# A Study on the Pools of a Granitic Mountain Top at Moonbi, New South Wales

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Flynns Rock in the Moonbi Ranges has many gnammas (rock pools) that have formed by rock solution and which fill in heavy summer rains and remain inundated for much of the year. The two largest pools support 41 taxa of invertebrates, with the smaller pools less speciose. A rehabilitated gnamma was colonized rapidly by local species. The flora and fauna are comprised almost entirely of widespread eurytopic species dominated by insects, with most typical gnamma genera absent, though *Isoetes, Glossostigma, Eulimnadia* and *Bennelongia* are represented. Diversity is much influenced by habitat size and to a far lesser extent by isolation.

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Key Words: aquatic invertebrates, aquatic plants, colonization, pan gnammas, phenology.

## INTRODUCTION

Mountain tops almost universally lack standing water, but should they be of granite and flat or domed then weathering pits (or pan gnammas) may form and hold water for weeks or months. Examples abound on the granitic inselbergs of southwestern Western Australia (Pinder et al., 2000) and northwestern Eyre Peninsula (Timms, 2015), on some granitic mountains in the Granite Belt of southern Queensland/northern New South Wales (Webb and Bell, 1979) and on sandstones of Uluru, Australia's iconic inselberg (Timms, 2016a). An instructive example, known locally as Flynns Rock, occurs near Moonbi, New South Wales at the southern edge of the New England granitic massif.

Pan gnammas have been well studied in southwestern Western Australia (Bayly, 1982,1997; Pinder et al., 2000; Jocque et al., 2007; Timms 2012a, 2012b, 2014; Brendonck et al., 2015) revealing a high diversity of invertebrates by world standards (Jocqué et al., 2010; Brendonck et al., 2016) and the influence of major factors such as habitat size and hydrological regime on community structure (Vanschoenwinkel et al., 2009). Yet in pan gnammas in the sandstones of the Sydney basin of eastern Australia invertebrate communities are simply structured though some fauna have some similar adaptations to those of the harsh gnamma environment (Bishop, 1974). The question arises, do granitic gnammas in eastern Australia share this low diversity? Studies on central Victorian granitic gnammas suggest diversity is lower than in Western Australia, but higher than in the Sydney sandstone pools (author, unpublished). Flynns Rock near Moonbi presents another site, though limited in scope and somewhat isolated.

It is the aim of this study to document the pools on this mountaintop by mapping the gnammas and environs, explaining their origin, examining the flora and fauna, and noting their adaptations for living in such an unusual habitat.

## THE STUDY SITE AND METHODS

Flynns Rock (Fig 1) is a rectangular block of granite about 35m long by 22 m wide and averaging about 8m above the surrounding mountain slopes. The rock surface slopes 7m north to south and has about 15 enclosed hollows, six of which regularly contain exposed water (labelled 1-6 on Fig. 1). The remainder are filled in with sediment and vegetation, though Nos. 5 and 6 are partially infilled and two (Nos. 7 and 8) were cleaned out during the study (Fig. 1). The dimensions of the six main pools are given in Table 1; conveniently for study, these comprise three pairs of pools, two large, two small and two very small.

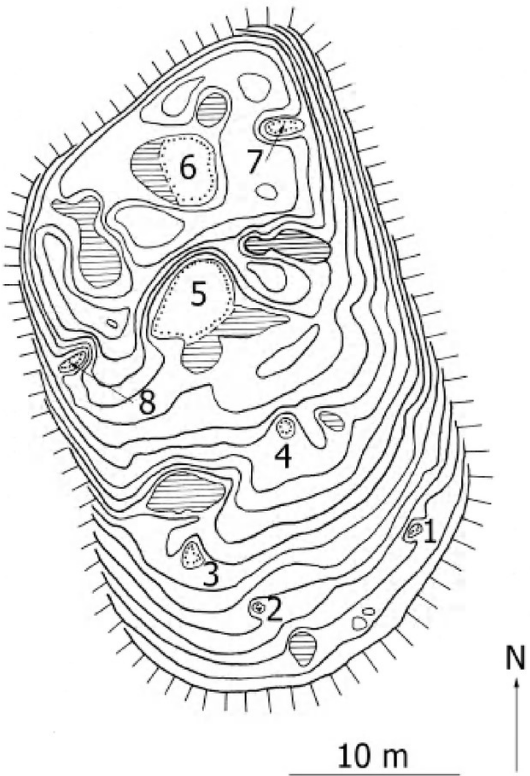


**Fig. 1 Map of Flynns Rock. Contour interval 50 cms. Active gnammas shown with dotted edges, infilled ones with horizontal bars. Bars at the rock edge indicate steep slopes.**

