Malleefowl, *Leipoa ocellata*, mound productivity in three regions of South Australia following a low rainfall year

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Abstract
This study examines the mound productivity of Malleefowl Leipoa ocellata at eight sites within three regions of South Australia towards the end of the breeding season, in February-April 2007. Thirty-four mounds were excavated to determine the number and fate of eggs laid. In total, 144 eggs were estimated to have been laid, with mean clutch size 4.7 (range 1-15), 57% of eggs hatched and 82 hatchlings fledged. Baseline data is provided for these South Australian sites and is compared with sites in the eastern States. The well-below average rainfall in 2006 was probably reflected in the number of eggs laid in the 2006/07 breeding season and reasons for this are discussed in light of previous studies. It is suggested that recurring drought presents a very real threat to Malleefowl mound productivity.

INTRODUCTION

Malleefowl, *Leipoa ocellata,* were once widespread throughout the arid and semi-arid mallee scrub regions of South Australia. However, during the last 50-60 years, the species has undergone a severe reduction in area of occupancy (Gillam 2006; Benshemesh 2007). In addition, the abundance of birds within occupied remnants also appears to be in decline. Various causes are believed to have prompted this decline, which is expected to continue unless management of Malleefowl habitat and populations is improved (Frith 1962; Benshemesh 2007). Indeed, Malleefowl are considered threatened across all remaining areas of their range.

A recent report (Benshemesh 2006) suggests a significant decline of 2-3% per year over the past decade in Malleefowl breeding activity in regularly monitored areas across southern Australia, with a definite downward trend shown in South Australia. In particular, winter rainfall was identified as a key variable affecting Malleefowl breeding density, which agrees with other studies on the ecology of Malleefowl (Benshemesh 2006). The effects of patch size and fire were found to be insignificant, and similarly, there was no evidence that foxes or fox control influenced Malleefowl breeding numbers (Benshemesh 2006), but this result should be interpreted within the scope of that study, and does not contradict the findings of previous studies.

Malleefowl use heat produced by decomposition of leaf litter and the sun to incubate their eggs in mounds (Frith 1959). Seasonal conditions, in particular winter rainfall, largely determine not only the productivity of the landscape (hence food supply), but also whether the composting material inside the Malleefowl's mound chamber will generate enough heat to incubate eggs, which in turn exerts a major influence on Malleefowl breeding success (Frith 1959; Booth and Seymour 1984; Priddel and Wheeler 2003, 2005). Annual reproductive success is also dependent on the fertility of both the male and female, the ability of the male to maintain incubation temperatures, and the survival of the male during the nesting season (Copley and Williams 1995).

The fecundity of Malleefowl is high, with birds typically laying an average of 14-25 eggs in a season, although this varies between years and locations (Frith 1959; Booth 1987;

Brickhill 1987; Priddel and Wheeler 2005). Variation in clutch size is determined by the length of the egg laying season and the laying interval between successive eggs, which in turn is influenced by the occurrence of winter rains, food supply, and availability of natural heat for incubation (Frith 1959; Priddel and Wheeler 2005).

The aim of this study was to gain an insight into the nesting productivity of Malleefowl in one season, across a number of different regions in South Australia, particularly during dry conditions. The study also looked at relationships between variables such as rainfall, vegetation type, landscape location, and soil type across locations and in relation to nesting productivity. Finally, the results obtained in this study were compared with results from previous studies.

METHODS

Study areas

The study sites were located across three regions in South Australia: the mid-lower South East, lower Yorke Peninsula, and central-northern Eyre Peninsula. Study areas were selected on the basis of previous long-term annual monitoring of Malleefowl mounds, with identification of supposed 'active' mounds determined during the previous months' monitoring regime. Monitoring methods and the definition of 'active' mounds are defined in the Victorian Malleefowl Recovery Group (2007). Grid and mound locations and corresponding GPS coordinates are stored with the Department for Environment and Heritage Biological Database of South Australia.

Survey sites

Eight sites were selected that are commonly referred to as grids, which are permanently marked areas used for long-term monitoring of Malleefowl nesting activity. The eight sites were: one site in Innes National Park (N.P.) on Yorke Peninsula (Innes N.P.. grid); three sites in the South East: Mt. Scott Conservation Park (C.P.), Gum Lagoon C.P., and Coorong N.P. (Mt. Scott grid, Naen Naen grid and Coorong grid, respectively); and four sites across central Eyre Peninsula: a Heritage Agreement (HA) property near the township of Cowell, Munyaroo C.P., another HA near Lock, and Hincks C.P. (Cowell grid, Munyaroo grid, Lock grid and Hincks grid, respectively) (Fig. 1). All sites were situated in patches of remnant vegetation of varying sizes. None of the grids had been subject to wildfire for many years, although part of the area (6,000 ha) surrounding the Naen Naen grid was burnt in October 2006. All sites are adjacent to or near agricultural cropping and/or pasture lands, with the Munyaroo site situated the furthest from farmland, at 3 km. The nearness of sites to cropping land provides another potential source of food to Malleefowl in the summer (Priddel and Wheeler 2005). Topographic, vegetative and soil descriptions of each site are provided in Appendix 1.

