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Morphology and incidence of Yabby (*Cherax albidus*) burrows in Western Australia

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Fish for the future

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Morphology and incidence of Yabby *(Cherax albidus)* burrows in Western Australia

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Abstract

Yabby (Cherax albidus) *burrows were recorded from dams, channels and ponds in Western Australia. Twenty five sites were sampled during Spring, 1998 and the burrow morphology and density was described from six of these locations where burrows were present. To improve the sample size and address seasonal trends 49 commercially harvested yabby dams were sampled over the summer of 1999/2000 and the number and density of yabby burrows were recorded. Burrow incidence and morphology was also recorded from 25 research ponds at the Avondale Research Station between 1995-1997. Soil and water chemistry values are presented and their relationships with burrow morphology are discussed. Burrow density (number of burrows/m2) was also recorded. Burrowing activity was investigated against the density, sex, and feeding regime of yabbies.*

Different techniques for casting and excavating the casts of burrows were evaluated. Expanding polyurethane foam was better than concrete, plaster or resin as it was lighter, less brittle and gave a three dimensional representation of the burrow. Excavating the casts of burrows using high pressure water was better than digging as it was more efficient and preserved the shape of the casts.

The morphology of burrows was characterised by burrow length, depth into dam wall, width, number of entrances and cavern width in the Spring 1998 survey. The average burrow length was 25.8 cm. The maximum distance a burrow penetrated directly into a dam was 64.5 cm, while the longest burrow was 148 cm. Based morphological features burrows were classified as either depressions, angular pits, U-shaped tunnels or networks.

The incidence of yabby burrows increased from 25% of dams in Spring 1999 to 70% in Autumn 2000. Burrow density increased significantly from 0.02 burrows/m2 of bank 0.5m above and below water level in Spring to 0.11 burrows/m2 in Autumn, but did not increase significantly between Summer and Autumn.

The majority of burrows (64%) had only 1 entrance to a simple tunnel (mean width 6.4 cm) leading to a terminal cavern (mean width 12.5 cm). Channels and large dams tended to have longer (22 - 40 cm) and more complex burrows than small dams or ponds (8 - 21 cm). Burrows were more complex where there was a greater variation in water table height. Consequently, burrows in levee banks of channels and dams tended to be more complex than those in the bottom of ponds.

In the research ponds, burrowing activity was less in ponds containing only males or unfed yabbies. Similarly the density of burrows during the spring 1998 survey was generally higher where there were more females than male yabbies. Fed yabbies are larger and fitter (physically and reproductively) possibly resulting in increased burrowing activity. There was no relationship between the density of yabbies and the number of burrows in the research ponds.

There was a strong relationship between soil type and burrowing in survey 1, with yabbies burrowing more in soil containing high levels of silt. This finding was not supported by the data from survey 2 which involved more dams.

Similarly, there was also a strong relationship between water chemistry and burrowing in survey 1. Yabbies burrowed more where calcium, potassium, sodium, chloride and conductivity levels were high, while there was a negative relationship between yabby burrowing and hardness. However, in survey 2 there was no significant relationship between water chemistry and burrowing.

When C. albidus *burrows were present in a dam, pond or channel they were relatively abundant. However, the burrows were generally much shorter than those described in published reports for crawfish* (Procambarus clarkii) *and in anecdotal reports for* C. destructor, *the commonly farmed yabby from South-eastern and Central Australia.*

1.0 Introduction

The common name yabby is derived from the aboriginal term yabber, which was used by wandering tribes to describe the native crayfish from central Australia (Smith 1912). Over the past 87 years the term yabby has been used to describe freshwater crayfish from central and eastern Australia, including *Cherax albidus* and *Cherax destructor*. Both *C. albidus* and *C. destructor* are farmed in Australia, although in WA, farming is restricted to *C. albidus* where it is found in most agricultural dams of the Wheatbelt region, where the State's expanding yabby farming industry is located (Lawrence, 1998).

C. albidus has been termed the "white yabby" in order to distinguish it from *C. destructor*, the "common yabby" (Clark 1936). Since 1936, scientists and farmers have distinguished *C. albidus* from *C. destructor* using a number of morphological characteristics, the most notable being the presence of a dense mat of setae on the upper surface of the chelae and a wider areola (Clark 1936, Sokol 1988, Campbell 1994). However, based on electrophoretic evidence, Austin (1996) proposed that *C. albidus* be reclassified as a sub species of *C. destructor* and renamed *C. destructor-albidus*. Regardless, the WA yabby industry continues to use the name *C. albidus*. Nonetheless, concern has been raised by WA yabby farmers and export markets due to Austin's (1996) reclassification of *C. albidus* to *C. destructor-albidus* because of the association between the name *destructor* with damage caused by burrowing.

Following the damage caused by the introduction of *Procambarus clarkii* into the natural water systems and agricultural fields of Japan (Hobbs *et al*., 1989), export markets have expressed concern at the potential damage which may be caused should imported *C. destructor* escape. With Austin's reclassification of *C. albidus* to *C. destructor-albidus* this concern has now spread to include the WA yabby *C. albidus*. The main focus of this concern is that these crayfish may burrow into rice paddies, canals or water storage dams and weaken these structures.

While it is commonly accepted that the term *C. destructor* was applied by Clark (1936) because of its profuse burrowing habits, the original description of this species makes no such statement. Clark (1936) actually stated that "<u>both</u> aquatic and terrestrial crayfish species are burrowing animals" and that "<u>all</u> aquatic crayfish species do much damage to retaining walls of channels and dams, and to banks of rivers and streams". Interestingly, Reik (1951) mistakenly claims that *C. albidus* is responsible for damage to bore drains in Western Queensland, which is well outside the distribution of *C. albidus*, and in retrospect it is clear that he is referring to *C. destructor*. This has added to the current confusion on the damage caused by burrows of *C. albidus*.

Anecdotal reports of burrowing by *C. destructor* suggest depths of 200 and 300 cm may be achieved (Huner & Lindqvist, 1995, and Frost, 1975 respectively). However no scientific reports have been published to support or discredit this hypothesis. Similarly no data has been published on the depth or burrow morphology of the WA yabby, *C. albidus*.

It has been proposed that several factors can affect burrowing in freshwater crayfish, including water chemistry (Rosewell, 1970), soil type (Grow, 1981, Correia and Ferreira, 1995) and reproductive strategies (Hobbs, 1981). Unfortunately, no research has been conducted on factors that affect burrowing in yabbies.

1.1 Background

Previous anecdotal reports have suggested that the burrows created by yabbies may damage pond banks. These reports are preventing the export of yabbies from WA to a number of countries including Japan and Mauritius.

In part the widespread acceptance of yabby burrows damaging pond banks may be attributed to the belief that the name *C. destructor* was conferred due to the damage caused by this animal to drainage canals throughout it's distribution. While this damage is accepted and has been observed by the principal investigator, no data has been published on the depth or burrow morphology of *C. destructor* or the closely related WA yabby *C. albidus*. Furthermore a recent revision of yabby taxonomy (Austin 1996) reclassified *C. albidus* as *C. destructor-albidus*, this has resulted in the WA yabby industry which exclusively farms *C. albidus* being denied access to international markets as it is considered by overseas authorities to be as damaging as *C. destructor*.

Given the widespread distribution of yabbies in farm dams in WA, and the lack of reports of farm dam banks being compromised by yabby burrows, evidence in Western Australia suggests that the burrowing by *C. albidus* yabbies from this state does not compromise the banks of farm dams. Nonetheless, while it is widely accepted that yabbies burrow, there has been no scientific study which reports the depth and therefore the possible degree of damage caused by *C. albidus* yabby burrows to pond banks.

1.2 Need

To ensure that farmers can continue to export yabbies from WA a scientifically valid report that can be used by both exporters and importers alike to evaluate the potential impact of WA *C. albidus* yabbies on ponds, canals and rice paddies is required. In addition, this report is also required to satisfy concerns by countries that currently ban the importation of WA yabbies due to concerns that animals may escape and cause damage due to burrowing.