Pools 7 and 8 were prepared as colonization sites, but studies on pool 8 were abandoned as it has crack near the floor which means it rarely retains water. The rock was mapped in February 2016 using a DJI Phantom 3 professional drone and Agisoft photoscan software.

The rock was visited 14 times over the two year study period (March 2014 to February 2016), generally at about 1 month intervals when the pools contained water, December/March to about September/October. Conductivity was measured with an ADWA AD332 meter and turbidity with a Secchi disc tube calibrated in Nephelometric Turbidity Units (NTU). This tube is not accurate at very low turbidities as values less than five NTU are noted as such rather than a lower figure. Depth (z) as determined with a stiff tape measure and when a pool was overflowing, its length and width (to give the average d) measured and volume calculated. Each was assumed to be saucer-shaped so the formula ($V = (\pi/2)\ xr^2$) for parabolic shapes was used. Catchments of each pool were independent.

Pool 7 was cleaned out in September 2014 and held water from December 2014 to September 2015 and again in January and February 2016.

Rainfall data were supplied by the Bureau of Meteorology, Station 055321 Mulla Crossing, 12 km south of the study site, with data for November 2014 added from station 055320 Lumbri 15 km away to fill in a gap. The private rain gauge of Warwick Schofield 1 km away from the mountain, but not always read regularly, suggest the Mulla Crossing values used are 5-10% lower than the mountain receives.

Meiofauna was caught in a zooplankton net (opening 10 cm by 8 cm, length 50 cm and mesh 159 μm) with the bottom stirred a little to catch epibenthic species. Macroinvertebrates were caught with a pond net of 1 mm mesh in the two large pools and with 12 cm household sieve of 1 mm mesh in the smaller pools and when the large pools were very shallow. It was difficult to thoroughly clean the nets after each pool as not enough clean water could be carried up to the rock. Pool 7 was always sampled first as a ploy to avoid introductions with possibly contaminated nets. On each sampling occasion, the zooplankton net was

**Table 1 Physicochemical features of the pools**

| Pool | dimensions in cms | maximum depth in cms | mean depth in cms | full volume in litres | Conductivity μS/cm ±SE | Turbidity NTU ± SE |
|---|---|---|---|---|---|---|
| 1 | 125 x 90 | 6 | 4.5 | 27 | 37.8 ± 7.5 | 62.4 ± 17.5 |
| 2 | 100 x 80 | 6 | 4.4 | 19 | 48.6 ± 22.7 | 50.2 ± 16.1 |
| 3 | 190 x 150 | 12 | 9.5 | 136 | 91.2 ± 29.3 | 14.0 ± 3.4 |
| 4 | 170 x 120 | 9 | 7.6 | 74 | 47.6 ± 9.0 | 16.3 ± 2.4 |
| 5 | 660 x 460 | 23 | 16.2 | 2832 | 59.9 ± 8.4 | 8.7 ± 1.3 |
| 6 | 550 x 500 | 19 | 13.5 | 2056 | 68.5 ± 11.8 | 12.3 ± 1.7 |
| 7 | 280 x 180 | 12 | 9.3 | 249 | 28.8 ± 5.5 | 29.9 ± 16.3 |

