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IMPACT OF A LIMESTONE QUARRY ON AQUATIC CAVE FAUNA AT IDA BAY IN TASMANIA

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A limestone quarrying operation has caused significant adverse impacts to aquatic cave-dwelling fauna at Ida Bay in Tasmania. Changes in water quality (sedimentation, eutrophication, or toxins) and flow regime may be responsible for causing the extinction of fauna in the Bradley Chesterman Cave subsystem. In the Exit Cave subsystem, sedimentation originating from the quarry has altered stream habitats and restricted the distribution of hydrobiid snails. During February 1992, when the quarry was operational, a study showed that snail abundances were significantly lower in sediment-affected streams compared with control streams. After closure of the quarry operation in October 1992 a rehabilitation program has sought to minimise further environmental degradation of the cave system by restoring natural inflow regimes and limiting the further influx of sediment. Continued monitoring of the snail populations now indicates similar abundances between the sediment-affected and control sites. There appear to be seasonal fluctuations in snail abundance, but there is a high degree of variability in the sample data. Continued monitoring in the Eastern and Western Passages of Exit Cave, combined with the monitoring of hydrological parameters, may give a clearer picture of the snail's environmental ecology which will have practical applications for the future conservation, management and human use of the Ida Bay karst system.

INTRODUCTION

The biological importance of the Ida Bay caves has been recognised for at least 100 years, when an article published in *Scientific American* described the spectacular glow-worm display in Mystery Creek Cave (Anon. 1895). Australia's first troglobitic beetle was described from these caves (Lea 1910), and over the years numerous other rare and endemic species have been discovered (Goede 1967; Harrison 1966; Hickman 1958; Hunt *et al.* 1993; Moore 1972; Richards 1964). In excess of 70 species including more than a dozen troglobites have been recorded from Exit Cave alone, and the Ida Bay karst is widely recognised as containing one of the more diverse and significant cave communities in Australia's temperate zone (Richards *et al.* 1976).

Despite listing in recent years of the Ida Bay Karst System on the Register of the World's Natural and Cultural Heritage for its nature conservation values, a limestone quarry operation has already caused significant impacts to some of the caves and their fauna. The impacts include destruction of caves, effects on the karst hydrology, alteration of habitats and extinction of aquatic cave fauna (Eberhard 1990, 1992a; Houshold *et al.* 1990; Kiernan 1992).

This paper summarises the results of studies initiated and supported by the Parks and Wildlife Service, Tasmania, into the impacts of the quarry operation on aquatic cave fauna in two of the Ida Bay karst subsystems. In the first case, at Bradley Chesterman Cave, virtually complete extinction of the aquatic biota has occurred. In the second case, involving part of the Exit Cave subsystem, the distribution and abundance of a species of aquatic snail were monitored in an attempt to assess the 'health' or otherwise of the waterbodies. During February 1992, when the quarry was operational, the biomonitoring results implied that degradation of the karst water resources was occurring. This evidence, along with other clear hydrological and geomorphological impacts (Kiernan 1993), contributed to closure of the quarry by the Federal

Government in October of the same year. After closure of the quarry a rehabilitation program immediately sought to minimise further environmental degradation of the cave system, by restoring natural inflow regimes and limiting the further influx of sediment. Monitoring of the snail populations has continued in tandem with hydrological monitoring studies, both being an integral component of the quarry rehabilitation program and contributing to management-oriented research of the Ida Bay karst system.

THE STUDY AREA

The Ida Bay karst area is located in southern Tasmania (146° 50' E; 43° 28' S), within the Tasmanian Wilderness World Heritage Area.

The present climate is a cool temperate type. The nearest meteorological station is eight kilometres to the north at Hastings, which experiences a mean annual precipitation of 1417 mm and mean daily maximum and minimum temperatures of 16.0° C and 6.1° C respectively (Bureau of Meteorology 1988). Precipitation occurs throughout the year but the wettest period is generally from May/June through to November/December.

Most of the karst area maintains its native vegetation cover, which is wet sclerophyll and rainforest, but selective logging and extraction of limestone have occurred in the past.

The karst is developed in Ordovician limestones (Sharples 1979) which outcrop between 50 and 300 metres above sea level. Cave development is substantial, with more than 140 cave entrances known, and in excess of 20 kilometres of mapped passages occurring within an area of about six square kilometres. Cave types represented include deep vertical shafts that are drained laterally from their base by horizontal stream passages. The caves have a long and complex history of development, with Cainozoic climate change exerting a major influence (Goede 1968). At least one cave fill predates 400 000 years BP (Goede *et al.* 1983), whilst ancient palaeokarst features are exposed in the quarry and in cave passages.

Four karst drainage subsystems have been recognised, the Exit Cave subsystem, Bradley Chesterman Cave subsystem, Loons Cave subsystem, and Arthurs Folly subsystem (Kiernan 1992). The Exit Cave subsystem is the largest of these, with more than 20 kilometres of mapped passages forming a branched network of passages and conduits which collect water from a variety of sources. Major inflow conduits are associated with Mystery Creek Cave, and the Eastern and Western Passages, amongst others. The Eastern Passage drains the water coming from Little Grunt Cave, which in turn collects its water from numerous small inflow points on the eastern side of Marble Hill where the quarry is situated. The catchments of the Western Passage and Mystery Creek Cave remain unaffected by the quarry.