All sites shared topographic similarities of low-lying, dunal systems, with the Coorong grid in closest proximity to the coast (adjacent to the Coorong South Lagoon). Soil types across sites were predominantly calcareous loams and sands. Mt. Scott was the only site also with clayey loam soils. The vegetation formation of mallee woodland or scrubland was common to all sites, although the density of the vegetation and plant associations varied somewhat. The foliage cover across the four more easterly sites was predominantly dense (70-100%) (from Specht 1972), while the four Eyre Peninsula sites showed a more open vegetative cover (30-70%) – a likely result of lower rainfall. The sites with higher rainfall (Mt. Scott, Naen Naen) supported a greater diversity of understorey plant species (personal observation), while the sites on Eyre Peninsula commonly supported an understorey dominated by *Triodia* spp.

Rainfall data

Rainfall data from meteorological recording stations closest to the study sites were obtained from the Bureau of Meteorology, or, for the Cowell grid, a landholder adjacent to the study site. These data were used to estimate annual, monthly and long-term rainfall for all sites. Mean annual (long-term and 2006) rainfall between stations located closest to Naen Naen, Munyaroo, Hincks and Mt. Scott grids was averaged between two of the nearest stations to each of these sites, assuming a steady gradient in rainfall based on the location of stations, to give the best estimate of rainfall (see Fig. 2). .

Sampling and data collection

Data collection took place towards the end of the Malleefowl breeding season for 2006/07, between February and April 2007. The study sites ranged in area between 2.6 km^2 and 4 km^2, with all known Malleefowl mounds, both active and inactive, individually staked and numbered and locatable via GPS. A total of 35 active mounds over the 8 sites were visited.

Mound height and perimeter of each mound were measured before excavation, and the height of the mound marked with tape or string on the nearest tree, so that the depth of eggs could be measured. Each mound was excavated and all eggs and egg sacs (membranes) were removed from the egg chamber and counted. Eggshell fragments and shell membrane found in one position within the mound were counted as a successful hatching, with a chick presumed fledged. Whole eggs were assigned a unique number, which was inscribed on the apex with pencil. Eggs that were cool to touch were deemed infertile/dead and were collected; warm eggs were returned to the mound at the same depth at which they were found. Mounds were subsequently reformed. The fate of eggs that were returned to mounds, other than those located within three mounds on the Innes N.P.. grid, remained unknown, therefore, estimates of hatching success are based only on the data collected on the day of sampling. The viability of cool eggs that were collected was determined by the South Australian Museum.

The length and breadth of eggs were measured using vernier callipers, and the volume calculated using the equation $V = \pi LB^2/6$, where V = volume (ml), L = length (cm), and B = breadth (cm) from Frith (1959).

General observations were recorded on scats or prints of the introduced European Red Fox *Vulpes vulpes*, on or around mounds, at each site. Results have been included in Appendix 3, but due to the limited scope of the study, no further conclusions were drawn .

RESULTS

Sites

In 2006 a total of 36 mounds had been prepared for breeding. Two of these mounds were discounted: mound 21 in Mt. Scott was flattened, possibly by deer and mound 12 in Innes N.P. had more than a dozen small trees growing through it. Thus 34 mounds were excavated, with a total of 144 eggs recorded. Twenty-five mounds contained eggs or egg sacs. The active mounds were located in various loamy and sandy soil types, in several vegetation associations, in swales and on top of dunes, and in different aspects, within and between sites. Table 1 provides an overview of the main variables examined per region, which are analysed in more detail below.

Rainfall

Long-term mean rainfall varied significantly across all sites, with the lowest ranging from around 250 mm at the two sites near the eastern coast of Eyre Peninsula (Cowell and Munyaroo), and the highest being just under 600 mm at Mt. Scott in the South East (Table 2). Annual rainfall for 2006 was below average across all sites, although it was noticeably

