow occurs when the cave air is warmer than that outside and the buoyant air is driven upwards by convection. Up-flow conditions lead to high evaporation rates in the cave and cave drying, both of which are damaging to the cave's ecosystem. In transitional conditions, where the cave-to-outside-air temperature difference is small, there is little or no air exchange.

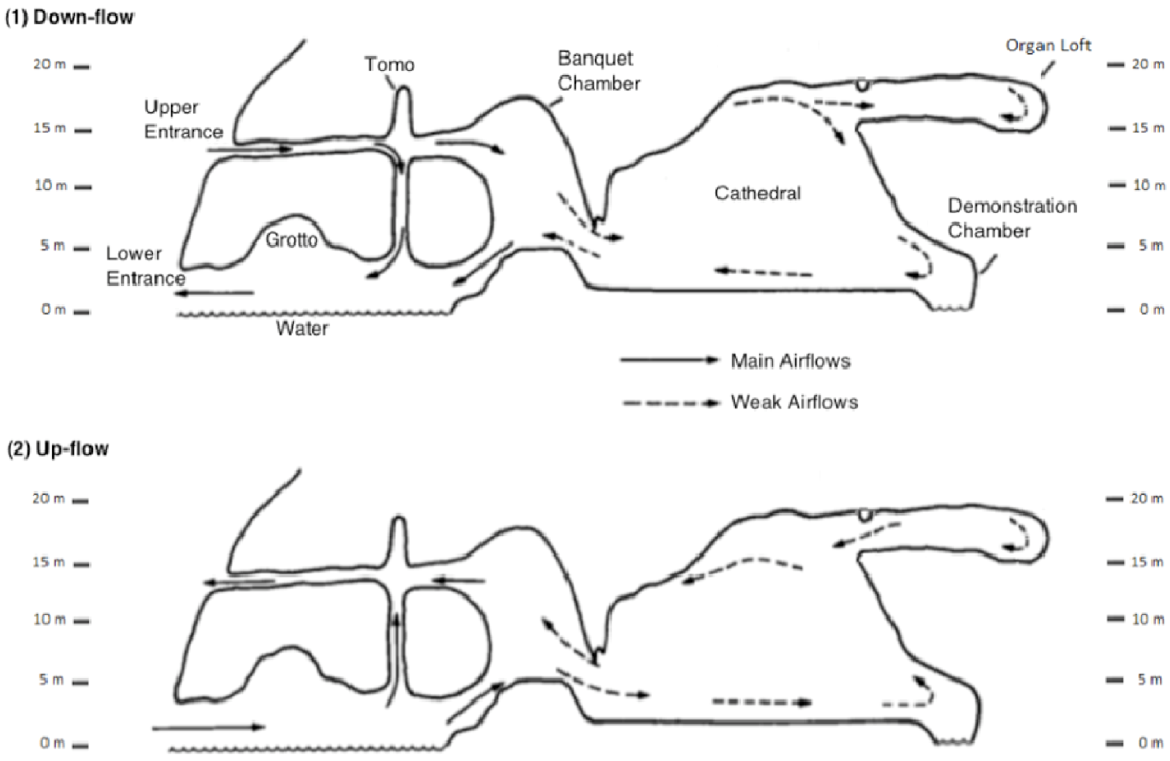

Figure 2: Cross-sectional view of the two thermally induced cave airflow regimes: (1) downflow when outside air temperature is higher than in the cave; and (2) upflow when the outside temperature is lower than in the cave (after de Freitas et al., 1982: 391).

Human use of the cave along with external influences can have a diverse range of impacts (Figure 3). Human use can affect ventilation through modification of cave entrances. Under certain conditions, high rates of air exchange lead to detrimental changes within the cave. Excessive evaporation and desiccation of the cave, as well as changes of temperature in the cave compromise the glowworms' habitat (de Freitas, 2010). On the other hand, ventilation of the cave prevents the build-up of carbon dioxide (CO_2). Elevated CO_2 levels in cave air from visitor respiration combines with moisture in the cave to form carbonic acid that corrodes calcite features of the cave. Cave management aims to mitigate the potential conflict that exists between the dual requirements of presenting the cave and protecting it. The Glowworm Cave is operated under licence issued by the New Zealand Government's Department of Conservation. The licence stipulates that the cave microclimate should be carefully monitored and maintained as to avert damage. The first condition is that CO_2 levels should not be allowed to rise above 2,400 ppm. The second is that cave drying should be minimised during upflow. Strong, prolonged upflow can cause evaporation in the cave than would otherwise occur. Glowworms, which are positioned in the cave rock-cave air boundary layer, suffer as they act as a wick in the vapour transfer process.

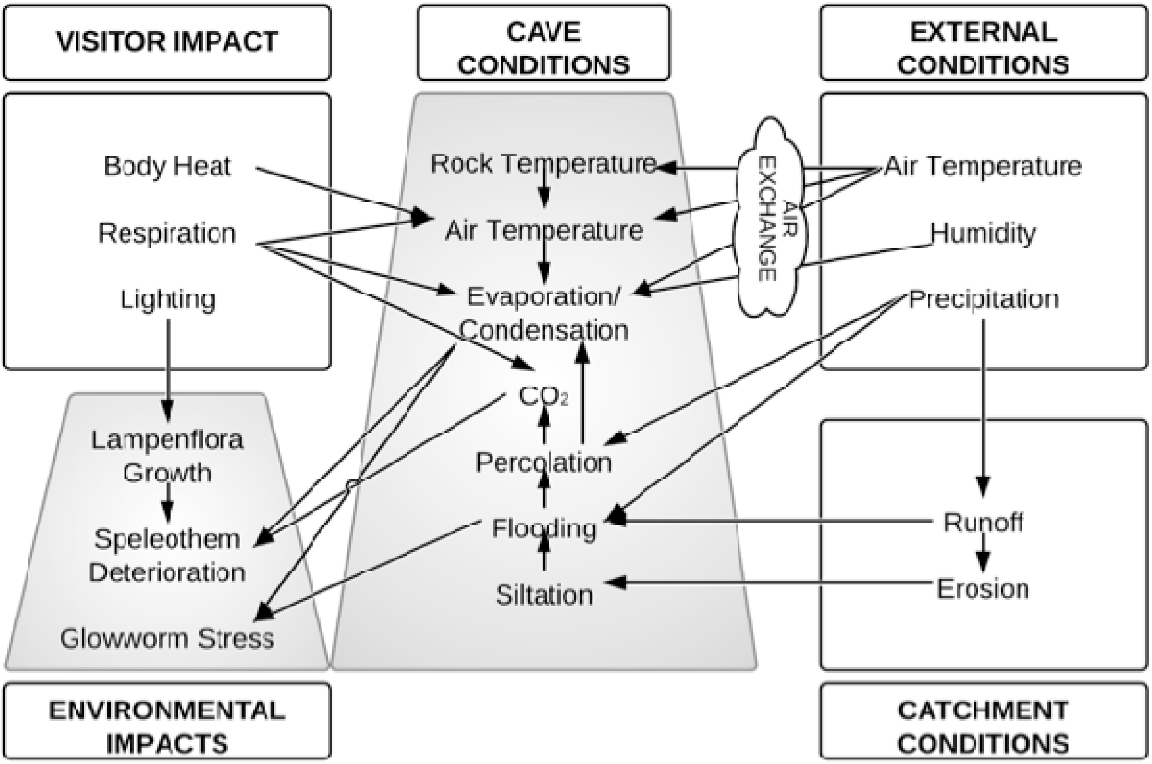

Figure 3: Key factors and processes affecting the Glowworm Cave (after de Freitas, 2010: 482).

The CO_2 concentration in the cave air depends on the size and frequency of tour groups and the length of time they spend in the cave, on the one hand, and the strength of cave ventilation on the other. The strength of cave ventilation is a function of cave-to-outside-air temperature gradient (T_d). In the case of the Glowworm Cave, ventilation is controlled by opening or closing an airtight door at the cave's upper entrance as required. This way cave microclimate can be managed, except at times when T_d is at or near zero. In practice, cave management is based on the fine balancing of tourist numbers and tour frequency with cave ventilation to minimise both evaporation and the rise of CO_2 concentration in the cave air. In light of this, the research here examines the extent to which cave management effectively minimises both cave drying and rising cave air CO_2 concentrations. Hence the aims of this study are, firstly, to assess spatial and temporal differences in ventilation and CO_2 build-up in the cave and rates of evaporation within the cave, and secondly, to evaluate how effectively cave drying and CO_2 are being regulated via active management.

Method

To achieve the stated aims of the research, two sets of data are used. Each is collected via automated monitoring systems and they are, hereafter, referred to as the: 'long-term data' and 'experimental field data'.

The long-term data, which are used for the statistical analysis, is comprised of five years (2008-2012) visitor numbers, microclimate, and CO_2 data. The data is taken from the Automatic Environmental Monitoring System (AEMS) that is permanently installed within the cave. Air temperature and CO_2 measurements are made at 30-minute intervals and stored on Campbell Scientific CR10X data loggers. Measurements of cave air temperature (dry-bulb) are made with a Campbell Scientific 107B fan-ventilated thermistor located in the cave's interior at the Banquet Chamber monitoring site (Figure 4). Another dry-bulb thermistor is located outside the cave nearby the Upper Entrance. Cave air CO_2 concentration is measured using Vaisala GMP222 sensors located at the Cathedral and Organ Loft (Figure 4). Visitor data are comprised of totals of the number of visitors inside the cave at any given time, taken from cave tour-group admission sales logbooks.

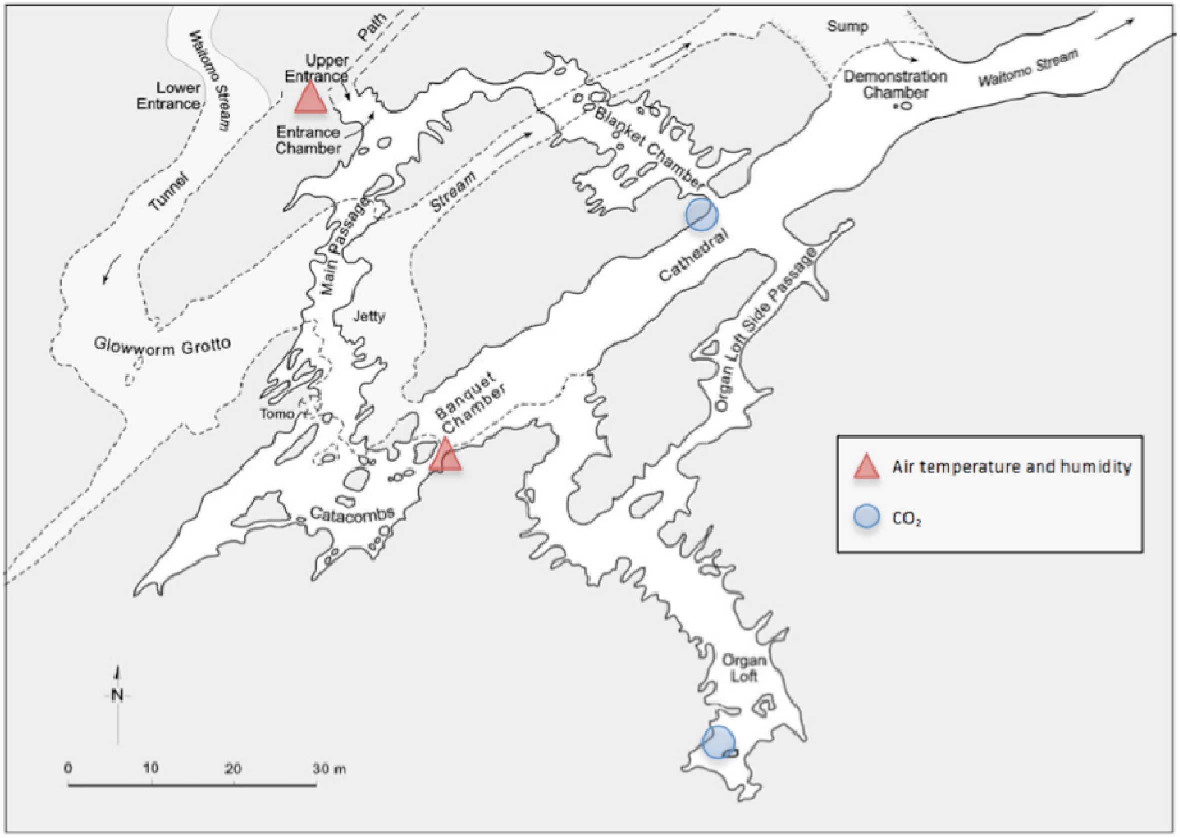

Figure 4: AEMS sensor monitoring sites in the Glowworm Cave from which long-term data is obtained (after de Freitas and Schmekal, 2003: 76)

The experimental field data is collected specifically for this research through detailed monitoring experiments carried out inside the cave over a period of approximately nine months from March 2012 through December 2012. Each experiment is conducted over a period of three days (72 hours). Weekends are selected for data collection to ensure reasonable visitor numbers in order to capture occasions when the cave might be at its most vulnerable.

For each experiment, 10-minute interval measurements of air temperature and relative humidity are made using Kestrel 4500 Weather Tracker Meters at eight sites in the cave. In addition to the CO_2 data collected by the AMES at the Organ Loft and Cathedral sites, Vaisala GMP222 sensors are installed at two other sites to measure air CO_2 concentrations in the lower reaches of the cave, namely the Banquet Chamber and the Jetty sites. Air temperature and humidity are also recorded outside the Upper Entrance. Sensor locations are given in (Figure 5).

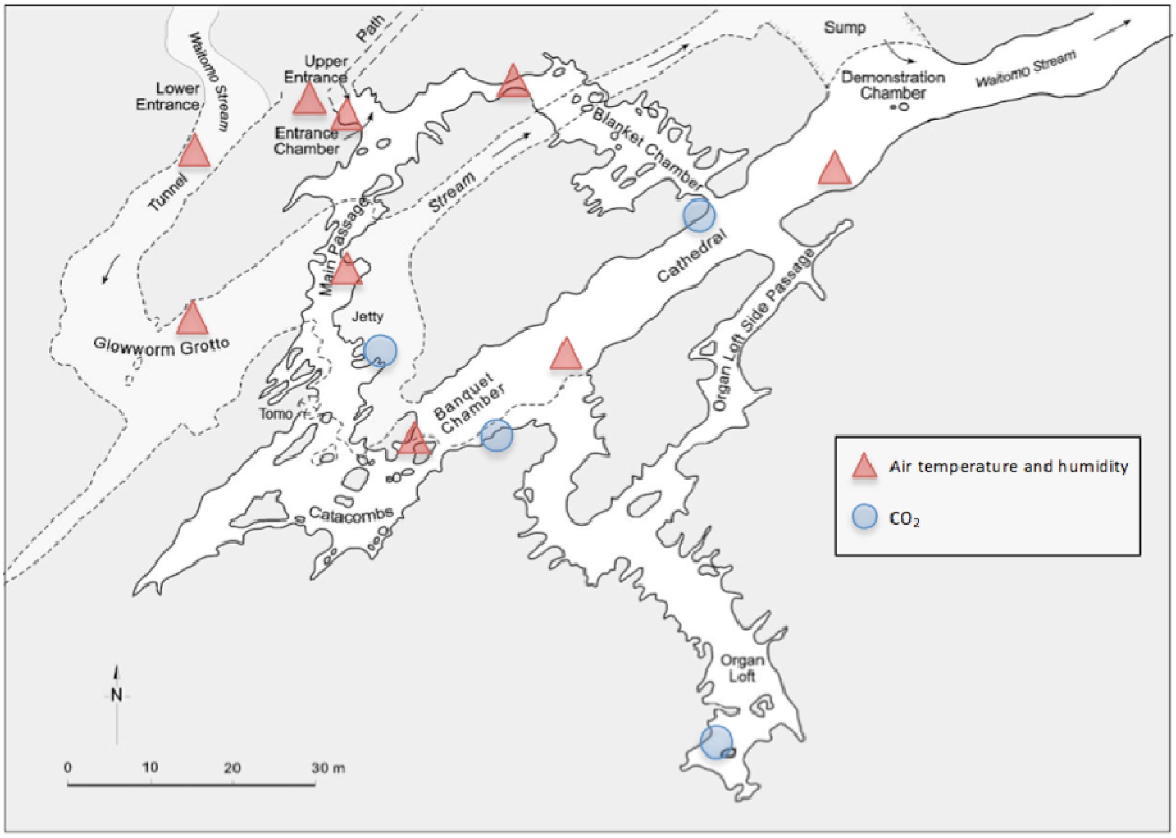

Figure 5: Sensor locations for experiments carried out in the Glowworm Cave (after de Freitas and Schmekal, 2003: 76).

Air samples of cave microclimatic variables, CO_2 concentrations, and airflow are simultaneously recorded so that the potential drying impact of air temperature and the moisture gradient (as influenced from external atmospheric conditions) may be determined. To provide a simulated thermal gradient profile, which is created by external air entering and moving through the cave, measurements are taken from the cave entrances towards the interior of the cave. With all elements of cave management, environmental conditions, and other miscellaneous circumstances known and accounted for, these experimental field data serve to explain and validate statistical findings of the long term data archive through the use of detailed time series data and cave profile plots.

T_d is a variable used as an indicator for airflow rate and direction. A simple equation for this, as used by de Freitas et al. (1982), is given as:

$$T_d = T_o - T_c \qquad [°C] \qquad (1)$$

where T_o is air temperature outside the cave and T_c is air temperature in the cave interior, for which the Banquet Chamber is used as an indicator site. Based on (1), occurrences of downflow return positive T_d values and upflow as negative T_d values, using criteria established by de Freitas et al. (1982).

Air moisture content can be determined through specific humidity (q) of cave air. This is a function of vapour pressure (e) and may be defined as the mass of water per unit mass of moist air, or the relative density of water vapour in the air. As given by Grace (1983), q is expressed as:

$$q = (\varepsilon\ e) \ / \ (P - e(1 - \varepsilon))/1000 \qquad [g\ kg^{-1}] \qquad (2)$$

where P is the atmospheric pressure and ε is the ratio of the molecular mass of water to the apparent molecular mass of dry air (= 0.6189 kg). q is used to gauge the level of cave air dryness in this study.

Day-to-day change in peak CO_2 levels is not only a function of visitor numbers (V_n) and ventilation (T_d). It would also depend on the CO_2 level at the start of the visitor day, which may be elevated due to poor flushing during the previous night. Overnight recovery of CO_2 is dependent on T_d being sufficiently large to flush the cave (de Freitas and Banbury, 1999).

To account for this, CO_2 concentration at the start of the visitor day ($CO_{2(0900)}$) is included as an independent variable in the regressions.

With the above in mind, both archived long-term and detailed experimental field data are used. The archived dataset is examined via a combination of stepwise regression and correlation analysis to determine the extent to which peak daily cave air CO_2 levels can be attributed to T_d, V_n, and $CO_{2(0900)}$. Calculations are carried out using Microsoft Excel 2011 and IBM SPSS Statistics 19. Case studies are undertaken using short-term data over the visitor day to reveal detailed real-time relationships to assess aspects of ventilation and ventilation control of the cave in more detail.

Results

The statistical procedure of multiple linear regression analysis allows prediction of values of a dependent variable from several other related independent variables. In this analysis, multiple linear stepwise regression models are used. Each independent variable is entered in sequence and its value assessed. If adding the variable contributes significantly to an increased explained variance (R^2), it is retained. All other variables in the model are then re-tested as another is added to ensure each is still contributing to the success of the model. Removal of variables that no longer significantly contribute is based on the F-level.

Independent predictor variables that showed good correlation and will be used are: mean visitor numbers inside the cave throughout the visitor day (V_n), CO_2 level recorded at the start of the visitor day (0900 hours) ($CO_{2(0900)}$), maximum upflow T_d (negative values) for the visitor day ($T_{dmax\uparrow}$), and maximum downflow T_d (positive values) for the visitor day ($T_{dmax\downarrow}$). To ensure that only data from times of normal operating conditions were used, flood days and days of cave closure were removed from the analysis.

Table 1 summarises the descriptive statistics and analysis results. F-level to enter is 0.05 and F-level to remove is 0.10. The Pearson's correlation coefficients (R) show that all independent variables are positively and significantly correlated with CO_{2max} under upflow conditions (combined R = 0.87). For downflow conditions, V_n and $CO_{2(0900)}$ are positively and significantly correlated (combined $R = 0.69$) while no correlation exists with $T_{dmax\downarrow}$ ($R = 0.04$). Under upflow conditions at the Cathedral, and with all three predictors included, linear stepwise regression modelling produced a strong significant positive relationship, where $R^2 = 0.75$, F (3, 1,236) = 1,245.4, and $p < 0.001$. Similarly, except under downflow conditions, the model produced a moderate significant positive relationship, where $R^2 = 0.47$, F (3, 1,135) = 228.7, and $p < 0.001$.

Overall, the values for Pearson's correlation coefficient (R) and the coefficient of determination (R^2) show that visitor numbers are the main determinant of daily peak CO_2 levels during both downflow and upflow conditions, accounting for up to 52% of the variation in CO_2. The regression model for downflow conditions displays a much weaker relationship between variables than that for upflow conditions. The T_{dmax} independent variables do not significantly contribute to either model, accounting for only 3 per cent and 9 per cent of CO_{2max} variability during upflow and downflow conditions respectively. This is likely due to a large range of CO_{2max} levels at T_{dmax} values for visitor days.

These results suggest that, firstly, there is a causal relationship between daily peak CO_2 values and the number of visitors in the cave, and secondly, that the driving force of ventilation may be nullified by cave-door management. Management of the cave is, therefore, successful in terms of airflow regulation based on the fact that it has overcome the effects of ventilation.

Cathedral CO_{2max} for upflow conditions						
Correlation coefficients (*R*) for variables						
	V_n	$CO_{2(0900)}$	$T_{dmax\uparrow}$	CO_{2max}		
V_n	1.000	0.304	0.345	**0.719**		
$CO_{2(0900)}$		1.000	0.571	**0.649**		
$T_{dmax\uparrow}$			1.000	**0.610**		
CO_{2max}				1.000		
Model Step	Variable entered	*R*	*R²*	*R²* Change	Std. Error of the Estimate	p-value
1	V_n	0.719	**0.516**	0.516	197.9	<0.001
2	$CO_{2(0900)}$	0.849	**0.204**	0.204	150.6	<0.001
3	$T_{dmax\uparrow}$	0.867	**0.031**	0.031	142.0	<0.001

Cathedral CO_{2max} for downflow conditions						
Correlation coefficients (R) for variables						
	V_n	$CO_{2(0900)}$	$T_{dmax\downarrow}$	CO_{2max}		
V_n	1.000	0.241	0.422	**0.523**		
$CO_{2(0900)}$		1.000	0.317	**0.450**		
$T_{dmax\downarrow}$			1.000	**0.035**		
CO_{2max}				1.000		
Model Step	Variable entered	*R*	*R²*	*R²* Change	Std. Error of the Estimate	p-value
1	V_n	0.523	**0.274**	0.274	214.4	<0.001
2	$CO_{2(0900)}$	0.621	**0.385**	0.111	197.4	<0.001
3	$T_{dmax\downarrow}$	0.687	**0.473**	0.088	183.0	<0.001

Table 1: Summary statistics, correlations, and results from stepwise regression analysis for CO_{2max} at the Cathedral site. R is Pearson's correlation coefficient and R^2 is the coefficient of determination. F-level to enter is 0.05 and F-level to remove is 0.10.