The Bradley Chesterman Cave, Loons Cave, and Arthurs Folly subsystems are considerably smaller in size than the Exit Cave subsystem. They exhibit less complicated hydrologies, with each subsystem consisting of a single major conduit draining a relatively small catchment area. The upper catchment area to Bradley Chesterman Cave abuts upon the catchment to Little Grunt Cave in the vicinity of the Marble Hill - Lune Sugarloaf surface divide. A significant portion of the Bradley Chesterman Cave subsystem underlies the quarry area, whereas the Loons Cave and Arthurs Folly subsystems are not affected (see Figure 1).

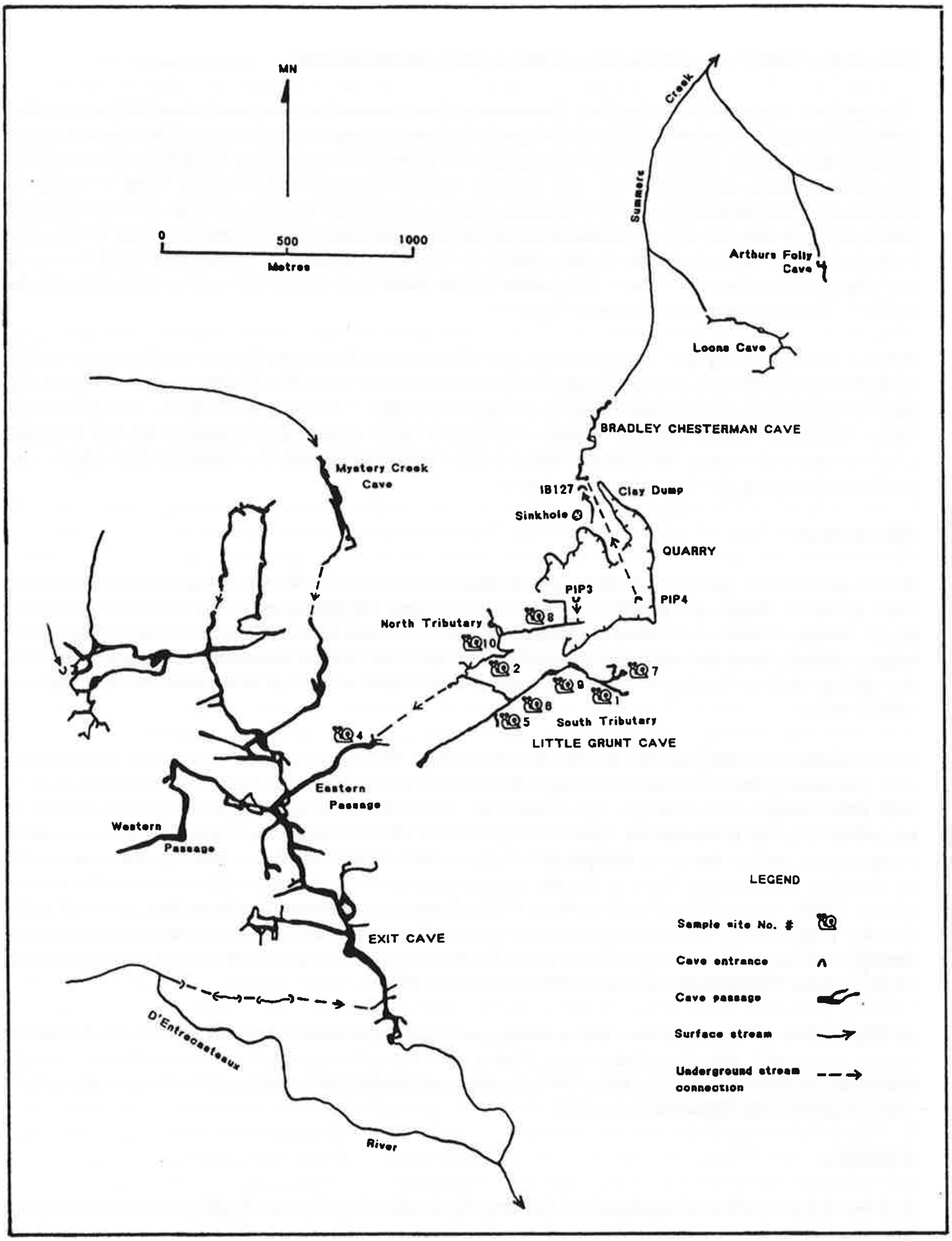


Figure 1. Plan of the Ida Bay karst system showing drainage relationships and locations of sample sites

BRADLEY CHESTERMAN CAVE: AN ECOLOGICAL DISASTER

The outflow entrance to the Bradley Chesterman Cave subsystem is located about 300 metres due north of the quarry working area. A horizontal stream passage extends some 200m linearly south towards the quarry, where the continuation of the passage is blocked by a siphon. Inflow points which have been established by dye tracing include the cave IB127 and a hole exposed by quarrying which is known as PIP4 (Potential Inflow Point No. 4) (Houshold *et al.* 1990; Kiernan 1992). IB127 is situated a short distance down slope of the quarry access road and clay dump, and very close to the known upstream passages in Bradley Chesterman Cave. PIP4 is located on one of the upper quarry benches some 130 metres higher than, and about 700 metres distant from the outflow. These features are shown in Figure 1.

After a rainfall event the stream in Bradley Chesterman Cave can appear highly turbid. The turbidity is due to fine clayey sediments derived from old cave fills being liberated during the quarrying process, and by the siting of a large clay dump in the vicinity of IB127. It is likely that other potential inflow points within the quarry area contribute drainage to the Bradley Chesterman subsystem, including a blind valley/sinkhole behind the weighbridge which was used as a dumping site for fuel and oil drums.