**Table 2 List of plant species found on Flynns Rock**

| Family | Genus and species | Family | Genus and species |
|---|---|---|---|
| Amaranthaceae | *Alternanthera denticulata* | Moraceae | *Ficus obliqua* |
| Chenopodiaceae | *Dysphania carinata* | Oxalidaceae | *Oxalis chnoodes* |
| Chenopodiaceae | *Dysphania pumilio* | Phrymaceae | *Glossostigma elatinoides* |
| Crassulaceae | *Crassula helmsii* | Poaceae | *Capillipedium spicigerum* |
| Crassulaceae | *Sedum acre* | Poaceae | *Eragrostris brownii* |
| Cyperaceae | *Cyperus polystachyos* | Portulacaceae | *Calandrinia eremaea* |
| Cyperaceae | *Fimbristylis dichotoma* | Pteridaceae | *Cheilanthes distans* |
| Geraniaceae | *Geranium solanderi* | Pteridaceae | *Cheilanthes sieberi* |
| Isoetaceae | *Isoetes muelleri* | Ranunculaceae | *Ranunculus inundatus* |
| Mackinlayaceae | *Xanthosia pilosa* | | |

used for 1 minute and the macroinvertebrate apparatus for 2 to 3 minutes, depending on pool size. Doubling the sampling time did not add further species. The whole meiofauna collection was preserved in alcohol for later study, but macroinvertebrate collections were sorted alive in a white tray, with representative specimens retained preserved in alcohol for study and the remainder returned alive to the pools. Abundances were estimated on a log scale. I did not have a licence to study tadpoles so the few caught were returned to the pools alive.

## RESULTS

The two largest pools contained water April to September in 2014 and December to September in 2014-15 and again January onwards on 2016. The two small pools had a similar hydroperiod but starting earlier in March in 2014, while the two very small pools lacked water both at the beginning and end of the study (ie dry in March 2014 and in 2016). The pools were full only a few times and very shallow mainly in each September; on average they were about three-quarters full (Table 1) so that pool volumes were often about three-quarters those listed in Table 1. Usually each had at least small areas of open water, thus facilitating zooplankton collection, though there were large open areas in the two large pools until macrophytes grew by about May.

Conductivities were always low, averaging less than 100 µS/cm, and often reading < 25 µS/cm when full (Table 1). When water levels were low values up to 344 µS/cm were recorded, but no relationship was noted between pool size/volume and conductivity. Also when pools 1 and 2 were low, turbidities were high (100-200 NTU), but otherwise there was no relationship between pool volume and turbidity, (r = -0.591, not significant) though the two very small pools were highly turbid and the largest ones clear (Table 1).

Some 19 species of vascular plants were found on the rock (Table 2), but most of these were in the grassed infilled depressions or growing on the shallower, irregularly inundated parts of pools 5 and 6. In the regularly inundated parts of these pools, plus the edges of pools 3 and 4, *Isoetes muelleri* was dominant and persistent. Some *Glossostigma elatinoides* grew patchily in all four pools while *Alternanthera denticulata* was common in the more amphibious parts of pools 5 and 6. The filamentous algae *Oedogonium* sp. and *Zygnema* sp. tended to smother the *Isoetes* by midyear. Pools 1 and 2 lacked plants.

Altogether 41 taxa of invertebrates were found in the six pools, comprising 10 crustaceans and 23 insects (Table 3). Pools 1 and 2, the very small pools lacking vegetation, had the fewest species with just four recorded, the small pools 3 and 4 had 30 taxa and the two large pools had 34 taxa (Table 3). Momentary species richness averaged 2.5 in pools 1 and 2, 5.4 in pools 3 and 4 and 10.2 in pools 5 and 6. Seasonal peaks in species richness varied between years but generally occurred in April/May and minima often at the beginning or end of a season (Fig. 2).

Dipteran larvae dominated in very small pools, and even when dry, the chironomid *Paraborniella tonnoiri* and the ceratopogonid *Dasyhelea* sp. could be extracted from the sediment by adding water. These two species also dominated in pools 3 and 4 with the unidentified brown planarian being common also. Most of the other species occurred spasmodically and often recorded as a single specimen. The large pools 5 and 6 had a variety of species common from time to time, including the brown planaraian, the clam shrimp *Eulimnadia australiensis*, two cladocerans, the ostracod