In light of the above multiple stepwise regression results, a 'working' model can now be applied to forecast CO_{2max} using a raw score model to compute predicted concentrations at the Cathedral for $T_{dmax\uparrow}$ ($CO_{2max\uparrow}$) and $T_{dmax\downarrow}$ ($CO_{2max\downarrow}$). A predictive tool such as this could be useful to cave operators so that high levels of CO_2 can be anticipated and prevented. Linear models are developed and calibrated using data from 2008 to 2011 and are validated using data from 2012. Unstandardized coefficients from all three predictors are included in the models given as,

Cathedral $CO_{2max\uparrow} = (V_n \times 5.564) + (CO_{2(0900)} \times 0.614) + (T_{dmax\uparrow} \times 18.091) + 550.0444$

and

Cathedral $CO_{2max\downarrow} = (V_n \times 4.877) + (CO_{2(0900)} \times 0.645) + (T_{dmax\downarrow} \times -25.989) + 607.603$

The computed CO_{2max} values help to predict conditions which may lead to CO_2 exceedances. It is also important to consider that, although the values estimated by the models are expected to be better than if CO_{2max} values were predicted by being simply assigned to the mean for the dataset, some values will be predicted more accurately than others. However, while the Cathedral $CO_{2max\uparrow}$ and $CO_{2max\downarrow}$ models, for example, account for 75 per cent and 47 per cent of the variance respectively, predicted CO_{2max} levels for each accordingly have an average error of 25 per cent and 53 per cent – not trivial amounts given the scale of CO_{2max}. In addition to the reliance of a given value on the fit of the model, each specific CO_{2max} estimate also depends upon the varying predictive power of individual variables involved. Therefore, when compared to observed values (Figure 6 and Figure 8), the calibration periods appear to successfully predict seasonal trends (most pronounced for $T_{dmax\uparrow}$, given in Figure 6) and middle range CO_{2max} values with reasonable accuracy, but become less accurate at extreme high-end and low-end concentrations. The daily maximums for the validation period (2012) are almost always under-predicted, although the typical seasonal trend that is evident in the observed data is maintained by the model. The variation between observed and predicted CO_{2max} for calibration and validation is given in Figure 7 and Figure 9. Improvements to the fit of each model are seen for the 2012 validation periods, where R^2 increases by 3 per cent for $T_{dmax\uparrow}$ and by 4 per cent for $T_{dmax\downarrow}$. This is likely to be due to the reduced variation of CO_2 maximums, as well as absence of very high values that the model is prone to under-predicting.

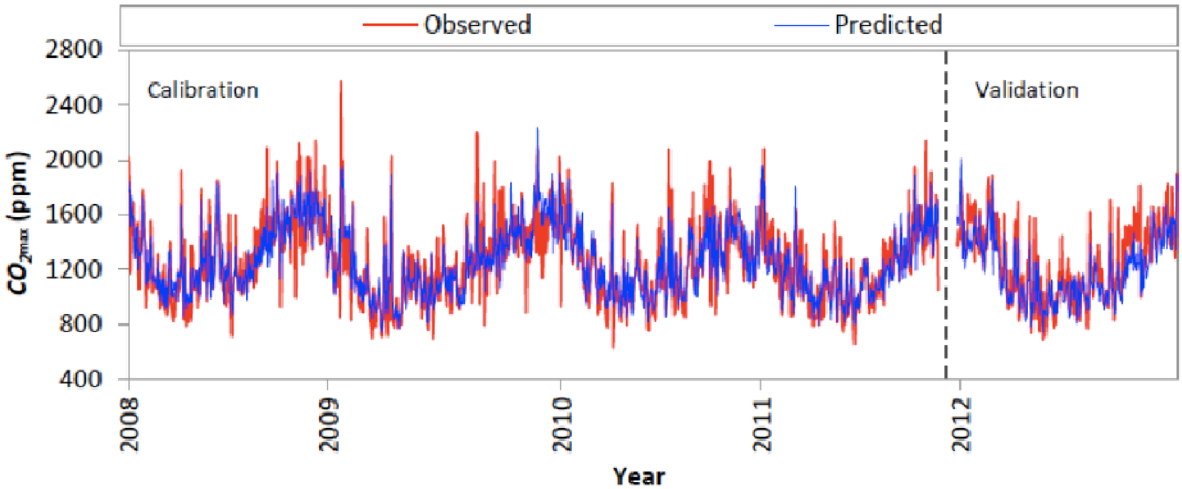

Figure 6: Observed CO_{2max} and predicted (modelled) CO_{2max} for $T_{dmax\uparrow}$ at the Cathedral based on computed estimates obtained using a raw score model. Calibration period is 2008-2011 and validation period is 2012.

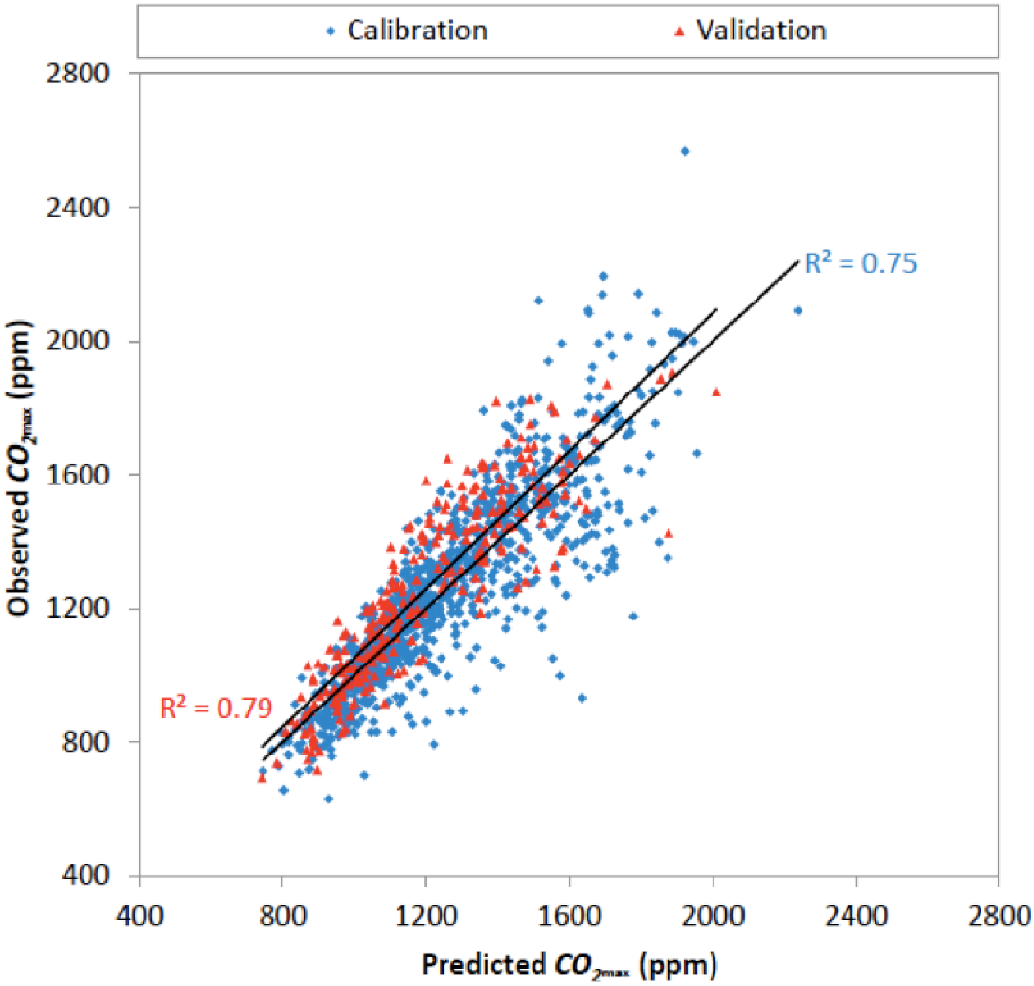

Figure 7: Observed CO_{2max} and predicted (modelled) CO_{2max} for $T_{dmax\uparrow}$ ($CO_{2max\uparrow}$) at the Cathedral for the calibration (2008-2011) and validation (2012) datasets. Regression equation is: $CO_{2max\uparrow} = (V_n \times 5.564) + (CO_{2(0900)} \times 0.614) + (T_{dmax\uparrow} \times 18.091) + 550.0444$

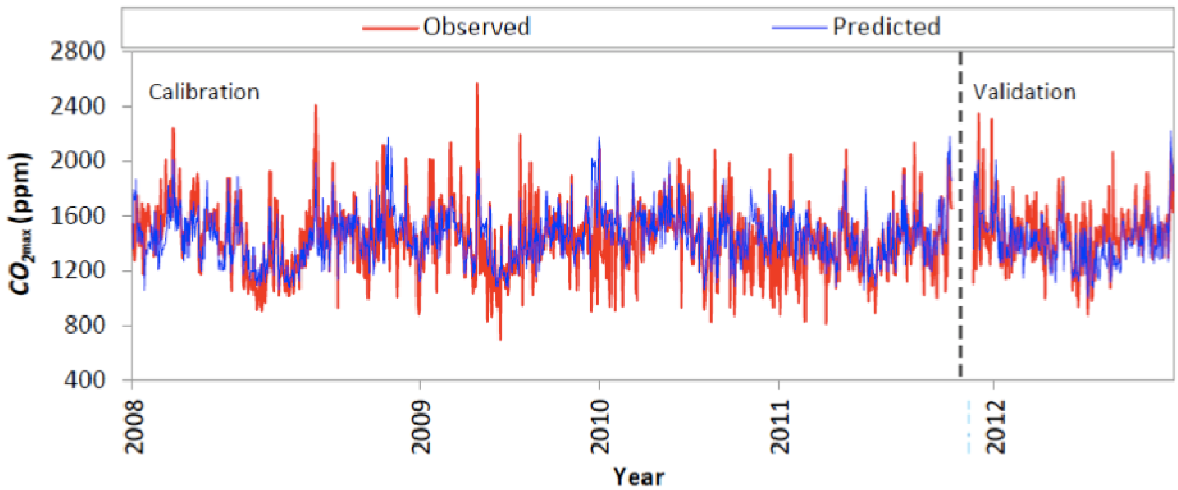

Figure 8: Observed CO_{2max} and predicted (modelled) CO_{2max} for $T_{dmax\downarrow}$ at the Cathedral based on computed estimates obtained using a raw score model. Calibration period is 2008-2011 and validation period is 2012.

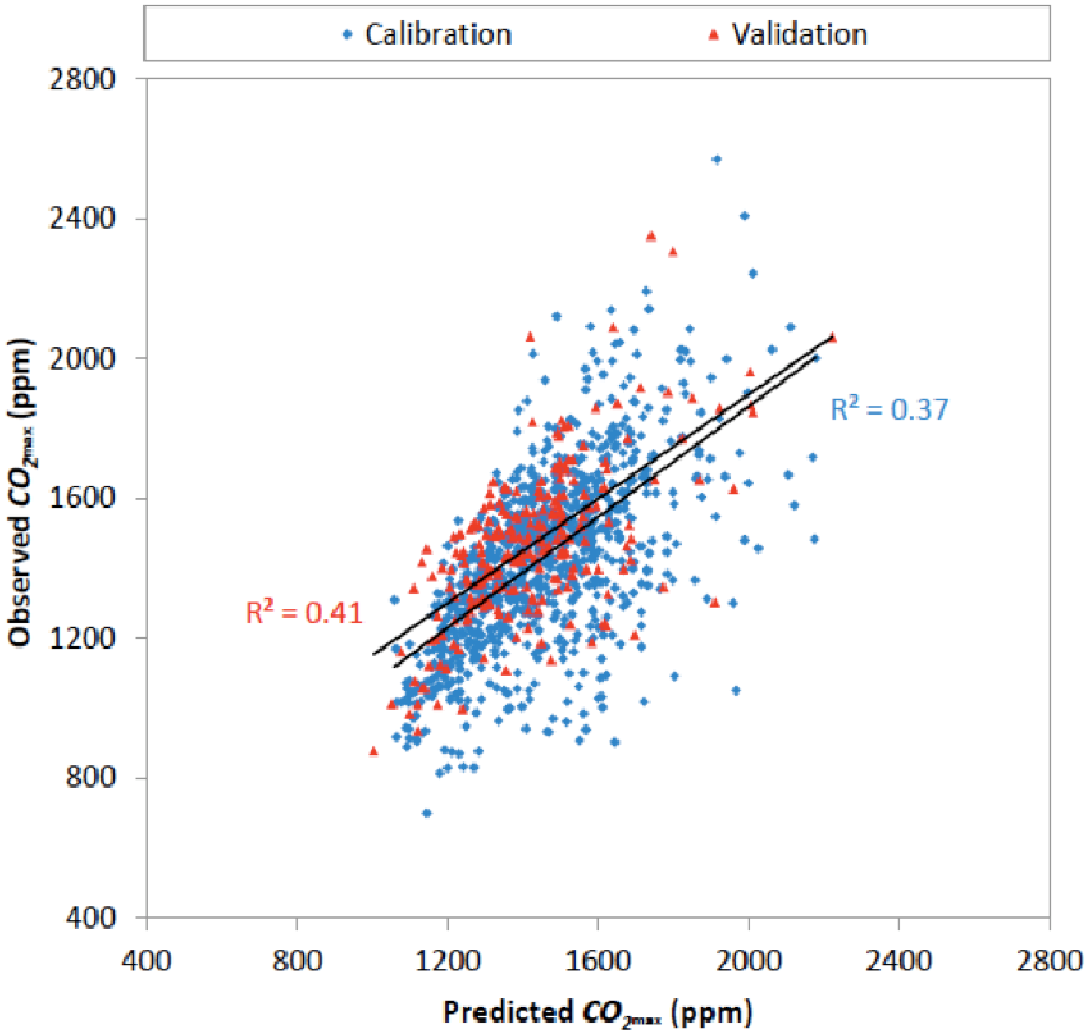

Figure 9: Observed CO_{2max} and predicted (modelled) CO_{2max} for $T_{dmax\downarrow}$ ($CO_{2max\downarrow}$) at the Cathedral for the calibration (2008-2011) and validation (2012) datasets. Regression equation is:

$$CO_{2max\downarrow} = (V_n \times 4.877) + (CO_{2(0900)} \times 0.645) + (T_{dmax\downarrow} \times -25.989) + 607.603$$

To further explore the nature of the relationship during down-flow conditions, a case study was conducted using half-hourly data from 0900 to 1800 h on January 2, 2010. This was a relatively warm summer's day during the peak of the cave's tourist season. Data for CO_2 in the Organ Loft are included to assess ventilation. Visitors to the cave are not routinely taken to the Organ Loft as CO_2 builds up rapidly in this cul-de-sac passage. The results in Figure 10 show that, despite the absence of visitors to the Organ Loft the build-up of CO_2 is greatest. This is because the Cathedral is better ventilated as it lies in the main airflow route through the cave. Consequently, CO_2 concentrations are generally lower in the Cathedral, with peak values almost one third lower. The results in Figure 10 also show the lag between the Organ Loft and Cathedral for peak CO_2 values, a phenomenon first discovered by de Freitas and Banbury (1999).

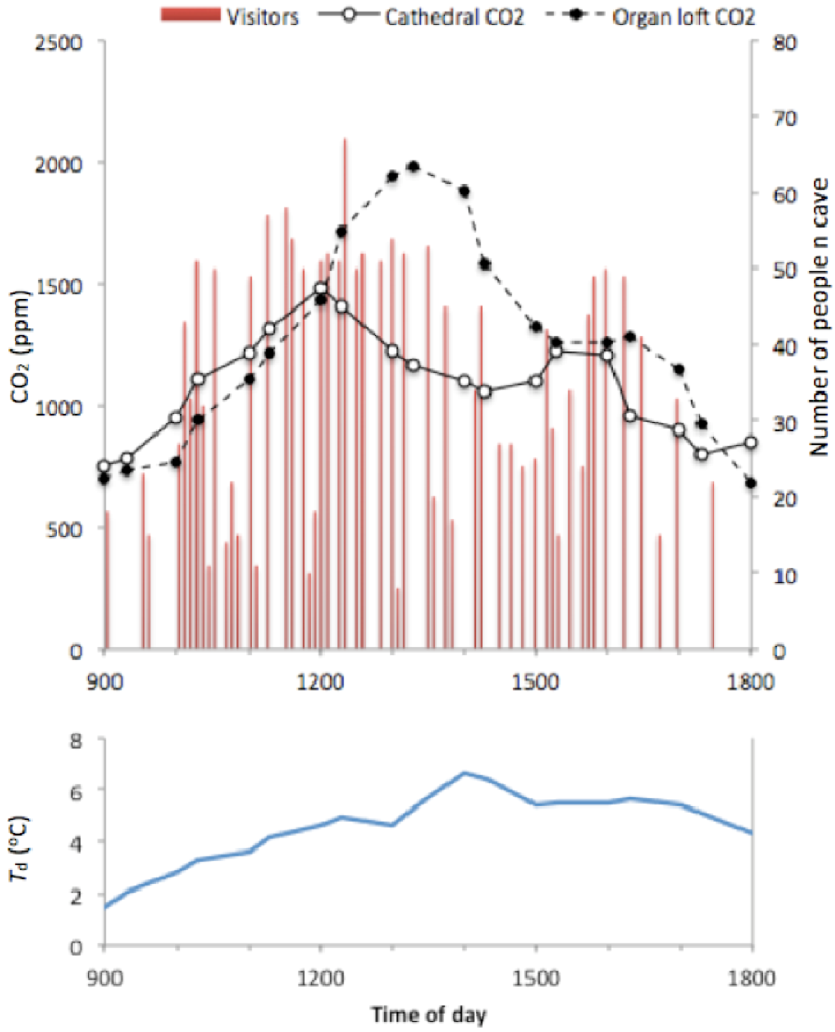

Figure 10: Effect of tour groups on CO_2 levels in the Cathedral and Organ Loft during one visitor day on January 2nd 2010. Each vertical line represents a visitor tour. CO_2 data are half-hourly. Concentrations of CO_2 ranged from an initial 700pmm at both sites to 1,500 ppm later in the day in the Cathedral and 2,000 ppm in the Organ Loft.

The below results are based on the 'experimental field data' collected from experiments conducted over 72 hours in the Glowworm Cave in 2012. These data are used to demonstrate the impact of visitor use and cave management on CO_2 levels. Data is explored through detailed time series and cave profile plots. For the experiment conducted over the period 20 to 22 October 2012, a series of circumstances came together to make the cave vulnerable to high CO_2 levels. This experiment extends Labour Day weekend. This is an annual national public holiday during which many people make short trips to tourist destinations such as Waitomo. Hence many larger than usual half-hourly tour groups of 40 or more people visited the cave during the peak periods of the first two recording days (Saturday and Sunday). The maximum number of people inside the cave on Day 1 was 188 at 1230 hours, and this increased to 204 people at 1530 hours on Day 2 (Figure 11a). On Day 3 the cave was closed to visitors. For the duration of the experiment T_d was near zero, so ventilation was minimal even with the door open. To compound the situation, 67 mm of rain fell over 24 hours (Figure 11d), which by mid afternoon on the second day saw the cave at near 'pipe-full' conditions at the lower entrance. In addition, runoff water flowing into the stream is likely to have picked up organic matter that would have been washed into the cave, releasing additional CO_2 into the cave environment.

The relatively large number of visitors on the first two days is a key factor in the ensuing events leading to an exceedance of the cave air CO_2 2,400 ppm limit (Figure 11a). On Day 1, before any rainfall, conditions in the cave were generally as per usual. Many people passed through the cave, which saw CO_2 rise until the cave door was left open for two hours (Figure 11b). A reasonable rate of upflow, with a mean T_d of around -4.0 ºC, allowed the cave to recover from raised CO_2 levels (Figure 11c). For the remainder of the experiment ventilation rates are small throughout entire diurnal cycles and hence the effectiveness of cave door management as a tool for reducing high CO_2 concentrations was significantly reduced.

By 1230 hours on Day 2 the water was declared too high for boat tours to operate, and visitors were made to retrace their steps at the conclusion of tours to exit through the Upper Entrance. At this point, and with the stream water level continuing to rise (resulting in a reduced area for air exchange to occur at the Lower Entrance), cave air CO_2 responded by rapidly increasing. Unlike for Day 1, the action of opening the cave door at 1100 hours had no real mitigating effect. The continuing rise in cave air CO_2 levels ceased quite promptly once the final large tour group of 33 people exited the cave at 1700 hours. This demonstrates that although cave air CO_2 could not be reduced through opening the cave door, the alternative management tool of restricting the tour groups is an effective one. During the evening of Day 2 cave air CO_2 lowered at all sites to be maintained at about 1,900 ppm. Overnight, T_d is minimal and the stream at the Lower Entrance is at near 'pipe-full' flow so only minor CO_2 recovery occurred.

According to the real-time CO_2 measurements available to supervisors over this period, the cave was managed effectively because cave air CO_2 levels at the Organ Loft and Cathedral indicator sites (both located at the upper-level) peaked under the 2,400 ppm limit. However, measurements recorded at the Jetty and Banquet Chamber lower-level sites (not taken into account by management) tell a different story, showing much higher peak CO_2 levels and both exceeding the 2,400 ppm limit. This would suggest the cave was not managed effectively.

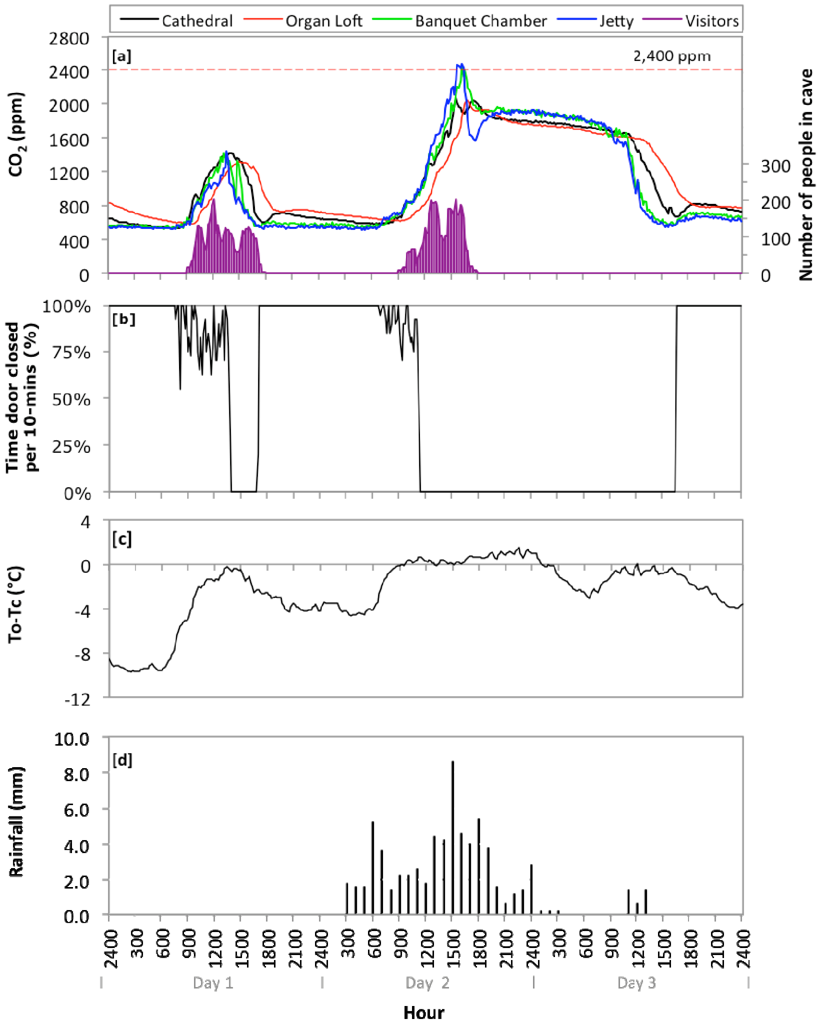

Figure 11: 10-minute experimental field data for days 20-22 October 2012. Panel [a] is cave air CO_2 alongside total visitors inside the cave, [b] is percentage time the door is closed per 10-minutes, [c] is the cave-to-outside-air temperature gradient, and [d] is rainfall.