1.3 Objectives

The objectives of this study are to:

1 record and describe the burrow morphology of WA yabbies (*C. albidus*) in terms of mean, minimum and maximum depth of burrows,

2 record burrow incidence (percentage of dams containing burrows)

3 record burrow density (number of burrows/m^2 of bank wall near the water level in dams containing burrows),

4 investigate any relationship between burrow depth or density, and either soil type or water chemistry, and,

5 investigate relationships between burrowing habits and sex, influence of feeding or geographical location.

2.0 Materials and methods

2.1 Evaluation of methods for casting yabby burrows

A pilot study was conducted in research ponds at the Avondale Research Station (Beverly (32°6'S, 116°55'E) Western Australia) to evaluate techniques for casting yabby burrows and excavating the casts.

Concrete, plaster, two-part epoxy resin and expanding polyurethane foam were poured into burrows (n=3 for each agent) and left to cure. Each agent was assessed by criteria of cost, sturdiness and ability to fill burrows in three-dimensions. Two techniques for excavating the casts, digging by hand and the use of high pressure water, were assessed on the basis of ease of excavation and structural integrity of the cast.

2.2 Survey of yabby burrows from WA

Two surveys of yabby burrows were conducted. An initial survey of 25 dams during Spring (September - October) 1998 investigated burrow morphology and collected baseline data on physical and chemical factors affecting burrow density in farm dams. A second survey, conducted in 49 commercial yabby dams during Spring 1999, Summer 1999 and Autumn 2000 investigated physical and chemical factors affecting burrow density, and recorded the change in burrow density over this period.

2.2.1 Survey 1: Study areas

In the initial survey of 25 dams, locations were selected to reflect a broad variety of physical and chemical conditions that may influence burrow morphology and density. Of these twenty five dams, burrows were observed in only six dams (24% of dams), (Figure 1), which were subsequently studied in further detail. A random sample of ≥4 burrows were taken from each site. At these 6 sites only burrows above the water level of the dam were investigated**.** In addition burrows were sampled from research ponds at the Avondale Research Station (Figure 1). At the research station burrows beneath the water level, including pond bottom burrows, could be sampled by draining the research ponds.

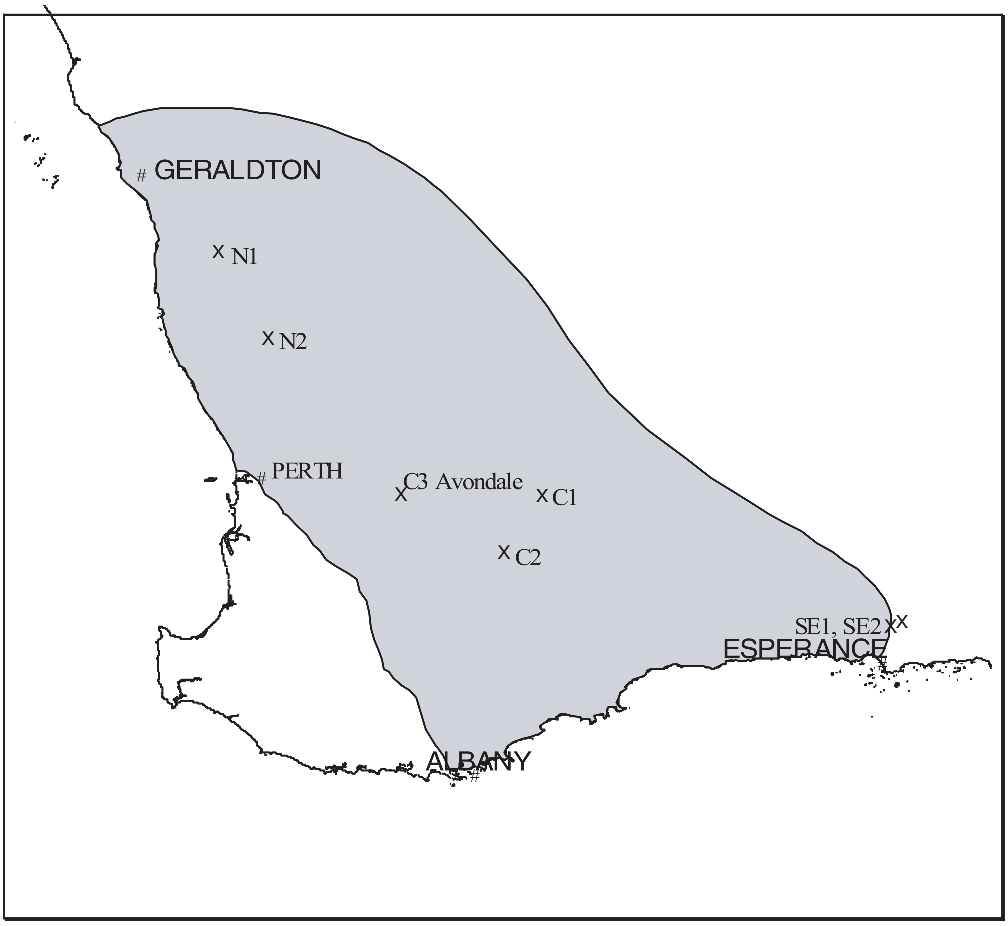

Figure 1. Commercial yabby harvesting region (shaded) in Western Australia with location of Survey 1 study sites (Avon = Avondale Research Station ponds, N1 = Northern large dam, N2 = Northern small dam, C1 = Central catchment channel, C2 = Central catchment channel, SE1 = South eastern dam and SE2 = South eastern channel).

SURVEY 1: Site descriptions

NORTHERN (N1, N2) (Figure 1)
Site N1: Typical W.A. Wheatbelt dam. Wall slope of 30-60 degrees and no vegetative cover. Dam size of 40m × 40m. Constant water level.
Site N2: Considerably smaller and shallow dam (10m × 5m). Wall slope of <30 degrees and no vegetative cover. Constant water level.

SOUTH EASTERN (SE1, SE2) (Figure 1)
Site SE1 (dam): Large flat dam (40m × 40m). Wall slope of <30 degrees with a small amount of fringing vegetation. Constant water level.
Site SE2 (channel): Narrow catchment channel feeding the main dam (SE (dam)). A 10m × 3m segment was sampled. Wall slope of 30-60 degrees with vegetative cover. Water depth very low (<30cm). Fluctuating water level.

CENTRAL (C1, C2, C3 Avondale) (Figure 1)
Site C1: Catchment channel running from paddock into main dam. A 10m × 4m segment was sampled. Wall slopes of >60 degrees with vegetative cover on top of channel. Water depth low (<50cm). Fluctuating water level.

Site C2: Catchment channel situated in farm paddock. A 20m × 4m segment was sampled. Wall slope of >60 degrees. Vegetative cover comprised of tall grass. Water depth much lower (>50cm) than burrow location. Fluctuating water level.
Site C3 Avondale: Fisheries WA Field Research Station, consisting of 25 research ponds (10m × 10m × 1.5m deep). Water levels were maintained by float valves preventing large fluctuations in water depth influencing burrowing, and thus allowing the effect of other variables on burrowing habits to be ascertained. In addition burrows beneath the water level could be sampled by draining the research ponds.

2.2.2 Survey 2: Study areas

In the second survey burrows from 49 dams which are commercially harvested for yabby farming were sampled. The sites were bordered by Mukinbudin to the North, Kojonup in the South and Hyden to the East (Figure 2). Burrow density was not recorded if livestock (cattle or sheep) had disturbed the integrity of the banks, or if the turbidity prevented observation of burrows <0.5 m below water level. In some cases turbidity increased over the sample period, so it was not possible to collect consecutive measurements for dams in spring, summer and autumn 1999-2000. In other cases the introduction of livestock to paddocks containing the study dams caused trampling of burrows and assessment of burrow numbers was discontinuous for these dams. This resulted in observations being recorded from 39 sites in total, rather than the initial 49 sites sampled.