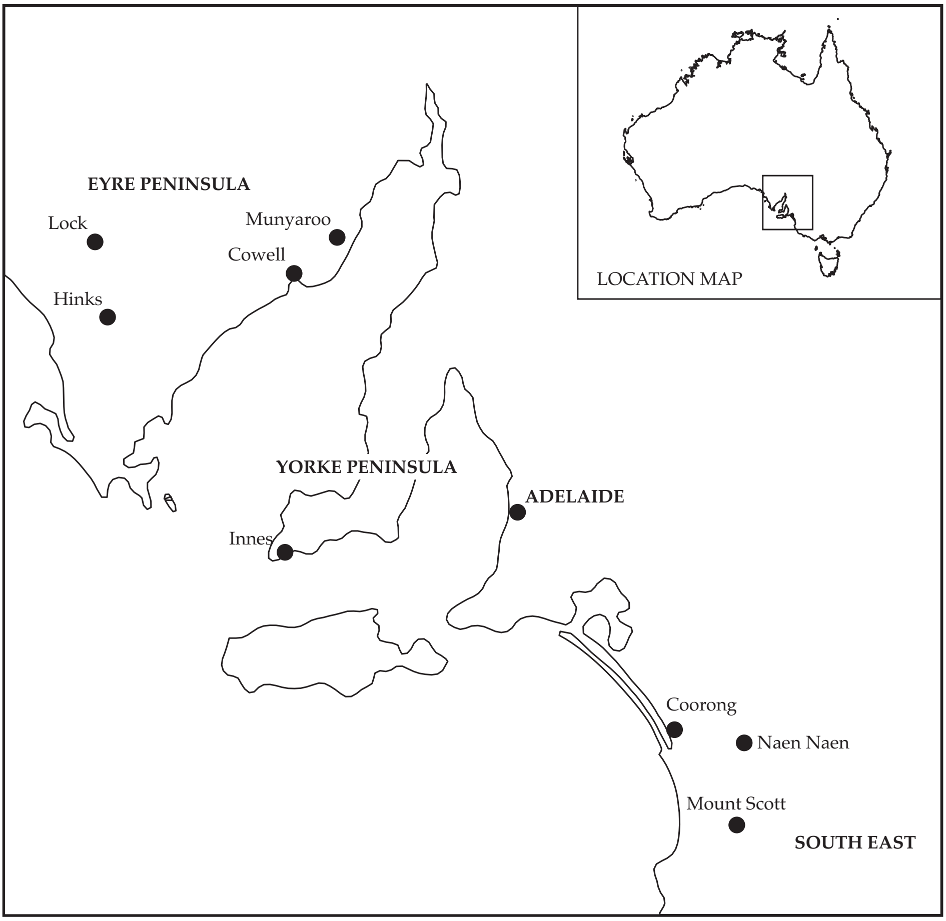

Fig. 1. Map showing location of survey sites in South Australia.

Table 1. Summary of rainfall and mound productivity for each of the three study areas.

Variable	Yorke Pen.	South East	Eyre Pen.
Annual rainfall (mm, 2006)	376	303	242
Number of active mounds (2006/07)	11	9	15
Mean active mounds/km^2	3.5	0.8	0.9
Mean clutch size	7.6	2.6	5.1
- range	6 - 14	1 - 5	1 - 15
- (±s.d.)	(±2.5)	(±2.1)	(±3.6)
Mean egg volume (ml)	155.3	166.1	170.4
Mean egg width (cm)	5.9	5.9	6.0
Mean egg length (cm)	9.0	9.1	9.1
Mean % infertile eggs	29%	7%	4%
Mean % fledging success	58%	53%	57%

Table 2. Long-term mean and 2006 rainfall (mm) for all sites.
(Data sources: Bureau of Meteorology and landholder Allan Zerna for Cowell).

Rainfall	Innes	Mt Scott	Naen Naen	Coorong	Cowell	Munyaroo	Lock	Hincks
Long-term mean rainfall (mm)	455	590	476	440	251	248	392	364
Annual rainfall 2006 (mm)	376	357	256	296	208	207	279	272

lower over the three sites in the South East and two sites on western Eyre Peninsula (Lock and Hincks) (Table 2).

During 2006, monthly rainfall was well below average long-term monthly rainfall most times between May and December for all eight sites, and particularly between August and November (Fig 2). The four Eyre Peninsula sites received little to no rainfall between August and October, while Innes N.P. and the three South East sites received very little rainfall during October and November. Despite these observations, all sites experienced one or more months of above average rainfall between January and April, while the Innes N.P. site had significantly higher rainfall in all four months. Only the two eastern Eyre Peninsula sites (Cowell and Munyaroo) had above average rainfall in July (Fig. 2).

Active Mound Density
The Innes N.P. grid showed the highest density of 3.5 active mounds per square kilometre (Table 2). All the other grids ranged between 1.6 (Mt. Scott) and 0.8 mounds/km^2 (Naen Naen, Munyaroo and Hincks), while at the Coorong there was no activity within the grid.

Fecundity and Hatching Success
A summary of the breeding data for each region is shown in Table 1 and for each site in Table 3, with more detailed figures for each mound in Appendix 2. The South East showed the lowest mean clutch size of 2.6 (range 1 – 5 ± 2.1) between regions (Table 1), while between sites, the mean clutch sizes of sites in the South East and Eyre Peninsula (except the Cowell site) were notably lower than those of the Innes N.P. site (Table 3). The largest clutch was found on the Cowell site and had 15 eggs, while the smallest clutch size was 1 egg, found on both the Mt. Scott and Lock sites (Table 3, Appendix 2). Thus excluding mounds with no eggs the mean clutch size across all sites was 4.7 (range 1 – 15 ± 3.1 s.d.) (Table 3).

Malleefowl had scraped 6 mounds out at the time of the initial survey, hence the breeding season had ceased for those birds, and no evidence remained of any eggs laid. No eggs were found in 3 mounds although the birds had worked those mounds, and 8 of the 11 active mounds at the Innes N.P. site had been excavated again by the birds on our second visit in April.

The estimated percentage of eggs that had hatched at the time of the survey was 50% or greater for all sites, except the Coorong which was unknown, and as high as 80% for the Hincks grid (Table 3). A total of 82 chicks were estimated to have fledged at the time of the survey – more than half of those at the Innes N.P. site (Table 3), while the percentage of fledging success was similar across regions (>50%, Table 1). Twenty-five eggs were found to be infertile, including four of the eggs that were broken. Twenty-two of these came from four mounds on the Innes N.P. grid (Appendix 2).

Some variation in mean egg volume was found between regions, however, mean egg width and length were very similar (Table 1).