Using the experimental field data, this study examines the processes involved in longitudinal spatial distribution of T_d, q, and relative humidity (*rh)* within the cave under upflow and downflow conditions. The key concepts from observations can be briefly summarised into four main points to give context for these results: 1) movement of external air into the cave has a modifying effect on cave air temperature (T_c) and *rh* through advection of heat and moisture from outside the cave; 2) the air moving through the cave is also modified by exchange of heat and moisture with the cave surfaces; 3) while air entering cave entrances has the thermal and moisture properties of outside atmosphere, it quickly adopts to the characteristics of the cave atmosphere; and 4) through advection, this air is modified as it moves deeper into the cave towards a heat and moisture equilibrium with the cave environment.

During upflow conditions, air temperatures increase and the amplitude of air temperature variation tends to decrease with distance into the cave from the Lower Entrance. Spatial trends for q inside the cave also mimic those of air temperature, whereby q increases (increasing moisture holding capacity of cave air) and amplitude of variation decreases with distance from the cave entrance. An exception occurs at the Entrance Chamber site where T_c and q levels are lower than those at the Main Passage, which is positioned deeper into the cave. This is likely due to its close proximity to the Upper Entrance where the cave door allows cooler outside air into the cave. Even small amounts of cool air infiltration can generate a near-entrance cold zone. This offsets the heating effect of the warmer cave air and passage surfaces.

A schematic of the thermal regime for an upflow profile is given in Figure 12. The spatial distribution of q, T_d, and rh during strong upflow conditions for the Glowworm Cave is presented in the form of a graphical cave profile plot given in Figure 13. The profile can be explained with reference to physical processes of heat and moisture transfer. The results show air moving up through the cave from the Lower Entrance, taking actual values for all sites measured at 0730 hours on 27 July 2012. This is when the minimum T_d value from within the experimental data (or strongest upflow) was recorded. In theory, this is the point at which the cave is most vulnerable to evaporative cooling and drying.

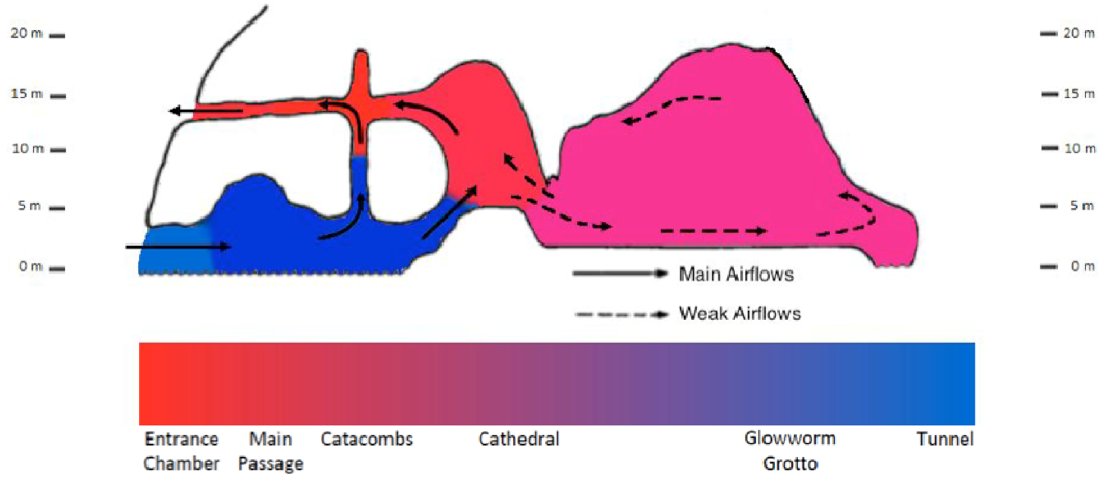

Figure 12: Schematic of cave airflow regime: upflow profile. Colours used are relative to other cave sections rather than indicative of actual temperatures (after de Freitas et al., 1982).

Measurements of T_d, q, and rh are given in Figure 13, which illustrates the spatial distribution for very strong upflow in the morning, when T_d is within the range of -11.0 ºC to -14.0 ºC, external rh is high at 85 per cent, and q of outside air (q_o) at 3.6 g kg^{-1} is lower than q of cave air (q_c) at 9.5 g kg^{-1} (mean of all cave sites).

Due to low outside air temperatures, the increase in cave air temperature upon reaching the Main Passage is as large as 14 ºC (Figure 13). There is, however, a small decrease in T_c and q between the Main Passage and Entrance Chamber. This is caused by infiltration of cooler outside air near the Upper Entrance, forming a cold zone that mixes with the warmer, moister cave air. Saturation of cave air is the result and condensation will occur on the cool surfaces within the Entrance Chamber.

The spatial distribution of air temperature within the cave is shown in Figure 13. The tendency is for T_c to increase, and thus T_d to decrease with distance from the Lower Entrance moving towards upper-level through deep-cave sites. The spatial distribution of q and rh in the cave profile increases with distance from the Lower Entrance. This begins when the dryer outside air is advected through the Lower Entrance and into the cave. For example, in Figure 13, the cool outside air entering the cave through the Lower Entrance, on reaching the tunnel site less than 10 m away, has achieved an increase of 4.6 g kg^{-1} q and very quickly warmed to 11.5 ºC. The change in q once air is expelled from the cave at the Upper Entrance is 6.5 g kg^{-1}.

At the same time and somewhat counter-intuitively, as incoming outside air is warmed, its evaporating potential is increased causing drying in the cave. This effect is most pronounced in the Lower Entrance zone (Figure 13). The large thermal gradient leads to energy transfer from the relatively warm and moist cave air and surfaces into the cooler outside air moving through the cave. The capacity of the air parcel to hold moisture increases as air temperature rises, while moving upwards through or deeper into the cave with increasing distance from the Lower Entrance. The constant heat and moisture exchange remains the case even when relative humidity is at, or close to, 100 per cent because the increasing temperature allows the vapour flux to continue. Thus it is possible that evaporation is occurring throughout the cave if a sufficient moisture supply is available. For example, in Figure 13 a 3 ºC rise in T_c between the Tunnel and Main Passage sites increases the moisture holding capacity of the air by 1.9 g kg^{-1}.

It is reasonable to assume that there is sufficient moisture available at the stream-level Glowworm

Grotto and Tunnel sites so that the air here maintains saturation. Between the Glowworm Grotto and Main Passage, which are dryer sections of the cave, there is evidence of evaporation; thus drying occurs since the vapour flux (moisture supply) is not sufficient to meet the evaporative demand. Because of this, the variability of *q* and *rh* between sites moving upwards is determined by the vapour content of outside air, net moisture advection, the vapour flux between the air and cave surfaces, and the distribution of moisture within the cave. In addition, the spatial distribution of T_d in the cave is determined by external air temperature and *q*, the advection of heat from outside the cave, as well as sensible and latent heat flux between cave air and cave surfaces.

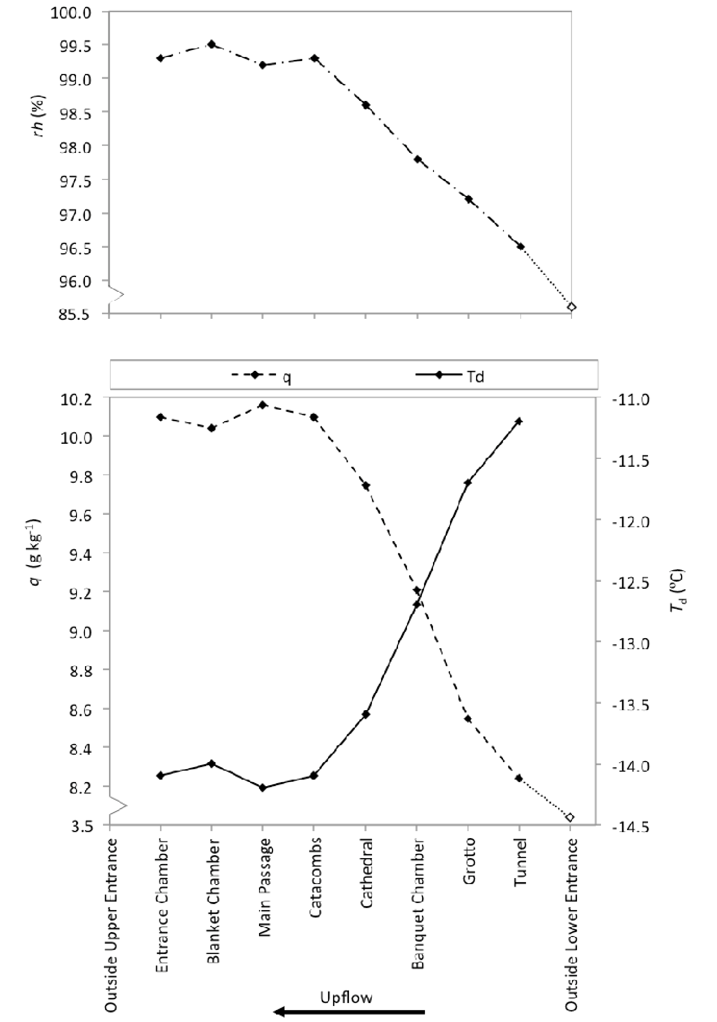

Figure 13: Cave q and T_d profiles for upflow conditions, 0730 hours, 27 July 2012. Values for q are also given for air outside the Lower Entrance (dotted connector line).

Under downflow conditions, the amplitude of temperature variation tends to lessen with distance into the cave from the entrances, while temperatures decrease as warm air entering the cave cools. Spatial trends for q_c are directly related to those of T_c, where q_c increases and the amplitude of variation decreases with distance from the cave entrances. The variation of T_c between all other sites, moving deeper into the cave, is significantly smaller and generally less than 1.0 ºC.

A schematic of the thermal regime for the following downflow cave profiles is given in Figure 14. The spatial distribution of *q*, T_d, and *rh* under downflow conditions in the cave is presented in the cave profile plot given in Figure 15. The profile used in the analysis show external air entering the cave via the Upper Entrance and moving downwards and out the Lower Entrance. The case taken occurs at 1500 hours on 14 December 2012. It typifies the distribution for when downflow T_d is greatest.

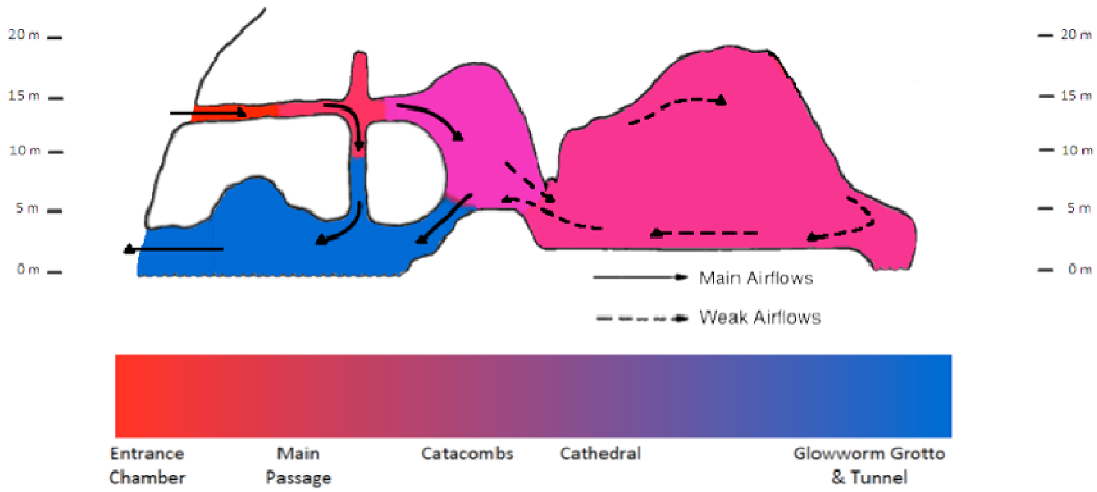

Figure 14: Schematic of cave airflow regime: downflow profile. Colours used are relative to other cave sections rather than indicative of actual temperatures (after de Freitas et al., 1982).

Illustrated in Figure 15 is the spatial distribution for strong downflow, where T_d is within the range of 3.0 ºC to 6.0 ºC, external *rh* relatively high at 80 per cent, and q_o (14.0 g kg^{-1}) is higher than mean q_c (10.9 g kg^{-1}). As the outside air temperature is relatively high in the given profile, the reduction in air temperature between the Upper Entrance and the Banquet Chamber is large. This is as much as 8.2 ºC in Figure 15, where outside air temperature at the Upper Entrance is 23 ºC. A rise in T_c and q is then observed between the Banquet Chamber and Tunnel sites. Air temperature recorded at the Tunnel site (located near the Lower Entrance) is higher than might be expected. This is likely due to increased temperature of water flowing into the cave via the Waitomo Stream, which is typically the case during summer months wherein the warmer stream water emits heat into cave air to adjust the stream-level microclimate.

The spatial distribution pattern shown in Figure 15 is such that T_c decreases, and thus T_d increases, with distance from the Upper Entrance. There is a decrease in q and increase in *rh* for both profiles with distance from the Upper Entrance. The process observed is warm, moist outside air moving through the Upper Entrance and into the cave, cooling, and losing its moisture holding capacity. The change in q once air reaches the Lower Entrance is 3.1 g kg^{-1}, while the air temperature has lowered by 4.7 ºC. Compared to the relatively large initial change in q (5.0 g kg^{-1}) observed in the strong upflow T_d profile (Figure 13), a smaller initial change in q for air entering the cave (3.0 g kg^{-1}) is observed in the downflow profile.

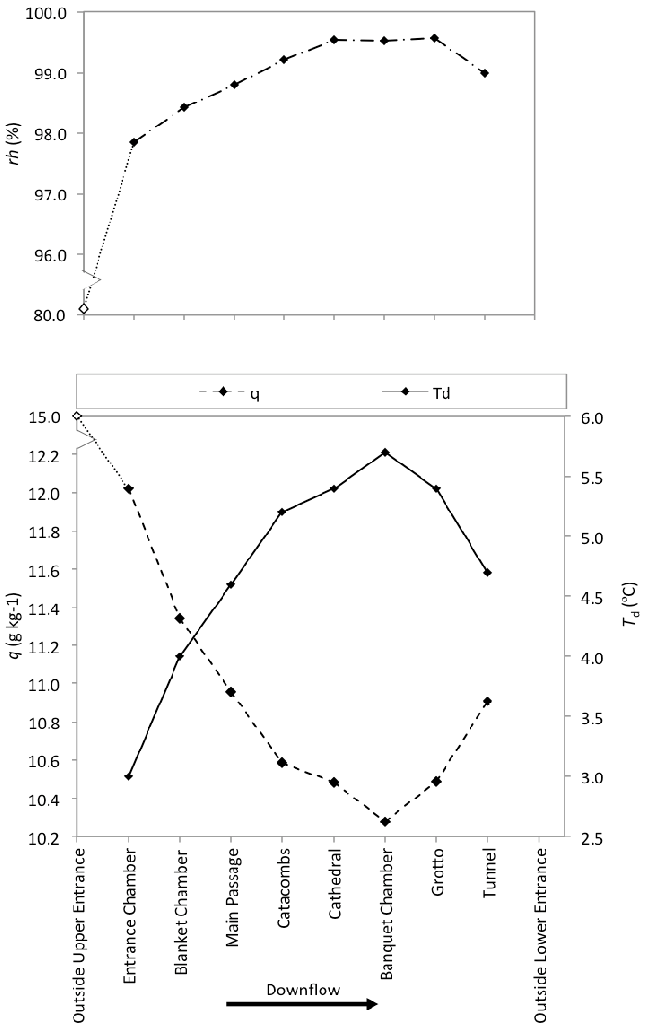

Figure 15: Cave q and T_d profiles for downflow conditions, 1500 hours, 14 December 2012. Values for q are also given for air outside the Upper Entrance (dotted connector line).

Discussion and Conclusion

The results show that daily peak CO_2 levels are largely insensitive to T_d. This suggests that cave management through ventilation control is effective, especially during downflow conditions, but only when T_d is sufficiently high to allow CO_2 drainage. Downflow occurs when the outside air is warmer than the air in the cave. Typically, condensation will occur in the cave along with some warming, but the latter is small because ventilation rates are relatively low (de Freitas and Schmekal, 2003). Upflow occurs when conditions outside are relatively cool or cold and below mean cave air temperature. Cold weather causes cave drying if air exchange with the cave is facilitated. For this reason, cave management guidelines dictate that cave ventilation should be minimised by keeping the upper entrance of the cave sealed when upflow conditions exist, other than when visitors enter the cave. However, if visitor numbers are not reduced or carefully controlled, CO_2 build-up will occur. The results of this research indicate this to be the case in that peak CO_2 is more highly correlated with visitor numbers.

The examination of high-frequency time series data is revealing and the results support the findings of the regression analysis. There can be a considerable difference in daily peak CO_2 levels for the different sections of the cave, with different degrees of spatial remoteness and ventilation efficiency appearing to have a significant effect on CO_2 build-up and diffusion rates.

The main determinant of cave climate is air exchange with the outside atmosphere. Sites within the cave closest to the entrances have the greatest range in temperature and humidity. The amplitude of variation between sites decreases with increasing distance from entrances. Cave profile plots constructed from the experimental field data show that cave air moisture varies longitudinally and is determined by the:

- vapour content of outside air
- amount of moisture moving into or out of the cave via advection
- vapour flux between cave air and surfaces through condensation and evaporation; and
- distribution of moisture throughout the cave

The results show that there is a marked difference between the upper-level sites, which are dryer sections of the cave, and lower-level sites. In the case of the former, there is evidence of relatively high evaporation rates that cause drying because the moisture supply is not sufficient to meet the evaporative demand. Under downflow conditions, the warmer air entering the cave generally has higher moisture content than that of the cave, so moisture availability is not an issue and condensation is more likely to occur.

Key Recommendations

The research presented here paves the way for further long-term monitoring and research projects that investigate the impacts of visitors in sections of the Glowworm Cave outside those covered by the AEMS. By carrying out field experiments of longer durations, seasonal cave air temperature and humidity distribution can be understood more comprehensively. These projects should be designed so that they are able to contribute new information that could be used for management of the cave environment.

Ideally, current management guidelines that treat the cave as a whole should be adjusted to more 'micro-management' based guidelines that regard the Glowworm Cave as a series of caves or caverns within a cave. These caverns may then be managed separately and according to their individual microclimates, degrees of remoteness, ventilation rates, and morphological differences. This requires a set of baseline microclimate conditions and CO_2 concentration thresholds and lag-times to be established for multiple parts of the cave.

To advance understanding of the spatial and temporal differences in CO_2 concentrations in the cave, more CO_2 monitoring stations in the cave are required. Potential monitoring sites could be at the Jetty and Banquet Chamber, where CO_2 levels are shown in this work to reach higher peaks than those observed at the Cathedral and Organ Loft during periods of high visitation, flooding, and small cave-to-outside-air temperature difference. Installation of further wet and dry-bulb temperature probes throughout the cave is also desirable so that spatial variability of air temperature and humidity can be monitored in greater detail. However, the installation of at least one or two additional CO_2 sensors should be given priority. Future studies that investigate the role of organic matter and soils on CO_2 levels in the cave would advance knowledge and understanding of CO_2 sources and rates of accumulation. Given this is a temperate cave system with vast areas of vegetation and soil input above the cave, this would be an ideal environment in which to carry out such a study.

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Constraints for Karst Landscape Evolution on Vancouver Island, British Columbia, Canada: Concepts, Research Plans and Outcomes.

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Abstract

A research project has been initiated to better understand the geologic, geomorphologic and hydrologic processes that have led to the evolution of karst landscapes on Vancouver Island – a mountainous region with a long glacial history and an active tectonic setting. This research aims to explain how bedrock geology, geological structures, recent and past tectonic uplift, glacial and inter-glacial events, sea level change and isostatic rebound may have influenced, constrained and/or promoted karst development in this region. Current research activities will include detailed field work and mapping at a number of carefully selected and representative karst areas on Vancouver Island, collecting information on bedrock geology, geologic structures, surface karst features, glacial materials/cover and hydrology. These surface data will be integrated with known caves that have been previously surveyed and mapped in the selected areas. It is anticipated that this research will lead towards a 'conceptual model' for karst development on Vancouver Island, and that results from this project will increase the overall scientific understanding, awareness and appreciation of karst issues and resource values on Vancouver Island.

Introduction

In the past 10-15 years considerable work has been completed on developing guidelines and standards in British Columbia (BC) for the assessment and management of karst landscape (RISC, 2003; BC Ministry of Forests, 2003). A recent publication titled 'Karst Geomorphology, Hydrology and Management' covers many of the issues and values that relate to karst in BC, and highlights methodologies for assessing and managing karst landscapes with respect to forestry activities (Stokes et al., 2011). A number of small research projects have also been carried out by the authors and other colleagues examining issues related to sinkhole microclimates, karst springs and karst aquifers (Stokes et al., 2007, 2008, 2011a and Stokes, 2012). However, less research has been done at the broader regional-scale to understand when and how karst landscapes on Vancouver Island have formed and developed over geologic time. Research is now underway to better understand the geologic, geomorphologic and hydrologic processes that have led to the evolution of karst landscapes on Vancouver Island. Through this research we aim to better understand how factors such as bedrock geology, geological structures, tectonic uplift, glacial events, sea level change and isostatic rebound may have influenced, constrained and/or promoted karst development in this region. This paper details what is currently known about karst in the region, outlines the planned research methodology and discusses possible outcomes. Some of the questions that this research will investigate are:

- What geological units and associated structures are likely to be important for karst formation on Vancouver Island?
- How have the various glacial and inter-glacial events affected karst landscape evolution?
- What influence have the past and current rates of tectonic uplift on the BC west coast had on karst development?
- Likewise, what roles have the changes in sea level and isostatic rebound played in the development of the karst?
- What are the likely ages of the surface karst features and subsurface caves/cavities?
- What can the nature and shape of known and mapped caves tell us about the rates and stages of tectonic uplift along the west coast of BC?
- What more can karst landscapes tell us about past geomorphological processes and climate history of Vancouver Island?