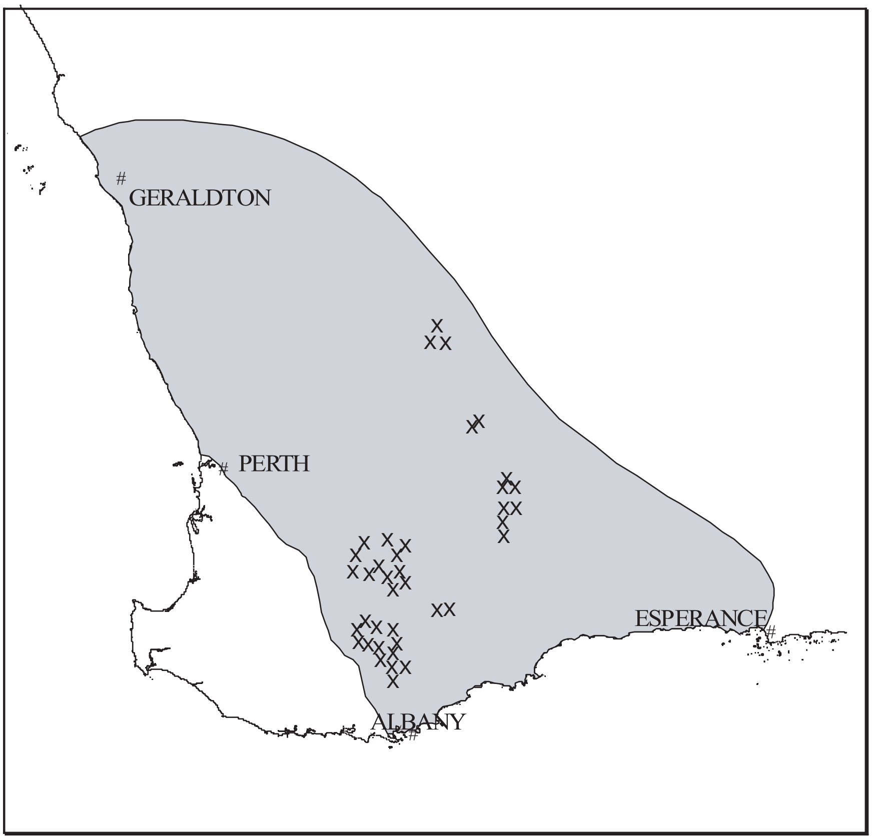

Figure 2. Commercial yabby harvesting region (shaded) in Western Australia with location of Survey 2 study sites.

2.3 Field measurement of burrows and yabby populations

As most burrows occur within 0.5 m either side of the water's edge, burrow density (burrows/m^2) during the initial survey was determined by dividing the number of burrows (not entrances) by the selected bank area circumference of the dam bank at the waters edge multiplied by 1m (Figure 3). During the second survey, burrows were not cast, so it was not possible to differentiate between entrances and individual burrows. As the initial survey of farm dams found the number of entrances per burrow ranged from 1-4, and averaged 2 (see results section); where ≥ 2 entrances were found in close proximity to one another it was assumed that this represented one burrow.

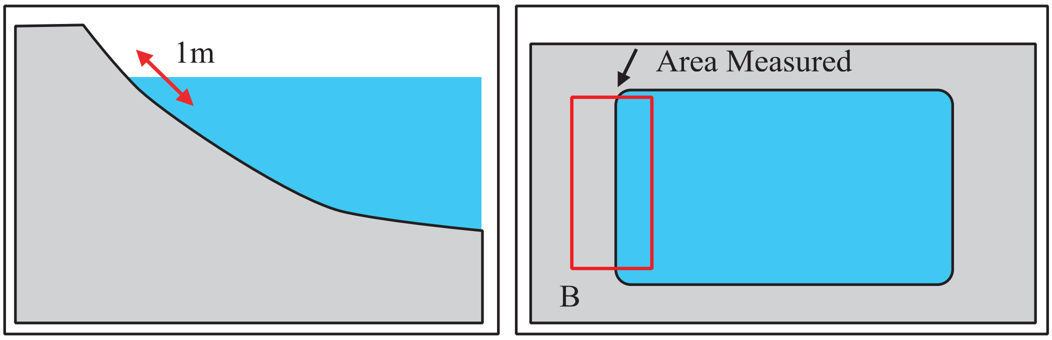

Figure 3. Graphical view of a farm dam with areas measured for burrow density: A - 0.5 m either side of the waters edge; B - Above view of area measured.

Casts excavated from burrows were measured for minimum and maximum tunnel width, cavern width, number of entrances, depth directly into dam wall (see Figure 4), and actual burrow length (see Figure 4).

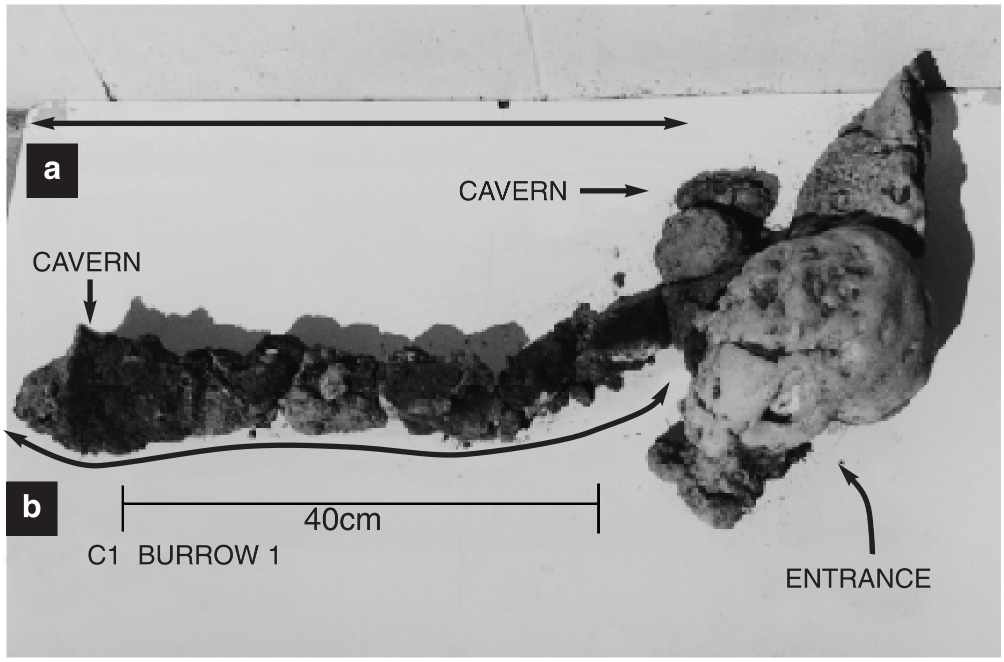

Figure 4. Polyurethane cast of a yabby burrow displaying measurements of depth into dam wall (a) and actual burrow length (b).

Minimum tunnel width was recorded and used to determine the size of burrowing crayfish based on the carapace width:weight regression reported by Morrissy (1995).

The classification of burrows followed that of Grow (1981) in which burrows were classed as depressions, angular pits, or U-shaped burrows. To this classification another burrow type, network, was added to describe the more complex network style burrows found in some yabby dams (see Figure 5).

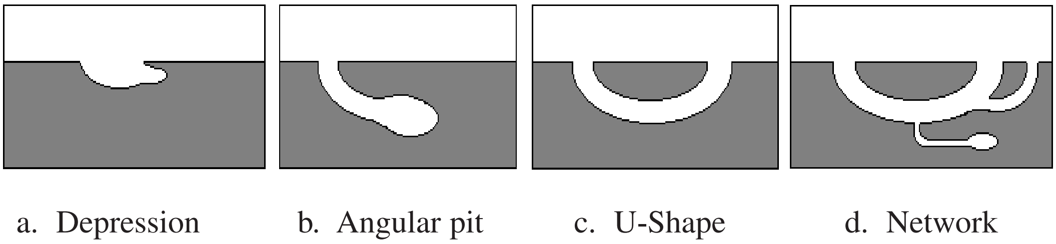

Figure 5. Burrow classification (after Grow, 1981).

