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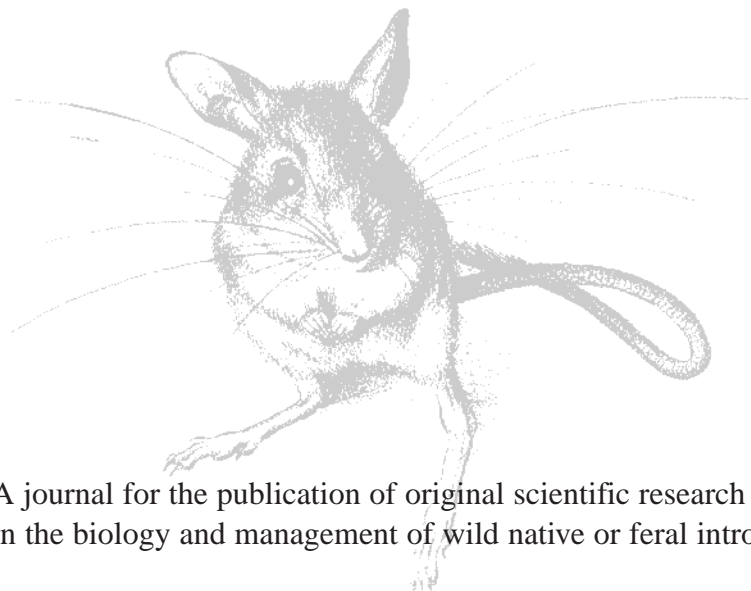
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## Aerial baiting of feral pigs (*Sus scrofa*) for the control of exotic disease in the semi-arid rangelands of New South Wales

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**Abstract.** An experiment that held the density of feral pigs constant while varying the effective density of aerially distributed baits was conducted at three sites in north-western New South Wales. Meat baits, containing one of the biomarkers iophenoxic acid, tetracycline or rhodamine B, were distributed at different intensities over each site, and a sample of pigs was shot from a helicopter at each site to determine bait uptake. Serum and tissue samples taken from each pig were analysed for the occurrence of the biomarkers; the proportions of pigs exhibiting biomarkers represented the proportions of the feral pig populations that had consumed baits at different baiting intensities (expressed as baits per unit of pig density).

The maximum percentage of sampled pigs that had eaten baits varied from 31% to 72% across the three sites. Bait uptake was regressed against baiting intensity. For two of the trials, the quantity of bait hypothetically required to eliminate a population of feral pigs was extrapolated to be 1577 baits per unit of pig density, while for the third trial 1874 baits per unit of pig density would have been required. Bait-uptake by non-target animals was substantial, posing potential hazards to birds and reducing the availability of baits to feral pigs. Most likely, seasonal conditions affected bait-uptake by feral pigs. We discuss the implications of these results for exotic disease contingency planning.

### Introduction

In Australia, feral pigs (*Sus scrofa*) are a major agricultural and environmental pest (Tisdell 1982; Pavlov *et al.* 1992, Choquenot *et al.* 1996) and are a potential reservoir and vector of a range of exotic diseases, including foot-and-mouth disease (FMD) (Geering 1990). Feral pigs are common and widely distributed in Australia, with an estimated population of 13.5 ( $\pm 3.6$ ) million (Hone 1990a). Because pigs act as a major amplifying host of FMD, feral pigs may accelerate the spread of FMD to domestic livestock and other feral pig populations in the event of an epizootic (Wilson and O'Brien 1989). This would impede attempts at containment and eventual eradication of the epizootic, and delay demonstration of disease freedom (Pech *et al.* 1988).

Disease-management plans must have achievable goals for disease eradication for Australia to re-establish and demonstrate disease freedom. To construct contingency plans for exotic diseases, it is necessary to quantitatively predict the potential role of FMD in feral pigs. In the absence of a disease, epidemiological models (e.g. Pech and Hone 1988; Pech and McIlroy 1990; Caley 1993; Dexter 1995) are used

to predict the threshold densities (Anderson and May 1979) at which FMD would establish or persist in feral pigs.

