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Feral pigs in north-western Australia: population recovery after 1080 baiting and further control

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Abstract. The recovery rate of a population of feral pigs (*Sus scrofa*) in the west Kimberley in north-western Australia was determined 12 months after a 1080 (sodium fluoroacetate)-baiting program. An estimated 56 pigs were present in the 15 000-ha study area in August 2005 compared with the prebaiting levels of 250–275 pigs in 2004 (11 pigs were known to be alive on site after the 2004 baiting). This represents a population recovery of 20–23% of the 2004 prebaiting levels. Although most pigs were in good body condition, environmental conditions were quite different between the two years. In 2005, some waterholes were dry or comprised mainly muddy water with little associated shelter for feral pigs. Consequently, and in contrast to 2004, no pigs were seen, and no bait take could be attributed to feral pigs, at the four resurveyed waterholes. Most pig sightings, and activity, were close to the Fitzroy River. Fermented wheat, with blood and bone, was used to determine areas of pig activity, and also used as prefeed before 1080-baiting commenced in 2005. Using the same bait stations as for 2004, plus additional stations established in new areas of pig activity, 1080-treated wheat and malted barley again proved highly effective in reducing pig numbers. The daily sighting index before and after 1080-baiting indicated that pig numbers had been reduced by ~90% within four days. Estimated pre- and postpoisoning density, with and without an edge effect, was 0.12–1.7 pigs km^{-2} and 0.05–0.67 pigs km^{-2}. Pig tracks decreased to zero on the six track plots within two days of baiting, but the number of macropod tracks remained constant over the four-day baiting period. Thirty-eight poisoned pigs were found after 1080-baiting, and these were generally in clustered groups within 200 m of an active bait station. Poisoned juvenile pigs were again found closer to the active bait stations than were adult or subadult pigs ($P < 0.05$).

Introduction

Feral pigs (*Sus scrofa*) occur over ~40% of Australia, where they can have considerable impact on the environment and/or agricultural production (Long 1988; Hone 1990; Choquenot *et al*. 1996; McLeod 2004). Feral pigs are also susceptible to several serious infectious animal diseases exotic to Australia (e.g. foot and mouth disease, African swine fever, Japanese encephalitis: Choquenot *et al*. 1996). However, until recently, little was known about the ecology and control of feral pigs in north-western Australia. We addressed some of this deficiency in August 2004 (dry season) by conducting field trials to determine the bait 'preferences', and then the efficacy of two 1080-baits, for feral pigs in the Fitzroy River region of north-western Australia. Information on the basic biology (e.g. group size, litter size) of these pigs was also collected as part of this study (Twigg *et al.* 2005). 1080-treated wheat and malted barley proved highly efficacious and reduced pig numbers by ~90% over a relatively large area (~15 000 ha). The baiting strategy was developed to provide a means for reducing pig numbers during an exotic disease emergency, and for routine, operational feral pig control. The agricultural and environmental impacts of feral pigs in the Fitzroy River region include the fouling of waterways, erosion of river banks, and the suspected spread of noxious weeds (Martin and Wheeler 2000; Twigg *et al.* 2005).

Although there have been several studies regarding the efficacy of a variety of control techniques for feral pigs (Saunders and Bryant 1988; McIlroy *et al*. 1989; Choquenot *et al.* 1990, 1996; Saunders *et al*. 1990, 1993; Mitchell 1998; Mitchell and Fleming 1998), information on the recovery of pig populations following control operations is limited (Hone and Pedersen 1980; Hone 2002), particularly regarding the medium term. For this reason, we resurveyed the feral pig population on Gogo Station (near Fitzroy Crossing) 12 months after the control program of 2004 to estimate the rate of population recovery. As part of the August 2005 study, we again tested the efficacy of 1080-treated wheat and malted barley against the small number of pigs found on site. A better understanding of both feral pig ecology and their control should enable the formulation of more informed management decisions, particularly for northern Australia.

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Our findings are therefore discussed largely with respect to their application to the ongoing development of management strategies for reducing the impacts of feral pigs, including the potential role of feral pigs in wildlife diseases (exotic and endemic).

Materials and methods

Study area

The study site, which is described in detail by Twigg *et al*. (2005), is located on Gogo Station (18°18′S, 125°35′E), ~30 km south of Fitzroy Crossing. Climate is tropical, with defined wet (December–April) and dry (May–November) seasons. The long-term mean annual rainfall (LTM) for Fitzroy Crossing is 541 mm. The Gogo land system comprises active flood plains with extensive levee zones, flanked by broad flat-bottomed depressions with moderate to extensive black soil plains of cracking clays, grassland savannahs and grassy woodlands. There are numerous creek systems and waterholes present, some of which dry up in most years. Beef cattle are the major enterprise on Gogo (see Twigg *et al*. 2005).