The sex ratio of the yabby population from dams sampled during Survey 1 was determined by obtaining a random sample of animals from the dam using a one-person trawl (Figure 6). It was not possible to obtain samples from channels. The trawl net was made from 5 mm knot-less mesh, with a mouth size of 2 × 1 meters (width × height) and a 3.6 meters long sock (Figure 6). A rope connected to an aluminium frame that was attached to the mouth of the net was used to pull the net across the dam by one person, whilst ensuring that the mouth of the net was fully open at all times. It was not possible to operate the trawl net within the channels but it operated well within dams.

Figure 6. Trawl net used determining sex ratios of dams.

Surface soil samples were taken from the substrate surrounding borrows at each site during Surveys 1 and 2 to investigate relationships between soil type, burrow morphology and density. These were air dried and sorted into clay (<2 µm), silt (2-20 µm), and sand particles

(20-200μm). Sand particles were further divided into fine (20-180 μm) and coarse (180-200 μm) in survey one, but only sand (20-200 μm) was reported from survey 2) (Australian standard analysis: AS 1289.C63). Soils from survey 1 were classified to type by using the triangular texture diagram (Figure 7).

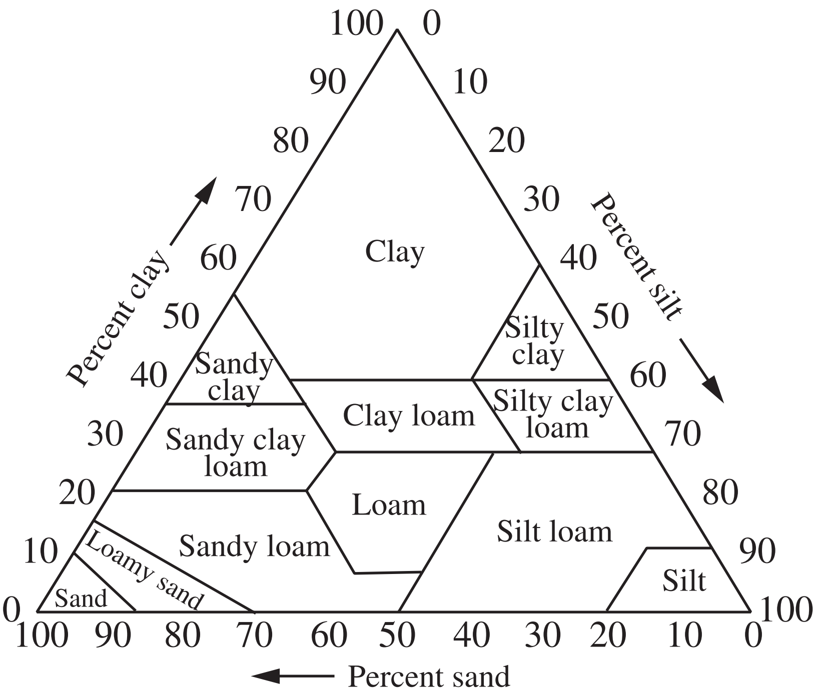

Figure 7. Soil classification (according to Boyd & Tucker 1992).

Excavated burrows were refilled using clay and bentonite to prevent the structural integrity of the dam from being compromised by cast excavation.

In Spring 1998 water samples were collected at sites N1 (dam), N2 (dam), C1 (channel), SE1 (dam) and SE2 (channel), during Survey 1, and in Autumn 1998 from all sites during Survey 2, and frozen immediately in preparation for analysis. Insufficient water was collected from site C2 during Survey 1 for water chemistry analysis.

Water samples were tested for pH, conductivity at 25ºC, alkalinity, sodium, potassium, calcium, magnesium, iron (soluble), hardness as $CaCO_3$, chloride, sulfate, nitrate as NO_3, Nitrite as NO_2, bicarbonate as $CaCO_3$, orthophosphate as P (PO_4-P), total phosphorus as P, ammonia as N (NH_3-N), chemical oxygen demand, chlorophyll, colour, turbidity, manganese (total), copper (total) and zinc (total).

2.4 The influence of damage, diet, yabby density, and sex on burrowing habits

The incidence of yabby burrows in 25 research ponds at the Avondale research station was recorded in 2 separate experiments investigating the effect of feeding, density and sex on the growth of yabbies as outlined below and in Lawrence *et al.* (1998) and Lawrence *et al.*

(2000). The change in burrowing habits across 6 experiments. over a four year period (1995-1997) (Lawrence *et al*., 1998) beginning shortly after construction of the research ponds, allowed investigation of the effect of dam age.
Results are presented as burrow incidence, calculated according to the following formula:

$$\text{Burrow incidence (No. burrows/yabby)} = \frac{\text{Total number of burrows in pond}}{\text{Number of yabbies in pond}}$$

Surviving density was chosen over stocking density as the minimum tunnel width at the research station was shown to be 45 mm. This approximately equates to a live weight of ≤120 g (see results section) which is much greater than the stocking weight of 20-30 g (Lawrence *et al*., 1998).

The effect of sex on burrow incidence was investigated in a 175 day trial, with yabbies stocked at a density of 1 yabby/m^2. The incidence of burrowing was tested between female only and male only treatments compared against a mixed sex (1:1 male/female) control, using 6 replicate ponds per treatment (Lawrence *et al*., 2000). At the conclusion of the trial, the ponds were drained and the number of burrows and yabbies were counted and burrow incidence calculated. Burrows were filled in to prevent carry-over between experiments.

The effect of diet and density on burrow incidence was investigated in a 105 day trial, with yabbies either fed (lupins at a rate of 2.5g/m^2/week), or not fed, and at two different densities (1 yabby/m^2 and 4.5 yabbies/m^2), using 6 replicate ponds per treatment (Lawrence *et al*., 1998). At the end of the trial ponds were drained and the number of burrows and yabbies were counted and corrected to the surviving density. Burrows were subsequently filled in to prevent carry-over between experiments.

2.5 Statistical analysis

Data was tested for normality using Lilliefors probability test. All data conformed to normality except for actual burrow length, which was restored using a square root transformation. The differences in burrow morphology between sites, effect of dam age and effect of sex on burrowing were analysed by one way analysis of variance. The effects of feeding and density on burrowing were tested by a two way analysis of variance. The change in burrow density due to season was investigated using unpaired students t-tests. The effects of water chemistry and soil composition on burrow morphology and density were investigated using Pearson's product-moment correlation.

3.0 Results

3.1 Evaluation of methods for casting yabby burrows

Of the four methods evaluated, the preferred agent was polyurethane foam. Foam had the advantage of expanding to 30 times its original volume; thus pressurising the burrow and creating a complete 3 dimensional mould. In contrast, when concrete, plaster and resin were poured into burrows, they filled the horizontal sections but only provided a cast of the lower portion of burrows and chambers (Table 1). The polyurethane burrow casts were also considerably lighter than the concrete and plaster moulds, thus making them easier to handle and transport. In addition, they were less brittle and therefore less prone to breakage. This was especially advantageous when conducting field work.

The only negative aspect of using polyurethane foam was that it set poorly when a lot of water was present in the burrow, such as those below the waters surface. As a result only dry burrows situated above water level were examined in the Northern, South Eastern and Central locations. As the research ponds were drained at the Avondale location, access to burrows in the bottom of the dams was possible and therefore these were investigated.

Table 1. Comparison of methods for casting yabby burrows.