Reduction in abundance of feral pigs below disease thresholds is potentially achievable by a variety of control procedures including poisoning with warfarin (McIlroy *et al.* 1989; Saunders *et al.* 1990; Choquenot *et al.* 1990), shooting from helicopters (Hone 1990b; Saunders 1993; Choquenot *et al.* 1999), trapping (Saunders *et al.* 1993; Choquenot *et al.* 1993), hunting with dogs (McIlroy and Saillard 1989; Caley and Ottley 1995), and ground baiting using 1080 poison on plant material (Hone 1983; O'Brien and Lukins 1988). Aerial baiting has the potential to reduce feral pig abundance (Mitchell 1998) below levels where disease transmission and maintenance is impossible. Alternatively, if an oral vaccine for FMD was developed, aerial baiting might be used to distribute inoculated baits to reduce the proportion of feral pigs susceptible to FMD. Because aerial baiting is more rapid than ground baiting and is applicable in widespread and remote areas, its use would allow rapid responses to outbreaks of exotic diseases at much reduced cost. Aerial control also reduces the necessity for people and vehicles to travel

through a disease-control area, thereby lowering the risk of spreading the disease.

Given this background, the objectives of our study were:

(1) to assess the efficacy of aerial baiting at different baiting intensities for the control of feral pigs in semi-arid environments,

(2) to obtain predictive equations of bait uptake and baiting intensity for use in exotic disease outbreaks involving feral pigs, and

(3) to compare the empirically derived effectiveness of aerial baiting for population reduction or vaccination with modelled FMD threshold levels.

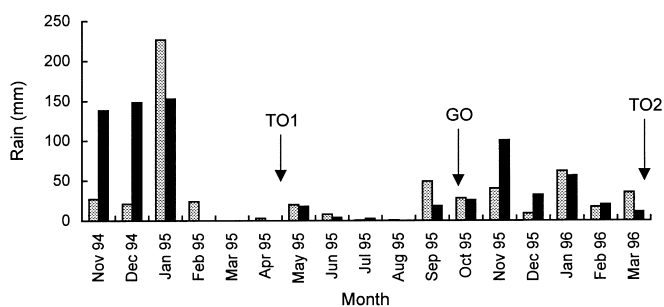
This information allows the prediction of baiting intensities necessary to achieve desired reductions in the density of feral pigs or required levels of vaccination for exotic disease control.

## Methods

### Study sites

Four study sites on the Paroo River near Wanaaring (29°42'S, 144°18'E) in north-western New South Wales were chosen. The study sites were within sites NC, TO and GO of Choquenot (1998), which gives detailed descriptions of the locations. NC was chosen as a nil-treatment site, two treatment sites were selected on TO (TO1 and TO2) and the third treatment site was on GO. The area of each treatment site was approximately 94 km<sup>2</sup>, being the area over which we aerially counted pigs and distributed baits.

We sampled site TO in two good seasons with abundant pasture biomass separated by 11 months. The first (TO1) followed a 2-year drought that ended with higher than average local rainfall compounded



**Fig. 1.** Rainfall at Wanaaring, north-western New South Wales from November 1994 to March 1996. Stippled bars show rainfall at site TO; solid bars show rainfall at Wanaaring Post Office (nearest official weather station, 46 km upstream of study site). Arrows indicate treatment dates at sites TO1, TO2 and GO.

by flooding of the Paroo system (Fig. 1). The second good season (TO2) resulted from good summer rainfall and minor flooding but pasture was not as abundant as at TO1. The GO site was treated once under conditions of low pasture biomass, 6 months after TO1.