Only 352 mm of rain fell at Fitzroy Crossing during the 2005 wet (December to April), compared with 743 mm in the wet of 2004. No rain fell during May or July 2005, but 55.2 mm fell in June (LTM, 8 mm). Rainfall for April 2005 was 2.2 mm, and 3 mm fell on 26 August after the trials were complete (LTM, 20 mm and 1.4 mm). The lowest recorded annual rainfall for Fitzroy Crossing is 189 mm (1964, Australian Bureau of Meteorology). Minimum and maximum temperatures at Fitzroy Crossing during the 2005 study (3–14 August) were 7.8–21.9°C (mean 12.0°C) and 30.1–32.9°C (mean 31.5°C), respectively. The relatively 'poor' wet of 2005 meant that, by August, the main waterholes used in the study had contracted severely to become relatively shallow, muddy waterholes. One was dry. Although not formally measured, pasture, and available shelter, for feral pigs in 2005 was also considerably reduced compared with that available during the 2004 trials, particularly around the waterholes.

Apart from our trials in 2004 where >90% of resident pigs were destroyed (Twigg *et al*. 2005), feral pigs, cattle and native animals were all naive with respect to the two baits used (i.e. had no other known exposure to wheat and malted barley). Several species of parrots, doves and pigeons, and agile wallabies (*Macropus agilis*), were present during the 2005 study. The very occasional *ad hoc* shooting undertaken by the local community was curtailed during the trials.

Site layout

The location of all bait stations, access 'tracks', and both dead and live pigs, were accurately recorded using a hand-held Garmin® GPS 12XL Personal Navigator (global positioning system; Garmin Corporation, Olathe, Kansas 66062, USA). Before undertaking the 2005 trials, a 1-h aerial survey of the study site was conducted using a two-seater, Robinson-22 helicopter and an experienced observer (M. Everett) to gain some understanding of the locations of feral pigs. The aerial survey was conducted at 0530 hours, one day (3 August 2005) before the trials commenced. Although not formally counted, ~35–40 pigs were seen at this time. The location of any pigs seen was recorded with the GPS.

The same bait stations, and 'access' tracks/routes (sighting transects), used in 2004 were again used in the 2005 trials (Fig. 1). However, because pig activity was restricted to the river habitat in 2005, additional stations were installed in this habitat once we had identified additional areas of pig activity using the fermented wheat/blood and bone 'looksee' survey procedure (see below). On the basis of pig sightings and activity, and although these pigs are likely to be operating as a metapopulation in the longer term, the three areas baited with 1080 in 2005 were believed to be independent of each other during the baiting period (Fig. 1).

Bait stations and bait-take

Bait stations comprised two 1-m^2 raked-earth plots 5 m apart. Where appropriate, bait stations were fenced to exclude cattle from the poison bait. These fences were constructed with steel posts and barbed wire, with the bottom wire ~65 cm above the ground (Twigg *et al*. 2005).

To more accurately determine areas of pig activity, looksee-baiting (see Twigg *et al*. 2005) was undertaken using one or two 1-m^2 raked-earth plots each with a ~500-g pile of fermented wheat with added blood and bone (~50 g). A 5–10-m 'light' trail of fermented wheat was usually spread out from one side of the looksee raked plots to increase the potential encounters of feral pigs with these plots (Twigg *et al*. 2005).

Once the pigs were feeding relatively consistently at a station, all residual fermented wheat was removed and two 1-kg piles of 1080-treated bait were placed on each raked plot within each bait station. The two 1080-treated baits were wheat (northern area) or malted barley (southern sites). The allocation of 1080-treatment for the areas baited was the reverse of that used in the 2004 trials. Again, to ensure that we attracted the maximum number of pigs, a small amount of fermented wheat (100 g) with blood and bone (50 g) was used as an attractant. 1080-treatment of grain was as per the current label directions for 1080 Concentrate Black® (Bait Production Unit, Department of Agriculture and Food, Forrestfield, Western Australia, Australia) and for feral pig control in WA (100 mL of a 40 mg mL^{-1} aqueous 1080 solution is thoroughly mixed with 6 kg of bait (or 667 mg kg^{-1} bait)).