Regional Setting for Karst Lands on Vancouver Island

Topographically, Vancouver Island is dominated by the Vancouver Island Mountain Ranges that form the northwest-southeast 'backbone' of the island, rising to elevations of 2200 m (Figure 1). The lowlands on the east coast of the island are adjacent to the Salish Sea (formerly the Georgia Strait) – a relatively shallow water body that extends across to the mainland of British Columbia. The more rugged west coast of the island is dominated by fiords, inlets and islands. Vancouver Island has a temperate climate with much of the rainfall (up to 5000 mm/year) falling on the west coast, while the east coast of the island is generally drier in comparison. Most of the island is forested and occurs in the Coastal Western Hemlock biogeoclimatic zone, while the less dominant and drier Douglas Fir biogeoclimatic zone occurs along the southeast coast line.

Figure 1 – Satellite image of Vancouver Island viewing towards the east and mainland British Columbia.

In total approximately 4% of Vancouver Island is underlain by limestone, much of which is karstified and occurs within the three units the Mount Mark, Quatsino and Parson Bay Formations (Figure 2). In the north of the island these limestone units occur as long and continuous belts, while in the south of the island these units are less continuous and smaller in size. A number of provincial parks have been established specifically for caves and karst on Vancouver Island, including Horne Lake Caves Park, Clayoquot Plateau Park, Weymer Creek Park, White Ridge Park, and Artlish Caves Park.

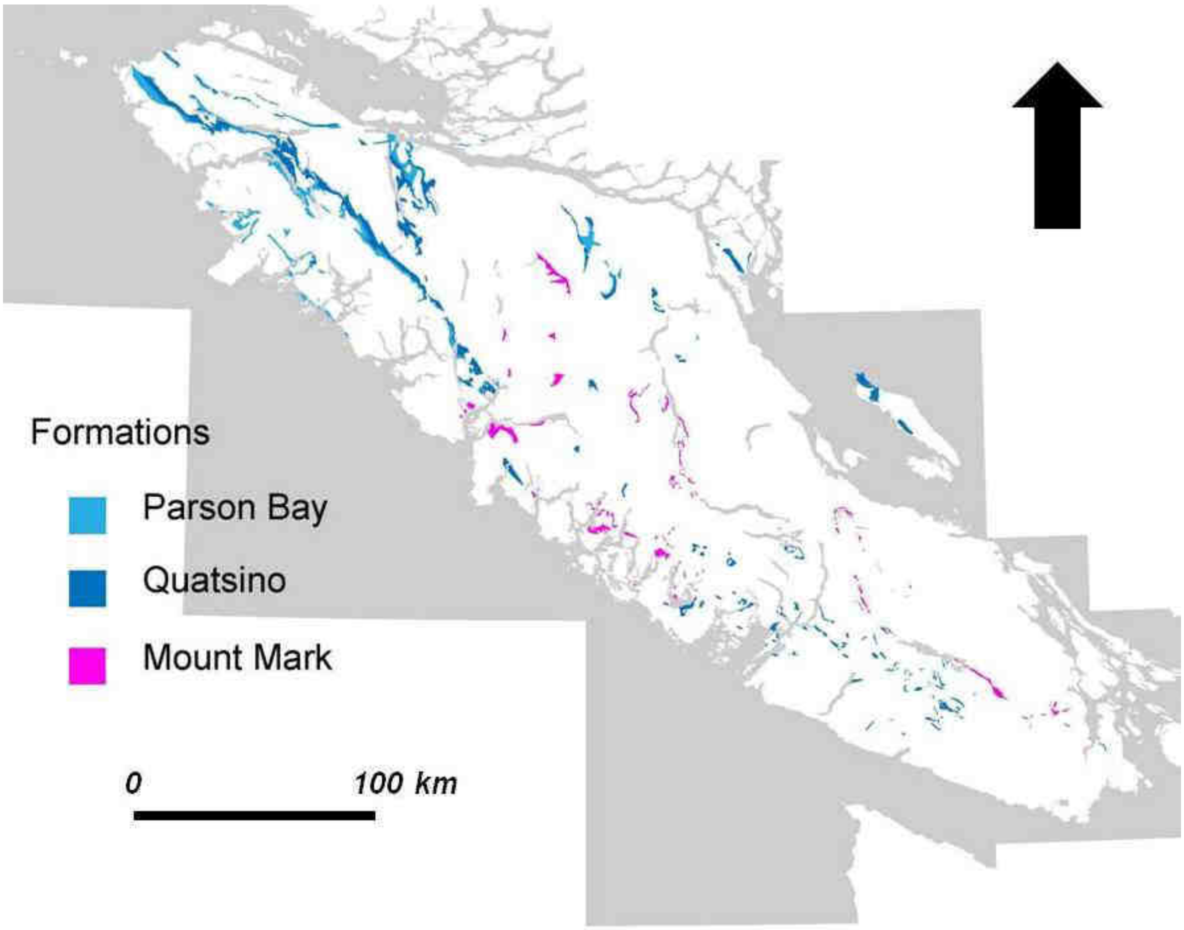

Figure 2 – Distribution of Limestone Formations on Vancouver Island

In comparison to Vancouver Island, carbonate bedrock (limestone and dolomite) underlies approximately 10% of British Columbia, but it is not all karstified. Significant areas of alpine karst occur in the northern and southern Rocky Mountains (Figure 3). Less well-known karst areas occur in northwest British Columbia (e.g., Atlin, Stuart, and Babine Lakes, as well as along the Stikine, Nakina, and Taku Rivers), and in the Interior (such as the Purcell and Pavilion Mountains). Well-developed karst areas also occur on Haida Gwaii (Queen Charlotte Islands), and in smaller areas along the north and mid-Coast, Texada and Quadra Islands, the Sechelt Peninsula, and near Chilliwack (BC Ministry of Forests, 1997).

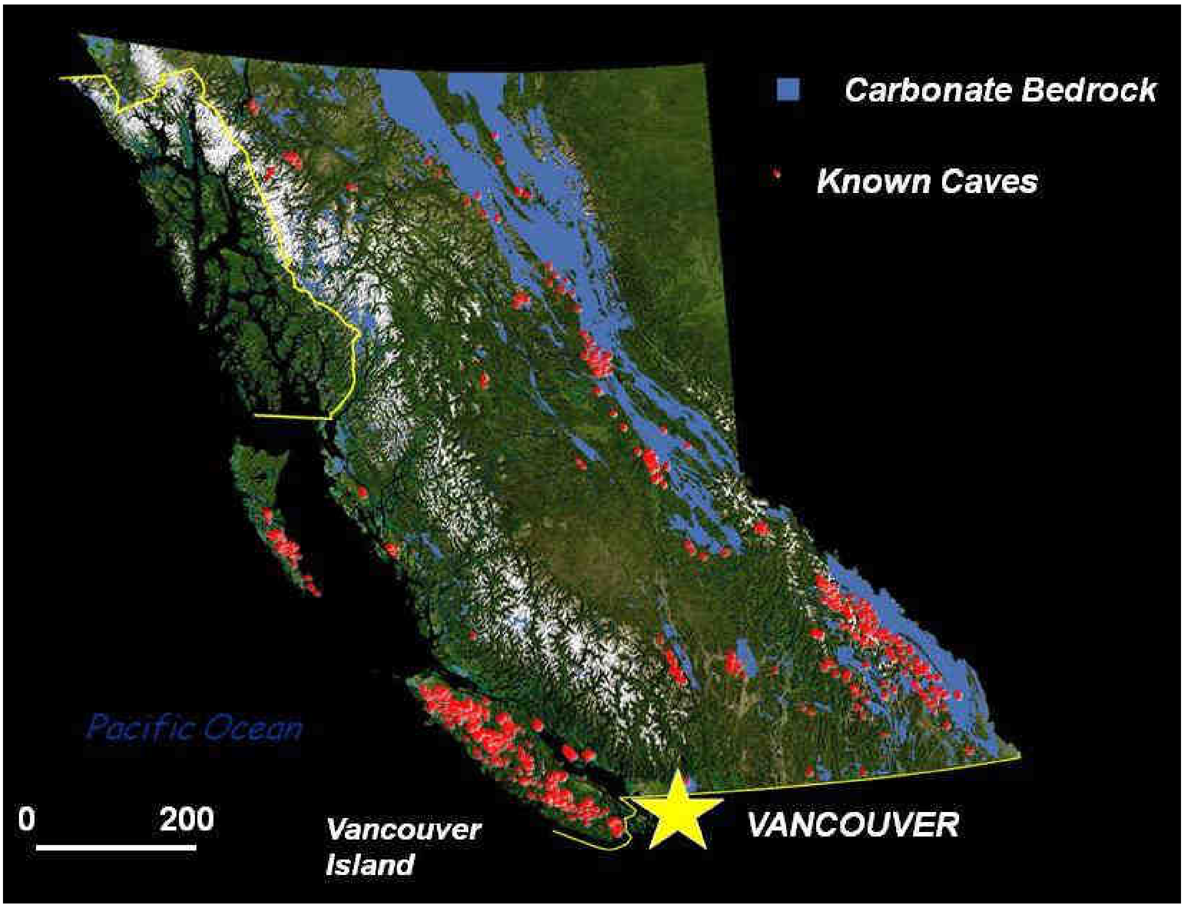

Figure 3 – Distribution of carbonate bedrock, potential karst and known caves in British Columbia

The karst landscapes on Vancouver Island occur in a wide range of geomorphic settings from alpine, mid and lower forested slopes, valley bottoms to the lowland and coast (Figure 4). Classification of these karst areas has not been formalized. A useful first approach is to consider them in terms of the physiographic regions for Vancouver Island (Figure 5), which subdivides the island into mountain ranges, fiord lands, plateaus, highlands, lowlands and basins. Examples of karst areas include White Ridge and Kinman in the northern mountain ranges, Weymer and Clayoquot in the fiord lands, Memekay and Holberg on the plateau areas, and Quadra Island and Horne Lake in the lowlands.

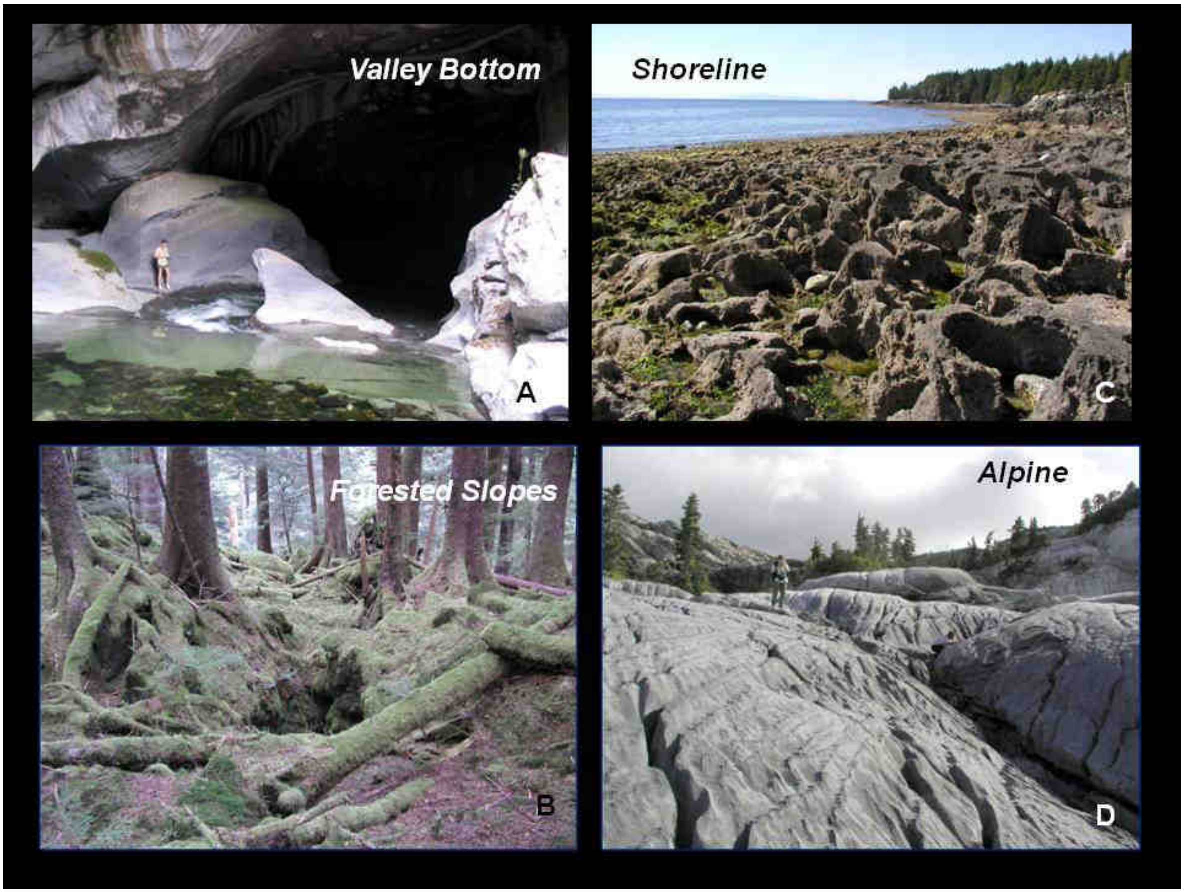

Figure 4 – Geomorphic settings of typical karst landscapes on Vancouver Island. A – Entrance to Little Hustan Cave on Atluck Creek, northern Vancouver Island B – Typical small sinkhole in forest karst. C – Limestone with solutional weathering from shoreline of Texada Island. D – Exposed and solutionally weathered limestone surface in alpine region of Central Vancouver Island.

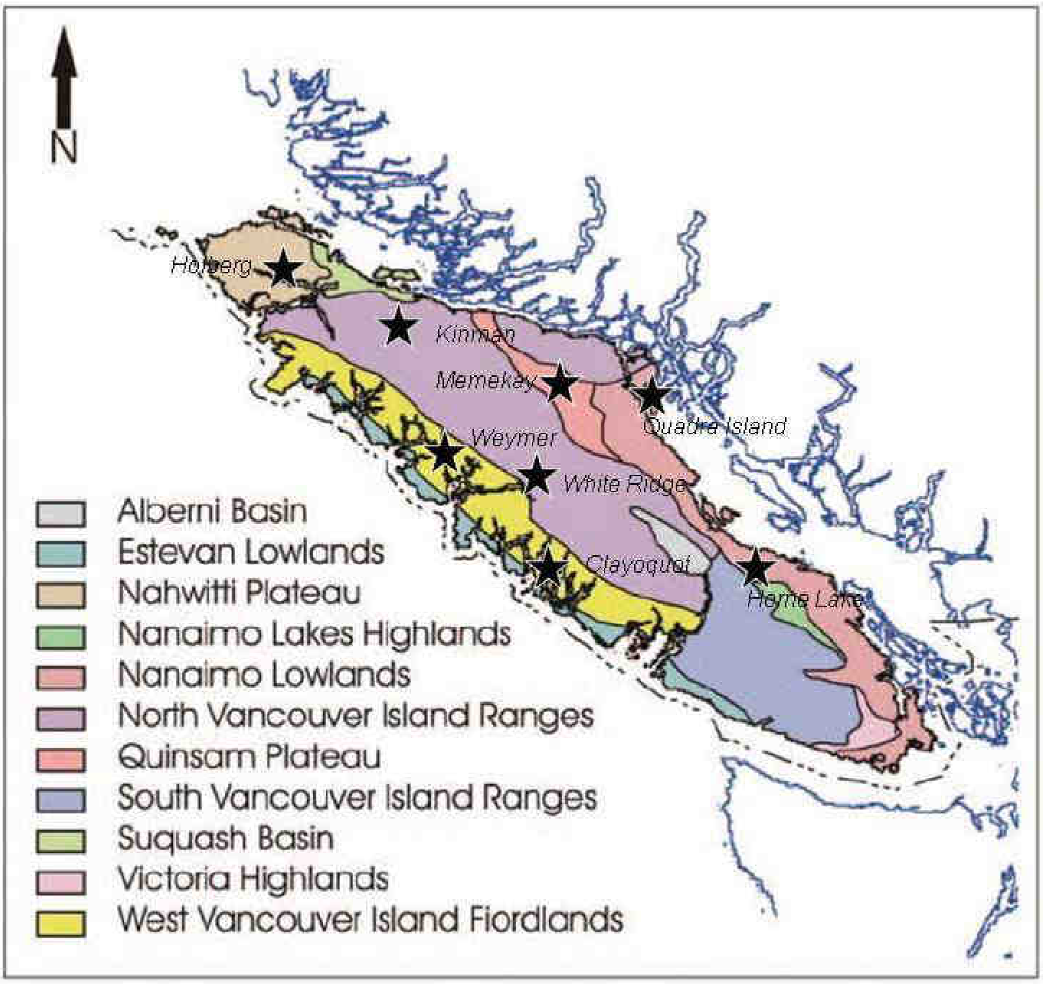

Figure 5 – Physiographic map of Vancouver Island and selected karst areas (Adapted from Yorath, 2005)

Previous Research

Research information specifically on the geology, geomorphology and hydrology of karst landscapes on Vancouver Island is quite varied. A number of theses were completed in the early 1980's under the direction of Dr Derek Ford – a preeminent karst scientist from McMaster University. Mills (1981) used multiple lines of evidence, including hydrochemical analyses, and examinations of surface and subsurface landforms to better understand groundwater flow patterns and their constraints on karst development in the Benson River Valley and Gibson Plateau areas of Northern Vancouver Island. Ecock (1984) focused on White Ridge, an alpine karst area on the west coast of the island, and examined the hydrological balance between the precipitation/infiltration on the upland karst surface to the spring discharge downslope. Harding (1987) focused on soil loss and timber harvesting activities of karst areas in northern Vancouver Island (Harding and Ford, 1993). A series of earlier studies were also completed at Horne Lake Caves Provincial Park (Ford, 1975; Copland, 1982; Smart, 1986) investigating issues related to hydrology and speleogenesis of the caves. Sediments and mineral formations indicated that cave development in this area possibly spanned the past 140,000 years. This data was supported with U-Th dating in Cascade Cave near Port Alberni, which indicated two periods of cave speleothem formation – 55,000 - 33,000 BP and less than 15,000 BP, both of which were linked to interglacial warming events (Gascoyne, 1981).

A number of other research projects using geochronological and geochemical analysis of speleothems from caves on Vancouver Island have also been completed. Latham et al., (1982) applied paleo-magnetism and U-Th dating to estimate the age of speleothems for a number of caves on the island, but there were some concerns with the accuracy of the results. Marshall et al., (2009) used C and O isotopes and U-Th dating of speleothems from a cave in the Port McNeill area to document climate/temperature changes for the past 12,000 years. A similar climate change study was completed by Zhang et al., (2008), who utilized H and O isotopic analysis of fluid inclusions within speleothems collected from a cave on the west side of Vancouver Island.

In terms of mapping of karst landscapes of Vancouver Island, a series of karst potential maps were developed for both Vancouver Island and the rest of BC, using existing geologic information on bedrock units and regional knowledge of karst and cave features (Stokes, 1999). Another karst potential map was also developed for Vancouver Island, as part of a series of Geomorphic Maps on Vancouver Island (Guthrie, 2005).

Primary Constraints of Karst Landscape Development and Evolution

Karst landscapes on Vancouver Island are primarily due to the dissolution of limestone. In general, this dissolution at upper elevation (alpine) areas is likely dominated by the vertical infiltration of rain and snow (i.e., more holokarst-type), while mid and lower elevations sites are also influenced by allogenic surface streams (i.e., more fluviokarst-type), and the valley bottoms by larger river systems. The rate and amount of dissolution, and the overall development process of these landscapes, is still open to discussion, and dependent on a wide range of chemical and physical factors such as: the nature and type of limestone, the amount and chemistry of the water, the type and thickness of soil-cover/regolith, the type and extent of vegetation cover, the thickness of and/or the presence of interbeds within limestone units, the intensity and orientation of fracturing, localized climatic conditions, and hydraulic head. Other geologic/geomorphic factors that may constrain the development of karst landscapes include: past glaciations, sea level rise and fall, and the rates of landscape uplift and erosion.

Nature & Characteristics of Vancouver Island's Limestone Units

The Late Permian Mount Mark Formation is the oldest of the three limestone units on Vancouver Island. This unit is generally comprised of a grey, well-bedded crinoidal limestone with minor interbeds of chert and argillite (Fischl, 1992). The type section, found at Horne Lake, is approximately 350 m thick and is characterized by a thick bedded lower unit that grades into thinner bedded and laminated middle unit with interbeds of shale and chert, that is overlain by an upper unit that is more massive and thicker bedded (Yorath et al., 1999). In many cases the Mount Mark Formation limestone is moderately to steeply dipping, and forms small (100-1000s m long and 10-100s m wide) geologic zones that are relatively deformed and generally separated from other rock units by faults.

The Late Triassic Quatsino Formation is proportionally the largest limestone unit on Vancouver Island and is comprised of a light grey to black, massive to thick-bedded and micritic limestone, with a general lack of obvious fossil material (Figure 6). The lower part of this approximately 750 m thick formation is dominated by massive to thick-bedded limestone, while the upper part grades into a dark grey to black and flaggy limestone with intercalations of black shale. These black shale beds gradually become thicker and change into the shale dominated Parson Bay Formation. For the most part the Quatsino Formation forms three belts that are 10s km-long, 100s m wide and occur in the north of the island. One belt can be traced for over 150 km (Fischl, 1992). Generally, the Quatsino Formation is gentler dipping and less deformed than the Mount Mark Formation. This might in part be a function of its younger age, and/or the different style of tectonic deformation in the north of the Island. The Parson Bay Formation conformably overlies the Quatsino Formation and is up to 600 m thick, and is comprised of thinly bedded layers of black argillite, calcareous siltstone and sandstone, and grey to black limestone. Typically, the Parson Bay Formation occurs in close proximity to the Quatsino Formation, however it can also be found as small and isolated bodies (or faulted blocks).