### Pig density

Before each sampling, feral pigs were counted from a helicopter flown at 100' above the ground and travelling at 80 km hr<sup>-1</sup> (Choquenot 1995). Single observers positioned on either side of the aircraft counted groups of feral pigs in a 150-m-wide strip demarcated by a vertical pole attached to either side of the helicopter. 'Groups' represented sighting entities rather than biologically meaningful aggregations of animals. We divided each site into equally spaced (300 m), parallel, east-west transects between 9.5 and 12 km long. From the equally spaced transects, randomly selected (without replacement) transects were flown to obtain between 50 and 96% coverage of each study site. Two surveys (replicates) were flown at TO1 and three were flown at GO and TO2. For each survey, the selected transects were flown in sequence from north to south. A global positioning system (GPS) was used for navigation and to check airspeed during each transect. Absolute abundance and density estimates of feral pig populations were calculated from the helicopter counts using habitat-specific correction factors (Choquenot 1995). The estimates of density were means of the two or three surveys taken for a treatment occasion, after correction for visibility bias (Choquenot 1995).

### Baiting treatments

Three biomarkers were used; tetracycline (TC) is a fluorescent biomarker that glows yellow under ultra-violet light, rhodamine B (RB) fluoresces bright pink under ultraviolet light, and iophenoxic acid (IPA) raises the seral iodine levels of an animal. Both TC and IPA are useful markers in pigs (Fletcher *et al.* 1990; Mitchell 1998) and Mitchell (personal communication) successfully used TC and RB to mark the flesh, hair and teeth of captive pigs.

Petfood-grade kangaroo meat was cut into baits (mean weight of 32 baits = 141.3 g, s.e. = 3.0 g) and dried overnight on wire racks. Each bait contained only one of the biomarkers (Table 1). IPA was dissolved in absolute ethanol and 1 mL of solution was injected into baits, giving a concentration of 24 mg IPA bait<sup>-1</sup>; Fletcher *et al.* (1990) used 20 mg pig<sup>-1</sup> and Mitchell (1998) used 40 mg bait<sup>-1</sup>. For those baits injected with TC solution, 1 mL resulted in 666 mg TC bait<sup>-1</sup>. Gelatinous capsules containing 0.215 g of RB were prepared; one capsule was inserted in each remaining bait with the aid of a fine-bladed knife. At these very high dosage rates of RB and TC, any pig that ate bait containing one of these markers would exhibit fluorescence in the flesh of the buccal cavity under ultra-violet light (J. Mitchell, personal communication).

Three baiting treatments were applied, one to each site. Table 1 shows the numbers of baits containing each biomarker for the three treatments and the resultant combinations of biomarkers at each treatment. The number of baits containing each biomarker at each treatment was varied to obtain different baiting intensities (see below). Baits were dropped from aircraft flown in straight lines that were oriented

**Table 1.** The number of baits containing one of three biomarkers that were aerially distributed over three 94-km<sup>2</sup> study sites in semi-arid north-western New South Wales  
TC, tetracycline; RB, rhodamine B; IPA, iophenoxic acid

Treatment	Biomarker			Possible biomarker combinations
	TC	RB	IPA	
TO1	2400	663	1200	TC, RB, IPA, TC+RB, TC+IPA, TC+RB+IPA, RB+IPA
GO		1500	3100	RB, IPA, RB+IPA
TO2		1500	3100	RB, IPA, RB+IPA

east–west and spaced 300 m apart. The interval between baits along transects was approximately 75 m. To avoid cross-contamination of biomarkers, we kept baits containing different biomarkers separated and dropped them at regular spacing in random order. Therefore, baits containing different biomarkers were distributed randomly with reference to habitat and dispersion of pigs in the landscape.

In April 1995, we dropped a predetermined quantity of baits (Table 1) onto TO1. Commencing at 0900 hours, bait distribution took approximately 7.5 h to complete. We repeated this process at GO in October 1995 and again at TO2 in March 1996. At GO and TO2, bait distribution commenced at 1000 hours and took approximately 7 h.

#### Baiting intensity

Bait uptake is dynamic as it is a function of the density of baits (units = baits km<sup>-2</sup>) and of the density of the target population (units = animals km<sup>-2</sup>) (Fleming 1996). When poisoned baits are used, the underlying density of animals reduces as animals are poisoned. The underlying animal density has often been ignored as a factor affecting bait consumption (e.g. McIlroy *et al.* 1993; Thompson and Fleming 1994). When animal density is ignored, studies of bait consumption from different locations (including the three sites used in this experiment) cannot be compared. To account for the densities of animals and baits, a more appropriate and comparable measure is 'baiting intensity', which is expressed as baits animal<sup>-1</sup> km<sup>-2</sup>.