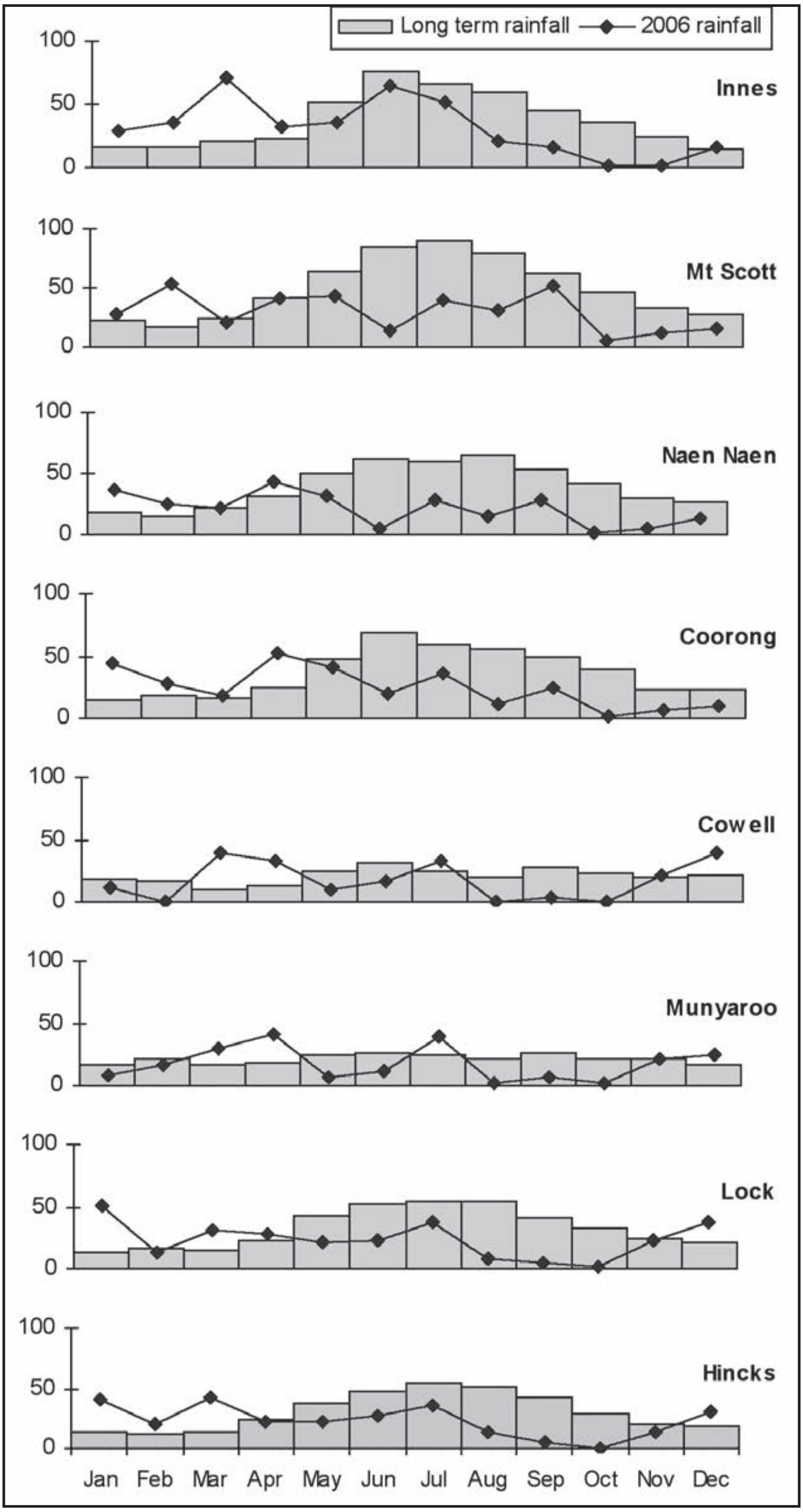

Fig. 2. Mean long-term rainfall (mm) per month and monthly rainfall (mm) for 2006, per site. (Data source: Bureau of Meteorology and landholder Allan Zerna for Cowell).

Table 3. Productivity of Malleefowl mounds and details pertaining to each survey site.

	Grid								
	Innes	**Mt Scott**	**Naen Naen**	**Coorong**	**Cowell**	**Munyaroo**	**Lock**	**Hincks**	**Total**
Area searched (km^2)	2.6	3.2	4	3.6	4.8	4	4	4	30.2
Active nests	11	5	3	1	5	3	4	3	35
Active nests/km^2**	3.5	1.6	0.8	0.0	1.0	0.8	1.0	0.8	1.2***
No. of nests checked	10	5	3	1	5	3	4	3	34
Clutch size - mean	7.6	3.3	2	?	7.5	5	2.7	5	4.7***
- range	6 - 14	1 - 5	2		2 - 15	3 - 7	1 - 5	5	1 - 15
- ±s.d.	±2.5	±2.1			±5.8	±2.8	±2.1		±3.1
Eggs laid (total no.)	76	13	2	?	30	10	8	5	144
% of eggs hatched*	58	54	50	?	50	50	75	80	57***
Eggs remaining	32	6	1	0	15	5	2	1	62
Egg sacs found	44	7	1	0	15	5	6	4	82
Eggs collected	22	0	0	0	2	0	0	1	25
Eggs unviable	22	1			1			1	25
Eggs broken	2	2	0	0	2	0	0	0	6
Eggs returned	9	4	1	0	12	5	2	0	33
Mean egg length (cm)	9.0	9.1	9.1		9.5	9.1	9.2	8.6	9.1***
Mean egg width (cm)	5.9	5.8	6.0		6.0	6.0	5.9	5.9	5.9***
Mean egg volume (ml)	155	161	172		181	180	165	157	167***
Hatchlings died in egg	1	0	0		2	0	0	0	3
Hatchlings fledged	44	7	1	?	15	5	6	4	82