Observations

The impact of the quarry operations on Bradley Chesterman Cave have been evident for more than 20 years. There are reports of sedimentation and oil pollution in the cave, also foul air, faecal contamination and sickness caused to visitors (Clarke 1989b; Kiernan 1973a, 1973b). More recent surveys have corroborated the reports of unnatural rates of sedimentation (Houshold *et al.* op. cit.), as well as finding evidence of eutrophication and extinction of aquatic fauna (Eberhard 1990, 1994b).

One aquatic invertebrate, the Tasmanian Mountain Shrimp (*Anaspides tasmaniae* Thompson), was previously recorded from Bradley Chesterman Cave (Mathews 1985) but searches in 1990 and 1994 failed to observe any specimens. In March 1990, the only aquatic macroinvertebrate recorded was an unidentified species of planarian (Platyhelminthes: Turbellaria), apparently adventitious within the cave, but present there in considerable numbers. The aquatic community in Bradley Chesterman Cave is clearly depauperate when compared with other nearby stream caves. Loons, Little Grunt, and Arthurs Folly Caves, for example, harbour five, six and eight species respectively including planarians, nemertines, molluscs, and crustaceans (syncarids, amphipods, isopods and copepods). These levels of species richness are typical of undisturbed stream caves throughout Tasmania (Eberhard *et al.* 1991).

In September 1994, nearly two years since quarrying operations had ceased and rehabilitation works instigated, the planarians were absent and the only aquatic life observed was a single specimen of an amphipod. In May 1995, many amphipods (*Antipodeus* sp.) and a few planarians were observed (A. Clarke pers. comm.)

Discussion

The most parsimonious explanation for the depletion of species in Bradley Chesterman Cave invokes the severe sedimentation with its modification of benthic habitats, however it is likely that the sedimentation may have worked in synergistic combination with other disturbances which include flow regime changes, eutrophication, and toxins.

A number of recent Australian studies (e.g. Doeg *et al.* 1991; Growns *et al.* 1994; O'Connor *et al.* 1994) implicate sedimentation as a primary cause of stream degradation and faunal decline. The changes in stream communities resulting from sedimentation most widely reported are reductions in species diversity, reductions in biomass and changes in species composition (Campbell *et al.* 1989). Suspended sediment increases invertebrate drift, which is a primary response of invertebrates to the onset of stressful conditions (Doeg *et al. op. cit.*). Suspended sediment may also contribute to the scouring of organisms from their stream-bed habitat during times of high flow (Tebo 1955; Chutter 1969). Sediment which settles on the stream bed can lead to long term deleterious changes to invertebrate populations because benthic invertebrates are highly influenced by substrate type with a sharp distinction occurring between the fauna on hard and soft bottoms (Hynes 1970). Deposited sediment may penetrate deep into the stream bed eliminating, or at least severely modifying, the interstitial habitat (Campbell *et al.* op. cit.).

In addition to sedimentation impacts, stripping of the native forest and soil cover consequent upon quarrying activities has caused significant hydrological changes within the cave catchment, particularly an increase in water yield (Kiernan 1988). The extensive areas of bare rock surfaces within the quarry result in very rapid run-off after a precipitation event, which has increased both the flashiness and peak discharge of the stream into the cave, and increased the aggressivity of the water during high flows (Houshold *et al.* 1990).

Eutrophication of the stream in Bradley Chesterman Cave was suggested by the presence of growths of ragged, brown hair-like filaments which resembled 'sewage fungus', a term used to refer collectively to a variety of microorganisms (bacteria and fungi) that characteristically associate under conditions of gross organic pollution (Bayly *et al.* 1981). A decrease in species diversity is a general effect of organic pollution of inland waters, whilst concomitantly, there will often be an increase in abundance of one or a few species which are tolerant to the effects of pollution (Bailey *et al. op. cit.*). This is consistent with the great abundance of planarians but complete absence of other species observed in Bradley Chesterman Cave when the quarry was operational. A similar occurrence has been documented in the U.S.A., where Holsinger (1966) found an exceedingly large population of planarians and isopods in an organically polluted cave. On a scale of 1 to 10, planarians are given a pollution sensitivity grading of 3 by Chessman (1995), which indicates a high tolerance to common types of pollutants. Similarly, Growns *et al.* (1994) recorded an increase in abundance of platyhelminths [presumably planarians] after disturbance by clearfelling in south-western Australia, although in this case the disturbance was an increase in suspended sediment rather than organic enrichment.

Organic and inorganic poisons are particularly toxic to aquatic life (Bayly *et al.* 1981), so the petroleum hydrocarbons dumped in the weighbridge sinkhole may also have been involved with elimination of the original aquatic community in Bradley Chesterman Cave. Mine effluents which include heavy metals have caused serious impacts to river communities elsewhere in Tasmania (Norris *et al.* 1982; Swain *et al.* 1985). In the USA, toxicant leaks including gasoline have caused massive kills of subterranean aquatic organisms (e.g. Crunkilton 1984; Hobbs 1988).

The small-scale ecological disaster witnessed in Bradley Chesterman Cave supports the widely acknowledged sensitivity and vulnerability of aquatic fauna to environmental disturbances. Growns *et al.* (1994) investigated the effects of clearfelling on stream macroinvertebrates in South-western Australia and found that the fauna appeared to recover quickly and to return to densities and richness comparable to undisturbed sites once loads of suspended sediment had returned to pre-logging values. The aquatic community in Bradley Chesterman Cave may recover to some degree in the future, providing of course that the environment has become suitable, and remains suitable, for recolonisation. Surface stream-dwelling species could colonise the cave stream by migrating upstream from adjacent connected surface watercourses. The sighting of amphipods in the cave stream in September 1994, and again in May 1995, along with a small number of planarians, suggests that this form of recolonisation is already occurring. Interstitial species might be able to disperse into the cave from neighbouring groundwater habitats, whilst cave-limited species might be able to disperse underground from adjoining cave streams via water-filled cracks and fissures, providing that these hydrological connections exist.