In each treatment of our study, different numbers of baits containing biomarkers were distributed over a measured density of pigs. Thus, we held the density of pigs constant for each density of baits and the baiting intensities could be calculated *a posteriori* for each of the three sampling occasions. We calculated baiting intensity (*I*) as:

$$I = n_i/D$$

where  $n_i$  was the number of baits containing biomarker *i* and *D* was the density of feral pigs calculated from the corrected aerial counts and the area of the site.

#### Bait uptake

Bait uptake is also a function of the time of bait exposure (Fleming 1996). Therefore, we measured bait uptake over standardised area and constrained the sampling time frame to 3–5 days after baiting.

At TO1, we shot from a helicopter a sample of feral pigs on the fourth and fifth days after baiting. Each pig was transported to a processing point where 1–10 mL of blood, a fore-foot and the lower jaw were taken from each pig. The sera, trotter and jaw tissues were later analysed for the occurrence of the biomarkers. The proportion of shot pigs that exhibited a particular biomarker or combination of biomarkers represented the proportion of pigs that had consumed baits for different baiting intensities (Table 1). Bait uptake was measured as the percentage of pigs exhibiting biomarkers (% bait uptake) at given baiting intensities (i.e. baits pig<sup>-1</sup> km<sup>-2</sup>).

The sex, age (as determined from tooth eruption (Matschke 1967) and wear (Barrett 1971)), weight and body condition (scored using a 5-point scale with 1 representing emaciated and 5 representing grossly fat) were determined for all retrieved pigs. This process was repeated at GO 3.5 and 4 days after baiting and at TO2 on the fourth and fifth days after baiting. This timing allowed feral pigs ample time to discover and eat baits and for the biomarkers to be expressed (Mitchell, personal communication). With the exception of one large 3-month-old piglet at GO, all shot pigs were 6 months old or older. Concurrent with trials TO1, GO and TO2, 5, 7 and 10 pigs respectively were sampled on NC to establish base iodine levels against which the sera from the treatment sites were compared.

#### Bait removal and non-target impacts

McIlroy *et al.* (1986) and Allen *et al.* (1989) identified the removal of baits by red foxes and various birds as a major impediment to the success

of surface-laid baiting programs for the control of wild dogs in south-eastern Australia. Birds of the family Corvidae were commonly observed on the study sites and red foxes were seen during aerial counts of feral pigs. To quantify the daily rate of bait removal and the impact of birds and foxes on bait uptake by feral pigs, meat baits without biomarkers were laid on the surface at 100 bait-stations to the west of TO in April 1995 (see Allen *et al.* 1989 for detailed methods). The bait-stations were distributed through the habitat types in proportion to the occurrence of each habitat type (15% black soil floodplain (BSF) and 85% other: Choquenot 1998). We checked the baits each morning for the following three days and replaced any removed by animals. Any bait-stations obliterated by livestock or rain were excluded from analyses (Fleming 1996).

#### Statistical analyses

To obtain predictive equations and to compare trials, an analysis of covariance (ANCOVA) was initially used with trial (TO1, TO2 and GO) entered as covariate. The ANCOVA showed a significant trial effect (see below) and so pairwise analyses of variance (ANOVA) were conducted between trials. Bait uptake was then regressed on baiting intensity (*I*).

Sex, age and season have all been suggested to affect bait uptake by pigs (Saunders *et al.* 1993; Choquenot and Lukins 1996). Therefore, we used chi-square statistics to compare the sex ratios of shot samples with parity, and contingency tables were used to contrast bait uptake between sexes. An ANOVA was conducted to ascertain differences in the age distributions of the sampled feral pigs. To compare the age distributions between trials and between pigs that took baits and those that did not, we used two-tailed Student's *t*-tests after first testing for equivalence of variances using two-sample *F*-ratios. The body-condition scores of the three samples were contrasted using Mann–Whitney *U*-tests after converting the *U* statistics to *z* statistics (Siegal 1956).