** Percentage eggs hatched was up to the date nests were excavated: Innes Feb 10 & 11, Apr 8; Mt Scott Feb 23; Naen Naen & Coorong Feb 24; Cowell & Munyaroo Mar 3; Lock & Hincks Mar 4*

***Nests 42 & 53 on the Innes Grid and Nest 23 on the Coorong Grid occur just outside the grid boundary and were not included in "Active nests per km squared'*

**** indicates means (all other totals are sums of)*

Table 4. Comparisons of the productivity of Malleefowl mounds between the current study and four previous studies. Shaded columns represent a year of low rainfall or drought.

Nest Productivity / Details	SA (Current study)	Booth (1987)	Booth (1987)	Frith (1959)	Frith (1959)	Brickhill (1987)	Brickhill (1987)	Priddel & Wheeler (2005)	Priddel & Wheeler (2005)
Study years/drought years	2006	3	1983-84	6	1957-58	3	1982-83	13	1994-95
Active nests/km^2	1.2	1.1	1.1		0.4		0.6	1.7	0.9
Number of nests checked	34	21	9	45	9	34	5	124	5
Clutch size - mean	4.7	13.8	9	18.6	10.6	15.6	10.4	14.1	5.2
- range	1 - 15	2 - 34	2 - 15	5 - 33	5 - 14	3 - 33	3 - 15	3 - 28	3 - 8
Eggs laid (total number)	144	289	85	1094	149	530	52	1705	26
Mean egg length (cm)	9.1			9.2					
Mean egg width (cm)	5.9			6.1					
Mean egg volume (ml)	167.1	160.7	159.7	178	168			161.2	
Rainfall (mm) mean	281	264	260*	386	234	411		481	343

*1983 was not a drought year, but followed a year of severe drought (1982 = 90mm)

Mean egg volumes varied somewhat between mounds within sites, with a minimum mean recorded at Innes N.P. Mound 42 (134 ml) and maximum mean at Cowell Mound 63 (192 ml) (Appendix 2). Interestingly, Innes N.P. Mound 42 also recorded the mean minimum egg width (5.4 cm) and Cowell Mound 63 the mean maximum egg length (9.8 cm), and all of the 8 eggs in Innes N.P. Mound 42 were infertile (Appendix 2). Mean egg volume across sites was 167 ml; mean length 9.1 cm; and mean width 5.9 cm (Table 3).

DISCUSSION

Sites and Rainfall

Long-term studies of Malleefowl identify three key variables for their occurrence: mallee habitat that has long been unburnt, sandy to loamy substrate, and a mid-dense to dense understorey and/or canopy (see also Frith 1962; Benshemesh 2007). The active mounds located in this study were found in areas characterised by these same habitat variables.

Malleefowl are known to abandon breeding in drought conditions, and for those that do breed, clutch size can be reduced (Frith 1959; Booth and Seymour 1984; Brickhill 1987; Priddel and Wheeler 2003). The dry conditions in 2006 offer an explanation for the low productivity found in the South East sites and the two western Eyre Peninsula sites (Hincks and Lock) (Fig. 2). During a three-year study near Renmark, SA, Booth (1987) recorded no Malleefowl breeding in 1982 probably due to the drought although four mounds had been prepared. Incidentally, no Malleefowl bred in that same study site (Cooltong C.P.) in 2006, or in seven other sites that are annually monitored in that region north of the Murray River (Setchell and Setchell 2007). Whilst 2006 was considered a 'drought' year due to low overall rainfall in SA, the higher-than-average rainfall experienced over a number of months at the Innes N.P. site and eastern Eyre Peninsula sites appeared to provide enough for birds to maintain reasonable productivity at these sites.

Active Mound Density

The average density of active Malleefowl mounds across the three study areas (1.2/km^2) was comparable to densities reported in low-rainfall areas of mallee and during drought years in other studies (see Table 4). Frith (1962) recorded mound densities near Griffith in New South Wales ranging from 5.2 active mounds/km^2 in high rainfall scrub with fertile soils, to 1.5 active mounds/km^2 in low rainfall scrub with poor soils. Booth (1987) described the following mound densities for the low-rainfall areas of mallee around Renmark, South Australia (220 – 300 mm annually): 1.1 active mounds/km^2 in 1981 (250 mm) and 1983 (260 mm); 0.6 active mounds/km^2 in 1984 (209 mm), and no activity at all in 1982 (90 mm). In a long-term study by Priddel and Wheeler (2003), active mound densities ranged between 2.8 and 0.9/km^2 over a 13 year period in an area of remnant mallee in central NSW (Yalgogrin), with an average rainfall of 481 mm.