It is unlikely that the aquatic community will restore itself to exactly the same as it was prior to the disturbance. This is because much sediment remains in-situ where it can be expected to have a long term influence through its alteration of benthic and interstitial habitats, and by its remobilisation during high flows with the associated scouring effects. To give another example, scouring of sediment deposits during winter and spring spates caused large seasonal declines in macroinvertebrate diversity and marked changes in community structure in a small lowland stream in Victoria (O'Connor *et al.* 1994). More importantly however, many cave-obligate species or populations have extremely low dispersal powers, and their distributional ranges are often confined to a single cave, or minor drainage system. The distribution patterns within groups of hydrobiid snails are a good example of this (Ponder *et al.* 1993).

BIOMONITORING IN LITTLE GRUNT AND EXIT CAVES

Fundamental to the effective management of water quality is the need for biological assessment of water quality, which is most appropriately assessed by direct observation of the biota, rather than by extrapolation from data on abiotic aspects of water quality (Cosser 1988; Norris *et al.* 1995). Benthic macroinvertebrates have been widely used as environmental indicators in the assessment of water quality because they have been found to be sensitive to a wide variety of impacts including organic effluents, heavy metals, sedimentation and complex, mixed discharges and disturbances (Barmuta 1987; Resh *et al.* 1995).

Although the Ida Bay quarry had been worked for many years, the operation was halted none too soon because the ecological degradation witnessed in Bradley Chesterman Cave was starting to impinge upon the much more extensive Exit Cave subsystem. Specifically, the Eastern Passage within Exit Cave is affected by the quarry operation, with potential for the impacts to extend further downstream into the main streamway of the cave. The Eastern Passage is a major conduit which drains the water coming from Little Grunt Cave, which in turn collects its water from numerous small inflow points on the eastern side of Marble Hill where the quarry is situated. The main conduit in Little Grunt is fed from two principal tributaries, referred to here as the North Tributary and the South Tributary. The North Tributary extends directly underneath the quarry area and dye tracing has proven the connection with surface run-off sinking into a hole (PIP3) exposed in the upper benches of the quarry. The South Tributary, on the other hand, appears to be largely unaffected by sedimentation from the quarry. Figure 1 shows the relationships between these features.

All streams in the Exit Cave subsystem contain naturally occurring sediments ranging from sandy silt to large cobbles. Most streams contain sediment of a bimodal composition, generally gravel to cobble sized clasts interspersed with finer material (Houshold 1992). These sediments form a compact hard-bottomed substrate. In contrast, the North Tributary contains a great deal of fine clay and silty clay which has originated from the quarry. Soft-bottomed substrates occur where these sediments are deposited.

What impact has the sedimentation, or other water quality and flow regime changes derived from the quarry, had on aquatic fauna in the North Tributary? It does not appear to have eliminated any species, but it has altered the habitat characteristics along substantial areas of stream bed, particularly in pools where the deposits of fine mobile sediment completely smother the underlying substrate of coarse-grained sediments. The sedimentation has evidently affected the distribution of a species of aquatic snail which lives in the Eastern Passage drainage system, and other tributaries within Exit Cave. The snail, an undescribed species of *Fluvidona* belonging to the Family Hydrobiidae (Mollusca: Gastropoda) (W. Ponder pers. comm.), occurs abundantly on the hard-bottomed substrates, but not at all on soft-bottomed substrates.

In view of the snail's sensitivity to substrate type it was felt that they might be useful indicators of the general 'health' or otherwise of the waterbodies but tolerant of organic pollution. Little is known of the biology of hydrobiid snails. They are apparently sensitive to trace metal contamination (Chessman 1995), and Ponder *et al.* (1993) predict that most taxa will have a rather narrow tolerance range for the major environmental variables (e.g. water temperature, pH, water flow, dissolved oxygen and conductivity).

If the environmental perturbations caused by the quarry operation have resulted in habitat conditions which are sub-optimal for the snails then the impact might be quantifiable if there is a reduction in snail abundance at the affected sites. During February 1992, when the quarry was still operating, an experiment was designed to test this hypothesis, which involved a comparison of snail abundances at the sediment-affected sites in the North Tributary with control sites in the South Tributary.

The quarry ceased operating in October 1992, shortly after the first measurements of snail abundances were undertaken. The Parks and Wildlife Service immediately commenced rehabilitation works at the site. The principal aim of the rehabilitation program was to restore, as much as possible, the drainage characteristics and natural infiltration rates of the unimpacted karst, and to minimise further influx of sediment into the cave system (Gillieson & Houshold 1995; Houshold 1995). This was achieved by controlling sediment movement with structures and filters, and reducing peak run-off from the quarry benches by dressing them with topsoil and sowing native plant species. Bunds were constructed around the sinking points for water in the quarry benches. Hydro mulch and fertiliser were applied in minimal concentration, away from karst inflow points. Monitoring of the snail populations subsequently continued in an attempt to assess the success, or otherwise, of the rehabilitation measures. These measurements were taken during August 1993, then twice again during 1994 to investigate apparent seasonal variations in abundance during both low flow conditions (May) and high flow conditions (September).