## Results

### Bait uptake

The highest density of feral pigs occurred at GO in October 1995 (Table 2). At TO1, 122 pigs were shot and 100 (27.9% of the estimated population) were sampled for biomarkers. We sampled 103 (19.9% of the estimated population) of 210 shot pigs at GO, and 71 (15.5% of the estimated population) of 89 pigs were sampled at TO2. The remainders were piglets that were too small to sample or pigs that could not be retrieved.

Variation in bait uptake was significantly related to baiting intensity ( $t = 10.164$ ,  $P < 0.001$ ) and to trial ( $t = -4.799$ ,  $P < 0.001$ ). Comparisons between trials, made by regressing bait uptake on baiting intensity plus a trial indicator variable for

**Table 2.** Density, age and body condition of feral pigs from three sites in semi-arid north-western New South Wales

Figures in parentheses are standard errors. Body-condition scores range from 1 to 5

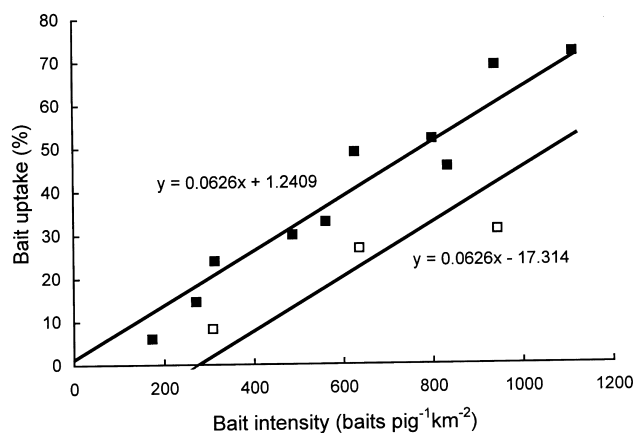
Trial	Density (pigs km <sup>-2</sup> )	Mean age (months)	Mean body-condition score
TO1	3.83 (0.10)	29.01 (1.85)	3.44 (0.05)
GO	5.52 (1.33)	35.4 (1.89)	2.48 (0.07)
TO2	4.88 (0.33)	15.3 (1.64)	2.81 (0.06)

each combination of trials (Table 3), indicated that the effect of baiting intensity on bait uptake was significantly different between TO1 and TO2, and nearly so between GO and TO2. As there was no significant difference between the data from TO1 and GO, these were combined and the regressions repeated with an indicator variable for the combined data and the TO2 trial (Fig. 2). The fitted model for the combined data of TO1 and GO explained 91% of the variation in bait uptake and was highly significant ( $F_{2,12} = 52.359$ ,  $P < 0.001$ ).

The extrapolated baiting intensity required to achieve consumption of at least one bait by all pigs in our study sites (calculated from the pooled data in TO1 and GO, and mean pig density) was approximately 1578 baits per unit of pig density.

**Table 3. Comparisons of bait uptake regressions between three trials in semi-arid north-western New South Wales**  
 $r^2$  values are from the pairwise ANOVAs

Trials	$t$	$P$	$r^2$
TO1 & GO	-1.967	0.090	0.96
TO1 & TO2	-4.250	0.004	0.93
GO & TO2	-3.134	0.052	0.93



**Fig. 2.** The relationship between consumption by feral pigs of meat baits aerially distributed at different baiting intensities. ■, combined April and October 1995 (TO1 and GO) trials; □, March 1996 (TO2) trial. Lines are least-squares lines of best fit, predicted by the combined regression.

From the regression for the TO2 trial, the hypothetical baiting intensity required was 1874 baits  $\text{pig}^{-1} \text{km}^{-2}$ .

#### *Pig age, body condition, sex ratio and bait uptake*

Age was found to be significantly different between trials ( $F_{1,530} = 475.71$ ,  $P < 0.001$ ). The pigs sampled at GO were older than those at TO1, which were older than those at TO2 (Tables 2, 4). However, age did not affect bait uptake at TO1 ( $t = 0.856$ , d.f. = 98,  $P = 0.394$ ) and GO ( $t = 0.869$ , d.f. = 100,  $P = 0.387$ ) but the pigs that took baits at TO2 were younger than those that did not ( $t = -2.585$ , d.f. = 61,  $P = 0.012$ ).