When looking at mound density per km^2 at a regional level, both the South East and Eyre Peninsula grids fall within the average range for a 'drought' year, while the Innes N.P. grid is more akin to activity that would be expected in a year of average or above average rainfall (Frith 1962) (Tables 1 and 3). Rainfall at Innes N.P. during 2006 was high not only during January to April, but good rainfall was also received during winter – more than at all the other sites (Fig. 2). Rainfall during August to October was very low across all sites (except September for Mt. Scott). Differences in Malleefowl breeding densities between the sites and regions in this study may be explained by differences in rainfall and vegetation type, as rainfall is the primary determinant of shrub density, which in turn provides the food resources for the birds (Frith 1962). The well-below average rainfall received in the winter and spring months in the South East and perhaps western Eyre Peninsula would almost certainly have impacted on the breeding activity of the Malleefowl in those regions.

Fecundity and Hatching Success

The mean clutch size of 4.7 (range 1 – 15) across all sites in SA is broadly consistent with the findings during drought years in previous studies (Table 4), with comparable mean clutch sizes from individual sites in the South East and Eyre Peninsula (Table 3). Small clutch sizes indicate a shorter egg laying period (Frith 1959; Priddel and Wheeler 2005), and resource limitation (Booth 1987). Priddel and Wheeler (2005) found rainfall from May to December to be the best predictor of clutch size, with these months covering the period of mound building and egg laying. Winter rainfall supplies the moisture necessary to stimulate the decomposition of leaf litter in the mound, and also probably influences the amount of food available for female Malleefowl at the commencement of egg-laying. Rain later in this period maintains the level of food throughout the egg-laying period (Priddel and Wheeler 2005).

Frith (1959) recorded a delay in egg-laying during dry winters and springs caused by a slower rise in temperature in the mound, due to lack of water in the mound to cause efficient fermentation of the organic matter. Malleefowl begin egg laying once the mound has reached an appropriate temperature between 26 – 32°C (Frith 1959). Similarly, the cessation of laying is triggered by air temperature and rainfall, and the breeding season is over when suitable mound temperature can no longer be maintained (Frith 1959). In the current study, from May to December rainfall was well below average across all sites (Fig. 2), indicating a shorter breeding season and reduced food resources, thereby explaining smaller clutch sizes.
Six of the mounds across five sites receiving low rainfall (South East and Eyre Peninsula – see Appendix 2) had been excavated by birds at the time of the survey (late February/early March), and one mound at Mt. Scott had been abandoned, which is not surprising given the dry conditions. The Innes N.P. site sustained better autumn and winter rainfall than all other sites as well as abundant rainfall in January 2007, perhaps providing better food resources for Malleefowl, which extended the breeding season.

Priddel and Wheeler (2005) in their study at Yalgogrin, New South Wales (NSW), describe high fecundity as mean clutch size >20 eggs; moderate fecundity as mean clutch size 13 – 18 eggs, low fecundity as mean clutch size 8 – 11 eggs, and a mean clutch size of 5.2 in one year of prolonged winter drought (Table 4). Considering the differences in rainfall at various sites: (1) both the Innes N.P. and Cowell sites were in the "low fecundity" range despite the much higher mean clutch size than other SA sites, and (2) nesting productivity in the South East and three Eyre Peninsula sites was extremely low in the 2006/07 breeding season.

Several hypotheses have been proposed to explain why three nests (one each at Mt. Scott, Naen Naen and Munyaroo) contained no eggs, although they were obviously being worked. Brickhill (1987) in his study at Yalgogrin NSW, found four active mounds without eggs and suggested that there were insufficient females to pair with all males with prepared mounds, and that some males may have maintained mounds in the hope of attracting a mate. Sub-adult males may also build practice mounds. Alternatively, Priddel and Wheeler (2003) suggested that mounds without eggs could be due to the failure of the female to lay. Two of the mounds in question, Mt. Scott Mound 1 and Naen Naen

Mound 1, were the two smallest mounds in the study (Appendix 2), suggesting that they were perhaps practice mounds maintained by young males. If so, this may be an indication of recruitment of sub-adult birds into the breeding population.

Whilst the Innes N.P. site had the greatest productivity in terms of total number of eggs laid, this site also had the greatest number of infertile eggs (Table 3). Infertile eggs may indicate a pair of breeding birds that are old and have low fertility or are infertile; failure by the male to maintain mound temperature; a young female; or it may indicate food shortages (Brickhill 1987). Small patches of isolated habitat that contain only a few pairs of breeding birds could be expected to cause inbreeding. However, there is no information as yet to support the idea of low genetic variation or inbreeding in Malleefowl (Benshemesh 2007). The infertile eggs found at the Innes N.P. site (29% of all eggs laid) were collected from four out of ten active mounds, with greater than 40% and up to 100% (Mound 42) of all eggs laid within those mounds found to be infertile.

The mean egg volume in the current study (167 ml ±10.6 s.d.) is comparable to the results of Frith in 1957-58 (Table 4), which was also a year of low rainfall. In his study spanning 6 years, Frith (1959) found that most egg volumes were in the range 165-184 ml (50% of eggs), while this study found eggs in the range 175-184 ml to be most common (28% of eggs). The variance in mean egg volumes between sites in the current study (Table 3) could be due to the availability of food at each site (Frith 1959, Booth 1987). However, there is considerable difference in mean egg volumes between individual mounds within sites, where it could be expected that birds had access to similar food resources. For example, the difference in mean egg volumes was almost 55 ml between Mound 42 and Mound 33 at the Innes N.P. site (Appendix 1), that were only 400 m apart. The small size and infertility of the eggs in Mound 42 suggests that at least one bird in the pair was very young, very old, and/or less fertile. Egg size has been noted to differ markedly between different populations of Malleefowl without a tested explanation for the difference (Priddel and Wheeler 2005; Benshemesh 2007).