Methods

Four sample sites were established in the sediment-affected North Tributary (3) and Eastern Passage (1), and four sample sites in the South Tributary as controls. Sample sites were chosen to be similar to each other in terms of substrate type, water depth and flow rate. At each site, a fibreglass tape was laid alongside the stream and snail abundances were counted (with the naked eye) within quadrats (20 cm x 20 cm) placed at successive 30 cm intervals. The number of quadrats taken at each site ranged from 20 to 30 (or sometimes 40) dependant upon the size of the site. Sampling was stratified into two habitat types, pools and riffles. Pools were defined by a flat water surface with laminar water flow whilst riffles had a riffled surface and turbulent flow. Half the quadrats were placed in pools and the other half in riffles. The location of sample sites is shown in Figure 1.

Over the course of the monitoring program one sample site (No. 7) in the South Tributary was discontinued due to problems of accessibility, but other sample sites were installed (Site No. 9 was installed in 1993, and Site No. 10 in May 1994) to give 4 control sites and 4 sediment-affected sites. The data from one of the control sites (No. 5) was not used in the analyses (except for August 1993) because of unusually high, or low, abundances which suggested it was a statistical outlier. More detail on the methods can be found in the study reports (Eberhard 1992a, 1993, 1994a, 1994b).

Results I: Variations in snail abundance between the sediment-affected sites and control sites

The sample data clearly showed that during February 1992 the mean abundance of snails at the sediment-affected sites was significantly lower than the control sites (Figure 2.1). During subsequent sample periods, there was no significant difference between the sediment-affected sites and the controls (Figures 2.2 to 2.4).

Results II: Variations in abundance between sample periods

The overall abundance of snails varied considerably between sample periods (Figure 3). The data implies that there are seasonal variations in snail abundance, as well as variations from year to year, which are irrespective of sedimentation or other impacts originating from the quarry. One obvious environmental variable which is linked to seasonality is flow rate. Although data is only available for four sample periods taken over a time span of 31 months, snail abundances are relatively greater during the generally low flow rates of the summer/autumn seasons (February 1992 and May 1994) compared with high flow rates of the winter/spring seasons (August 1993 and September 1994). During 1994, a reduction in snail abundance of approximately 30% occurred between May and September suggesting some mortality during the season of high flow conditions.