**Table 3 Number of occurrences of invertebrate species in the pools of Flynns Rock, Moonbi**

| Higher rank | Species | Pool 1 | Pool 2 | Pool 3 | Pool 4 | Pool 5 | Pool 6 | Pool 7 |
|---|---|---|---|---|---|---|---|---|
| Platyhelminthes | unidentified pink/grey planarian | | | 7 | 7 | 9 | 10 | 1 |
| | unidentified clear planarian | | | 2 | | 2 | 2 | 1 |
| Nematoda | unidentified nematodes | 1 | 1 | 5 | 4 | 3 | 2 | 1 |
| Rotifera | *Asplanchna* sp. | | | | | | | 1 |
| | *Keretella* sp. | | | | 1 | | | |
| Branchiopoda | *Eulimnadia australiensis* | | | 3 | 3 | 4 | 4 | 1 |
| | *Daphnia carinata* | | | 1 | | | | |
| | *Armatalona imitatoria* | | | 4 | 4 | 5 | 6 | 3 |
| | *Ephemeroporus* sp. (*barrosi* group) | | | 1 | | 7 | 4 | |
| Ostracoda | *Bennelongia* n. sp. | | | | | 10 | 9 | 2 |
| | *Cypretta* sp. | | | | | | 1 | |
| | *Cyprinotus* sp. | | | 1 | | 2 | | |
| | *Ilyodromus* sp | | | 2 | 1 | 1 | | 2 |
| | *Sarscypridopsis* sp. | | | 1 | | 2 | 1 | |
| Copepoda | *Mesocyclops notius* | | | | | 2 | 5 | 1 |
| Odonata | *Austrolestes leda* | | | 2 | | 5 | 4 | |
| | *Austrolestes heterostricta* | | | | | 1 | | |
| | *Hemicordulia tau* | | | | | 5 | 3 | 2 |
| Ephemeroptera | *Cloeon* sp. | | | 1 | 1 | 6 | 7 | 1 |
| Hemiptera | *Agraptocorixa parvipunctata* | | | 4 | 1 | 12 | 11 | 3 |
| | *Micronecta* sp. | | | 3 | 3 | 7 | 9 | 3 |
| | *Anisops gratis* | | | | 1 | 5 | 4 | 1 |
| | *Anisops thienemanni* | | | 1 | 1 | 7 | 4 | |
| | *Anisops* spp. | | | | 1 | 6 | 4 | 1 |
| | *Enithares* sp. | | | | | | 1 | 3 |
| Coleoptera | *Allodessus* larvae | | | 3 | 2 | 5 | 2 | 2 |
| | *Berosus* larvae | | | 2 | 1 | 1 | 2 | |
| | *Sternopriscus* larvae | | | | 1 | | | |
| | a hydrophilid larvae | | | 2 | | 1 | 1 | |
| | *Allodessus bistrigatus* | | | 1 | | | 1 | |
| | *Antiporus gilberti* | | | | | | | 1 |
| | *Berosus* sp 1 | | | 1 | 1 | 2 | 3 | |
| | *Berosus* sp 2 | | | 1 | 1 | 3 | 2 | |
| | *Sternopriscus multimaculatus* | | | 3 | 4 | 1 | 1 | |
| Diptera | *Aedes alboannulatus* sensu lato | 5 | 6 | 4 | 1 | 2 | 1 | |
| | *Paraborniella tonnoiri* | 10 | 11 | 14 | 14 | 8 | 9 | 7 |
| | *Procladus* sp. | | | | 1 | | | |
| | *Dasyhelea* sp. | 10 | 11 | 7 | 10 | 2 | 3 | 6 |
| | *Eristalis* sp. | | | | | 2 | 2 | |
| | unidentified maggot | | | | | | | 2 |
| Arachnida | unidentified hydrocarinid mite | | | 1 | 1 | | | |
| Mollusca | *Ferrissia* sp. | | | | | | 1 | |