Method	Advantages	Disadvantages
Polyurethane foam	3 dimensional burrow, quick setting, light weight	Does not set well under water.
Concrete	Low cost	2 dimensional burrow, or does not mould all parts of the burrow, brittle
Plaster	Low cost	2 dimensional burrow, brittle
Resin	Transparent	2 dimensional burrow

High pressure water proved to be the most efficient method for excavating the casts of burrows. The use of water had the added bonus of preserving the shape of casts, as opposed to digging which frequently caused the casts of burrows to break (particularly where concrete or plaster were used as the casting agent). Although high pressure water was effective at removing most of the soil surrounding the cast, some digging was still required to carefully excavate the burrow cast from the surrounding soil structure.

The pilot study to evaluate methods for excavating burrow casts used a petrol powered, industrial high pressure spray cleaning unit. Although this unit worked adequately on a small scale, it had the disadvantage of requiring a clean filtered source of water, which was not readily available for excavating casts of burrows in the field. Therefore, a petrol driven (5 hp.) fire fighting unit with a 5 mm nozzle was used for field excavations. This unit permitted excavation of burrows using small amounts of extremely turbid water in isolated conditions.

3.2 Survey of yabby burrows

There were significant site differences for both mean burrow depth into dam walls (P=0.003) and the actual burrow lengths (P=0.0004) (Table 2). Burrows in the small dam were shallower and shorter than those in larger dams and channels (Table 2).

Table 2. Mean depth of burrows directly into dam wall (n = number of burrows characterised in each water body).

Site	Description	Surface area (m2)	Mean depth (cm)	S.D.	Mean actual burrow length (cm)	S.D.	n
N1	Large dam	1600	34	72	80	20	2
N2	Small dam	50	8	23	8	0.4	3
SE 1	Large dam	1600	22	30	26	0	2
SE 2	Catchment channel	30	28	57	44	6	4
C1	Catchment channel	40	40	45	62	2.4	7
C2	Catchment channel	80	30	27	62	1.7	3
C3 Avondale	25 Research ponds	100	21	27	30	1.5	18

The maximum depth which a burrow penetrated into a bank was 64.5 cm (Table 3). Mean burrow length was 25.8 cm (Table 3). The maximum actual length of a yabby burrow was 148 cm (Table 3).

Table 3. Summary of the morphology of yabby burrows in farm dams, channels and research ponds.

Site (no. of burrows investigated)	Depth directly into dam (cm)	Actual burrow length (cm)	Number of entrances	Minimum tunnel width (cm)	Cavern width (cm)
3 Farm dams and 3 channels (n=21)					
Mean (s.e.)	29.6 (3.0)	52.1(7.8)	2.0 (0.2)	5.4 (0.4)	12.8 (1.9)
Minimum	5.5	5.5	1.0	2.5	2.7
Maximum	64.5	148	4.0	8.5	33
3 Avondale research ponds (n=18)					
Mean (s.e)	21.4 (2.7)	31.3 (3.0)	1.2 (0.1)	7.7 (0.5)	12.2 (0.8)
Minimum	9	11	1.0	4.5	8
Maximum	50	51.5	2.0	12.5	17.5
Farm dams, channels and research ponds combined (n=39)					
Mean (s.e.)	25.8 (2.1)	42.5 (4.8)	1.6 (0.2)	6.4 (0.4)	12.5 (1.1)
Minimum	5.5	5.5	1.00	2.5	2.7
Maximum	64.5	148	4.00	12.5	33

Significant differences existed between burrows in field samples (farm dams and channels) and those in research ponds at Avondale in the number of entrances to each burrow ($p=0.007$), minimum tunnel width of burrows ($p=0.0007$), actual burrow length ($p=0.02$) and depth of burrows into the dam wall ($p=0.049$) (Table 3). There was no significant difference in the cavern width ($p=0.795$) of burrows between field samples and research ponds at Avondale.

Although most burrows had only 1 entrance (64.1% i.e. consisting of depressions and angular pits), the mean number of entrances was generally greater than 1 due to the occurrence of burrows with multiple (>2) entrances (Table 5). Where burrows with multiple entrances occurred generally one entrance was above water level and one was below. The overall minimum tunnel width was 2.5 cm (Table 3). The minimum tunnel width in Avondale ponds was 4.5 cm (Table 3). Average tunnel width for both the field sites and in Avondale ponds was 6.43 cm (Table 3).

During the initial survey, only 24% of the dams investigated (6 out of 25 dams) had burrows, and the average number of burrows per m^2 at these sites was 0.58 (Table 4). The catchment channel at site C1 had the highest burrow density with 2.2 burrows/m^2 (Table 4). Site SE1, a large dam, had a very low burrow density of 0.014, while site SE2, a catchment channel located 20 m from SE1, had a much higher burrow density of 0.6 burrows/m^2.

The highest density of burrows was recorded at the site with the highest female : male ratio (Table 4).

Table 4. Burrow density and sex ratio of yabbies from dams.

Site	No. of burrows	Density (no./m^2)	Ratio (female:male)
N1	7	0.04	1.39
N2	23	0.29	*
SE1	4	0.01	1.14
SE2	6	0.60	*
C1	22	2.20	1.61
C2	8	0.80	1.18
C3 Avondale	9	0.11	1
TOTAL	79	0.58	-

* Sex ratio was not obtained for channels

Most burrows could be classified as angular pits, consisting of simple tunnels leading to a terminal chamber (Table 5). Of the remaining burrows there was an even representation of depressions, U-shaped tunnels and network style burrows (Table 5).

Multiple entrances characterised catchment channels (C1, C2, and SE2), with U-shaped or network burrows occurring in 71% of cases (Table 5). In contrast the burrows in dams (SE1, N1, N2) and Avondale research ponds were mostly depressions or angular pits (81%) (Table 5). It is worth noting however that a number of angular pits appeared to be progressing towards forming a U-shaped burrow. Another notable observation was that although depressions or chambers were most common in research ponds at Avondale, the three U-shaped burrows that were observed were levee burrows situated at the waters edge.

Table 5. Classification of burrows (based on Figure 5 after Grow, 1981).

Site	Depression	Angular pit	U-shaped	Network
N1	0	1	0	1
N2	2	1	0	0
SE1	0	2	0	0
SE2	1	0	0	3
C1	0	2	3	2
C2	0	1	1	1
C3 Avondale	4	11	3	0
% OF TOTAL	17.9	46.2	17.9	17.9

During the second survey, the occurrence (dams in which at least 1 burrow was found) of burrows increased steadily from 24% in September 1999 to 70% in March 2000 (Table 6). The density of yabby burrows increased significantly between spring and summer ($p = 0.03$), but did not increase (significantly) between Summer and Autumn ($p = 0.29$).

Table 6. Change in burrow occurrence and density in commercial yabby dams over time.

Season	% Occurrence	Mean density(No./m^2 ±s.e.)	n
Spring	25	0.02(0.01)a	36
Summer	46	0.07(0.02)b	35
Autumn	70	0.11(0.03)b	30

* Different superscripts depict significant differences

3.3 Relationship between burrows and environmental parameters

3.3.1 Soil composition

Both surveys sampled burrows from a range of soil types (Table 7, Table 8).

Table 7. Survey 1 soil composition and type from burrow sites (n=7).

Site	Coarse sand %	Fine sand %	Silt %	Clay %	Soil type
N1	64	12	2	23	Sandy clay/loam
N2	46	50	5	9	Sandy loam
SE1	20	41	3	36	Sandy clay
SE2	20	41	3	36	Sandy clay
C1	43	36	6	15	Sandy loam
C2	60	28	4	8	Loamy sand
C3 Avondale	49	17	5	30	Sandy clay

Table 8. Survey 2 Summary data of soil composition from burrow sites (n=39).

	Sand %	Silt %	Clay %
Mean (se.)	73.2(2.5)	5.9(0.5)	21(2.2)
Minimum	42.5	1	2
Maximum	97	14	48

There was a strong relationship between soil type and burrowing in survey 1, where yabbies burrowed more in soil containing high levels of silt. (Appendix 1, Table 1). This finding was not supported by the data from survey 2 (Appendix 2, Table 2)

3.3.2 Water chemistry

Both surveys sampled burrows from a range of water chemistry types (Table 9, Table 10).