The pigs sampled at TO1 had the highest mean body-condition score, followed by TO2 and GO (Tables 2, 4). However, body condition did not affect bait uptake within trials TO1 ( $t = 1.665$ , d.f. = 75,  $P = 0.49$ ), GO ( $t = 1.663$ , d.f. = 83,  $P = 0.64$ ) or TO2 ( $t = 1.67$ , d.f. = 62,  $P = 0.46$ ).

At each trial, the sex ratio of the shot sample showed marked divergence from parity ( $\chi^2 = 100.0$ , d.f. = 1,  $P < 0.001$  for TO1:  $\chi^2 = 8.165$ , d.f. = 1,  $P = 0.004$  for GO;  $\chi^2 = 7.451$ , d.f. = 1,  $P = 0.006$  for TO2) with females being predominant (overall 1.71 females : 1 male). There was no significant difference in the proportional uptake of baits by male and female pigs ( $\chi^2$  for pooled trials = 0.341, d.f. = 1,  $P = 0.56$ ).

#### *Bait removal by non-target animals*

Ground-placed baits were exposed for a total of 251 bait-nights; most were removed by birds (57.8% of total baits) and foxes (30.3% of total baits). Only six baits (2.4%) were removed by pigs. One bait was removed by a cat and eight by unidentified animals. Some baits (4.0%) were visited but not removed and 2.0% were not removed or visited. During the first 24 hours' exposure, 94.8% of baits were removed by animals.

## Discussion

#### *Factors influencing bait uptake*

The regression for TO2 (Fig. 2) suggests that under some circumstances there may be a threshold baiting intensity below which no pigs take bait. The combined regression (Fig. 2) passes through the origin, suggesting that in other circumstances there is no such effect. A number of factors might affect bait uptake by feral pigs and account for the differences between the regressions.

**Table 4. Contrasts of mean age and body-condition scores between feral pigs from three sites in semi-arid north-western New South Wales**

Between-trial contrasts of age were conducted with Student's  $t$ -tests and contrasts of body-condition scores were by Mann-Whitney  $U$ -tests converted to  $z$  statistics.  $n_1$  and  $n_2$  are the sizes of the contrasted samples of body-condition scores

Contrast	Age			Body-condition score		
	$t$	$P$	d.f.	$z$	$P$	$n_1, n_2$
TO1 v. GO	-2.418	0.02	201	-41.847	<0.001	100, 101
TO1 v. TO2	5.516	<0.001	171	-37.811	<0.001	100, 71
GO v. TO2	8.036	<0.001	174	-38.065	<0.001	71, 101

### *Baiting intensity*

The effect of pig density on bait uptake in our trials was incorporated in baiting intensity. In our experiment, the relationship between variation in bait uptake and baiting intensity indicated that, while baiting intensity positively influenced bait uptake, the nature of this influence differed between trials.

In a northern Queensland dry season, Mitchell (1998) found that 63% of feral pigs had eaten aerially distributed meat baits. The underlying density of feral pigs in Mitchell's (1998) work was 4 pigs km<sup>-2</sup>, which was within the range of densities measured in our trials (Table 2). Our trial varied the baiting intensity whereas Mitchell (1998) distributed baits at one intensity only (279.6 baits pig<sup>-1</sup> km<sup>-2</sup>). Mitchell's (1998) bait uptake fitted on neither of our regressions, indicating that different conditions affected the two studies.

### *Seasonal conditions and foraging behaviour*

The differences in bait uptake evident in our trials were possibly related to the availability of pasture and water. Saunders *et al.* (1993) found that ground-based bait uptake (of fermented grain) by feral pigs varied significantly between seasons in Kosciusko National Park, with bait acceptance being highest in autumn. Seasonal differences in bait consumption have also been found in the high country of the Australian Capital Territory (McIlroy *et al.* 1993), an area that is contiguous with Kosciusko National Park. Feral pigs were more likely to consume baits in late autumn and winter, and the greater consumption in that period was attributed to the dispersion of feral pigs within the 'bait-catchment' and hence more discovery of bait by pigs. Both of these studies were carried out in the highlands of south-eastern Australia where changes in the availability of pasture are more aligned to the traditional four seasons than at our study area.