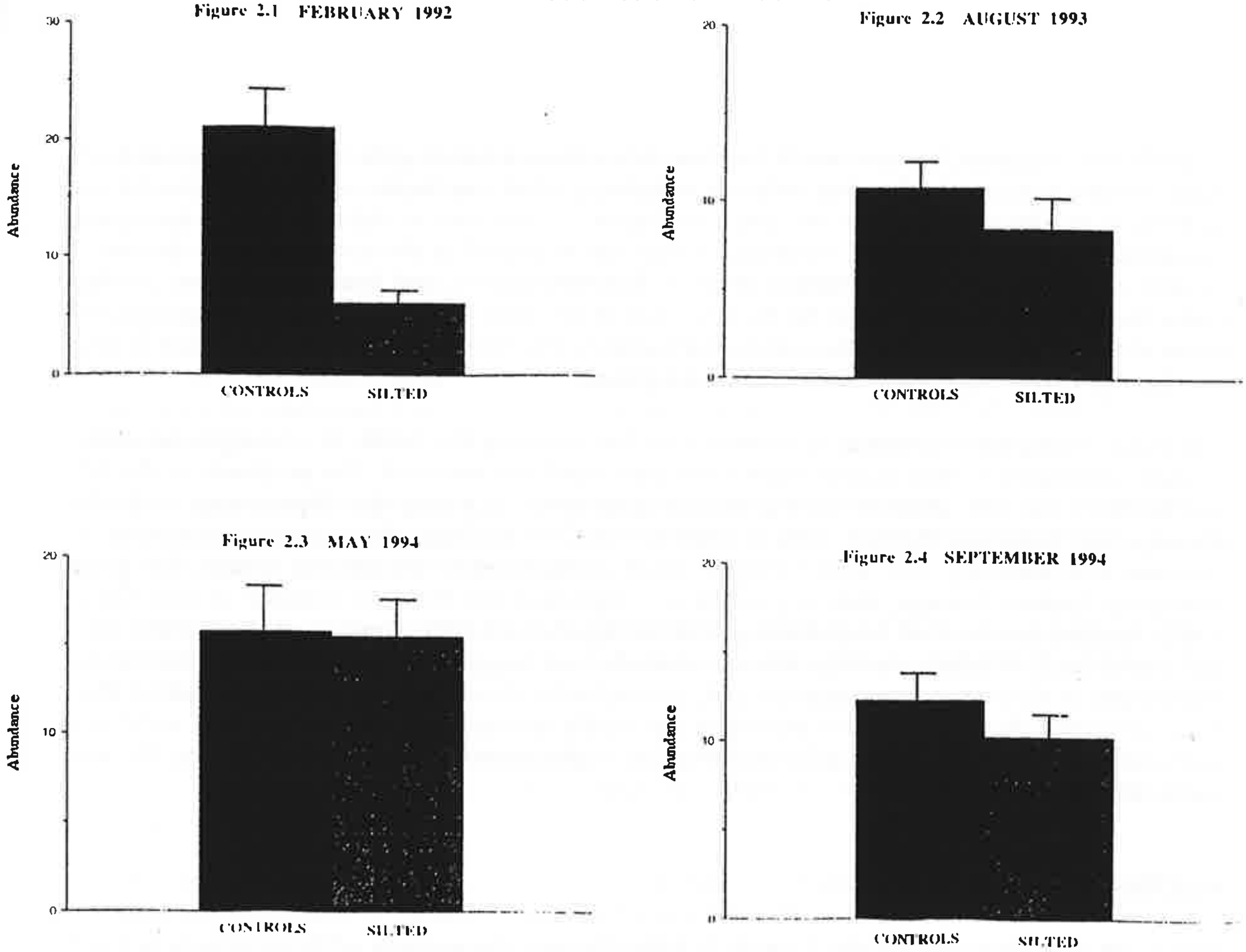
Discussion

By altering the substrate characteristics, sedimentation derived from the quarry has restricted the distribution of aquatic snails within the Exit Cave subsystem. The sampling results obtained during February 1992 strongly imply that snail abundances may also be limited by other water quality or flow regime changes induced by the quarry. Other Australian studies have showed that hydrobiids appear to be sensitive to trace metal contamination (Norris *et al.* 1982), and two hydrobiid taxa (one widespread, the other exotic) were found to be tolerant of organic pollution (Campbell 1978; Cosser 1988). The family as a whole has been awarded an average pollution sensitivity grade of 5, on a scale from 1 to 10 (Chessman 1995), although this grading could well be misleading and the majority of taxa are likely to be substantially more sensitive (W. Ponder pers. comm).

Conductivities measured in the North Tributary during this study were consistently higher than those in the South Tributary, ranging from 460 - 755 µS/l (n = 11) compared with 268 - 445 µS/l (n = 17). The high conductivities may be due to elevated sulphate concentrations derived from the weathering of pyrites within palaeokarst sediments which have been exposed by the quarrying process, and water analyses have shown sulphate concentrations in the North Tributary which are more than 10 times higher than the South Tributary (Houshold 1995). The elevated conductivities measured in the North Tributary during this study are consistent with the findings of other studies (Growns *et al.* 1991, 1994) which attributed the faunal differences between clearfelled and undisturbed forest catchments, at least in part, to higher conductivities which resulted from the disturbance.

The flashiness and peak discharge of the North Tributary stream is predicted to have increased as a result of rapid infiltration of water off the quarry benches. Another study showed that winter and spring scouring spates caused seasonal declines in the abundance of macroinvertebrates within a small lowland stream in Victoria (O'Connor *et al.* 1994).

The quarry rehabilitation programme appears to have been largely successful in restoring, as far as practicable, the natural flow conditions of diffuse input whilst minimising the further influx of sediment. The results from sampling undertaken after rehabilitation works commenced support this, as evidenced by the similar abundances observed between the sediment- affected sites and



Figures 2.1 to 2.4. Comparisons of mean abundances in pools at the control sites and silted sites, for each of the four sample periods. Error bars are 95% confidence limits

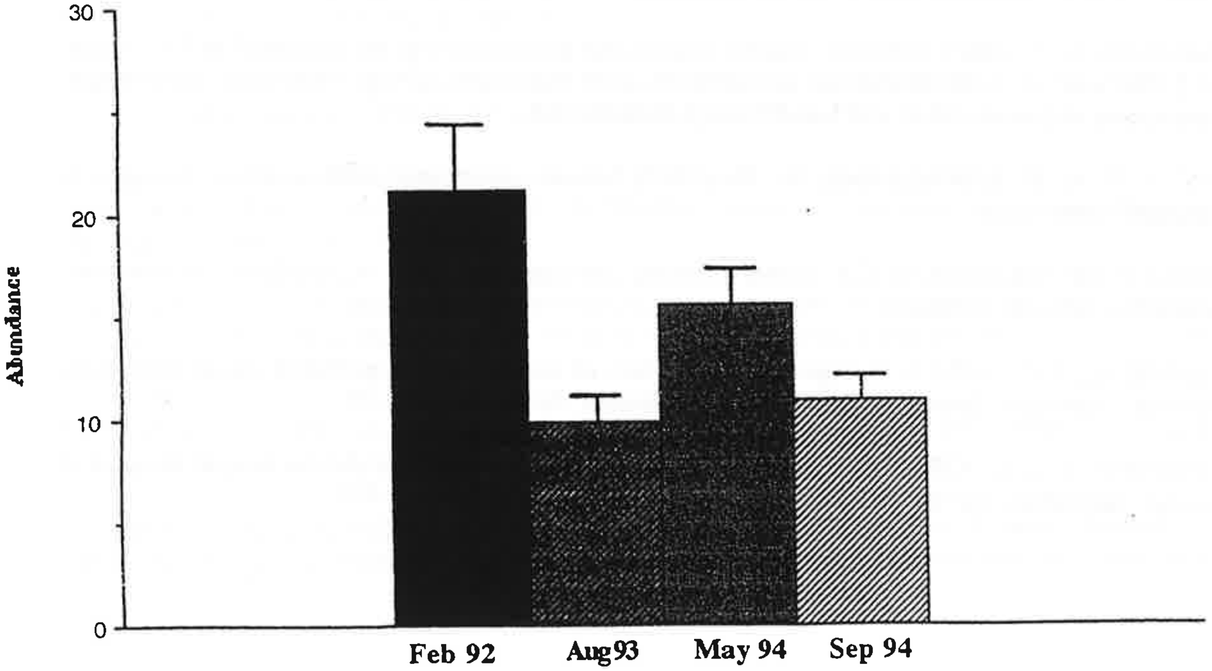


Figure 3. Comparison of mean abundances in pools between sampling periods. Control sites and silted sites are combined, except for February 1992 which is control sites only. Error bars are 95% confidence limits

control sites. However, the absence of baseline data collected before quarrying commenced more than 25 years ago, and the fact that only one sampling period was conducted in Little Grunt Cave in the few months existing from the initial exploration of the cave to the cessation of quarrying operations, restricts the level of reliability which can be placed in the data. The high degree of natural variability in snail abundances between different seasons, and from year to year, further limits the conclusions which can be drawn. Thus, it can only be inferred that the significantly lower abundances observed in the sediment-affected North Tributary and Eastern Passage during February 1992 were an impact derived from the quarry.