Table 9. Water chemistry for burrow sites from Survey 1.

Parameter	units	SE1 (dam)	SE2 (channel)	N1	N2	C1
pH		8.7	8.9	7.7	7.3	9.1
Conductivity at 25°C	uS/cm	450	410	270	2600	3400
Sodium	mg/L	60	60	20	360	610
Potassium	mg/L	8	5	14	1	12
Calcium	mg/L	17	12	9	17	26
Magnesium	mg/L	11	9	6	62	45
Iron (soluble)	mg/L	0.1	<0.1	0.5	<0.1	<0.1
Hardness as $CaCO_3$	mg/L	87	65	40	230	86
Chloride	mg/L	50	50	50	660	890
Sulfate	mg/L	22	8	12	130	110
Total oxidized nitrogen as N	mg/L	<0.01	0.02	0.66	0.21	0.046
Orthophosphate as P, (PO_4-P)	mg/L	0.047	<0.005	0.059	<0.005	<0.005
Total phosphorus as P	mg/L	0.64	0.056	0.45	0.031	0.11
Total Ammonia as N	mg/L	0.19	0.12	0.57	0.25	0.3
Total Copper	mg/L	<5	<5	<5	<5	<5
Total Manganese	mg/L	<5	<5	<5	<5	<5
Total Zinc	mg/L	<10	<10	<10	<10	<10

Table 10. Water chemistry for burrow sites from Survey 2.

	units	Mean	S.E.	Min.	Max.
pH		8.1	0.09	6.7	9.3
Conductivity at 25°C	uS/cm	1240	252	380	9800
Alkalinity	mg/L	204	27	25	960
Sodium	mg/L	182	42	20	1600
Potassium	mg/L	15	2	2	67
Calcium	mg/L	19	2	1	56
Magnesium	mg/L	23	5	7	180
Iron (total)	mg/L	26	7	1	170
Hardness	mg/L	140	23	32	870
Chloride	mg/L	251	81	10	3100
Sulfate	mg/L	36	5	6	170
Carbonate as $CaCO_3$	mg/L	39	15	4	95
Nitrate as NO_3	mg/L	6	0.8	1	13
Bicarbonate as $CaCO_3$	mg/L	197	24	25	870
Orthophosphate as P, (PO_4-P)	mg/L	0.07	0.02	0.01	0.59
Total PO_4-P	mg/L	0.35	0.06	0.05	1.7
Total Ammonia as N	mg/L	0.28	0.06	0.05	1.8
COD	mg/L	132	18	32	700
Chlorophyll	mg/L	0.04	0.01	0	0.35
Colour	C unit	150	25	19	790
Turbidity	NTU	422	84	18	2100
Total Zinc	mg/L	93	57	9	2100
Total Manganese	mg/L	97	17	15	540
Total Copper	mg/L	61	29	5	460

There was also a strong relationship between water chemistry and burrowing in survey 1. Yabbies burrowed more where calcium, potassium, sodium, chloride and conductivity levels were high, while there was a negative relationship between yabby burrowing and hardness. (Appendix 1, Table 2). However, in survey 2 there was no significant relationship between water chemistry and burrowing (Appendix 2, Table 1).

3.4 The influence of diet, yabby density, sex and location on yabby burrowing habits

During the three year period in which burrow incidence was recorded from the research ponds at Avondale Research Station, 2508 individual burrows were recorded. There was a slight significant difference in the number of burrows in each pond over the 3 year period ($p=0.0261$) ($n=139$) (Figure 8). Students t-test (assuming unequal variances) revealed that there was a significant increase ($p=0.00367$) in burrow incidence between the first and second sampling dates (Figure 8).

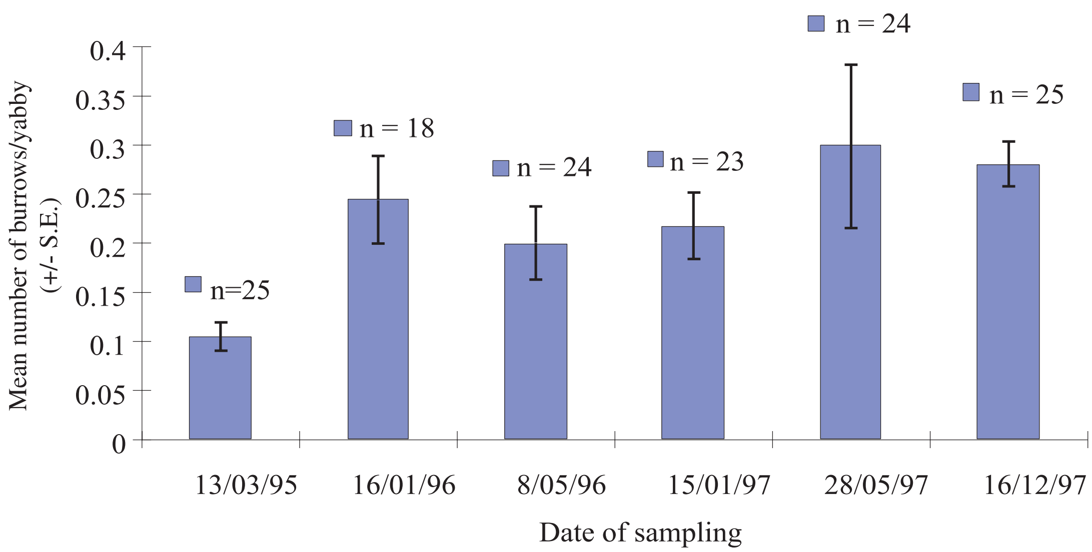

Figure 8. Change in burrow incidence in research ponds over time (n=139).

Fed yabbies burrowed significantly more ($P=0.0106$) than unfed yabbies (Figure 9). Density had no effect ($P=0.640$) on the burrow incidence of yabbies (Figure 9).

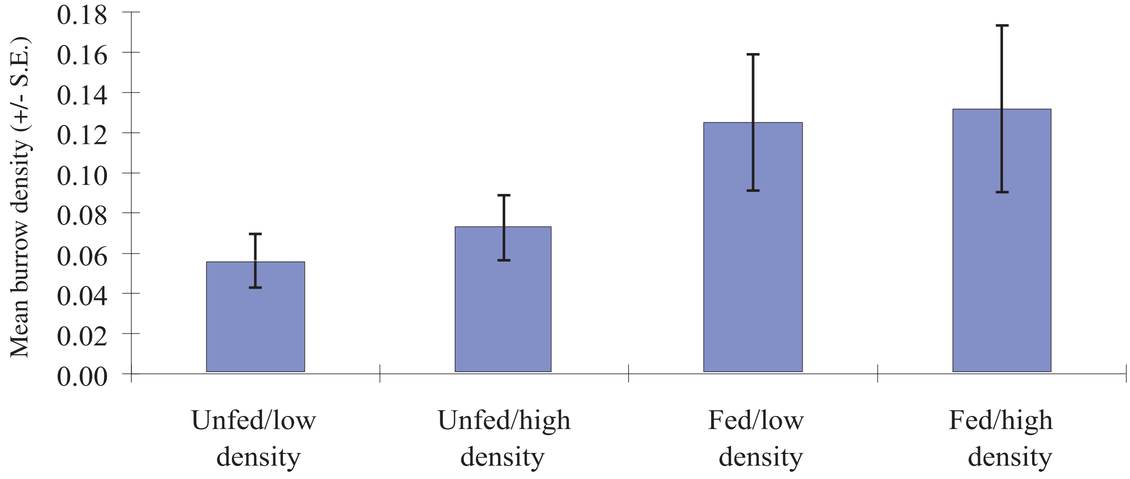

Figure 9. Effect of feeding and density on burrow incidence of yabbies (n=6).

Male yabbies in male only ponds burrowed less than yabbies in female only or mixed sex ponds (P=0.037) (Figure 10).