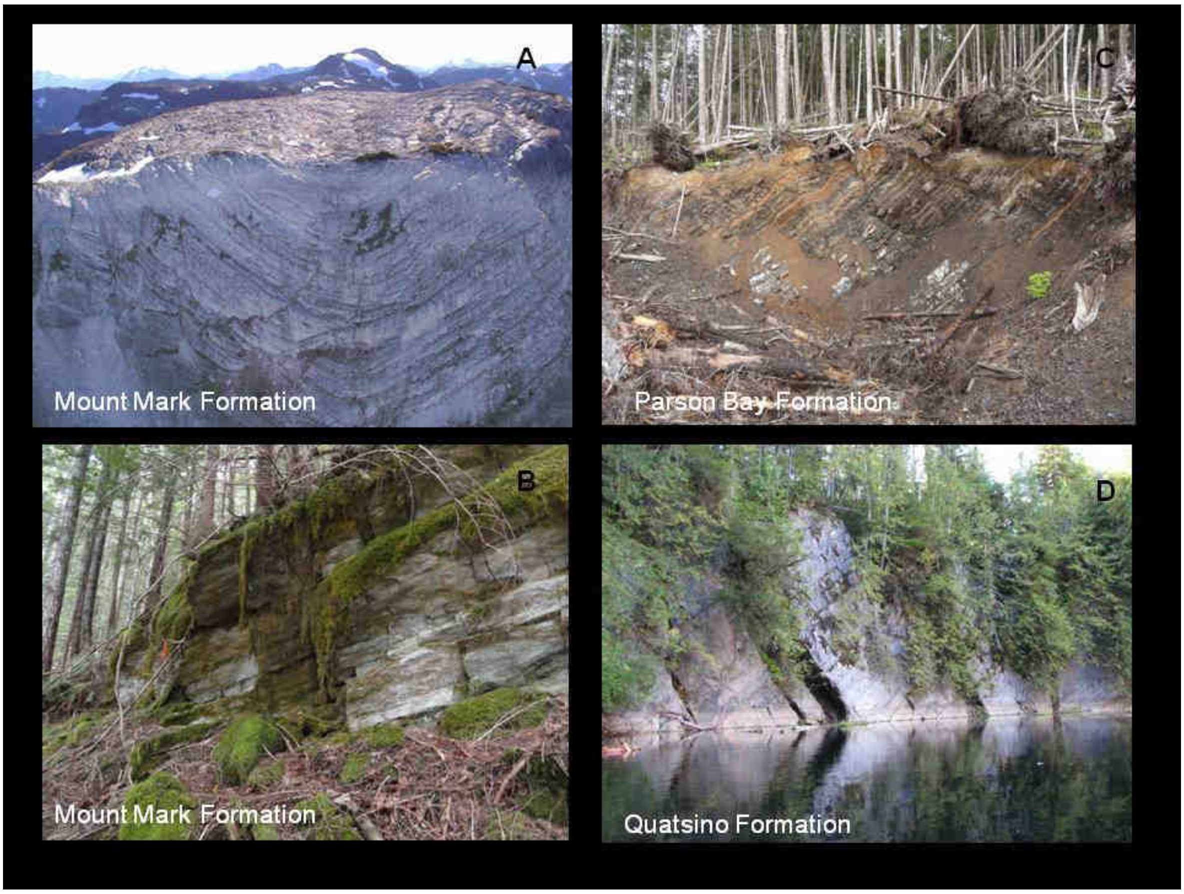

Figure 6 – Field Photographs of the Mount Mark, Quatsino and Parson Bay Formations. A – Aerial view of large synclinal fold in limestone of Mount Mark Formation in Strathcona Park. B – Moderately dipping and slightly foliated limestone beds of the Mount Mark Formation, Port Alberni Area. C – Thin interbedded limestone and black shale beds of the Parson Bay Formation, Holberg Area. D – Moderately dipping and medium to thick beds of Quatsino Formation, Devil's Bath, northern Vancouver Island.

Karst is known to develop in all three of the above formations. However, it is generally better developed and more extensive in the limestone-dominated and calcite-rich (>90% $CaCO_3$) Mount Mark and Quatsino Formations. Karst does develop in the limestone layers of the Parson Bay Formation, but is often inhibited in the clastic and carbonaceous-rich layers, commonly resulting in karst with a more striped appearance.

Geologic History and Tectonic Deformation

The Mount Mark, the Quatsino and the Parson Bay Formations are all part of the Wrangellia Terrane, which is Devonian to Jurassic in age, and primarily comprised of inter-layered volcanic and sedimentary units along with some late stage granitic intrusions (Figure 7). Wrangellia is considered to have formed a significant distance offshore from North America within the ancient Pacific Ocean by a combination of intraplate superplume volcanism and island arc activity (Richards et al., 1991). Over time Wrangellia gradually drifted towards continental North America, and eventually collided with this region approximately 100-120 Ma. Vancouver Island, Haida Gwaii and parts of Southeast Alaska are all now remnants of this terrane. Two smaller terranes, the Pacific Rim and Crescent, collided with the southeast end of Vancouver Island approximately 55 Ma and 42 Ma ago, respectively.

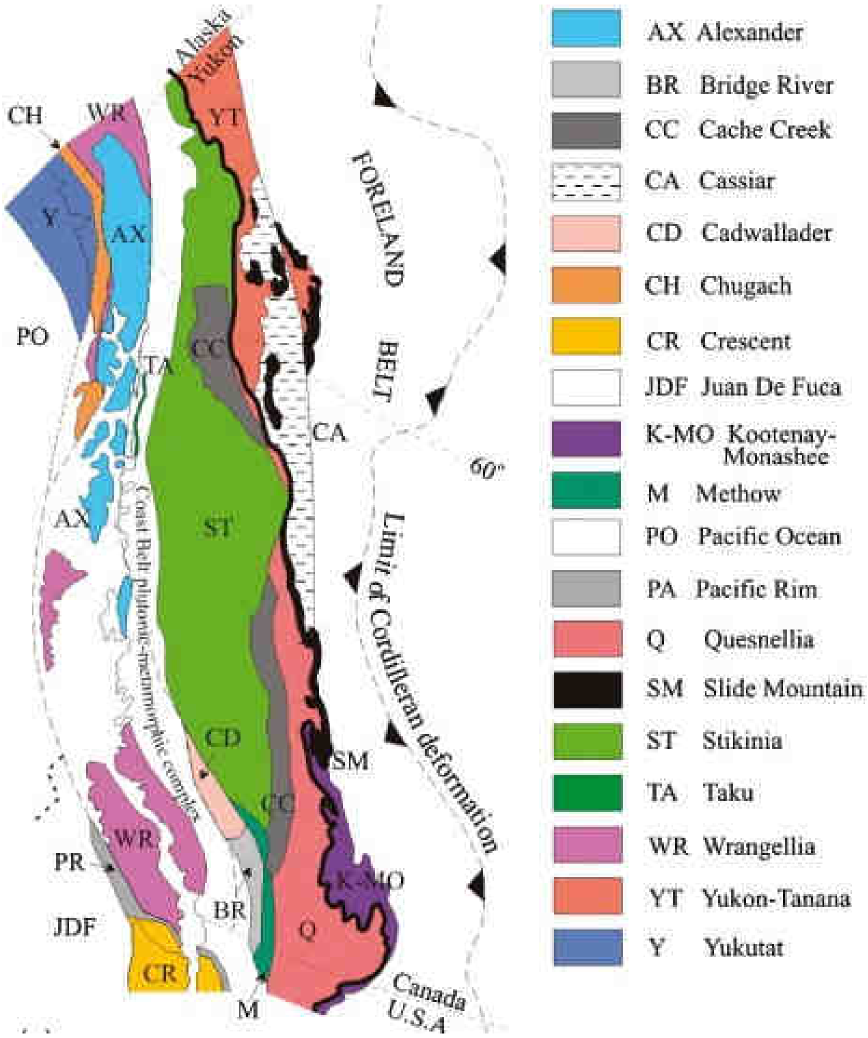

Figure 7 - Geologic terranes of British Columbia and the Yukon. Note, Wrangellia Terrane (lilac) that was accreted onto the west coast of British Columbia and Alaska (Sourced from Ricketts, 2008)

Past tectonic activity, terrane collisions and associated structural deformation have played a major role in developing the landscape of Vancouver Island, resulting in a region dominated by northwest-southeast trending mountain ranges and river valleys. Some of the earliest structures are found in the oldest rocks of Wrangellia – the Devonian Sicker Group – which has been exposed and uplifted, resulting in regional anticlinal structures with northwest-southeast axial traces that can be followed along much of the island's length (Yorath et al., 1999, Figure 8). These fold structures are likely related to early compressive deformation prior to and/or during the collision of Wrangellia to North America in the Late Jurassic. After and/or during the terrane collision strike-slip faulting became dominant in the north and centre of the Island, as evident from conjugate faults sets with northeast and northwest trends (Jones et al., 2006). Normal faulting then developed in the Mid Cretaceous during a period of extension, and resulted in a major basin forming between Wrangellia and the North American continent. Late Cretaceous and clastic sedimentary rocks of the Nanaimo Group then accumulated within this basin. In the Eocene a fold and thrust belt system developed in the south of the Island due to the collisions of the Pacific Rim and Crescent Terranes (England and Calon, 1991) and resulted in numerous northwest-trending and southwest-verging thrust fault zones (e.g., Cowichan Lake Fault).

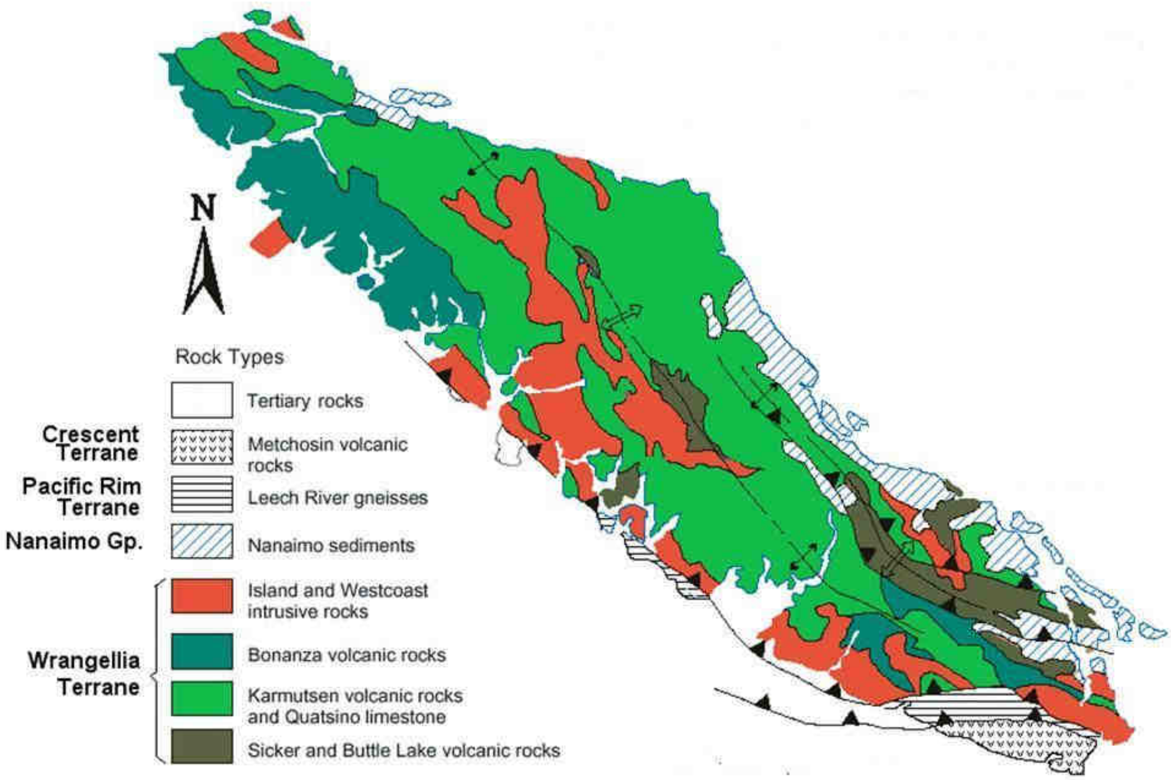

Figure 8 - Geology of Vancouver Island illustrating different rock units and major structures -anticlines and thrust faults. (Sourced from teaching web site of Steve Earle, Vancouver Island University. http://web.viu.ca/earle/geol111/geology-of-vancouver-island.pdf Accessed July 31, 2013)

The Mount Mark Formation underwent some of the early compression and deformation on the island, as evident from major fold structures apparent within this unit. Subsequent strike-slip faulting in the north and central parts of the island were likely responsible for much of the tilting and separation of the Quatsino and Parson Bay Formations into elongated belts. The late Eocene thrust faulting may have also played a role in the deformation and separation of the small limestone zones found in the south of the island. Fracturing would have accompanied all deformational phases and resulted in a wide range of joints that cross-cut and transect bedding within the limestone units. These joints, along with faults and the bedding planes, likely constrain the orientation and shapes of many karst solutional openings present in the limestone units. Mills (1981) also noted that intrusive structure (e.g., dykes) also played a role in constraining the location and shape of subsurface openings.

Vancouver Island remains a tectonically active region, with the subduction of the Juan de Fuca Plate below North American Plate (Figure 9). This subduction started approximately 35-40 Ma ago and has resulted in many of the major volcanic centres that have formed along the west coast of North America (Wood and Kienle, 1990). The configuration and rates of this plate subduction have changed over time, with part of the Juan de Fuca plate splitting off to the north and forming the Explorer Plate 4 Ma ago, and part splitting off to the south forming the Gorda Plate 5-18 Ma ago (Wood and Kienle, 1990). Current rates of subduction convergence are in the order of 40-50 mm/year, while associated rates of uplift on Vancouver Island are 1-4 mm/year (Hyndman and Rogers, 2010). The rates and directions of convergence and uplift have likely varied over time, and have also periodically changed during large, cyclical (300-600 years) subduction earthquakes (Hyndman and Rogers, 2010). Tectonic uplift has resulted in mountain building, which in turn is responsible for a range of factors that could influence karst landscape development, such as changes to hydraulic heads, stream base levels, erosion rates and local climatic conditions. All of these factors are important constraints to consider in the 10,000's to 100,000's years time scale of karst landscape evolution on Vancouver Island.

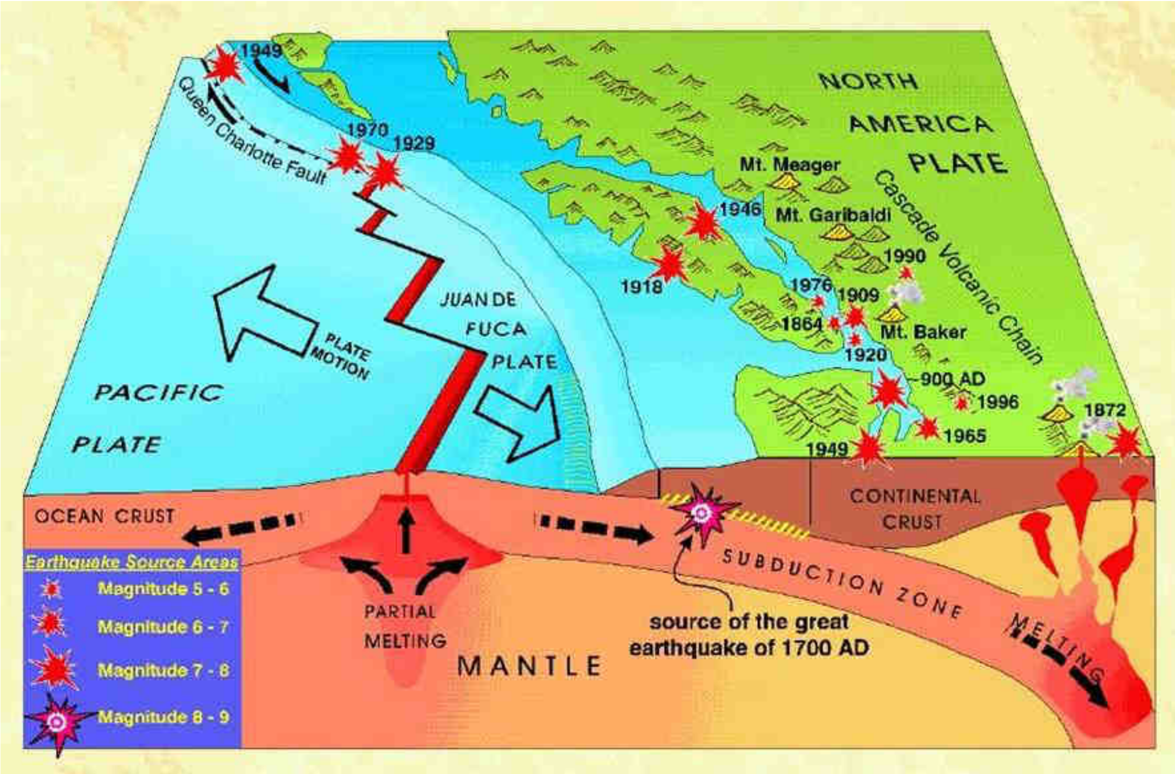

Figure 9 - Current plate tectonic setting of Vancouver Island including recent earthquake activity and volcanic centres on Mainland BC. (Sourced from Natural Resource Canada web site http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.earth-sciences/files/gif/vancouver/images/earth2_e.gif , July 31, 2013.)

Glacial History

Vancouver Island has undergone extensive glaciations with at least twenty glacial cycles during the last 2.6 Ma of the Quaternary. Many of the earlier glacial events have been masked by later ones, however, evidence for the last 2-3 glacial events are well documented on Vancouver Island and Southwest BC (Yorath, 2005). The Fraser Glaciation is the last and most well documented glacial cycle that started 29,000 years BP, which began to retreat 14,500 years BP and had almost disappeared by 11,500 years BP (Ryder et al., 1991). This glacial event and others are tied to advances and retreats of the Cordilleran Ice Sheet, which developed as a large ice mass extending out from the Coast Mountains and Vancouver Island Ranges, and then met in the Salish Sea and moved southward to the Puget Sound (Figure 10). This km-thick ice sheet would have covered most of Vancouver Island, except for possibly the highest peaks (>2000 m), and some isolated refugium areas on the west coast (e.g., Brooks Peninsula; Hebda et al., 1997). Significant amounts of bedrock would have been scraped from the landscape surface and moved downslope, eventually being deposited as glacial sediments of varying thicknesses on the mid-slopes, lower slopes and valley bottoms.

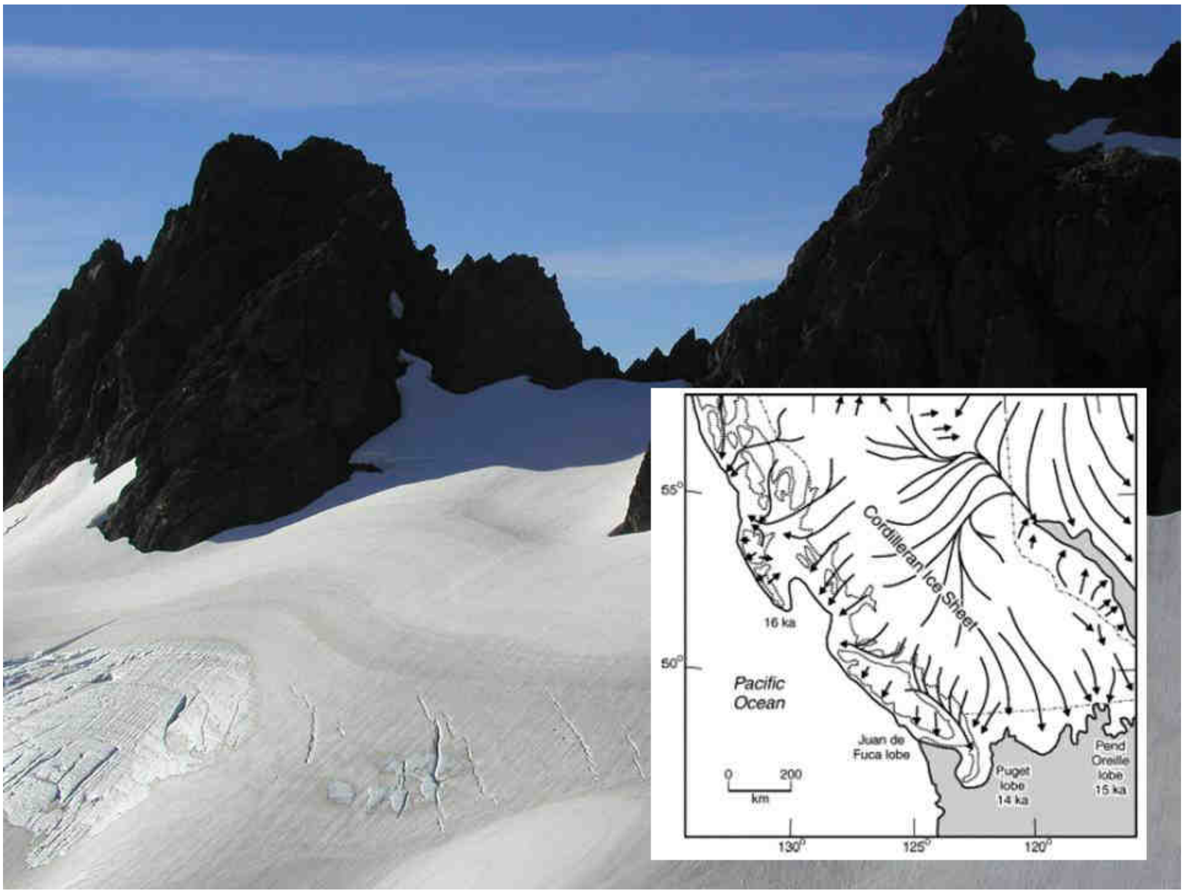

Figure 10 – Glacier from Northwest of Tahsis in Central Vancouver Island, with inset illustrating extent of the Cordilleran Ice Sheet at the peak of the Fraser Glaciation 14,000-16,000 years ago. (Inset sourced from Clague and James, 2002)

Past glacial events would have had a dramatic effect on any existing karst landscapes on Vancouver Island, as the thick ice sheets moved across the surface. The upper (epikarst) layer of any karst landscapes present could easily have been removed, based on an estimate of 4.8 $\pm$ 2.8 mm/year for bedrock removal due to the ice sheet erosion (Cowton et al., 2011). The exact nature and extent of glacial erosion might also be dependent on the topographic setting of the limestone units – alpine, shoreline, valley bottom, etc. In some cases the slightly softer limestone units (relative to surrounding basaltic and granitic rocks) might be preferentially eroded forming lowlands (e.g., Central Quadra Island). Glaciation will also have a major effect on the karst hydrology (Ford, 1983), hindering karst development by infilling subsurface conduits with sediments, redirecting flows and freezing, or alternatively enhancing karst development with sub-glacial water flow and melt-water floods being directed into sink points. Glacial waters would also move significant amounts of glacial sediment into and/or through karst conduit systems. At the end of glacial cycles, sediment also buried lower elevation karst landscapes, which function hydrologically with water flow in subsurface conduits, but whose presence might only become evident when openings breach the surface – over time and/or following land disturbance. It is therefore evident that glacial events have great potential to remove, disrupt, bury, infill and flush material through karst landscapes (Figure 11). All of the processes may have affected the karst landscapes on Vancouver Island not once, but possibly a number of times.