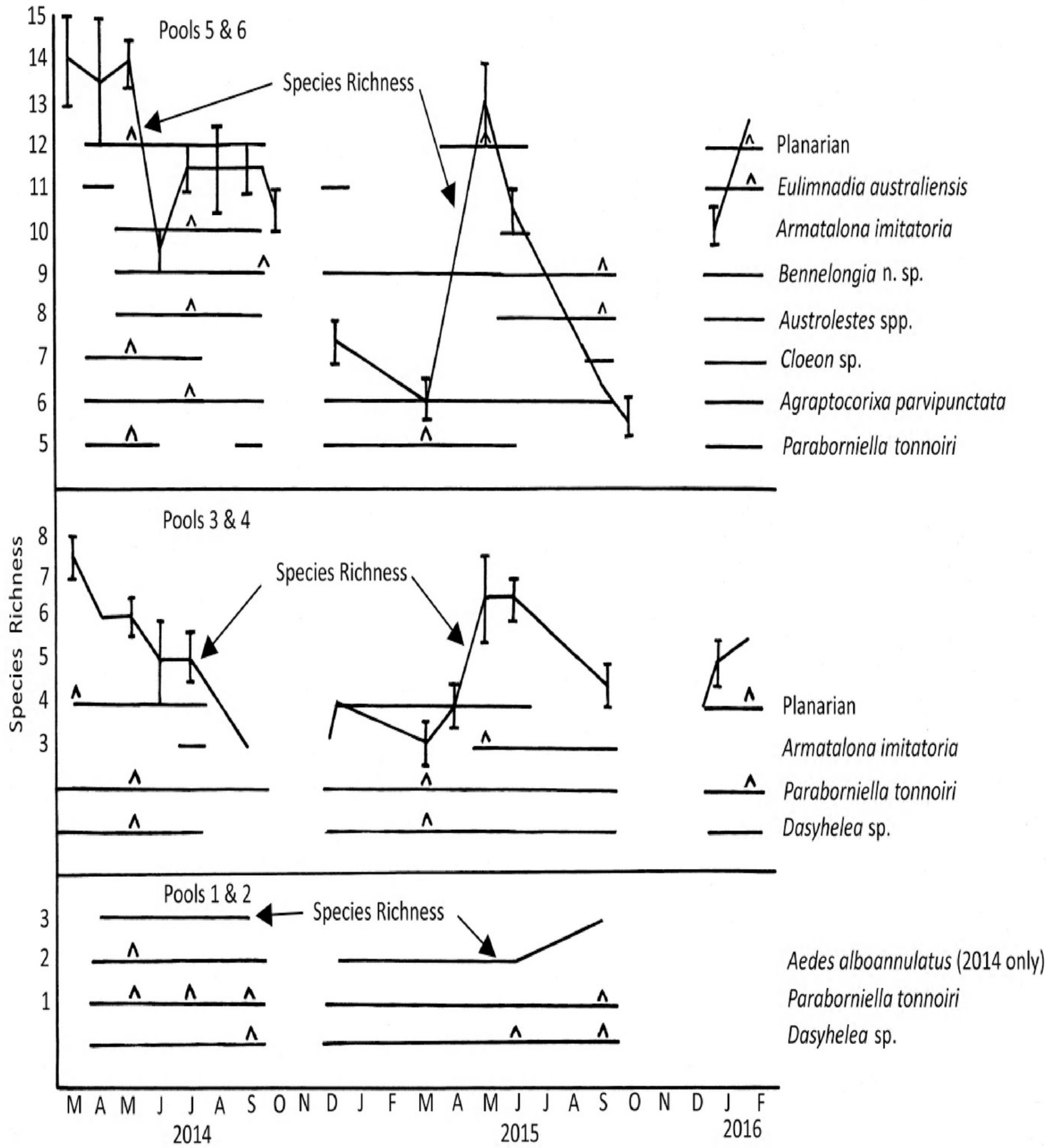


**Fig. 2. Invertebrate phenology at Flynns Rock. Species richness curves based on average of two values for the paired pools; variability shown by vertical bars, but on many dates (all dates for pools 1 & 2) both values the same. Seasonal distribution of major species are indicated by horizontal lines, with inverted v's showing peaks in abundance.**

*Bennelongia* n. sp., the odonatan *Austrolestes leda,* the mayfly *Cloeon* sp., the hemipterans *Agraptocorixa parvipunctata, Micronecta* sp. and *Anisops* spp. plus *Paraborniella tonnoiri.*

The dominant species had very different phenologies. *Eulimnadia australiensis* only appeared briefly at the first filling each season (Fig 2). *Cloeon* sp. developed early in each filling cycle and variation in specimen sizes suggested at least 2 generations. *Austrolestes leda* and *Hemicordulia tau* were much slower developers, only appearing numerous later in the season and there was only one cohort per year (Fig 2). *Anisops* spp. were caught early in each season, bred and then persisted. The two years were not exactly the same in occurrences and abundances, the second year, 2015, had fewer cladocerans, *Cloeon* sp, odonates and no mosquitoes.