Bait uptake in our trials most likely reflected foraging range, which is set by a combination of cover, prevailing temperature and water and food availability (Choquenot and Dexter 1996). In poor seasons in semi-arid areas, the distribution of pigs is limited by availability of pasture and by the availability of water (Giles 1980). Pasture biomass on the Paroo is related to lagged rainfall and flood incidents (Choquenot 1998). In good seasons, particularly in association with flood events, pigs forage away from permanent water holes because both pasture and water are dispersed throughout the landscape (Dexter 1995). In contrast, Dexter (1995) also found that the movements of feral pigs increased when food was scarce, with long foraging forays away from permanent waterholes being necessary to obtain sufficient food. Therefore, the likelihood of pigs encountering randomly distributed baits would be greater in such circumstances than when their movements were more restricted by the availability of drinking water and dense cover for thermoregulation near permanent water (Dexter 1995). In addition, while pigs are omnivorous, they are primarily

herbivores that take meat opportunistically (Giles 1980). Therefore, the meat baits in our trials were probably eaten as pigs happened upon them rather than as a result of active foraging for meat.

During our experiment, availability of pasture was most dissimilar between TO1 and GO yet variation in bait uptake was less between these two trials than in comparison with that of TO2. Foraging behaviour might explain this. Both TO1 and GO were carried out when pigs were probably widely dispersed while foraging, albeit for different reasons. The highest bait uptake occurring in TO1 when surface water and pasture were most abundant. During October 1995 (trial GO), pasture availability in response to rainfall (Fig. 1) was low and water was limited to the main streams and waterholes. To achieve nutritional requirements, pigs would have needed to forage over a larger area and further away from permanent water (Dexter 1995; Choquenot and Dexter 1996) in the GO trial than in the TO2 trial. Both the TO1 and TO2 trials occurred in good seasons with abundant plant material, but widespread flooding was only apparent during the former. During the TO2 trial, pig movements may have been limited because their nutritional requirements were met close to permanent water in the Paroo River and Cuttaburra Creek (Dexter 1995, Choquenot and Dexter 1996). The differences in availability of pasture predicted from rainfall were reflected in the differences in body-condition score evident between our samples. We conclude that while the consumption of plant-based baits is predictable from seasonal pasture availability (Choquenot and Lukins 1996), variation in the uptake of meat baits appears less so and may be related to seasonally determined differences in foraging behaviour.

### *Effect of age and sex ratio of pigs on bait uptake*

Difference in age distributions between samples of feral pigs might result in different bait uptake. However, age was unimportant in bait uptake within trials except in TO2. Why this was so is not known but, generally, the age of the target pig population did not affect bait uptake except when uptake was lowest. In practice, the age distribution of a population of pigs would be unknown at the time of reduction.

The disparate sex ratio of the sampled pigs may not have represented the sex ratio of the population, was dissimilar to Giles' (1980) findings (1 female : 1.15 males for pigs older than 20 weeks), and therefore might not have reflected the total uptake of baits by the population. The higher proportion of females in the samples probably reflected the different behaviours of male and female pigs and our search patterns while hunting pigs: males are more likely to be solitary than are females (Choquenot *et al.* 1996). Our samples might have been biased towards groups of pigs (mostly females), resulting in the disparity in sex ratio. Despite this, the similarity of bait uptake between the sexes implies that the samples were representative and that the conclusions may be applied across the whole population. In all Australian studies, male feral

pigs have larger home ranges than females (e.g. McIlroy *et al.* 1989; Dexter 1995; Caley 1997). This implies that the probability of boars and sows happening upon baits, and hence bait uptake, would be dissimilar. No such difference in bait uptake was evident in our study.