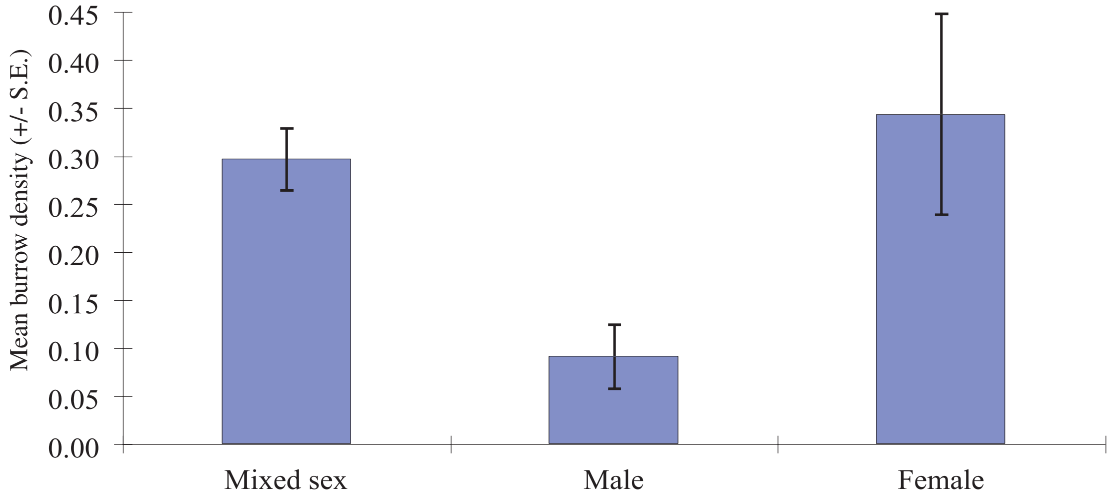

Figure 10. Differences in burrowing habits between male, female and mixed sex populations of yabbies (n=6).

4.0 Discussion

4.1 Burrow morphology and implications for export markets

Compared to other freshwater crayfish species that have caused problems by burrowing into water reservoirs and agricultural fields, *C. albidus* appears far less damaging. It is possible that in the absence of valid scientific data, overseas markets have assumed that this species has similar burrowing habits as *C. destructor* or worse still, the highly documented American crawfish, *P. clarkii*. *P. clarkii* has been shown to cause considerable damage to the levee banks of rice fields in Japan (Penn, 1954), mainland America (Sommer & Goldman, 1983), Hawaii (Penn, 1954), Spain, (Ackefors & Lindqvist, 1994) and Portugal (Correia & Ferreira, 1995). It is obvious from this report however that the burrows of *P. clarkii*, ranging from 127 - 420 cm (Huner, 1992 and Correia and Ferreira, 1995 respectively) are much longer than those of *C. albidus.* Furthermore, the data from this study suggests that the burrowing habits of *C. albidus* are not as bad as those of *C. destructor* (reported anecdotally by Frost 1975 and Huner and Lindqvist, 1995).

Given the widespread distribution of *C. albidus* yabbies in farm dams throughout WA, the low percentage of dams containing burrows and the lack of reports of farm dam banks being compromised by burrows, evidence suggests that burrowing by *C. albidus* does not damage dams.

The size and shape of yabby burrows in Western Australia differs significantly between locations and different sized water bodies. In general however burrows are longest in larger dams and catchment channels and shortest in small dams.

The density of burrowing is generally lower for *C. albidus* compared to *P. clarkii*. Correia and Ferreira (1995) reported average burrow densities for *P. clarkii* from 0.013m^2 to 0.29 m^2 for water reservoirs, and 0.395 m^2 to 4.24 m^2 for rice paddies. In comparison the burrow density for *C. albidus* ranged from 0.014 m^2 to 0.11 for dams and 0.6 m^2 to 2.2 m^2 for drainage banks.

4.2 Burrow morphology

The morphology of yabby burrows in WA farm dams is characterised by a single entrance with a narrow tunnel leading to a wider terminal cavern. Although the maximum recorded length of a *C. albidus* burrow was reasonably long (at 148 cm) the maximum depth a burrow penetrated into a dam wall was less than half this distance (65 cm). However, most burrows are shorter than this with an average penetration depth directly into the dam wall of 26 cm.

Numerous classification systems have been proposed for identifying the burrow types of crayfish (e.g. Hobbs, 1981; Grow, 1981; Horwitz & Richardson, 1986; Hasiotis 1993; Correia & Ferreira, 1995). Of these, only Grow (1981) considers the progression of burrow formation, accounting for the possibility that at the time of discovery burrows may be still under construction or abandoned. The abandonment of burrows has been shown to be common in other species, for instance Grow (1981) found that 75% of the time *C. diogenes diogenes* will progress to stage 1 (Figure 3a) or 2 (Figure 3b) and subsequently abandon the burrow. However when animals do not abandon burrows, (i.e. continue to burrow to stage 3

(Figure 3c)) most (85%) subsequently construct a network of burrows (Figure 3d). The network may either consist of a number of additional entrances to a U-shaped burrow, or develop into a burrow leading off of the U-shaped burrow to a cavern (Grow, 1981). A stable water table appears to be a cue for the construction of a network of entrances to a U-shaped burrow, whilst a drop in water table appears to induce burrowing off the bottom of the U-shaped burrow and the construction of a terminal cavern (Grow, 1981).

The types of burrows dug by *C. albidus* conform to the classifications given by Grow (1981). Most burrows constructed were angular pits, with an even distribution of burrows to the other styles, however it appeared as though a number of angular pits were progressing towards forming a U-shaped burrow. Whether such angular pits were abandoned or still under construction is not known. Given *C. albidus* does not construct as many complex burrows as simple ones, the likelihood that burrowing could lead to the collapse of a dam wall is reduced.

The complexity of *C. albidus* burrows was affected by location, with network burrows most common in catchment channels. Grow (1981) suggested that there may be a relationship between complex burrowing behaviour and ground water levels. The state of inundation of catchment channels would be expected to fluctuate regularly, supporting the theory that water table height is a cue for inducing complex burrowing habits (Grow, 1981, Merrick, 1993). This is supported by the observation of greater numbers of U-shaped levee burrows at Avondale, where only minor changes in water table occurred. Merrick (1993) suggested that the steep banks of channels are the preferred burrowing site for crayfish, supporting the concept that a noticeable change in water table height may be a cue for inducing burrowing habits.

4.3 Why do yabbies burrow?

Fed yabbies and female yabbies burrowed more than unfed or male yabbies.

The burrows constructed in this study were all of a size which mature females could easily occupy. Huner (1992) believes that burrow diameter is clearly proportionate to crayfish size for *P. clarkii*, but unfortunately he provided no data to estimate crayfish size from burrow width. This study used the carapace width : weight regression developed by Morrissy (1995) to estimate maximum crayfish size from burrow width. Obviously this method over-estimates the maximum size of the yabby (as appendages would take up some space within the burrow), and thus additional data is required to correct burrow width to crayfish weight. In the absence of this data however maximum yabby sizes are quoted. The minimum tunnel width observed in the state-wide survey for *C. albidus* in this study equates to a <50 g yabby, whilst the minimum tunnel width at Avondale equates to a <125 g yabby.

According to the classification of Hobbs (1981) *C. albidus* as a type 1b burrower, characterised by female animals spending only a short period of its life in the burrow when gravid (in berry). Given sexual maturity in *C. albidus* yabbies can occur in females as small as 10 g (Lawrence *et al*., 1998) it is possible that burrows may have been constructed for purposes associated with reproduction and/or rearing of young. Further research on the occupancy and function of burrows is required to confirm such relationships.

C. albidus is an *r*-strategist that has evolved in a semi-arid environment. Two of the characteristics of an *r*-strategist are the ability to reproduce at an early age or size and the ability to rapidly produce many juveniles (Stearns, 1976). Female yabbies mate if fluctuating environmental cues, increased temperature and light, indicate oncoming dry summers and drought typical of central and south-eastern Australia. It is possible that yabbies burrow to ensure wet conditions exist, so as juveniles can be released into a moist atmosphere rather than the dry exterior. A strategy such as this may increase the chances of juvenile survival during drought periods, whereupon they can leave the burrows with winter rain.