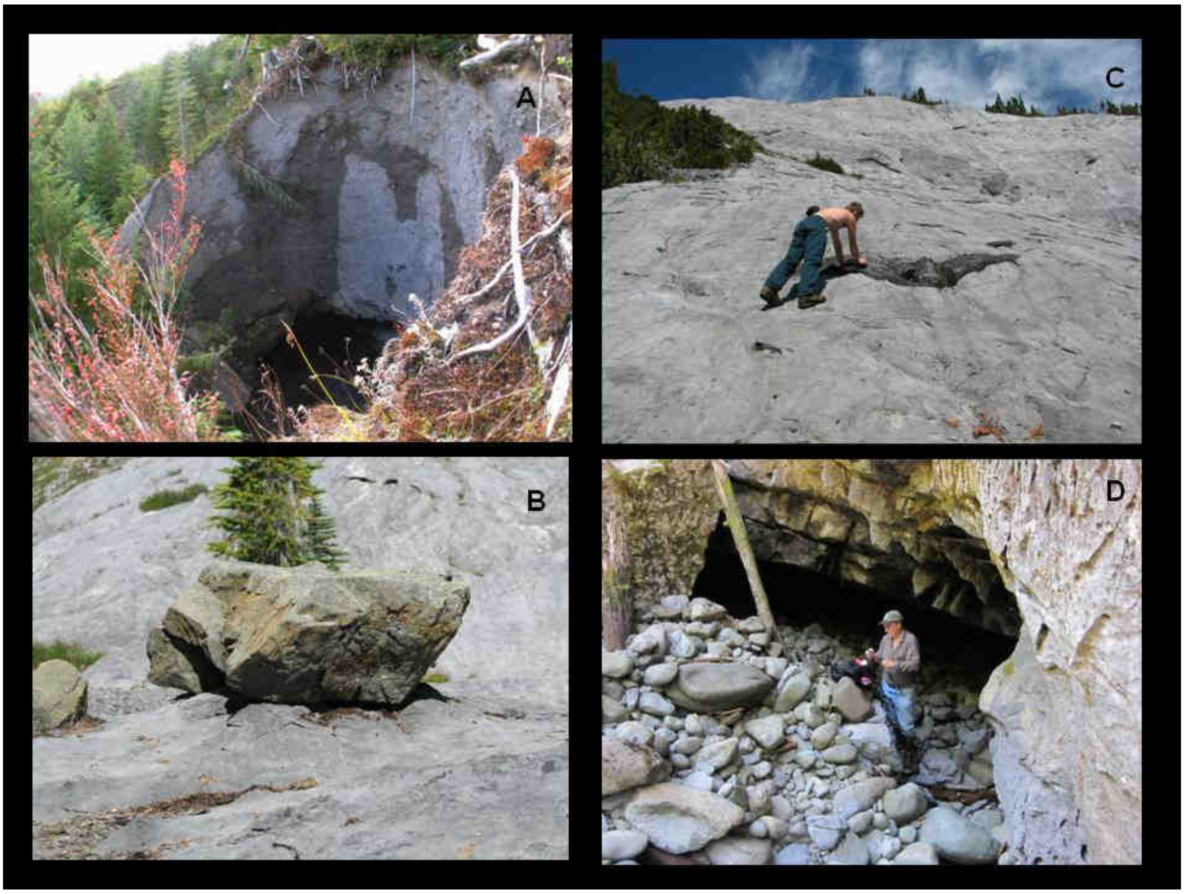

Figure 11 – Glacial effects on karst of Vancouver Island. A – Large collapse feature in glacial till above known cave openings. B – Glacial erratic upon limestone pedestal that has formed since placement of rock. C – Striated limestone pavement in alpine karst setting. D – Rounded glacial and fluvial rock debris infilling cave entrance

Sea Level Change and Isostatic Rebound

Glaciation has also played a major role in sea level change and isostatic rebound of Vancouver Island. The best record for sea level change and isostatic rebound comes from the most recent glacial cycle when during the onset of the Fraser Glaciation sea level is thought to have dropped by up to 150 m and the overlying ice sheet depressed Vancouver Island by up to 300 m (Yorath, 2005). Following glacial retreat 14,500 years ago and removal of the ice mass, rapid isostatic rebound occurred and was faster than sea level rise. This result resulted in a number of raised beaches now found along the coastline of southwest BC (Figure 12, Clague and James, 2002). Eventually sea level reached its current level around 5000 years ago. These changes in sea level rise and associated isostatic rebound would probably have had profound effects on karst landscape development by altering groundwater circulation patterns, stream base levels, hydraulic heads and the exposure of karst landscapes, particularly at lower elevations.

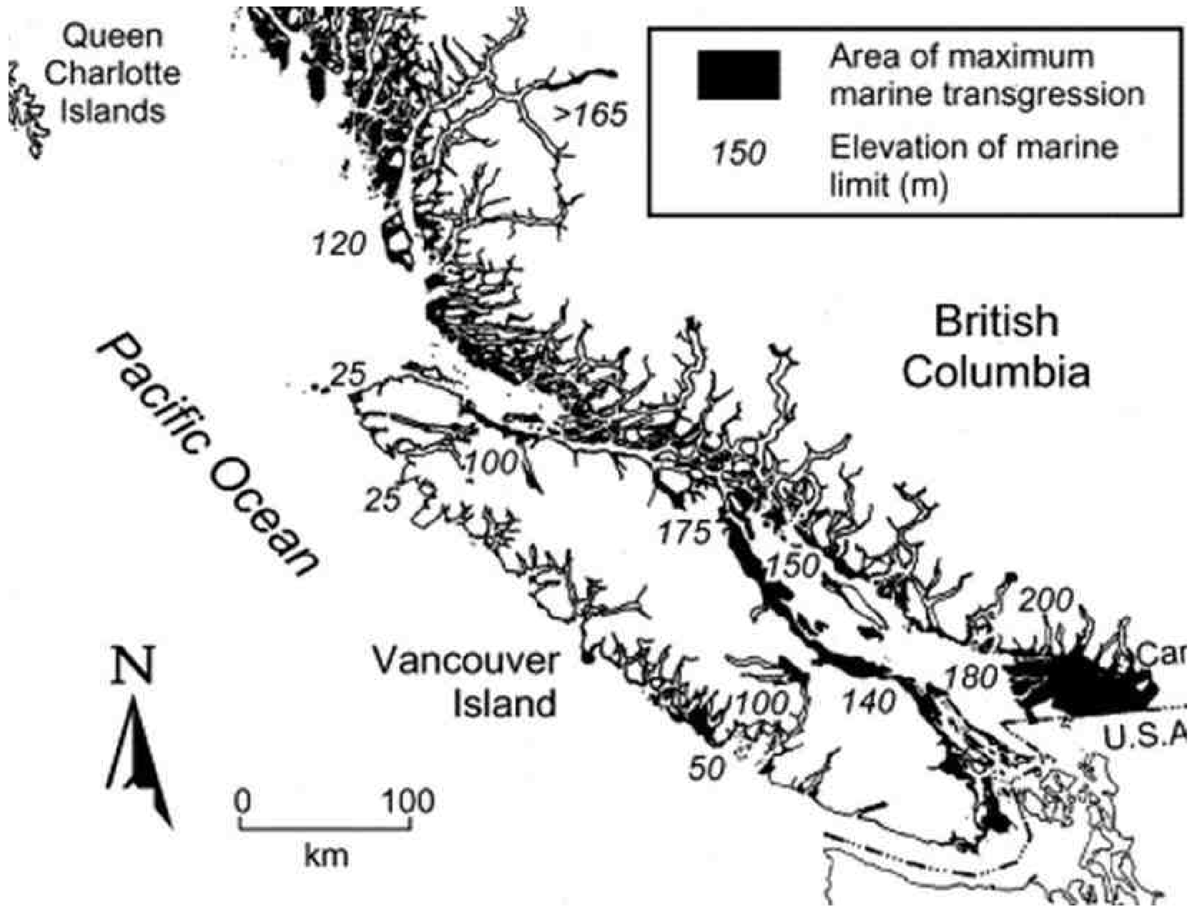

Figure 12 – Raised beaches in British Columbia that developed since the end of the last glacial period 11,000 years ago. (Sourced from Clague and James, 2002)

Research Methodology

Current research activities aim to complete detailed fieldwork at a number of carefully selected and representative karst areas on Vancouver Island. It is anticipated that these areas will include: examples of the three carbonate units on Vancouver Island (Quatsino, Parson Bay and Mount Mark Formations), different geographic locations (north, central and southern Vancouver Island), varied geologic/structural domains, and diverse topographic settings (alpine, mid-slopes, coastal). It is intended that the sites will have close spatial association to known caves that have been previously surveyed and mapped. Possible sites include: Benson River, Kinman Creek and Memekay River areas in the north and central part of Vancouver Island, White Ridge on the west coast, Horne Lake and the Port Alberni area in the southern part of the Island, and Quadra Island. An important part of the project will be to examine some of the available cave maps of the selected areas, and to integrate these into their respective geographic and geologic context. The shape, nature and elevation of cave passages when correlated to the host limestone unit, geologic structures and topography may provide indications as to how, when and why the karst landscape developed. Significant vertical or horizontal passages in caves could also provide clues for rapid landscape uplift or stability, respectively (Piccini et al., 2003). Field work in the selected sites will focus on mapping the boundaries of the host karst units, the types of surface karst features, and distribution of bedrock fractures and geologic structures. Field data will also be collected on host bedrock lithology, glacial/surficial materials and hydrological features. A key part of the data compilation will be to develop detailed geological maps for the selected sites and to incorporate this information into a GIS database. Where possible cave maps will be digitized and incorporated into 3D models, integrating surface and subsurface data.

Anticipated Outcomes and Applications

The main outcome of this research will be to develop a better understanding of how and when karst landscapes have developed on Vancouver Island integrating what is observed on the surface with what is known from the underground. It is anticipated that this research will gradually lead towards a 'conceptual model' for karst development on Vancouver Island that will take into account the various constraints discussed above. It is intended that results from this project will increase the overall scientific understanding, awareness and appreciation of karst issues and resource values on Vancouver Island. For example, issues related to the age of the host rocks and timing of karst development are either not included, or are unclear, on interpretative signage at a number of karst recreation sites on the Island (e.g., Alice Lake Loop, Upana Caves, Little Hustan Caves). A better understanding of these issues can be used to enhance the general public's interest and understanding of these valuable resources. Research will also highlight the importance of karst landscapes to other scientists, and possibly provide additional information on the glacial, climate change and tectonic history of Vancouver Island and Coastal British Columbia. This research will also contribute to the ongoing discussions related to forestry and other land use activities on karst, by providing sound geoscience information for decision makers in terms of the characteristics, nature and functions of this important, but different, landscape.

Conclusion

It is apparent that the geology, tectonic history and past glacial events have been significant in forming the mountainous terrain of Vancouver Island, and that these factors are key constraints for the development of karst landscapes in this region. Recent tectonic uplift, sea level changes and isostatic rebound are also other important constraints to consider. Previous geochronological dating within caves of Vancouver Island has indicated at least two periods of speleothem growth during the last and present interglacial events (55,000 – 33,000 years BP and less than 15,000 years BP, respectively), with some cave morphological evidence suggesting older ages (>100,000 years BP) for subsurface karst development. In many areas the karst features encountered at the surface are likely post-glacial (<14,500 years BP), with any earlier features removed by glacial erosion. However, it is possible that in some areas glaciation may have altered or enhanced surface karst features by channeling of melt waters and other processes, rather than eroding them (Mills, 1981). Current research activities entail mapping selected and representative areas of karst on Vancouver Island, as well as collecting data on landscape characteristics, bedrock structures and surficial geology. Cave morphological information, including the orientation and shape of subsurface passages, will be integrated with the surface bedrock/karst geology and topographic/elevation data. Overall, this research will aim to better understand the geologic and geomorphologic processes that have led to the evolution of these unique and valuable landscapes on Vancouver Island. It is anticipated that this research will eventually lead towards a 'conceptual model' for regional karst development on Vancouver Island. Research may also aid in unraveling other aspects of the glacial processes, climate change and tectonic history of Vancouver Island and the west coast of BC.

Acknowledgements

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Scrubby Creek Cave Acquisition, Murrindal, Victoria

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Abstract

Scrubby Creek Cave was an exploration focus in the late 1950's by the Sub Aqua Speleological Society who tried to dive the resurgence. It was not until 1961 that entry to the cave was gained by bypassing the resurgence. This revealed an initial section above the water until a difficult section was found which required immersion and very little breathing space. The cave continues along the stream for more than a kilometre and the cave has excited cavers for the last 50 years. There are a number of related caves on the Scrubby Creek Property and the neighbouring properties. The caving community has worked with the owners to control access because of the caving difficulties and in doing so developed a very strong conservation ethic for what is a very beautiful and complex cave.

Several cavers were advised that the property was on the market in late 2011 and quick action was needed as this was a once-a-generation chance to acquire the property. Rimstone Cooperative Ltd was started in 1973 with speleological aims and it acquired the Homeleigh property in Buchan. This has provided accommodation for Rimstone members, their friends and families and has always been open to cavers. Rimstone Cooperative is a Community Advancement Society and cannot make or distribute profits to its members. This fulfilled the requirements of compliance for the ASF Karst Conservation Fund to support the acquisition of the Scrubby Creek Cave Property by Rimstone. We thus signed contracts to purchase it and set about raising the funds. We were able to settle in May 2012 with the donations and a few loans.

Rimstone is now preparing a Management Strategy, which involves protecting the cave and karst, particularly the tufa banks and continuing the grazing regime.

The ownership structure will be discussed in relation to private versus public cave conservation of karst resources. The support of all the donors from across the caving community and their friends is acknowledged in this the first such purchase in Australia.

Introduction

Scrubby Creek Cave, M-49 is in the Murrindal area of the Buchan District and is on the western side of the Buchan Basin at the contact with the Snowy River Volcanics and Buchan Caves Limestone (Mill, 1979). The cave is some 1.7 kilometres long. The cave was first entered in 1961 but was known from the Scrubby Creek resurgence at the foot of a limestone bluff much earlier. The exploration of the cave has a rich history because of the challenging obstacles in the way such as sumps, mud and rock falls. There is still much to explore and investigate.

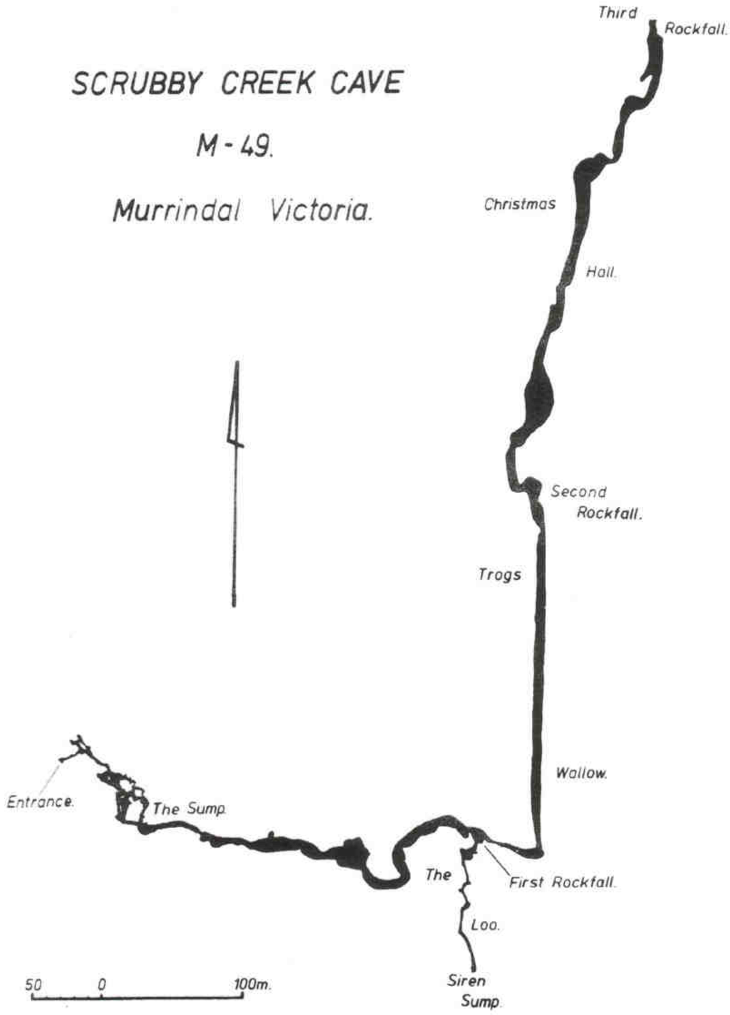


Figure 1. Scrubby Creek cave survey

The caving community has enjoyed good relations with the Woodgate family since the first successful entry into the cave. Daryl Carr and Lou Williams were offered the Scrubby Creek Cave property when John (Grub) Woodgate's daughter Lauren decided to put the property on the market in October 2011. They were not able to purchase it themselves and put it up as a proposition that cavers through Rimstone Cooperative Ltd could buy the property. I need to fill in some background here because in 1974 the Victorian caving community established Rimstone Cooperative Ltd to support cave conservation and the aims of the caving community. Rimstone Cooperative is a Community Advancement Society which cannot declare a dividend and has to pass on its assets to a like-minded organization if wound up. The first objective after the Cooperative was formed was to resolve a problem with caver accommodation at Buchan and Rimstone purchased the Homeleigh guesthouse shortly after being established. This had become necessary because there were no suitable premises suitable for rent and the alternatives of camping were not good for year round caving. At the time the purchase price of $12,000 seemed enormous. The funds were raised in several stages until the full $1.00 share capital was all paid up. Funds from accommodation fees have been used to renovate the property ever since. At several stages we have investigated purchasing caving properties but we did not have the money or resolve at the time. However, we have successfully operated in Buchan since 1974.

Figure 2. The Homeleigh guesthouse at Buchan, Victoria

With Rimstone Cooperative Ltd we had both an organization and structure applicable to acquiring a cave property and experience in managing property. The Scrubby Creek Cave property had one of Victoria's iconic caves with other prospects as well.

Property Acquisition

During November and December 2011 the Directors' of Rimstone established that there was sufficient support for us to negotiate with the estate agents to acquire the property but we needed the support of the wider caving community to do so. This is where the ASF and the ASF Karst Conservation Fund came in. We needed to have the acquisition as an approved project of the Fund to firstly have tax deductibility for donated money and secondly to pull in the support of the wider ASF caving community. On behalf of Rimstone, I made application to the Directors' of the ASF Karst Conservation Fund with background on the Cooperative as being a suitable body to acquire the Scrubby Creek Cave Property for posterity. This hit the summer period and the Fund Directors were on holiday that necessitated some prevarication on my part in negotiating with the estate agents until the Fund Directors approved the project. There was also the problem of holding the property from being sold out from under us. I placed a deposit of $200 on the property, not the usual 10% of contract price, to prevent it being snapped up by firstly a group of motorcycle riders and then a builder who liked the area. The ASF Karst Conservation Fund Directors approved the project at the end of January and established conditions for the project. The Rimstone directors immediately signed a Contract of Sale for the 105 acres with the cave entrance, the spring and tufa terraces and paid a full 10% deposit with settlement in early May 2012.

Figure 3. Murrindal Area, Overview

Fundraising was the next stage in the process. Raising over $100,000 for the property was a challenge as only some of it was promised and only a small amount was available from Rimstone Cooperative funds as these are used to upgrade and renovate the Homeleigh premises. The Rimstone Directors' resolved that all new membership fees should go to the capital purchase. Publicity was immediately set in place with an appeal brochure and article in Caves Australia (White, 2012); follow-up contact with VSA and Rimstone members and an ASF Website appeal notice. Many friends of VSA and Rimstone members additionally were asked to donate to the project. Additional to this we investigated obtaining a loan or part loan to purchase the property. It was instructive to learn that despite Rimstone Cooperative always showing a small profit for over 30 years, our advisor said after looking over five years of audited accounts that "we were not a lendable entity". This advice came within 24 hours of initiating the discussion with the finance advisor and we then knew that with a contract to meet we had to obtain personal loans for any shortfall on the fundraising side.

By the end of March 2012 we had raised or had in place the funds to pay the full Contract price for the property. I was able to go on the VSA Nullarbor trip comfortable that settlement could be met in early May. This was made up of over $60,000 raised through the ASF Karst Conservation Fund and about $15,000 donated directly to Rimstone Cooperative. The balance was from Rimstone's consolidated accounts and loans from individuals. I will record here that VSA and Rimstone members contributed 80% of the raised funds; ASF members interstate 11%; ASF clubs 3.5 %; other non-caving friends 5.5%. We always knew that the funds would come mainly from Victoria but we were very heartened by the support of individuals and member clubs directly. The fund raising is not finished as we have loans from a number of individuals that still need to be acquitted. The Contract was met in early May and we now have the Title to the property.

Scrubby Creek Cave Property Management

Farming properties need management. It is a "rough" grazing property. Buchan was settled following drought on the Monaro in NSW during the 1830's. The limestone land in the Buchan district had grassland and box woodlands suitable for grazing. The adjacent Snowy River Volcanic lands were not arable or suitable for grazing. The good limestone land was taken up early and later broken up.

It is important in the very conservative community of the Buchan and Murrindal district that as new owners we do not take the land out of primary production. With this in mind we are developing a sustainable management regime which provides for commercial grazing but protects the character and nature of the karst landscape. We have now leased the property for grazing but retained access and responsibility for weeds.

A caving access agreement is broadly in place with the Victorian Speleological Association Inc and is based on a continuation of the Special Leadership for Scrubby Creek Cave that was in place with the previous owners. This is based on cave leaders with a familiarity and knowledge of the cave, in particular the sump as well as a respect for the upper level passages which are very well decorated. Caving access for Scrubby Creek Cave and the other caves on the property will require each trip to be on the VSA trip calendar and participants will require ASF insurance cover or similar. Similarly, cave exploration and investigation involving digging will require a full plan approved by VSA and Rimstone. Rimstone Cooperative Ltd is the property owner and cavers need to realise it is not VSA, although there are close links.

Rimstone is currently planning protective works for the tufa terraces. This may involve fencing, the installation of run-of-stream water troughs and some enhancement work on the terraces. These have suffered from trampling and clay build-up due to cattle access. Scrubby Creek has remnant rainforest species typical of East Gippsland. This riparian vegetation along the creek will be further investigated as it is in very good condition and deliberate protection may attract funding support. Little is known of the cave biota but this needs studying particularly for any stygofauna.

Figure 4. Scrubby Creek Tufa Terraces

Weed control planning is underway for blackberry, thistle (several species) and horehound etc. This will involve a serious amount of work initially and then will be ongoing.

In October 2012, we had a formal launch on the property to celebrate becoming the new owners. This was attended by adjoining land owners, Buchan community members and VSA and Rimstone members. The East Gippsland MLA for Victoria Mr Tim Bull attended and officially opened the event with an acknowledgement of the part cave tourism contributed to the local community and our part in this. We then had lunch followed by tours of the property including the cave entrance and tufa terraces. In the evening we had a barbeque at Homeleigh and a Scrubby Creek Cave trip the next day. This was all reported in the local community newsletter (Brain, 2012).