#### *Bait uptake by non-target animals*

In our trials, birds and foxes removed far more surface-laid meat-baits than did feral pigs, and as little as 12% of baits may have been available to pigs. If this was the case then the level of bait uptake by pigs, particularly in TO1, was surprisingly high. The high number of baits taken by non-target animals may also partly explain the threshold for bait uptake by feral pigs implied in the TO2 regression (Fig. 2).

Pigs require a large 1080 dosage to kill them and so aerially-distributed 1080-meat baits for pigs may be hazardous to birds (McIlroy 1986). The large uptake by foxes may be beneficial to the local prey species but, combined with the large proportion removed by birds, bait removal by foxes reduces the number of baits available to feral pigs. This means that a larger number of baits must be distributed to compensate for bait removal by non-target animals.

McIlroy *et al.* (1993) identified birds as significant consumers of surface-laid grain-baits. As both surface-laid grain and meat baits are removed by birds, an alternative poison may be required for aerial baiting of feral pigs to become universally acceptable in Australia. Warfarin is a safer toxin to use (McIlroy *et al.* 1989) than 1080 and has been shown to be a suitable toxin for feral pigs (McIlroy *et al.* 1989; Choquenot *et al.* 1990; Saunders *et al.* 1990).

#### *Implications for feral pig control in exotic disease contingencies*

##### *Required baiting intensities*

If aerial baiting is to be used to halt the progress of a disease then we must know the baiting intensity required to achieve a particular threshold density of pigs in the targeted population. Using the regressions from Fig. 2 it is possible to predict the baiting intensity required to hypothetically poison or vaccinate all the pigs in an area, assuming similarities of habitat and demography. It is, of course, impossible to achieve 100% poisoning or vaccination because not all feral pigs will take baits (Hone 1983), irrespective of how many baits are placed in the field. The relationship between the percentage of pigs consuming baits and baiting intensity would more likely describe an asymptotic curve similar to the cumulative bait consumption curve found by Saunders *et al.* (1990). In all, 72% of pigs shot in our TO1 trial consumed one or more baits and the regression was strongly linear. It is likely that an asymptotic curve would closely approach the impossible 100% uptake before plateauing. Therefore, our linear function is most likely a good approximation of the bait uptake curve for values less than or approaching 100%. To

test whether the curve was asymptotic would require greater baiting intensities than we used.

#### *Predictions from models*

Because FMD is exotic to Australia, models (e.g. Pech and Hone 1988; Pech and McIlroy 1990; Caley 1993) are required to predict the establishment and progress of FMD in feral pigs. The most recent estimates of threshold density range from 0.027 pigs km<sup>-2</sup> (the spatial model of Pech and McIlroy 1990) to <0.7 pigs km<sup>-2</sup> (the second stochastic model of Dexter 1995), to 1.97 pigs km<sup>-2</sup> (the deterministic model of Caley 1993). If the models' predictions are correct, initial pig densities at TO and GO would have been high enough for FMD to establish. Had poisoned baits been used in the TO1 trial (when the initial density of pigs was highest and the proportional reduction was potentially greatest; 72% bait acceptance), the density of pigs that remained would have been 1.11 pigs km<sup>-2</sup>. This is below the modelled threshold of Caley (1993) but above the estimated thresholds of Pech and McIlroy (1990) and Dexter (1995).

The threshold density for the persistence of FMD in wild populations of pigs has not been estimated but, because there is no evidence that immune pigs are carriers of the disease, the persistence threshold may be higher than the establishment threshold (Caley 1993). This is encouraging because, if Caley's (1993) suggestion holds, the level of population reduction or immunisation through oral vaccination of an infected population might well be achievable through aerial baiting.

Counter to this discussion is the lack of evidence that pigs are implicated in outbreaks of FMD overseas (Chamnanpood *et al.* 1995). However, clinical signs of FMD have been observed in wild boar concurrent with epizootics in domestic livestock in Israel (Brightling and Buchanan 1995). A lack of density estimates or estimates of transmission rates in the overseas work makes it difficult to conclude whether such observations are relevant to Australian feral pigs.

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