The use of burrows for reproduction in crayfish is common to other species. For *P. clarkii*, Correia & Ferreira (1995) found mature female were more abundant than mature males in burrows in half of the sites they studied. In the other half of burrows investigated cohabiting males and females were found most frequently (Correia & Ferreira, 1995).

The positive relationship between food availability and burrowing may be due to processes associated with increased physiological fitness. This could be due to two factors, either, fed animals may have greater amounts of reserve nutrients for vitellogenesis, and so the greater incidence of burrowing may be associated with reproduction. Or, alternatively unfed animals may lack the energy reserves necessary for the building of burrows.
Higher densities did not lead to an increase in burrowing habits. As burrowing does not increase with increased density, burrows probably serve a purpose other than to decrease density induced interactions between crayfish.

4.4 How do physical or chemical parameters induce burrowing?

There was a strong relationship between soil type and burrowing in survey 1, where yabbies burrowed more in soil containing high levels of silt. However, this finding was not supported by the data from survey 2.

Similarly there was also a strong relationship between water chemistry and burrowing in survey 1. Yabbies burrowed more where calcium, potassium, sodium, chloride and conductivity levels were high. While there was a negative relationship between yabby burrowing and hardness. However, in survey 2 there was no significant relationship between water chemistry and burrowing.

While these results are inconclusive, it is possible that burrowing is prompted by increased levels of cations as would occur with increasing ionic concentration due to evaporation and for crayfish within the water body could provide a signal of impending drought. This hypothesis is supported by the greater incidence of burrows as seasons progress from Spring through the dry summer to Autumn recorded in survey 2. However the results of survey1 were not supported by the data from survey 2, this may be due to the small sample size or time of year.

Generally speaking tunnelling is a complex process depending on variables such as the density and moisture content of the soil, soluble salt content of the stored water, the rate of filling of water and soil properties (Rosewell, 1970). Some previous studies have suggested relationships between various physical and chemical parameters and burrowing in crayfish. For instance Correia and Ferreira (1995) found that the amount of fine sediment (silt & clay) must be 10-20% of the total amount of sand plus gravel to allow burrowing by *P. clarkii*. They further suggested that clay was necessary for maintaining moist conditions, but coarse sediments were structurally unstable for constructing burrows (Correia & Ferreira, 1995).

Similarly Grow (1981) found that burrowing by *C. diogenes diogenes* increases proportionately with the amount of fine sediments in the substrate. Soils with a greater than 30% clay component have been suggested to be susceptible to burrow failure. The expansion and contraction of the soil associated with changes in water content observed in substrates with high clay contents have been implicated in such failures (Crouch *et al.*, 1991).

The burrowing habits observed in ponds at the Avondale Research Station increased significantly as the ponds aged over the first year. It is possible that the lower occurrence of burrows observed on the first sampling date was due to poor soil compaction. The rate of burrowing has steadily increased after the first sampling date, suggesting that the banks of the dams progressively consolidated over time.

Given there was no interaction between soil composition, water chemistry and burrow density found in this study, factors other than these (i.e. sex ratio, or the nutritional status of the animal) must have had a greater influence on burrowing habits.

4.5 How do burrows disappear from farm dams?

The three major processes are likely to be a) trampling by livestock as water levels recede in summer b) erosion from summer and autumn storms which are likely to cause soil erosion prior to water levels rising above old burrows and c) sustained winter rains which flood previously exposed burrows.

5.0 Conclusions & recommendations

The burrowing habits of yabbies vary between locations, but appears to influenced by sex ratio and feed availability.

C. albidus burrows less and shallower than *P. clarkii* which has been responsible for damaging water reservoirs in other countries. The burrowing impact of *C. albidus* was much less than that reported anecdotally for *C. destructor*. However equivalent detailed studies interstate with *C. destructor* may be warranted.

The results of this survey be published and disseminated to provide information on burrowing by *C. albidus* to scientists, exporters and importers.

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7.0 Appendices

APPENDIX 1:

Table 1. Matrix of correlations of burrow morphology and density and soil conditions from survey 1.

Burrow Parameter	Coarse sand	Fine sand	silt	clay
BURROW DENSITY	0.02	0.29	0.63	-0.40
ACTUAL BURROW LENGTH	0.48	-0.56	-0.34	-0.10
DEPTH DIRECTLY INTO DAM	0.17	-0.27	-0.08	0.03

Table 2. Matrix of correlations of burrow morphology and density with water chemistry from survey 1.

Burrow Parameter	pH	Conductivity at 25°C	Sodium	Potassium	Calcium	Magnesium	Iron (soluble)	Hardness as $CaCO_3$
BURROW DENSITY	0.54	0.76	0.84	0.37	0.93	0.44	-0.36	-0.03
ACTUAL BURROW LENGTH	0.18	-0.23	-0.13	0.88	-0.24	-0.50	0.75	-0.80
DEPTH DIRECTLY INTO DAM	0.63	-0.02	0.13	0.86	0.17	-0.42	0.33	-0.84

Burrow Parameter	Chloride	Sulfate	Total oxidised nitrogen as N	Orthophosphate as P, (PO_4-P)	Total phosphorus as P	Total Ammonia as N
BURROW DENSITY	0.75	0.54	-0.40	-0.34	-0.16	-0.04
ACTUAL BURROW LENGTH	-0.19	-0.42	0.59	0.41	0.17	0.71
DEPTH DIRECTLY INTO DAM	0.01	-0.31	0.11	0.16	0.12	0.36

APPENDIX 2:

Table 1. Matrix of correlation coefficients for burrow density and water chemistry and soil parameters from survey 2.

SAMPLE MONTH	n	Stones	Sand	Silt	Clay	pH	Conductivity at 25°C	Alkalinity	Sodium	Potassium	Calcium	Magnesium	Bicarbonateas as $CaCo_3$
SPRING	28	0.23	0.04	0.08	-0.06	-0.10	-0.19	-0.10	-0.18	-0.24	-0.05	-0.06	-0.09
SUMMER	28	0.05	0.16	-0.01	-0.19	-0.32	-0.17	-0.26	-0.16	-0.26	-0.33	-0.17	-0.27
AUTUMN	28	-0.14	0.27	-0.20	-0.26	-0.30	-0.16	-0.14	-0.12	-0.22	-0.25	-0.19	-0.14
MEAN	38	-0.03	0.12	0.01	-0.15	-0.31	-0.18	-0.17	-0.16	-0.24	-0.28	-0.17	-0.17

SAMPLE MONTH	n	Iron (total)	Hardness	Chloride	Sulfate	Nitrate as No_3N	Carbonateas as $CaCO_3$	Turbidity	Total	COD	Chlorophyll
SPRING	28	0.07	-0.05	-0.22	-0.02	-0.11	0.18	-0.20	-0.11	-0.12	0.14
SUMMER	28	0.29	-0.22	-0.15	-0.09	-0.33	0.17	0.02	-0.10	-0.18	0.31
AUTUMN	28	0.07	-0.23	-0.17	-0.06	-0.06	0.19	-0.05	-0.12	-0.16	0.02
MEAN	38	0.21	-0.21	-0.16	-0.05	-0.24	0.23	0.00	-0.10	-0.18	0.18

SAMPLE	n	Orthophosphate as P, (PO_4-P)	Total PO_4-P	Total Ammonia as N	Colour	Total Managanese	Total Copper
SPRING	28	-0.10	-0.20	-0.01	-0.12	-0.22	-0.14
SUMMER	28	0.23	-0.21	-0.29	-0.08	-0.33	-0.10
AUTUMN	28	0.11	-0.22	-0.19	-0.02	-0.24	-0.16
MEAN	38	0.13	-0.19	-0.22	-0.03	-0.29	-0.17

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