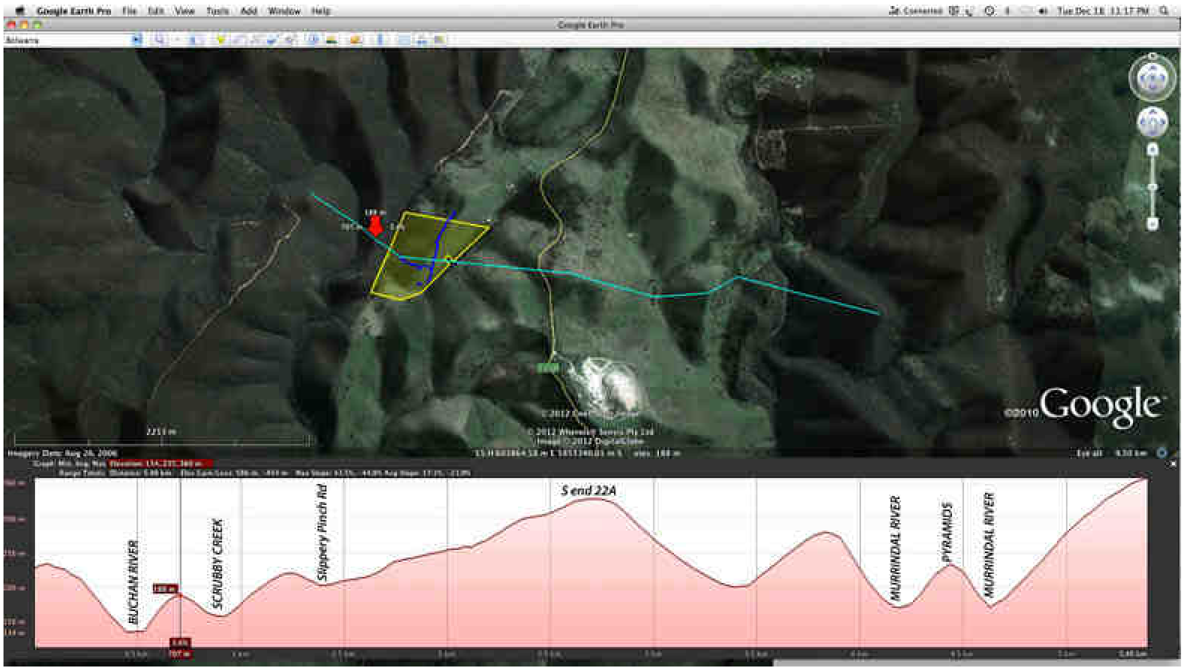
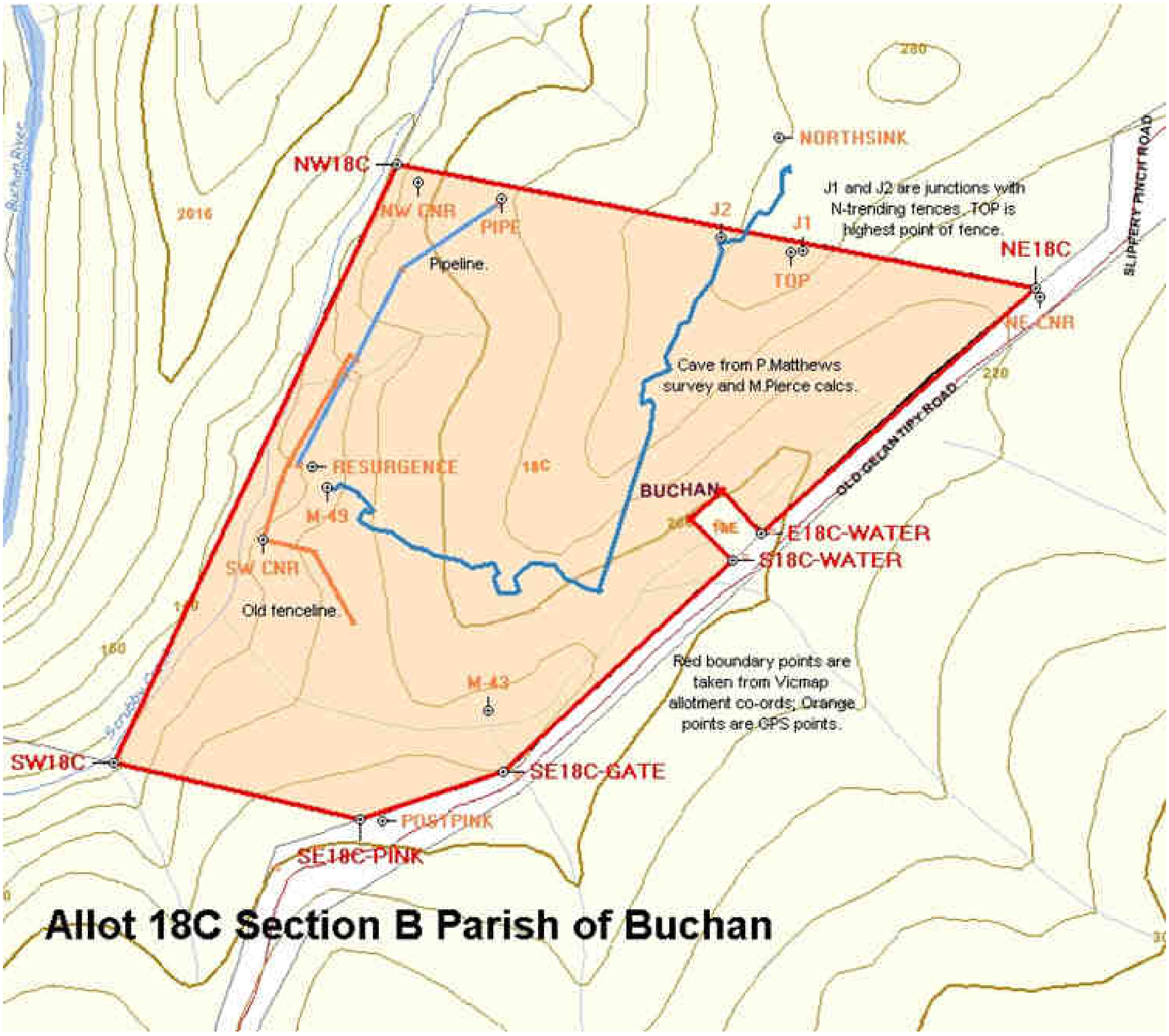


Figure 5. Profile Buchan River to Murrindal River

Reflections on the Acquisition

Before and after becoming Chair of the ASF Conservation Commission, I have made a point of trying to have caves protected. Certainly a large proportion of cave areas have now been reserved around Australia through State Government processes and because of conservation pressures exerted by the caving community and others. This process of adding cave areas to National Parks and Reserves is coming to an end. In Eastern Australia, most arable land was taken up at the time of settlement and this included limestone areas often with significant caves and karst. These areas are now part of the privately owned cave estate.



Scrubby Creek Cave Property with Cave Outline

In USA, the NSS have responded to need by establishing Cave Conservancies (White, 2009). These provide for protecting a range of caves important for recreation but also significantly for their wider cave values such as bat habitat. In Hawaii the Cave Conservancy of Hawaii has been purchasing properties with lava tubes in a serious way with annual purchases of allotments with caves.

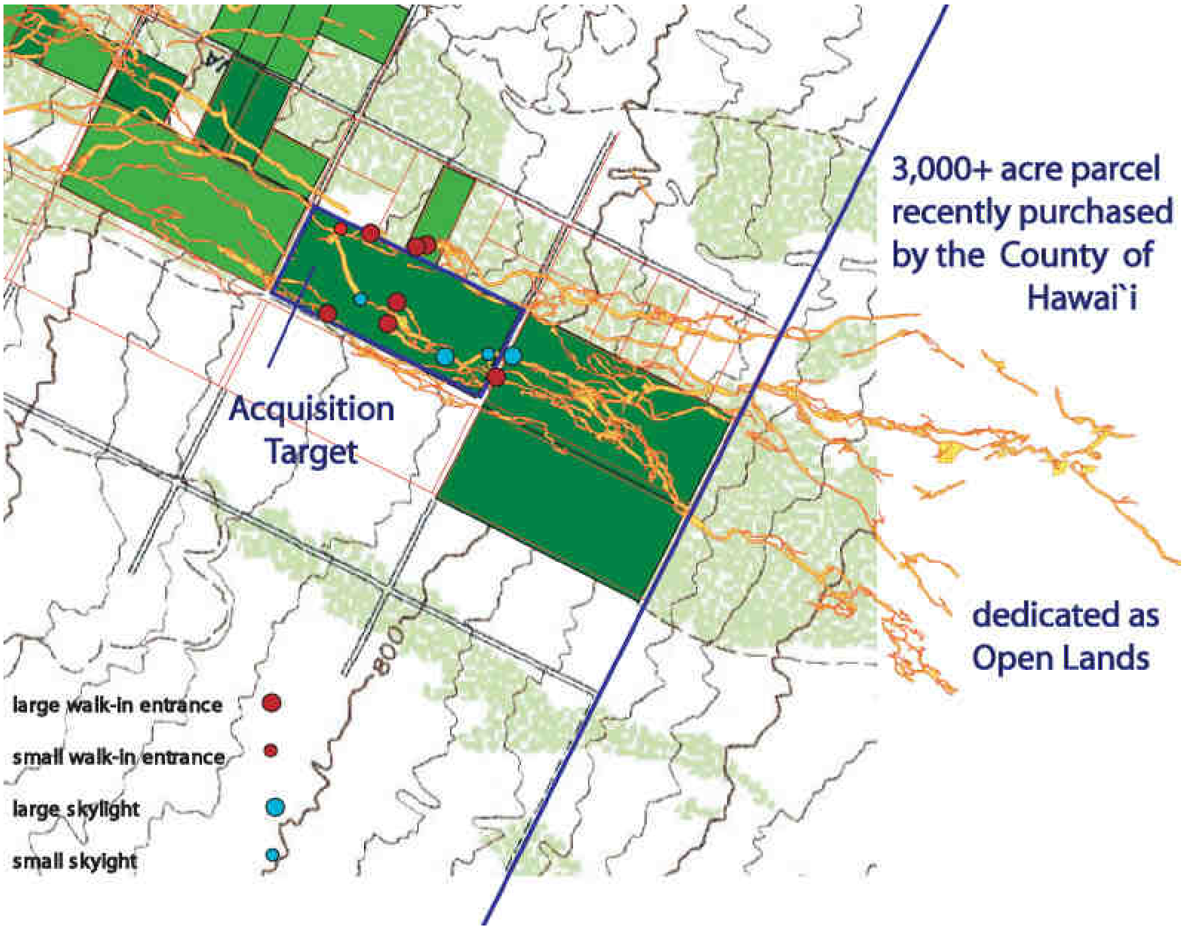


Figure 7. Hawaii, Bigelow Purchase

In Australia, significant privately owned karst areas deserve our attention as it is becoming much more difficult to persuade State Governments that particular pieces of land need acquisition for features such as caves. Sand Cave at Naracoorte was considered for caver acquisition but it was out of our price range. We provided cave information to the Naracoorte Caves staff which enabled the property to be acquired by the State and this property has now been added to the Naracoorte Caves National Park. A significant property at Mt Sebastopol near Kempsey NSW was out of our price bracket but is high on a NSW Government acquisition list. Pungalina Station on which VSA has been exploring caves was purchased by the non-government agency, the Australian Wildlife Conservancy in 2008. Other properties at Mole Creek Tasmania might deserve caver interest. There is a very significant cave property in Western Victoria that warrants evaluation but Victorian cavers need to recover and consolidate after the Scrubby Creek Cave purchase before contemplating another such venture.

I did not expect that having talked up the proposition that cavers acquire caves in Caves Australia in 2009 that it would be Victorian cavers that would be the first to do so. At least we have a very suitable organization in Rimstone Cooperative with the right aims and objectives and the management experience to purchase a cave property. ASF member clubs and ASF itself are now incorporated and can acquire property but as in Victoria it would be extremely useful to have ownership and management of cave properties at arms length from cavers. In fact, during several years of negotiations with Cement Australia regarding part of Mt Etna Quarry in Queensland ASF Inc itself was to be gifted the land on the basis it was not wanted by the Queensland Department of the Environment for addition to the Mt Etna Caves National Park. Details of how ASF was to manage the land were never worked through by ASF because the land was gifted to the State instead of ASF when a Minister before an election asked his Department where in the State could Parks be enlarged or extended.

Conclusion

Rimstone Cooperative Ltd purchased the Scrubby Creek Cave property with the support of its members, cavers, friends and ASF itself. This purchase was a once-a-generation opportunity to acquire it for cave protection and recreation purposes. The chance would have been lost in a matter of weeks without prepared minds able to commit to the project immediately. We still owe money but we have an iconic cave to manage together with the weeds! Acquisition of Scrubby Creek Cave is the first of what should be further purchases to protect caves by the caving community in Australia.

Acknowledgements

The acquisition would not have been possible without the support of Rimstone Cooperative Ltd members, the caving community at large and the support of the ASF's Karst Conservation Fund.

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Digital Media

"A Modern Conundrum in an Ancient Landscape"

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Abstract

The last ten to fifteen years has seen an increase in the use of digital devices to record images. In 2013, it is not uncommon for all family members to be carrying at least one device capable of capturing digital images. This paper will explore what impact, if any, this exponential increase in image generation capability has had on the conduct of a guided show cave tour. It will also seek to explore ways of mitigating any identified impact in order to strike a balance between visitor satisfaction and profitable tour operations with conclusions drawn from personal experiences guiding the Lucas Cave tour at Jenolan Caves.

Key Words: Digital Media
Image Generation
Show Cave
Visitor Satisfaction
Profitable Operations

Introduction

Jenolan Caves, located approximately 180 kilometres west of Sydney in the Greater Blue Mountains World Heritage Area, is an award winning show cave destination. Jenolan Caves has been part of the Australian "psyche" for over 150 years and millions of visitors have visited one or more of the ten guided show cave tours on offer. As such, it would be impossible to even estimate the number of images captured both on film and by digital media. It would be conceivable to say however, that the majority of these images have been captured in the last 10 years by digital media. Personal experience from twenty years of guiding tours at Jenolan Caves has shown that despite a decrease in the number of visitors on a Lucas tour (from 75 to 60), it can often take longer to complete the tour with much of this slowdown attributable to an increase in the use of digital media. On a recent tour of the Lucas Cave, 28 visitors had 35 devices between them capable of capturing digital images. These devices included phones, cameras and tablets.

The Early Years

For an excellent account of the early days of photography at Jenolan Caves, the 2010 publication "*Click go the Cameras at Jenolan Caves 1860-1940*" by Elery Hamilton Smith (Hamilton-Smith, 2010) is recommended reading. This publication outlines the development of photographic services at Jenolan that were offered by various commercial operators and contains an excellent selection of the early works of photographers such as Charles Kerry and Frank Hurley.

A popular souvenir of a visit to Jenolan Caves was a group photo taken at Hartley Court House with the driver and his Charabanc (an early form of open topped motor coach).

This was only the beginning of things to come however...

The Post War Years

The decades following the Second World War saw an increase in visitation to Jenolan Caves as more people could afford to travel. To cater for the needs of photographers, special photographic inspections were conducted at 11.00am and 4.00pm. These tours however, were phased out by the 1960's. Camera technology evolved and by the mid 1960's, small compact cameras were affordable for the majority of visitors and were commonplace on tours (B. Richard, pers. comm. 2013). A downside of these cameras however, was the external removable "flash cube" which, once expended, was often discarded along the pathways within the caves. A large number of these were located in the Lucas Cave by Dan Cove and Russell Commins during the relighting project in 2003-2004 (D. Cove, pers. comm. 2013).

During a fifth class school visit to the Lucas Cave in 1977 as an 11 year old, my mother would only buy me one four shot cube as she wanted me to take photos of places other than Jenolan Caves. The wisdom of mothers as none of the four photos taken in the cave turned out...

Early experiences as a Guide

I commenced guiding at Jenolan Caves on Boxing Day 1993. At the time the Lucas Cave had a limit of 75 visitors although I would often take 80-90 people on a tour. Even so, it was still possible to visit the well decorated Mafeking Chamber and finish the tour on time.

On tours, it was common for visitors to ask what scenes they should save their remaining photos for given that most rolls of film were either 12, 24 or 36 exposures. In addition, a typical family would only have one camera. Popular photographic subjects in the Lucas Cave included the Cathedral Windows, the Lace Curtain, Mafeking, the Pink and White Terraces, Underground River and the Coloured Lights in the Bone Cave – a typical average of six photos only. I would also offer to take photos of visitors with the Lace Curtain as a backdrop; which was an offer which many people availed of.

The Digital Revolution

In the space of the last 10 to 15 years, the capturing of images of the Lucas Cave has changed significantly. From a film roll of 36 where possibly 6 photos may have been allocated to the Lucas Cave, the introduction of digital cameras and the San Disk (SD) Card, amongst other devices, has allowed almost unlimited generation of images. For example, on my own digital camera, a 4GB SD card can conceivably hold 2700 images dependant on the pixel setting. This has allowed visitors the ability to capture more of the cave but – to what extent has this impacted on the tour?

Impacts on Tours

So the obvious question is – what impacts has the increasing use of digital media had on the conduct of a guided cave tour and what are the ramifications, if any, for managers/owners of these sites? The following potential impacts have been identified:-

- Perceived slowing of tours.
  Nowhere is this more evident than in the Lucas Cave where ten years ago a tour could be completed with 75 clients where as now it can be a struggle with a number reduction to 60. This may cause tours to run overtime with clients possibly missing other tours or even coach connections. This may detract from the reputation of a site.
- Blocking Pathways.
  With an almost unlimited ability to take photographs, visitors will often stop in narrow sections to take photographs with little regard paid to fellow visitors. The guide may be placed in a situation where they are continually asking the group to move on (getting visitors to move into the Anteroom in the Lucas Cave is a prime example) which may cause the group to perceive the guide/site in a negative manner.
- Guest irritation with photographers.
  Guests may become irritated with photographers without purpose taking photos of non subject specific matter. In other words, people taking excess photos (for example "selfies") simply because they can. This may create a negative impact in the minds of visitors of a site. However, it should be pointed out that photos of family members are important in many cultures.
- Excessive use of flash.
  This can have several ramifications. Firstly, it can reduce the ability of the guide to present the cave as there is an excess of light generated by digital devices. Secondly, clients can use this excess light to move forward from the group, risking injury to not only themselves but also the resource. Thirdly, clients may inadvertently fire the flash in the eyes of visitors and/or guides creating possible safety issues.
- Trip Hazards.
  Visitors looking at the cave/site through the view finder may trip and fall, risking injury to themselves and/or the resource. This could lead to compensation claims.
- Inattention to Commentary.
  How often have you just spent five minutes explaining cave geology only to have a visitor who has been taking excess photos ask you – How does a cave form? Clients may also miss important safety information from the guide.
- Photo Editing
  Many clients will edit their photos during the tour, either to delete failed photos or often to remove photos to make room for new ones. Again, this can delay tours unnecessarily.

These are just some of the impacts that have been identified that can potentially affect a tour and, given the right circumstances, could also have more serious consequences for cave managers/site owners. Before discussing what can possibly be done about mitigating these impacts, perhaps it would be best to look at policies (if any) in place at other cave sites.

Photographic Policy at other Cave Sites

Discussion with colleagues at Jenolan Caves and at other sites has indicated the following policies are in place:-

Mole Creek Caves

Haydn Stedman of Mole Creek Caves in Tasmania advises that they do not have an official policy regarding the use of digital devices on tours. They do not allow tripods and do not allow photography in the glow worm areas. They allow visitors a reasonable amount of time before they turn the lights out (H. Stedman, pers. comm. 2013).

Naracoorte Caves

Frank Bromley of Naracoorte Caves in South Australia advises they too do not have any official policy regarding digital device use. They do ask people to stand still when recording. Frank also advised that video recordings were banned in the past but that rule was discontinued due to all devices now being able to record (F. Bromley, pers. comm. 2013).

Wellington Caves

Barry Kelly of Wellington Caves advised that they have no specific policy. (B. Kelly, pers. comm. 2013).

Cave Works

Supervisor Heidi of Cave Works in Western Australia advised that they have no ban other than the use of tripods. On larger tours they ask visitors to restrict photography to the main platforms only. (Heidi, pers. comm. 2013).

Mammoth Cave National Park

The policy in place at Mammoth Cave National Park in Kentucky USA when I participated in a guide exchange in 2001 was no video recording. This policy was in place before the increase in the use of digital devices so it would be interesting to find out if this policy has been modified since then.

Jeita Caves

ACKMA member Dr. Julia James advises that Jeita Caves in Lebanon has a strict no cameras policy and even goes so far as to provide lockers for people to store cameras. (Dr. J. James, pers. comm. 2013).

The Spanish Experience

ACKMA member and Jenolan Guide Sasa Kennedy advised the following from her recent travels in Spain (S. Kennedy, pers. comm. 2013):-

- Grotte de la Maravilles - No photos allowed
- Cueva de la Pileta - No photos allowed
- Cueva de la Nerja - Photos allowed but no flash

Has anyone ever been told you cannot take a flash photo in a cave as it will fade the formations?

The Jenolan Policy

Other than a ban on tripods on tours, Jenolan does not have a firm policy regarding the use of cameras on tours. Various guides do ask people to be mindful of their camera use at the start of and during their tours. At the start of my Lucas tours I request the cooperation of visitors not to take photos in the narrower sections of the cave and advise them that there will be times on the tour where I will ask for all devices to be turned off for presentation reasons (cave darkness and the music presentation in the Cathedral). Generally I receive a good level of cooperation from visitors.

What can we do about it?

What can we do, as cave managers/guides about this exponential increase in digital device use? Perhaps the most obvious answer is to accept the status quo; that is to accept the problem which leads to the obvious question – does anyone not see a problem? This would appear to be the easiest and least confrontational solution. This will of course require tolerance and acceptance on behalf of both guides and management as we need to bear in mind that the overriding factor is the satisfaction of our guests as it is after all their experience.

The following however, may be alternative solutions/suggestions with any potential issues arising noted:-

- Ask visitors to restrict photographs to the main platforms only.
- Decrease tour commentary to accommodate more photography time.

This could however, lead to a decreased perception of the professionalism of a tour/site.

- Give visitors a ten second warning and then turn the lights out in order to move on.
- Take photos and sell them to visitors.
  This was the practice in 1988 at The Lost Sea in Tennessee but had been discontinued upon my return visit in 2000. When I asked the guide why he stated that there are now too many cameras in groups! A similar set up was trialled at Jenolan Caves in the late 1990's in the Lucas Cave but was not a success with a very limited uptake by clients. We do however, take photos of visitors on our Plughole Adventure Tour which they can download for free from the Media Fire website and this is a popular value added service.
- Ban the taking of photos altogether.
  This would solve the problem but would be almost impossible to police in this digital age and would of course lead to customer dissatisfaction and a possible reduction in visitor numbers.
- Specialist Photographic Tours.
  Would visitors be willing to pay the price required to offer such tours?
- Reduce Tour Numbers.
  This may be an option but could result in increased costs and possible reduced viability for the business as extra staff would need to be employed.

There is no easy solution and what could work at one site may not necessarily work at another site. Perhaps the time has come for cave sites to develop a digital media use policy in conjunction with an organisation such as ACKMA or ISCA (International Show Caves Association).

Conclusion

The capturing of images at Jenolan Caves is not a recent phenomenon; from the days of Kerry and Hurley to the current digital age, photography has always been an intrinsic part of the cave tour experience. While this paper has documented the issues and impacts that the increasing use of digital media can have on tours and business success, it has also explored several ways for potential mitigation of these. A cave visit can mean various things to different people and cultures and as guides/managers, we need to be adaptive and take these factors into consideration during our presentations. As cave managers/owners we also need to be mindful of the benefits that these images will bring for us in the form of promotion of our sites. As the saying goes – a picture is worth a thousand words. However, the issue is perhaps best summarised by Jenolan Caves guide Tina who said "*as people can take almost limitless numbers of photographs to document their experience, they may in fact be missing their experience through their own actions. However, perhaps as guides we need to be accepting that photographs of their visit will provide meaningful memories for them*". (T. Willmore, pers. comm. 2013).

Who knows where technology will take us in the future...

Acknowledgements

After returning home to Australia I downloaded my SD card to the Harvey Norman photo lab – all 1359 photos...!!! After eight hours and jamming their system four times, 1242 photos eventually ended up in my photo albums. Photos are a great way of documenting your travels and it is certainly much easier (and cheaper) than even 20 years ago to do so.