Bait-take was visually estimated for all stations using 10% increments and 1-kg reference samples contained in plastic bags. Bait stations were monitored each morning (generally after 0730 hours to avoid interfering with pig behaviour) and topped-up each afternoon (generally completed by 1700 hours, also to avoid interfering with pig behaviour) as required (i.e. replenished back to the original amount). Animals (e.g. pigs, cattle, birds, macropods) visiting the bait stations and/or taking bait were identified by their tracks, and any other spoor, that were present on the raked plots. The plots were scored each morning and reraked each afternoon (Twigg *et al*. 2005).

Three Trailmac® Olympus remote-sensing digital cameras were also used at several bait stations to confirm that pigs had visited a station and that they had consumed bait. These photographs proved to be a valuable aid in identifying those pigs that needed to be found during the carcass searches.

Abundance estimate and efficacy

All live-pig sightings were recorded using the GPS locations of either nearby bait stations or uniquely created waypoints when pigs were further than 200 m from known GPS reference points. These records included the time of day, group size and, where possible, the sex, age and coat colour of pigs, and were used to determine the number of pig sightings each day before and after poison-baiting. These records, and the observed behaviour of pigs (e.g. same pigs seen at a similar location each day), were also used to estimate the number of individual pigs and, hence, the likely number of feral pigs present before baiting (Twigg *et al*. 2005).

The efficacy of 1080-treated grain was determined using three relatively independent areas: the Northern (NLS in 2004: Twigg *et al*. 2005) and Water Bore (WB in 2004) sites were combined and baited with 1080-malted barley, the Southern (SLS in 2004) and West River (WR in 2004) sites were combined and baited with 1080-wheat, and the Far South (FS in 2004) site was also baited with 1080-wheat. The Northern and Water Bore sites were combined because pigs from the Northern Site were observed feeding at the Water Bore bait station (WB1), but no pigs were seen and no bait was taken on the nearby bait stations on the adjacent Southern site (SLS: Fig. 1). Efficacy was estimated using the number of pig sightings for each day of the six days before, and the four days after, poison-baiting. These values were calculated using the total number of sightings divided by the number of days for each relevant period. The percentage decrease was calculated as the change in the 'before' and 'after' sightings per day expressed as a percentage of the 'before' values. Bait take was also monitored daily during the efficacy trials. Further, because we were unable to undertake postefficacy follow-up monitoring in 2005 (Twigg *et al*. 2005), most of the looksee bait stations were also left active (fermented wheat only) and monitored daily during the 2005 efficacy trials. This enabled assessment of whether pigs were present (and feeding) elsewhere within the study site at this time.

Track plots were also established in two areas (near NLS18 and WB1) to further monitor pig abundance/activity. These areas had four and two raked-earth plots (~1.5 m^2), respectively. The raked plots were located on active track-pads of feral pigs, and were at least 5–10 m from an active bait station. No bait material was provided on these plots. Track plots were monitored twice daily before (three days) and after (four days) poison-baiting was undertaken. Plots were raked clean after each morning and afternoon monitoring/recording session (Twigg *et al*. 2005). No other areas had pads suitable for monitoring.

Pig carcasses and measurements

Carcass searches, which generally involved three people, were undertaken systematically using a combination of vehicle (two people on back of tray-back 4WD vehicle) and 'foot' (line-search coordinated using hand-held two-way radios) searches. These searches were most concentrated on the first three days after poison-baiting. On average, there was 2.5 person-hours (±0.7 h, s.e.m.; excludes autopsy time) search time per day for each site on these days. However, observation continued routinely during the ongoing conduct of the trials at each site. The GPS location was recorded for all dead pigs found. After calibra-