CONCLUSION

The link between Malleefowl fecundity and rainfall follows those of previous studies and applies to the results for the 2006/07 breeding season for Malleefowl at eight sites in SA. The well-below average rainfall in 2006 and the very low mound productivity in the 2006/07 season indicate that conditions were not favourable for Malleefowl nesting productivity. While previous studies have recognised the detrimental effect that drought can have on Malleefowl breeding, droughts are considered transient and reproductive output is expected to return to previous or better levels with ensuing years of better rainfall. In South Australia, years of low rainfall have recurred in 9 of the previous 10 years, (Benshemesh 2006), and thus represent a very real threat to Malleefowl.

Malleefowl are generally long-lived and may produce hundreds of chicks in a lifetime, suggesting that only a small percentage of birds need to survive to breeding age to sustain the population. The average breeding life is assumed to be ten years (Copley and Williams 1995; Benshemesh 2007). The reproductive output of the birds nesting within the eight survey sites suggest that, at the time of the study, 82 chicks may have fledged in the 2006/07 season (Table 3), although it is not known how many will survive to breeding age. Previous studies have recorded very high mortality in young Malleefowl, with predation by foxes and starvation the primary causes of death (Priddel and Wheeler 1990; Priddel and

Wheeler 1999; Benshemesh 2007; Priddel, Wheeler and Copley 2007). In their long–term study at Yalgogrin, NSW, Priddel and Wheeler (2003) found the mortality had exceeded the rate of recruitment, and predicted the extinction of this population before 2008. Other local extinctions have already been recorded in several mallee remnants in NSW (Priddel and Wheeler 2003).

With the downward trend in Malleefowl breeding activity in SA shown by Benshemesh (2006), little recruitment into a population has several implications: the remaining population would have an ever-increasing proportion of older individuals, with consequences such as a higher incidence of infertility and a lower reproductive output. Whilst this is speculative, it is a likely scenario. Given the small, isolated patches of mallee that harbour most Malleefowl populations, it is critical that recruitment remain higher than mortality if Malleefowl are to be conserved.

Future studies on the genetic structure and variation in Malleefowl populations will provide information on how habitat fragmentation and isolation is affecting Malleefowl, and will assist in determining the long-term viability of isolated populations. This information, together with an Adaptive Management framework planned under the National Recovery Plan for Malleefowl (Benshemesh 2007), will assist in assessing how successful recovery actions are in halting the decline of this species.

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Appendix 1. Topographic, vegetative and soil descriptions of each site.

The soils at all sites contained numerous calcrete and limestone nodules.

Yorke Peninsula

- Innes N.P. - The topography of Innes N.P. is undulating plain with dunes, salt lakes and coastal cliffs (DEH 2003). The vegetation structure in and around the Innes N.P. grid can be described as closed mallee woodland, with a dense upperstorey of *Eucalyptus diversifolia, E. rugosa, E. oleosa;* a midstorey of *Melaleuca lanceolata*, and a patchy understorey of heath plants including *Templetonia retusa, Exocarpos aphyllus, Acacia sp., Leucopogon sp.* and *Dodonea sp.* Soils are calcareous loams and sands, overlaying limestone (DEH 2003).

South East

- Mt. Scott C.P. - The topography of Mt. Scott C.P. is characterised by undulating slopes with deep sandy loams, with outcrops of limestone on the ridge tops, and flats which have clayey loam soils. The flats are subject to flooding and become waterlogged during wet periods. The vegetation formations are low open forest, heathland and sedgeland. The flats are dominated by *Eucalyptus camaldulensis*, with patches of *Melaleuca halmaturorum* and *M. brevifolia*, while the ridges support mallee vegetation including *E. leucoxylon* and *E. fasciculosa* (Laut et al. 1977a; DENR 1994).

- Gum Lagoon C.P. - The topography of the western portion of Gum Lagoon is described as an extensive calcarenite dune complex overlain with sand dunes. Sandy rises in the north-west area of the park (west Naen Naen Swamp area) are characterised by closed heath dominated by *Banksia ornata* and *Melaleuca brevifolia*, with patches of open mallee woodland comprising *Eucalyptus camaldulensis, E. arenacea, E. fasciculosa* or *E. leucoxylon* (DEH 2005).

- Coorong N.P. - The landscape area of the grid is stabilised dunes over calcareous sands. The grid area is characterised by open mallee heath dominated by *Eucalyptus diversifolia, Melaleuca lanceolata, Olearia axillaris* and *Leucopogon parviflorus* (Laut et al. 1977b).

Eyre Peninsula

- Cowell HA and Munyaroo C.P. - The landscape of this region is sandy plain with frequent short dunes, interspersed by low fault scarps or granite outcrops. Vegetation is open mallee woodland, dominated by *Eucalyptus incrassata, E. socialis, E. gracilis* and *Melaleuca uncinata* (Laut et al. 1977c). *Triodia sp.* is a dominant understorey species.