The snails clearly have potential as bioindicators for assessing the health of underground water courses, although no other studies have been done that I am aware of. The emphasis of the Ida Bay research has now shifted from the initial impact study to a long term monitoring study for management purposes. Further work in Little Grunt Cave has been discontinued because of its extreme inaccessibility, but monitoring of snail abundances is continuing within the more accessible Eastern Passage, and to provide a comparison the Western Passage of Exit Cave, which remains undisturbed by quarrying or other significant human impacts. At both these sites the Parks and Wildlife Service have installed data loggers to record the hydrological parameters of flow stage, temperature, pH, conductivity, dissolved oxygen and turbidity. This data will hopefully give a clearer picture of the snail's environmental ecology which will have practical applications for the future conservation, management and human use of the Ida Bay karst system.

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REFERENCES

ANON. (1895) The glowworm caves of Tasmania. *Scientific American* 23: 332.

BARMUTA, L. A. (1987) 'Polemics, aquatic insects and biomonitoring: an appraisal' *in* J. D. Majer (ed.) *The role of invertebrates in conservation and biological survey.* Western Australian Department of Conservation and Land Management Report.

BAYLY, I. A. E. & WILLIAMS, W. D. (1981) *Inland waters and their ecology.* Longman Cheshire, Melbourne.

BUREAU OF METEOROLOGY (1988) *Climatic averages Australia.* Australian Government Publishing Service, Canberra.

CAMPBELL, I. C. (1978) A biological investigation of an organically polluted urban stream in Victoria. *Australian Journal of Marine and Freshwater Research* 29: 71-90.

CAMPBELL, I. C. & DOEG, T. J. (1989) Impact of timber harvesting and production on streams: a review. *Australian Journal of Marine and Freshwater Research* 40: 519-539.

CHESSMAN, B. C. (1995) Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and a biotic index. *Australian Journal of Ecology* 20: 122-129.

CHUTTER, F. M. (1969) The effects of salt and sand on the invertebrate fauna of streams and rivers. *Hydrobiologia* 34: 57-76.

COSSER, P. R. (1988) Macroinvertebrate community structure and chemistry of an organically polluted creek in south-east Queensland. *Australian Journal of Marine and Freshwater Research* 39: 671-683.

CRUNKILTON, R. (1985) Subterranean contamination of Maramec Spring by ammonium nitrate and urea fertilizer and its implication on rare cave biota. *Proceedings National Cave Management Symposium,* Missouri,Speleology, 25(1-4).

DOEG, T. J., DAVEY, G. W., & BLYTH, J. D. (1987) Response of the aquatic macroinvertebrate communities to dam construction on the Thomson River, southeastern Australia. *Regulated Rivers* 1(3): 195-209.

DOEG, T. J. & MILLEDGE, G. A. (1991) Effect of experimentally increasing concentrations of suspended sediment on macroinvertebrate drift. *Australian Journal of Marine and Freshwater Research* 42: 519-526.

CLARKE, A. (1989) *Re Caves north of the South Lune Road and proposed WHA boundary.* Submission to Department of Lands, Parks & Wildlife 10 April 1989. 7 pp.

EBERHARD, S. M. (1990) *Ida Bay Karst Study: the cave fauna at Ida Bay in Tasmania and the effect of quarry operations.* Report to Department of Parks, Wildlife and Heritage, Hobart. 25 pp.

EBERHARD, S. M. (1992a) *The effect of stream sedimentation on population densities of hydrobiid molluscs in caves.* Report to the Department of Parks, Wildlife & Heritage, Hobart

EBERHARD, S. M. (1992b) *The invertebrate cave fauna of Tasmania: ecology and conservation biology.* MSc thesis, University of Tasmania.

EBERHARD, S. M. (1993) *Ecological monitoring during rehabilitation of the Ida Bay limestone quarry.* Report to the Department of Parks, Wildlife & Heritage, Hobart. 14 pp.

EBERHARD, S. M. (1994a) *Ecological monitoring of aquatic cave fauna at Ida Bay in Tasmania: results for May 1994.* Report to the Parks & Wildlife Service, Department of Environment & Land Management, Hobart. 10 pp.

EBERHARD, S. M. (1994b) *Ecological monitoring of aquatic cave fauna at Ida Bay in Tasmania: results for September 1994.* Report to the Parks & Wildlife Service, Department of Environment & Land Management, Hobart. 17 pp.

EBERHARD, S. M., RICHARDSON, A. M. M., & SWAIN, R. (1991) *The invertebrate cave fauna of Tasmania.* Report to the National Estate Office, Canberra. 174 pp.

GILLIESON, D. & HOUSHOLD, I. (1995) Rehabilitation of the Lune River Quarry, Tasmanian Wilderness World Heritage Area, Australia. Draft contribution for chapter on Extractive

Industries Impacts,*Karst Hydrogeology and Human Activities: Impacts, Consequences and Implications.* International Association for Hydrogeology Karst Commission.

GOEDE, A. (1967) Tasmanian cave fauna: character and distribution. *Helictite* 5(4): 71-86.