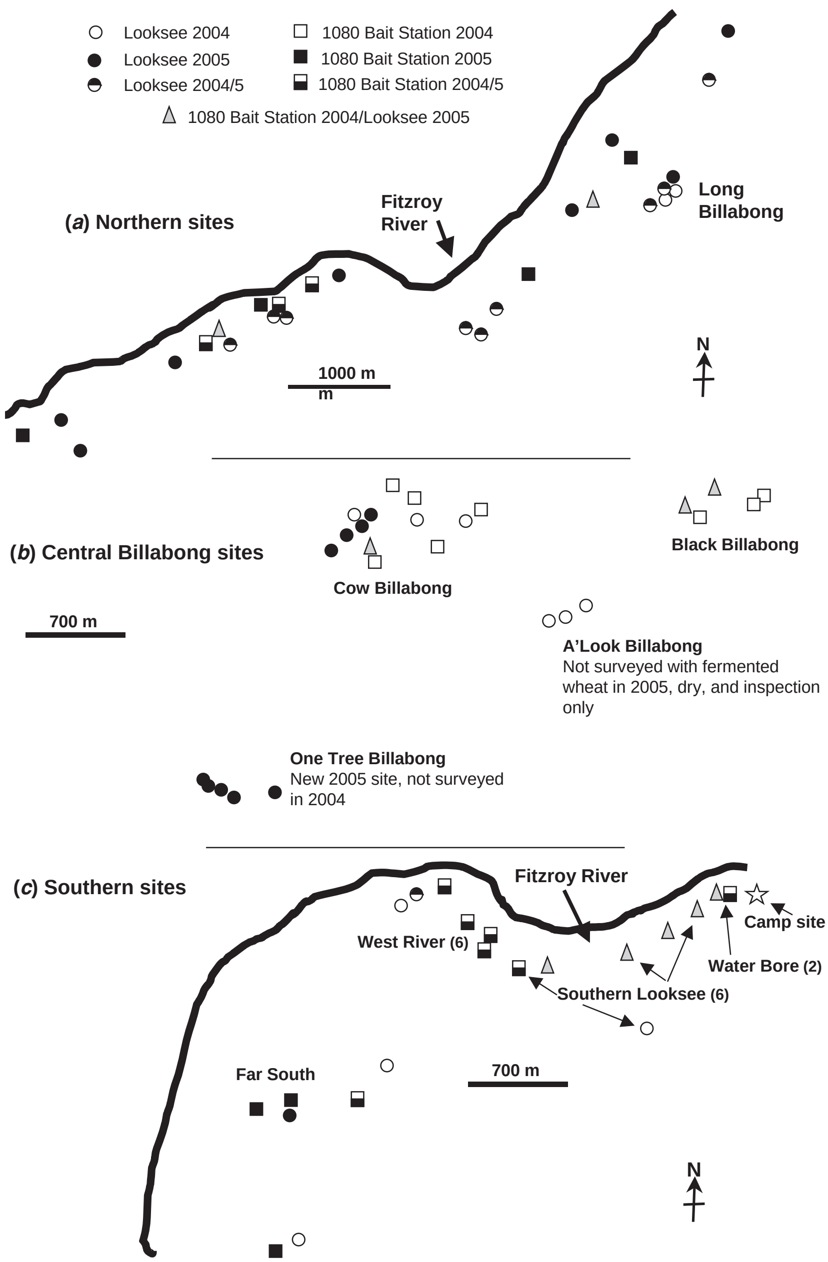

Fig. 1. Schematic presentation of the bait stations used during the 2004 and 2005 surveys and baiting trials on Gogo Station in the Fitzroy River region of Western Australia. For clarity, the location of some bait stations and the Fitzroy River are approximate. Further detail can be found in Twigg *et al*. (2005).

tion with known weights, bodyweight was estimated by the same person for all dead pigs. Head–body length (HBL) was determined by measuring the curved distance over the back from the tip of the nose to the base of the tail (±1 cm) (Saunders 1988; Choquenot and Saunders 1993). Our age classes were: juveniles, 1–15 kg; subadults, 16–24 kg; adults, >24 kg. 'Suckers' are a subclass of juveniles and refer to young pigs <5 kg (Twigg *et al.* 2005).

Data analysis

Bait take from the bait stations used in the efficacy trials was determined as a percentage of the amount of bait available on each raked plot at each station (usually 2 × 1-kg piles × 2 plots or 4 kg per station). However, these assessments excluded any station that was not visited by feral pigs during the 1080-baiting period. Further, as not all stations were visited by feral pigs on Day 1 of the 1080-baiting, the values for subsequent days do not always correspond to the same date. That is, Day 1 corresponds with the day that each station was first visited by feral pigs regardless of whether they actually consumed any bait. Once a station was visited by pigs, it was then included in all subsequent assessments regardless of whether it was visited by pigs, and whether any bait was taken.

A single-factor (age) ANOVA (Zar 1984) was used to analyse the distance (dependent variable) that poisoned pigs were found from bait stations.