The first colonizer in Pool 7 was the chironomid *Paraborniella tonnoiri* which was present in small numbers in the December filling. It was joined by *Dasyhelea* sp. by March and both were abundant by May. A few hemipterans appeared in

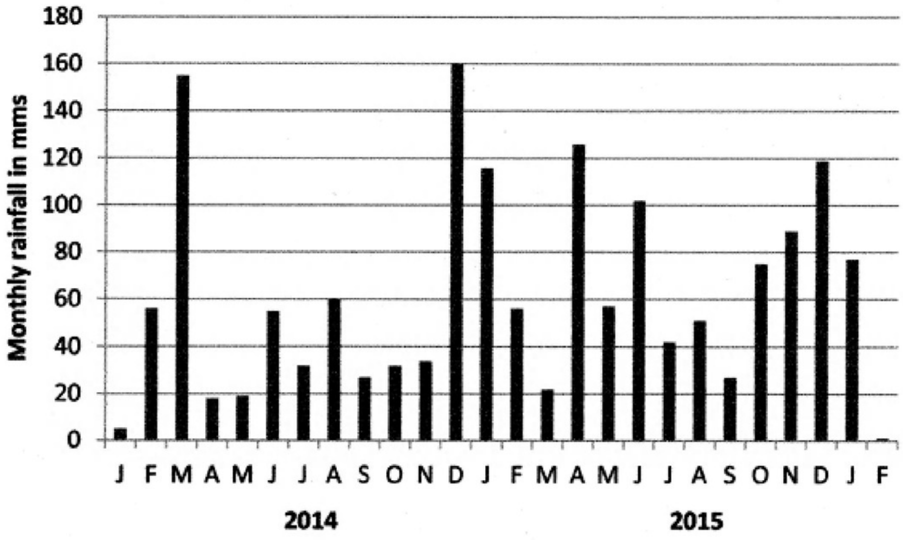


**Fig. 3. Rainfall nearby to Flynns Rock.**

March and the brown flatworm had arrived by May. The first crustacean to be present was the claoderan *Armatalona* by June followed by the ostracod *Bennelongia* sp. in September. The first *Cloeon* sp appeared also in September. The new filling in January 2016 added the ostracod *Candonocypris* and the clam shrimp *Eulimnadia australiensis* and a sparse population of hemipterans and some dytiscid larvae. The clam shrimp had disappeared again by February (but present still in pools 3-6).

## DISCUSSION

The gnammas of Flynns Rock are of two types: pools 1-4 are simple pan gnammas and 5-8 armchair pans (Timms and Rankin, 2016). Pools 1-4 have slightly sloping shore profiles indicative of weathering along surface exfoliation laminations (Twidale and Corbin, 1963) while pools 5-8 have a characteristic exponentially-curved shore profile indicative of water layer weathering. Such armchair pans begin as shallow pans where lamination-controlled weathering predominates but as they incise water layer weathering dominates and the back (and sides) are lowered by subaerial weathering (Timms and Rankin, 2016). Incision is a relatively large 2.5 m in pool 5 (Fig. 1), indicating a much older age for this pool than the others, especially pools 1-4.

The large difference in volumes of the six main pools mean that the small shallow pools, especially 1 and 2, have shorter hydroperiods and it is suspected they dried occasionally between visits. Pools 5 and 6 once filled early in the season remained inundated for 8-10 months. Generally these pools filled in a summer month with >100 mm rainfall (December to March) then the monthly totals of 20-50 mm coupled with lower evaporation in winter, maintained water for much of the year, till increasing evaporation in spring dried the pools in September/October (Fig 3). This is a different filling-drying cycle from that for the gnammas in the mediterranean climate of southwest Western Australia and Eyre Peninsula, South Australia where pools fill in late autumn or early winter, retain water during the winter and dry in spring (Timms, 2012a, 2014).