Sure enough, on my first public Lucas Cave tour upon my return to Jenolan, I had five "escapees" who used their camera lights to move ahead through the cave and catch up with the group that was half an hour in front...!!!

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Abstracts only

Australasian tourism market forces and the triple bottom line

Dave Bamford, TRC Tourism

An overview of key market influences, such as the Global Financial Crisis, and key markets, including emerging markets from countries such as China and India. The role of markets in tourism including the domestic, nature and adventure, cruise, and conference markets.

Creating Unforgettable Holidays – Profitably

Grant Webster, Tourism Holdings Ltd

In an industry that struggles to deliver above cost of capital returns, how do we continue to deliver to the customer?

The Waitomo Glowworm Cave - providing for its people

Peter Douglas, Ruapuha Uekaha Hapu Trust

A review of the recent history of the Waitomo Glowworm Cave and the ownership role of the Ruapuha Uekaha Hapu Trust. The issues and challenges facing the Trust and its future direction.

Geological background of karst in New Zealand

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Zealandia is a piece of Gondwana, about one-third the size of Australia, but most of its continental crust is underwater as submarine plateaux. The emergent part, New Zealand, covers about the same area as Victoria plus Tasmania, and carbonate rocks occupy about 3% of its area (compared to 4.7% in Australia). So karst is scarce in NZ, making its conservation all the more important. Before the present Australia-Pacific plate boundary was established at the end of the Cretaceous Period, about 80 Ma ago, Zealandia had been eroded almost to sea level. By 60 Ma the Tasman Sea had reached its full extent, the oceanic crust was cooling and the subsiding sea floor drew down the land, such that by 35 Ma only small low islands protruded above sea level. The sinking continental crust first accumulated estuarine sediments, then sheets of shell fragments, silty sandstones and mudstones. Deep burial compressed the shell layers into limestones. Sediment accumulation ended in the late Miocene-Pliocene once the present plate boundary was established and resulted in convergence and uplift. Uplift started about 15 Ma and accelerated around 5 Ma. This resulted in the emergence of tilted blocks of country bounded by faults. Erosion commenced immediately uplift occurred, so the marine sediments were dissected as they were uplifted. This removed most of the Tertiary sediments from the highest country leaving fragments round the edges where uplift was less intense. Consequently, there are remnant patches of Oligo-, Mio-, and Plio-cene limestones in many parts of the country, predominantly located on the flanks of ranges but sometimes found to 1500 m. These carbonates range from a few 10s to 700m in thickness. In some places, exhumation of the eroded basement has revealed more ancient carbonates, including marble bands in Fiordland and especially NW Nelson where they attain up to 1000 m in thickness and occur to 1875m above sea level.

Most karst development has taken place in New Zealand since plate convergence generated uplift, mainly over the last 5 Ma and especially in the last 1 Ma. By the early Pleistocene the Southern Alps began to form and gravel accumulations started to develop the Canterbury Plains. During uplift the Cenozoic marine sediments were simultaneously eroded leaving the remnant patches we see today. In NW Nelson the Ordovician marbles were re-exposed and our greatest caves (to 1026 m deep; to 67.2 km long) started to develop, a process that still continues. In western North Island, near Waitomo, the Oligocene-Miocene limestones were exposed in places by the early Pleistocene, but the evolving karst was overwhelmed about 1.25 Ma ago by a vast thickness of ignimbrite from the central volcanic zone. This has now been largely stripped off and karstification has resumed. Most caves in the Waitomo region are probably less than 250,000 years old. Meanwhile in eastern North Island marine shelly limestones of Plio-Pleistocene age were uplifted only about 1 Ma ago and these thin young limestones have been karstified only in the last 10,000 years or so.

Going Deeper - the Quadruple Bottom Line – People, Planet, Profit, *Papatūānuku*'

Daniel Hikuroa, University of Auckland, Research Director Nga Pae o te Maramatanga/NZ's Indigenous Centre of Research Excellence

The conference theme is 'the triple bottom line'. Also known as 'people, planet, profit' – triple bottom line is a framework for looking at social and environmental outcomes, as well as financial outcomes – in short sustainability. More broadly for us, what does cave tourism really deliver for its stakeholders – financially, environmentally and socially? But can we go deeper? – to incorporate the fourth dimension, articulated in the title as *Papatūānuku*', but representing culture. Quadruple bottom line reporting requires an organisation to be responsible and accountable to all **stake**holders of an organisation, not just the **share**holders. The stakeholders of an organisation are anyone who is affected by the business activities of a company including shareholders, customers, employees and suppliers. The difficulty faced by many organisations is how to accurately reflect that responsibility and account for cultural values and other outcomes (social and environmental) in a cost benefit analysis. The assumption is that all four outcomes can have a quantifiable financial assessment to determine if they have been effective or not. I propose that money is not a useful measure of sustainability, and that there might another concept that could be applied – mauri.

Exploring cultural heritage values of karst: the development of indigenous interpretation Jenolan caves

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Cave and karst areas have been important cultural sites throughout human history and prehistory. The interpretation of the cultural values of karst has often been seen as automatically secondary to the geological or other scientific values. At Jenolan Caves, NSW Australia, there was traditionally limited interpretation and little to no available information regarding the long association of Aboriginal tribal groups with the local area. The past 18 months has seen the development of a collaboration between the Jenolan Caves Reserve Trust and the Gundungurra Tribal Council which has led to the development of several new products including a self guided cave tour and surface walk both available as smart-phone apps. This collaboration has also dramatically improved general understanding of the connection of local Aboriginal peoples to the Jenolan area and to the cave system.

What Waitomo speleothems tell us about environmental change

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The most important information that speleothems can reveal is about climate. These days we hear a lot about climate change and what's likely to happen in the near future, but most evidence is derived from the Northern Hemisphere and we're not sure if predictions really apply downunder. So we need to determine if known NH climate events (like the Medieval Warm Period and Little Ice Age) are found in the SH. If this can be confirmed then it increases the likelihood that climate predictions will apply to both hemisphere – even if there are leads or lags in events. To reach unambiguous conclusions about this we need well dated high resolution data from the SH that can be compared to data of similar quality from the NH. The best interval to examine is the last 2000 years, because that's when the NH has its most accurate historical data and it's also the period of most relevance to our near future. This contribution will therefore focus on evidence from a 29.4 mm long section of a small stalagmite from Waitomo that grew from 59 BC to 2005 AD. It shows that temperature changes at Waitomo have been generally asynchronous with respect to the NH, except in the 20th Century when warming occurred in both hemispheres. Recent 'global warming' started in Waitomo about 1913 (25 years later than in the NH), but both the amount and rate of warming through last century was not unusual in the context of the last 2 millennia. It was about as warm and sometimes warmer around 1840, 1380 and 750 AD. The general conclusion is that on a centennial scale the SH and NH are generally out of phase, except in the 20th Century when global warming affected us both. although starting slightly later and being less severe (so far?) in NZ.

Dong Thiên Đường (aka Paradise Cave), a new world class show cave in north-central Vietnam

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During October-November 2012, Arthur Clarke and Siobhan Carter joined a group of American cavers on a specialist tour of wilderness caves and show caves in remote areas of central and southeast Laos and northern Vietnam. Promoted as "Focused Tours", run by Dwight Deal and Mary Fletcher, a highlight of their recent karst cave tour was the visit to Dong Thiên Đường (aka Paradise Cave) in the Phong Nha-Kẻ Bàng National Park of north-central Vietnam. Situated near the west branch of Ho Chi Minh Highway in the Quang Binh Province of north-central Vietnam, the park itself is quite remote nestled beside the small township of Son Trach and several smaller villages including the adjacent Phong Nha. Lying about 42km inland (west) from the South China Sea, by road it is about 500 km south of Hanoi and 260 km north of the port city of Đà Nẵng. The Phong Nha-Kẻ Bàng National Park is adjoins the Hin Namno Nature Reserve in Khammouan, in neighbouring Laos. Both regions contain zones of karstified limestone, each area being approx. 2,000 km². Listed in 2003 as a UNESCO World Heritage Area (WHA), the karst of the Phong Nha-Ke Bang National Park was first recommended for WHA nomination by one of ACKMA's founders and luminaries: Elery Hamilton-Smith. The national park derives its name from its magnificent Phong Nha Cave and its unique, biodiversity rich, Kẻ Bàng forest.

Aside from the historically known Phong Nha Cave, where tourists visit the huge, highly decorated chambers via motorised "dragon boats", the national park is particularly known for its Hang Vòm cave system and the more recently discovered Hang Sơn Đoòng. Commonly known as Sơn Đoòng, with its main chamber over five kilometres in length, 200 metres high and 150 metres wide, it has taken the title of the world's largest cave chamber away from Deer Cave in Sarawak. Prior to the 2009 discovery of Hang Sơn Đoòng (in Vietnamese: meaning Mountain River Cave), the Hang Vòm cave system was the largest and longest known cave in the Phong Nha-Kẻ Bàng park. Led by Howard Limbert, Son Trach resident and British ex-pat, the exploration of the Hang Vòm system commenced in 1990; the length now exceeds 35km.

Located at an elevation of 200m, the Dong Thiên Đường (Paradise Cave) entrance to the Hang Vòm system was discovered in 2005. The entrance chamber is 150m wide and 100m high with some of the massive stalagmite formations extending almost to the rooftop. Paradise Cave (Thiên Đường in Vietnamese) was opened for tourism on 3rd September 2010; with reportedly multi-million dollar expenditure, the site was sensitively developed in a very short period of time. From the vehicle park, tourists are taken by battery-operated golf car buggies 1.6km to the gathering place where a gently graded wheelchair pathway or steps climb 100m to the cave mouth reception and kiosk. Entry to Dong Thiên Đường costs 120,000dong (about AUS$6.00; NZ$7.00). The standard commercial tour of the first 1.1km of this massive cave is self-guided along well designed elevated walkways with viewing platforms all with good railings to contain the visitors and well lit with state-of-the-art LED lighting (and no coloured lights). From the far end of the walkway, an adventure caving option provides the opportunity for adequately equipped visitors to have a guided "wild cave" experience going a further 6km into the Hang Vòm system. Continuing along the silty clay and sandy floor, you pass through massive 40-100m high chambers and 300-400m long straight passages, crossing small creeks and wading shallow pools, walking to the Vom Grotto with its sandy beach below the 255m deep "Daylight Beckons" (Tang Hole) skylight shaft. The round trip including the developed show cave section is about 14km, with lunch and bottled water provided at the halfway point, below the "Daylight Beckons" shaft.

The International Union of Speleology

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The International Union of Speleology has now been in existence for over 60 years. The first International Congress of Speleology was in France in 1953. Since that time there has been a International Congress of Speleology every four years, in fourteen different countries. It was in the USA in both 1981 and 2009.
The next Congress is in Brno, Czech Republic on 20th to 28th July 2013. The International Union has a Management Bureau of thirteen people. Under the umbrella of the organisation come a number of working Commissions with such titles as, volcanic caves, hydrogeology, speleogenesis etc. There is currently a list of nearly thirty Commissions, some are more active than others, associated organisations to the UIS is, the International Show Caves Association which is also associated with ACKMA.
More recently regional bodies have been formed, including Central America and Europe.

The structure of aquatic macro-invertebrate communities within cave streams

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Cave aquatic macroinvertebrate communities are structured by a host of abiotic and biotic factors unique to their environment resulting in variations between cave and surface aquatic communities. Primarily, cave stream invertebrate communities are presumed to be resource limited with a dependence upon surface-derived energy resources, such as FPOM and CPOM. This dependence upon surface derived energy was assessed down a longitudinal gradient within a cave stream using stable isotopes of carbon and nitrogen, pre-conditioned replicate algal tiles, and leaf packs. Furthermore, I investigated the potential for cave aquatic communities to subsidise subterranean terrestrial communities. Resource additions and stable isotopes confirmed that cave aquatic communities were resource limited and dependent upon surface derived materials, with an isotopic signature similar to that of C3 plants. Seston, benthic FPOM, and epilithon (i.e. bacterial, fungal, and diatom communities) were the most important basal resources within the cave, compared with seston, benthic FPOM, and filamentous algae outside of the cave. CPOM did not appear to be readily incorporated into the food-web. Furthermore, in the absence of an alternative carbon source aquatic derived energy would seem to support subterranean terrestrial predators, such as glow-worms, harvestmen, and spiders. Therefore, both aquatic and terrestrial cave invertebrate communities, including the iconic glow-worm populations, were supported by surface originating organic material, intricately linking their health to that of the surface system, leaving cave communities vulnerable to surface land-use changes.

Towards managing the carbon dioxide partial pressure in caves with both anthropogenic and non anthropogenic sources

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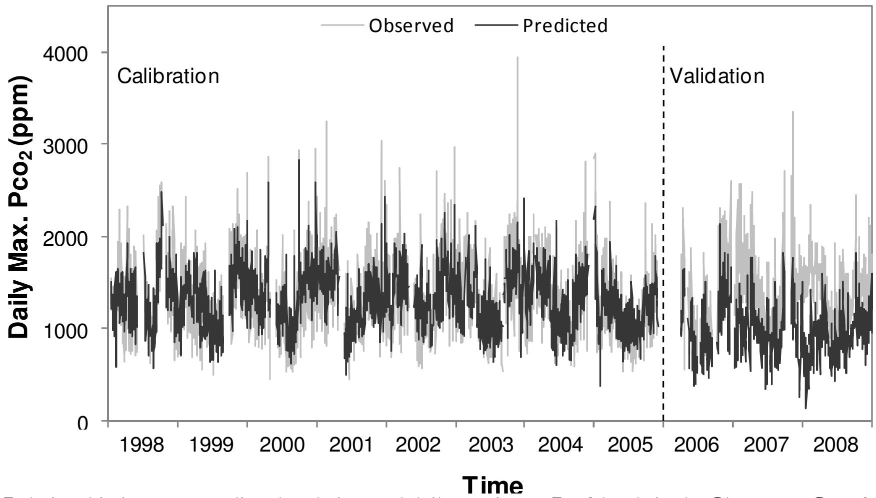
Based on historic data operators of the three Waitomo tourist caves (Glowworm, Ruakuri and Aranui) have been required to maintain the partial pressure of carbon dioxide in the cave atmospheres to less than 2400 $ppm_{(v)}$. Ten minute monitoring since 1998 has shown most exceedances of this limit has come from visitor respiration and exceedances have mostly been avoided in recent years by careful management of visitor numbers and passive ventilation. However one or two exceedances have occurred each year when no visitors were present. Non anthropogenic sources of high carbon dioxide partial pressures were observed in glowworm cave following periods of intense rainfall with exhalation from both stream and drip waters. A linear regression model involving the previous day mean P_{CO2} tourist numbers, temperature gradients, rainfall and Waitomo Stream discharge successfully predicted the daily maximum P_{CO2} for Glowworm Cave.



Relationship between predicted and observed daily maximum Pco2 levels in the Glowworm Cave for the calibration period 1998 – 2005 (R2 = 0.56; Nash-Sutcliffe = 0.56) and the validation period 2006 – 2008.

Ruakuri Cave showed a different problem with a side passage (Drum Passage), into which a newly constructed entrance was placed, regularly displaying continuously rising P_{CO2} when outside temperatures exceeded cave temperatures throughout the diurnal cycle. A natural source of undersaturated infiltration waters containing at least 6000 $ppm_{(v)}$ appears to be active. Management of this can be achieved increasing ventilation.

Cave science: sampling for science in caves

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Calcite speleothems have become a significant component of research into past environments, especially climate research. A particular strength of speleothems in this regard is their unique ability to be accurately dated over a long period of geological time by either U/Th or U/Pb dating techniques. Stalagmites are also useful as they contain a range of climatic and environmental proxies such as oxygen and carbon isotopes, trace cations and organic compounds. How can such scientific sampling be managed and what restraints need to be placed? Do we want or need the science? Speleologists and cave managers cannot ignore the pressures for samples and need to understand the valid requirements of the science whilst balancing the need for good cave management. If we understand in general terms why particular numbers of samples are required, we will gain the best from the science without seriously damaging caves. This presentation will look at issues relating to cave conservation and makes some suggestions regarding scientific sampling, publication and use of science.

People, Planet, Profit…Palaeontology!

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Palaeontology – the study of ancient life – has long been a fascinating subject for young and old. Interest in bones and fossils has skyrocketed over the past decade as documentaries, books and popular films bring the past to life (what modern child does not know the animated Ice Age films?). Cave systems are natural repositories for collection of bones, and the constant temperature and humidity permit excellent preservation of past life in karst areas. Cave palaeontology can teach us much about our world: the past, present and perhaps even the future (importantly, distributions of animal species through periods of climate change).

Cave products reflect the significance of the area, and include cultural, geological and palaeontological values. Jenolan Caves is moving forward from a past focus on crystal, with more than one string to its bow. Today's savvy visitors want more. The palaeontological record tells a story, one that not only enthrals visitors but lends itself to development of targeted tours, activities and programs. Palaeontology provides a popular conduit bringing current scientific ideas/cave science to a broad audience. Naracoorte Caves in South Australia is internationally recognised for its remarkable fossil deposits and has parlayed this into a highly successful caves operation. However, although Jenolan Caves boasts many superlatives, including the discovery that Jenolan has some of the oldest open dated caves on earth, palaeontology has never been adequately explored over the years. My aims as a vertebrate palaeontologist working at Jenolan include the discovery of potentially rich fossil deposits, identification of this material and publication of results to a wide audience, adding a deeper level of interpretation and scientific integrity to the Jenolan visitor experience.

All aspects of the 'Jenolan experience' have commercial value, and in recent years Jenolan has become increasingly more mainstream. Palaeontology is undeniably a major drawcard. To that end, Jenolan is incorporating palaeontology into forward marketing plans as one of three main initiatives for 2013-2014. Plans include palaeontology-themed activities and tours (Musser, 2012), palaeo-themed product lines and production of peer-reviewed scientific publications on cave fossils (Australian Ice Age megafauna). One of the highlights of the program will be the re-opening of the Nettle Cave 'dig', a highly significant deposit of small mammal bones collected under an owl roost along the path of the complimentary self-guided Nettle Cave tour. Interaction between palaeontologist and visitor will provide a unique opportunity to engage in 'live science', establishing a vital connection for visitors to our past, re-energising the visitor experience and encouraging repeat visitation – 'win'win' for people, profits and palaeontology.

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The Auckland Lava Caves

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Auckland is a city of almost 2 million built on 50 recent basalt volcanoes. These have lava tube forming flows, and have produced more than 100 caves. Aside from the obvious interest of the caves, there is the association of caves with the various civilisations that have lived on top of them from the original Maori to modern suburbia. The effects of developers, bulldozers and sporadic council protection will be discussed along with a little geology to set the scene.

Conference acknowledgements and introduction

Welcome to the Conference

Our conference organising committee welcomes you to Waitomo Caves 20th Australasian Cave and Karst Management Conference. We have had a great deal of pleasure designing this conference for you. We hope we have been able to create a programme that follows all the well-established traditions of ACKMA conferences but gives you a truly Waitomo flavoured experience.

For those who are visiting for the first time, we hope you begin to feel at home very quickly. Waitomo is a small village and everything you need can be found within a short walking distance. We are a friendly bunch and by the time you leave here you will probably know most of us quite well.

For those returning, welcome back. I'm sure you will notice some changes. We have gained some impressive new buildings at Waitomo Glowworm Cave and sadly we have lost an old friend with our local Tavern burning down. You may notice some new tours and activities too. Happily Waitomo has experienced an upward trend with new business and some reinvigorated older ones bringing more employment and new people to the district.

Our choice of Triple Bottom Line (People, Profit, Place) as a conference theme is a way of expressing our way of life in Waitomo and our optimism for the future. Cave tourism here is firmly rooted in private business enterprise, we all look towards encouraging lots of visitation and a healthy profit. Some of the caves we operate from are privately owned under farmland, some by hapu and some are publicly owned and administered by the Department of Conservation. No matter who owns them we are all very aware of the need to look after our precious karst environment for the benefit of ourselves and future generations.

Lastly we all have great pride and confidence being part of this wonderful community and look towards a shared future in Waitomo. The Triple bottom line theme lets us introduce ourselves to you and gives us scope for self-reflection as we show you around our region.

Our enthusiasm for putting this conference together is demonstrated by the size of our committee, I would like to say it has been a pleasure to work alongside friends and neighbours to bring this conference together.

- Conference Organising Committee

Acknowledgements - Support for the conference

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• Background information	Chris Hendy and Cam Nelson, University of Waikato
• Caveworld	Ross Barnes, cave tours
• Waitomo Adventures	Nick Andreef, cave tours
• Dave Williams	Hotel tours
• Kiwi Cave Rafting	Simon Hall, cave tours
• Caitlin Ash Trust	Projector
• Waitomo Caves School	PA system
• Tony Green	Maniapoto's Cave
• MacDonald's Lime	Quarry tour
• Otorohanga Museum	Nan Owen
• Helen Fortescue	Organisational assistance

And the organising committee!

Conference Photo, Waitomo Caves, New Zealand (Steve Bourne. photo)

List of delegates

(alphabetically arranged)

1. John Ash
2. Ann Augusteyn
3. Rohana Bell
4. Steven Bourne
5. George Bradford
6. John Brush
7. David Butler
8. Dale Calnin
9. Deborah Carden
10. Siobhan Carter
11. Libby Chandler
12. Peter Chandler
13. Judy Christensen
14. Arthur Clarke
15. Marjorie Coggan
16. Neil Collinson
17. Daniel Cove
18. Travis Cross
19. Peter Crossley
20. Pat Culberg
21. Tony Culberg
22. Brett Dalzell
23. Laura Dawson
24. Geoff Deer
25. Trish Deer
26. Kirsty Dixon
27. Judith Dixon
28. Andy Eavis
29. Kerryann Flohr
30. Grant Gartrell
31. Mark Gibson
32. Matt Gillies
33. Don Haider
34. David Head
35. Gordon Hewson
36. Amanda Hinton
37. Cameron James
38. Assoc. Prof. Dr. Julia James
39. Sasa Kennedy
40. Rich Kersel
41. Moira Lipyeat
42. Hans Loder
43. Greg Martin
44. Derek Mason
45. Ted Matthews
46. Mary McCabe
47. Phillip McGuinn
48. Scott Melton
49. Dr. David Merritt
50. Greg Middleton
51. Ian Millar
52. Dr. Timothy Moulds
53. Dr. Anne Musser
54. Patrick Nykiel
55. Lily Petrovic
56. Cathie Plowman
57. Debbie Ray
58. Barry Richard
59. Regina Roach
60. David Rowling
61. Catherine Sellars
62. Dave Smith
63. Andy Spate
64. Haydn Stedman
65. Lyn Stedman
66. Dirk Stoffels
67. Tim Stokes
68. Angus Stubbs
69. David Summers
70. Tom Summers
71. Robert Tahi
72. Te Maunga Haruru
73. Mary Trayes
74. Troy Watson
75. Rauleigh Webb
76. Samantha Webb
77. Manuwai Wells
78. Jordan Wheeler
79. Nicholas White
80. Susan White
81. Prof. Paul Williams
82. Anne Woodward
83. Phil Woodward
84. David Wools-Cobb
85. Celina Yapp
86. Lucas Zielke