Results

Abundance and demography

There were 275 sightings of feral pigs during the 14-day 2005 trials. Of these, 56 were determined as different individuals according to our abundance criteria (range 51–56 pigs, see Twigg *et al.* 2005). In total, 61% were adults, 2% juveniles or subadults, and 37% were suckers (<5 kg). The maximum number of pigs present before the 2005 baiting (56) represents 20.4–22.4% of the upper and lower abundance estimates for the 2004 prebaiting levels (250–275 pigs: Twigg *et al.* 2005). That is, prebaiting pig numbers in 2005 were only ~21% of those recorded 12 months previously before any poison-baiting took place. In 2005, no pigs were seen in the vicinity of the waterholes monitored in both years (Table 1) although two adult pigs (boars?) were seen grazing with cattle at the new 2005 One Tree Billabong waterhole site. No bait was taken from any waterhole that could be attributed to feral pigs, including One Tree (see below). No pigs were seen away from the Fitzroy River during the aerial survey of the River Junction paddock. Using a minimum polygon of the area occupied by all bait stations (~3300 ha or 33 km^2, excluding the area occupied by One Tree Billabong which was used only in 2005), and the maximum estimated abundance of feral pigs before the 2005 baiting (56), then the estimated density of pigs in the immediate area of our study sites was ~1.7 pigs km^{-2} (7.6 pigs km^{-2} in 2004: Twigg *et al.* 2005). However, if an edge effect (see Saunders and Kay 1991) of 5 km, excluding the north-western boundary abutting the Fitzroy River, is included then this density becomes ~0.12 pigs km^{-2} (3.0 pigs km^{-2} in 2004). Corresponding values after 1080-baiting in 2005 were 0.67 and 0.05 pigs km^{-2}. The most common coat colour in 2005 was ginger/brown, accounting for ~53% (82% in 2004) of the 38 dead pigs found; 50% were brindled (~14% in 2004), and ~2% were black, tan and white.

Although large adult males (>50 kg) were usually solitary during 2005 surveys, they were also seen with adult females and in family groups (Table 2). No large males were seen near other pigs in 2004. This may reflect the differing resource availability between the two dry seasons surveyed. In 2005, some adult females were associated with family groups, with the most common group size being 1–3 sows with 3–13 juveniles. Other adult females occurred in groups of 2–3 adult pigs only (Table 2). Of the 11 adult sows (>24 kg) found after the 2005 poisoning, 6 (i.e. 55% cf. 88% in 2004) were pregnant or lactating. The pregnant sows had

Table 1. The efficacy of 1080-treated grain against feral pigs during the 2005 dry season (August) on Gogo Station in the Fitzroy River region, Western Australia
Sites: NLS, northern; WB, water bore; SLS, southern; WR, west river; FS, far south. MNKA, minimum number known alive; NB, not baited as no evidence of feral pigs present; n.a., not applicable

Site	Bait type	MNKA[A]	Sightings per day[B] Before	After	Decrease (%)
NLS/WB	Malted barley	40	5.7	0.6	89.5
SLS/WR	Wheat	?	?	?	100.0?[C]
FS	Wheat	16	2.7	0.3	90.6
BBL	Not baited	0	0	0	n.a.
CBL	Not baited	0	0	0	n.a.
All sites[D]		56	4.19	0.42	90.1–93.4

[A]Estimated from all pig sightings but excluded any obvious 'replicate' sightings over the trial period.
[B]Based on all pig sightings, including any repeats between days, for each site. There were 275 sightings of pigs during the 2005 trial period.
[C]No live pigs sighted before or after baiting, but four 1080-killed pigs found after baiting and bait take ceased within 2 days.
[D]With and without the SLS/WR site set to a 100% reduction. Excludes the BBL and CBL sites.

Table 2. Frequency of group sizes/structures of all feral pigs sighted during the August 2005 dry season on Gogo Station in the Fitzroy River region of Western Australia
Each sighting was treated as unique, regardless of whether the pigs had been seen previously

Class	Group size (no. of individuals) <3	3–6	7–10	>10	Other frequencies
Juveniles		2	1		
Adult males (solitary)	12				
Adults, males with females					2
Adult males with family groups					1
Adult females only		1			
One sow and juveniles					1
Two sows and juveniles					5
More than two sows and juveniles					5
Adults, sex unknown	4	3			
All pigs	16	10	6	2	

1–6 viable embryos and 1–5 resorbing embryos. Those sows that had obviously bred weighed 50–75 kg; the non-breeding sows weighed 40–75 kg.