- Lock HA - The landscape is plains with deep sands and closely spaced dunes. Soils are alkaline calcareous sands. Vegetation is open mallee scrub, dominated by *Eucalyptus incrassata, E. diversifolia* and *Melaleuca uncinata* (Laut et al. 1977c).

- Hincks C.P. - The landscape is represented by undulating plains and low hills, with irregular dunes consisting of alkaline calcareous sands (DEH 2007). Vegetation is open mallee scrub, dominated by *Eucalyptus diversifolia, E. incrassata* and *Melaleuca uncinata,* with *Triodia sp.* prevalent in the understorey (Laut et al. 1977c).

Appendix 2. Individual mound data per grid. **%

	Innes N.P.										Mt. Scott					Naen Naen		
	53	**7**	**17**	**20**	**1**	**4**	**8**	**42**	**21**	**33**	**1**	**3**	**17**	**28**	**26**	**1**	**8**	**3**
Mound height (cm)	130	105	62	100	70	115	90	70	75	100	55	70	50	80	80	55	55	50
Mound diameter (m)	6	4.6	4.1	5.9	3.7	5.3	4.4	3.6	5.4	6.5	320	400	370	500	480	3.2	4	3.4
Clutch size	6	14	8	6	6	6	9	8	6	7	0	2	5	5	1	0	?	2
% eggs hatched**	83	43	63	67	83	100	56	0	50	71	0	100	40	40	100	0	?	50
Eggs remaining	1	8	3	2	1	0	4	8	3	2	0	0	3	3	0	0	0	1
Egg sacs found	5	6	5	4	5	6	5	0	3	5	0	2	2	2	1	0	0	1
Eggs collected	0	7	0	0	0	0	4	8	3	0	0	0	0	0	0	0	0	0
Unviable eggs		7					4	8	3					1				
Eggs broken	0	1	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0
Eggs returned*	1	1*	3	2	1	2*	0	0	0	2	0	0	3	1	0	0	0	1
Mean egg length (cm)		8.7	9.3	8.9	9.1	9.0	8.7	8.8	8.5	9.7			8.9	9.3				9.1
Mean egg width (cm)		5.7	6.0	6.0	5.9	6.0	6.0	5.4	6.0	6.1			5.6	6.0				6.0
Mean egg volume (ml)		149	178	164	166	166	161	134	160	189			144.7	176.6				172
Hatchlings died in egg	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hatchlings fledged	5	6	5	4	5	6	5	0	3	5	0	2	2	2	1	0	?	1

**Eggs returned to Mound 7 & Mound 4 were found hatched on 8th April*

*** Percentage eggs hatched was up to the date nests were excavated: Innes 10 & 11 Feb, 8 Apr; Mt Scott 23 Feb; Naen Naen 24 Feb.*

	Coorong	Cowell					Munyaroo			Lock				Hincks		
	23	**3**	**32**	**58**	**78**	**63**	**35**	**14**	**26**	**7**	**62**	**29**	**21**	**30**	**12**	**43**
Mound height (cm)	70	55	90	65	65	90	85	73	50	100	65	60	80	68	65	40
Mound diameter (m)	4.2	4.8	5.4	6.3	4.8	5.2	4.6	4.7	5	5.3	6.5	5	5	4.6	5.6	3.9
Clutch size	?	2	4	?	9	15	7	3	0	5	?	1	2	5	?	?
% eggs hatched**	?	50	75	?	33	53	40	100	0	20	?	0	50	80	?	?
Eggs remaining	0	1	1	0	6	7	4	1	0	1	0	0	1	1	0	0
Egg sacs found	0	1	3	0	3	8	3	2	0	4	0	1	1	4	0	0
Eggs collected	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0
Unviable eggs						1								1		
Eggs broken	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Eggs returned*	0	0	1	0	6	5	4	1	0	1	0	0	1	0	0	0
Mean egg length (cm)			9.1		9.5	9.8	9.3	8.9		9.1			9.3	8.6		
Mean egg width (cm)			5.9		5.9	6.1	6.2	5.8		5.9			5.8	5.9		
Mean egg volume (ml)			166		171	192	185	157		166			164	157		
Hatchlings died in egg		0	0	0	0	2	0	0	0	0		0	0	0		
Hatchlings fledged	?	1	3	?	3	8	3	2	0	4	?	1	1	4	?	?

*** Percentage eggs hatched was up to the date nests were excavated: Coorong 24 Feb; Cowell & Munyaroo 3 Mar; Lock & Hincks 4 Mar.*

Appendix 3. Sightings of fox scats and prints at each of the mounds excavated in 2007. The table also includes data from a previous survey in 2006. Numbers in brackets indicate total number of active mounds per site for the current study, and total number of mounds (active and inactive) during the monitoring season.

	Current study		2006 monitoring	
Site	**Scats**	**Prints**	**Scats**	**Prints**
Innes N.P.	0 (11)	0 (11)	0 (46)	0 (46)
Mt. Scott	0 (5)	0 (5)	9 (39)	10 (39)
Naen Naen	0 (3)	1 (3)	5 (14)	5 (14)
Coorong	0	0	2 (34)	0 (34)
Cowell	3 (5)	0 (5)	17 (50)	5 (50)
Munyaroo	2 (3)	0 (3)	4 (35)	2 (35)
Lock	2 (4)	0 (4)	12 (54)	1 (54)
Hincks	1 (3)	0 (3)	17 (34)	6 (34)