Conductivities are low compared to those of these western gnammas, this is no doubt influenced by the relative greater salt load in the rain feeding the western gnammas (Hutton and Leslie, 1958; Timms and Rankin, 2016) and by the overflowing of the Moonbi gnammas generally at least once a year during the heavy rainfalls of summer. Turbidities are higher however, probably due to the denser plant populations and higher organic matter load, though this has not been quantified. Aquatic plant growth, particularly of *Isoetes muelleri* (a quillwort) in pools 5 and 6, is luxuriant compared to that in western gnammas (Timms, 2014). *Isoetes* is widespread in gnammas and a characteristic genus in many (Hopper et al., 1997; author, unpublished).

Diversity and community composition of invertebrates are very different from those in these western gnammas (Bayly, 1982,1997; Pinder et al., 2000; Jocque et al., 2007; Timms 2012a, 2012b, 2014; Brendonck et al., 2015). A typical rock outcrop in southwest WA may have 60-70 species (Jocque et al., 2007) and an individual pool 30-40 species (Timms, 2012a), all dominated by crustaceans with many regional endemics (Pinder et al., 2000). Pools 5 and 6 approach this diversity, but crustaceans are few and there is only one possible endemic. The fauna of pools 1-4 is restricted by their small size (Vanschoenwinkel et al., 2009), but again the comparative lack of crustaceans is the salient feature.

Almost all the invertebrates of the Moonbi gnammas are eurytopic species (ie widespread and tolerant). The only possible exception is the new *Bennelongia* sp. and maybe the planarians when they are identified. While various clam shrimps are often endemic in gnammas (Timms, 2016a) the species (*Eulimnadia australiensis*) in Flynn Rock gnammas is widespread in northeast Australia and moreover lives in a variety of habitats (Timms, 2016a). The few cladocerans and other ostracods present are also widespread and not restricted to gnammas, a contrast to a significant component of the fauna of gnammas of Western Australia (Pinder et al., 2000).

Only the chironomid *Paraborniella tonnoiri* and the ceratopogonid *Dasyhelea* sp. have cryptobiotic adaptations to survive in the temporary environments of these gnammas. As such, they are well suited to the precarious fluctuating habitat provided by pools 1-4. The crustaceans present are preadapted for temporary environments in that they lay eggs capable of surviving the dry times. Most of the insect inhabitants take advantage of the temporary presence of water which generally lasts long enough for many to breed successfully, though perhaps isolation of the pools on a mountain top may restrict dispersal as it apparently did for mosquitoes in 2015. Colonization of the new pool was restricted to fauna already in nearby pools on the rock, again suggesting the isolated mountain top position may be restrictive. Though tadpoles were encountered from time to time, they were not regular and predictable faunal component, suggesting breeding frogs could be restricted by the rock's high steep sides and isolation from other waters.

The conclusion is that these gnammas, while physically similar to many elsewhere, support a generalised fauna with few species characteristic of gnammas. For smaller temporary waters a study of just the crustaceans of 41 pools in southeastern Victoria yielded an average of 9.3 species per pool (Morton and Bayly, 1977), well in excess of those in the Moonbi pools. This low diversity of the Moonbi pools is largely due to their small size and also to the lack of long term climatic variation thought to contribute to the relatively high faunal diversity in southwestern Australian gnammas (Pinder et al., 2000). The low diversity is also partially due to their isolation on a mountain top, with dispersal from rock pools nearby often essential to maintain local diversity (Vanschoenwinkel et al., 2013). However, at Moonbi this is thought to be of minor influence, comparable to very low faunal diversity in desert gnammas of southeastern Western Australia, where lack of similar pools in the greater district and their very small size to receive colonizers, impose severe restrictions (Bayly et al., 2011). On the other hand, compared to the diversity in Sydney basin gnammas (Bishop 1974) and to gnammas in the Granite belt of Southeast Queensland (author unpublished data) the comparatively larger Moonbi pools are speciose, probably because they are vegetated (ie. more complex habitat structure as well as larger habitat size) (Vanschoenwinkel et al., 2009). However, both these gnamma groups have a specialised endemic limnadiid clam shrimp (Timms, 2016b), a specialisation lacking at Moonbi.

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