Efficacy

1080-treated malted barley and wheat were again highly efficacious against feral pigs on Gogo station (Table 1), with most bait-take (Fig. 2) and associated pig deaths occurring within 2–3 days of baiting. Pig sightings (numbers) were reduced by 90% after poisoning. This excludes the SLS/WR site as no live pigs were sighted in this area before or after poison-baiting. However, four 1080-killed pigs were found after baiting on this site, and bait-take decreased to zero within 2 days of 1080-baiting (Fig. 2). As was the case in the 2004 trials, pigs on the FS site took some time to feed consistently at these bait stations, and there were at least four separate groups of pigs feeding in this area. Consequently, due to time constraints, we had to cease 1080-baiting before all known pigs were destroyed. Even so, efficacy was still an acceptable 91% reduction of known pigs on the FS site (Table 1).

The consumption of the fermented wheat the day before baiting, and that of the 1080-treated grain during the efficacy trials, is shown in Fig. 2. With the exception of the FS site, most bait-take ceased within 1–3 days. This includes both the toxic bait (generally 2 × 1-kg piles × 2 raked plots per station) and fermented wheat/blood and bone attractant (~100 g and ~50 g respectively per raked plot). Although the looksee bait stations were still active, no consumption of the fermented wheat that could be attributed to feral pigs occurred on any of these looksee stations once the 1080-treated bait stations were established. This suggests that our poisoned-stations were covering the main feeding areas of feral pigs on our study area. However, during the looksee, fermented wheat survey of the waterhole sites, and very occasionally at other sites, mature adult cows with calves at foot showed a minor interest in this bait material and consumed small amounts (<60 g) of fermented wheat (6 of 311 bait station nights or 1.9%). Agile

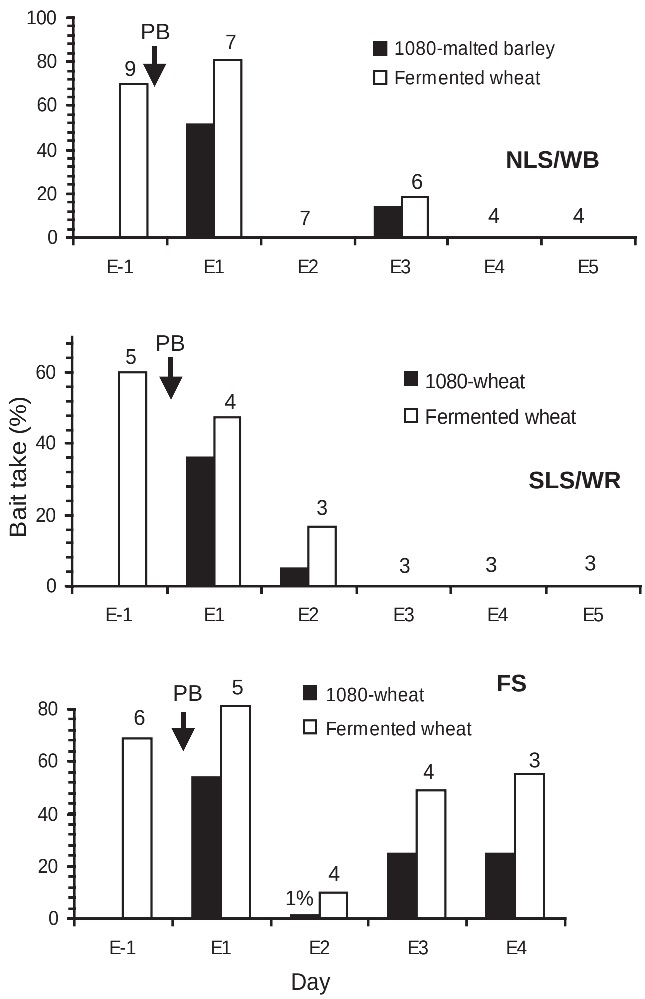

Fig. 2. The consumption of fermented wheat and 1080-treated grain by feral pigs from bait stations on Gogo Station in Western Australia during the 2005 dry season (August). Internal numbers refer to the number of bait stations and these vary over time as not all stations were visited by pigs on the first night that 1080-bait was on offer (see Materials and methods). PB indicates when poison baiting commenced. Bait procedures are given in Materials and methods.