GOEDE, A. (1968) Underground stream capture at Ida Bay, Tasmania, and the relevance of cold climatic conditions. *Australian Geographical Studies* 7: 41-48.

GOEDE, A. & HARMON, R. S. (1983) Radiometric dating of Tasmanian speleothems - evidence of cave evolution and climatic change. *Journal of the Geological Society of Australia* 30: 89-100.

GROWNS, I. O. & DAVIS, J. A. (1994) Effects of forestry activities (clearfelling) on stream macroinvertebrate fauna in South-western Australia. *Australian Journal of Marine and Freshwater Research* 45: 963-975.

HARRISON, R. A. (1966) Australian glow-worms of the genus *Arachnocampa* Edwards (Diptera; Mycetophilidae). *Pacific Insects* 8: 877-883.

HICKMAN, V. V. (1958) Some Tasmanian harvestmen of the family Triaenonychidae (sub-order Laniatores). *Papers and Proceedings of the Royal Society of Tasmania* 92: 1-116.

HOBBS, H. H., III (1988) Gasoline pollution in an Indiana cave. *Proceedings of the National Speleological Society Annual Meeting,* August 3 - August 7, 1987, Michigan.

HOLSINGER, J. R. (1966) A preliminary study on the effects of organic pollution of Banners Corner Cave, Virginia. *International journal of Speleology* 2: 75-89.

HOUSHOLD, I. (1992) *Geomorphology, water quality and cave sediments in the Eastern Passage of Exit Cave and its tributaries.* Report to the Department of Parks, Wildlife and Heritage, Tasmania. 18 pp.

HOUSHOLD, I. (1995) Rehabilitation of the Lune River limestone quarry. *Proceedings of the 11th Conference Australasian Cave and Karst Management Association, Tasmania.*

HOUSHOLD, I. & SPATE, A. (1990) *Geomorphology and hydrology of the Ida Bay karst area.* Ida Bay karst study report to Department of Parks, Wildlife & Hertitage, Hobart.

HUNT, G. S. & HICKMAN, J. L. (1993) Revision of the genus *Lomanella* Pocock with implications for family level classification in the Travunoidea (Arachnida: Opiliones: Triaenonychidae) *Records of the Australian Museum* 45: 81-119.

HYNES, H.B.N. (1970) *The ecology of running waters.* Liverpool University Press: Liverpool.

KIERNAN, K. W. (1973a) Yet another Tasmanian conservation problem. *Australian Speleological Federation Newsletter* 59: 13.

KIERNAN, K. W. (1973b) Area reports. *Southern Caver* 5(1): 17- 20.

KIERNAN, K. W. (1988) *The management of soluble rock landscapes: an Australian perspective.* The Speleological Research Council Ltd, Sydney, Australia. 61 pp.

KIERNAN, K. W. (1992) *Exit Cave Quarry, Ida Bay karst area, and the Western Tasmania World Heritage Area: a hydrogeological perspective.* Report for the Department of Parks, Wildlife & Heritage, Tasmania.

KIERNAN, K. W. (1993) The Exit Cave Quarry: tracing waterflows and resource policy evolution. *Helictite* 31(2): 27-42.

LEA, A. M. (1910) On some Tasmanian cave inhabiting beetles. *Tasmanian Naturalist.* 2: 53-58.

MATHEWS, P. G. (ed) (1985) *Australian karst index.* Australian Speleological Federation Inc., Sydney.

MOORE, B. P. (1972) A revision of the Australian Trechinae (Coleoptera: Carabidae). *Australian Journal of Zoology, Supplementary Series* 18: 1- 61.

NORRIS, R. H., LAKE, P. S. & SWAIN, R. (1982) Ecological effects of mine effluents on the South Esk River, north-eastern Tasmania III. Benthic macrinvertebrates. *Australian Journal of Marine and Freshwater Research* 33: 789-809.

NORRIS, R. H. & NORRIS, K. R. (1995) The need for biological assessment of water quality: Australian perspective. *Australian Journal of Ecology* 20: 1-6.

O'CONNOR, N. A. & LAKE, P. S. (1994) Long-term and seasonal large-scale disturbances of a small lowland stream. *Australian Journal of Marine and Freshwater Research* 45: 243-255.

PONDER, W. F., CLARK, G. A., MILLER, A. C. & TOLUZZI, A. (1993) On a major radiation of freshwater snails in Tasmania and eastern Victoria: a preliminary overview of the *Beddomeia* group (Mollusca: Gastropoda: Hydrobiidae). *Invertebrate Taxonomy* 7: 501-750.

RESH, V. H., NORRIS, R. H., & BARBOUR, M. T. (1995) Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology* 20: 108-121.

RICHARDS, A.M. (1964) The Rhaphidophoridae (Orthoptera) of Australia, 1: Tasmania. *Pacific Insects* 6(1): 217-223.

RICHARDS, A. M. & OLLIER, C. D. (1976) *Investigation and report on the ecological protection of Exit Cave near Ida Bay in Tasmania for National Parks and Wildlife Service - Tasmania.* Unisearch Ltd., Sydney. 73pp.

SHARPLES, C. E. (1979) *The Ordovician system in the Ida Bay area.* BSc Hons thesis, University of Tasmania.

SWAIN, R. & WHITE, R. W. G. (1985) Influence of a metal- contaminated tributary on the invertebrate drift fauna of the King River (Tasmania, Australia). *Hydrobiologia* 122: 261-266.

TEBO, L. R. (1955) Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. *Progr. Fish. Cult.* 12: 64-70.

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