Table 3. Mean (s.d.) changes in the tracks of feral pigs and macropods before and after baiting with 1080-treated grain on Gogo Station in the Fitzroy River region, Western Australia

Track plots were ~1.5-m^2 raked earth and were located on an active pad at least 5–10 m from a bait station. Tracks were monitored twice daily for three days before, and four days after, baiting with 1080-malted barley. There were two plots near WB1 and four plots near NLS18 that contained no bait material

	Proportion of monitoring periods with tracks		
	Before	Day 1	Days 2–4
Pigs	0.31 (0.13)	0.00 (0.00)	0.00 (0.00)
Agile wallabies	0.27 (0.18)	0.27 (0.43)	0.28 (0.10)

wallabies also consumed small amounts of fermented wheat (<20 g) on at least three occasions. Besides the above, there was no other evidence that non-target species (e.g. granivorous birds) had consumed significant amounts of fermented wheat or 1080-bait.

That 1080-treated grain was again highly efficacious against feral pigs on Gogo Station was further supported by the evidence from the track plots established on the site where we could reliably use these plots to monitor changes in pig activity/abundance (NLS/WB). The proportion of monitoring periods with recorded pig tracks decreased to zero within one day of 1080-baiting (Table 3). This decrease corresponded with the cessation of bait-take at the bait stations associated with these track plots. In contrast, the ongoing presence of macropod (agile wallabies) tracks provided further support for the field observations that few wallabies sampled bait, and that macropods were unaffected by the 1080-baiting.

Recovery of carcasses

Thirty-eight pig carcasses were found after the 2005 1080-baiting (Table 4). Of the pigs found, 46% were adult, 13.5% subadult and 40.5% were juvenile. The presence of subadult pigs was in contrast to the 2004 trials where no subadult individuals were recorded. In all, 80% of the juvenile pig carcasses found (n = 15) were suckers (i.e. ≤5 kg). The frequency distributions of the estimated bodyweights and HBLs of the pigs found are given in Fig. 3. The relationship between the HBLs and estimated bodyweights were again well correlated and was very similar to that found in 2004 (see fig. 9 of Twigg *et al*. 2005). The associated 2005 equation was:

$$\mathrm{HBL} = 30.819 \times \mathrm{Ln(bodyweight)} + 2.2384 \qquad (R^2 = 0.96).$$

The relatively uniform distribution of HBLs for each weight class, and the high R^2 value provide further general support for the observation that all dead pigs found, except one heavily lactating sow, were generally in good condition.

On average, feral pig carcasses were found within 150 m (range 25–351 m) from the nearest bait station from which poison-bait was consumed (Table 4). This is less than that recorded in 2004 (230 m: Twigg *et al*. 2005). Similar to the 2004 trials, and again with the exception of solitary adult males, poisoned pigs were usually found in groups. These groups comprised 3–15 individuals, and were generally tightly clustered, with most pig carcasses found over an area of much less than 0.5 ha (Table 4). Mean distances between individual members in these groups were generally less than 50 m (range 25–174 m). As in 2004 (Twigg *et al*. 2005), there were again age-specific, but not sex-specific, differences between the distances travelled by juvenile and adult pigs before they succumbed (Table 4). That is, distances for juvenile male and female pigs (ANOVA: F = 4.75, d.f. = 1,12, P = 0.358), and for adult male and female pigs (ANOVA: F = 2.07, d.f. = 1,15, P = 0.171), respectively, were similar. However, juvenile pigs (mean ± s.d. = 95 ± 33 m) were found significantly closer to the bait stations than were adult pigs (151 ± 84 m) or subadult pigs (146 ± 46 m) (ANOVA: F = 3.27, d.f. = 2,34, P = 0.050) (Table 4).

Table 4. The distances that feral pig carcasses were found from the nearest bait station from which bait was taken, and the area over which each group of pigs were found

Sites: NLS, northern; WB, water bore; SLS, southern; WR, west river; FS, far south

Site/age[A]	Distance from station (m)					Area (ha)[B]
	Minimum	Maximum	Mean	s.d.	n	
NLS/WB	69	195	114	40	24	0.006, 0.076, 0.554
SLS/WR	56	185	104	56	4	0.069
FS	25	351	174	106	10	0.004, 0.028, 0.070
All sites	25	351	129	69	38	
Juvenile males	69	96	84	9	6	
Juvenile females	56	173	101	44	8	
Subadult males	78	186	153	50	4	
Subadult females			118		1	
Adult males	90	351	194	112	5	
Adult females	25	215	130	72	12	

[A]Excludes the remains of two pigs that could not be sexed.
[B]Excludes solitary pig carcasses.

The stomachs of all recovered pigs contained bait material (usually in large quantities), and they also contained considerable amounts of other food. These other foods were mainly grasses and other herbage, with no fruiting bodies seen. Despite considerable search time, no vomitus was found on any site. This, and the presence of large quantities of food in the stomachs of autopsied pigs, suggests that, as in 2004 (Twigg *et al*. 2005), very little/no vomiting had occurred in poisoned pigs.

Discussion

The estimated observed annual rate of increase (*r*) for the recovery of the feral pig population in the River Junction paddock on Gogo Station after the completion of the August 2004 1080-baiting until August 2005 was 1.6 (prebaiting 2005/postbaiting 2004, 56/11 pigs). This is within the range observed for recovering populations ~12 months after a baiting program in NSW (Hone and Pedersen 1980). The relatively low recovery rate (to 20–23% of 2004 prebaiting levels) of the feral pig population 12 months after the initial knock-down in the 15 000-ha River Junction paddock is consistent with the known behaviour of feral pigs. Although large boars may travel considerable distances to secure paternity (>50 km), unless exposed to a lack of adequate resources or to persistent persecution, feral pigs are generally sedentary in nature and usually remain within well defined home ranges (Caley 1997; Dexter 1999; Saunders and McLeod 1999; Hampton *et al*. 2004*a*, 2004*b*; Spencer *et al*. 2005; Spencer and Hampton 2005). The size of these ranges is generally small (1–43 km^2, usually <12 km^2); however, home ranges often decrease as pig density increases (Choquenot *et al*. 1996; Spencer *et al*. 2005). Home-range size may also vary inversely with resource abundance (Singer *et al*. 1981; Caley 1997; Dexter 1999). Home-range size of adult males is often limited by access to females (i.e. reproductive success), whereas those of adult females is likely to be limited by available resources (Saunders and Kay 1991; Dexter 1999). Adult sows are particularly philopatric, and migration events seem to be relatively rare (Caley 1997; Saunders and McLeod 1999; Hone 2002; Spencer and Hampton 2005). Feral pigs are also, generally, relatively slow invaders of new habitat (Caley 1997; Hone 2002; Spencer and Hampton 2005; Spencer *et al*. 2005).

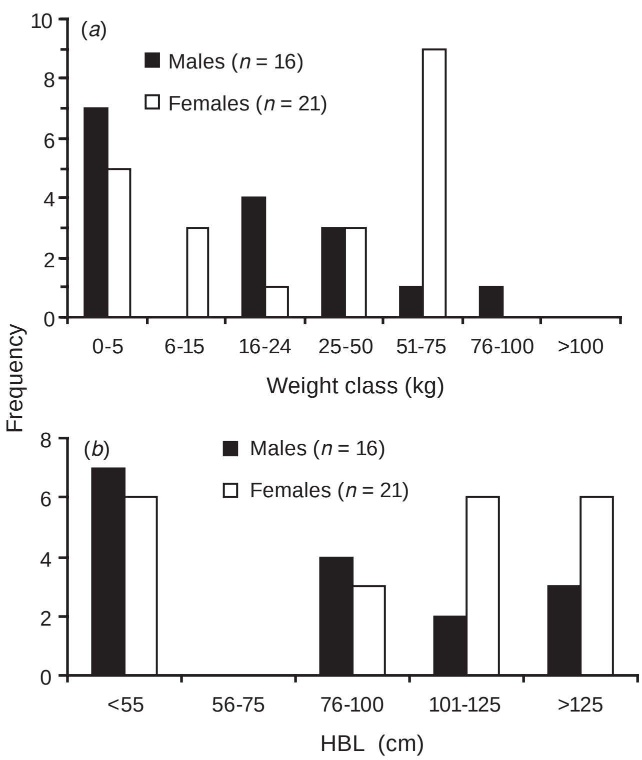

Fig. 3. Frequency distributions of estimated (*a*) bodyweight (kg) and (*b*) head–body length (HBL, cm) of the feral pigs found after 1080-baiting during the 2005 dry season (August) on Gogo Station, Western Australia.

The relatively slow recovery of the feral pig population in the River Junction paddock on Gogo Station was likely to have been further enhanced by several other factors. (1) Rainfall during the preceding 2004–05 wet season was relatively poor, which, in turn, resulted in reduced shelter (and food?) for pigs, particularly around the waterholes. (2) The area of the Fitzroy River used in the trials is adjacent to Alexander Island, which is bounded by the Cunningham River on the western side (see Twigg *et al*. 2005). This provides a physical barrier and restricts/prevents the immigration/emigration of pigs from the east/west in most years. (3) Some controlled shooting was undertaken by the Sporting Shooters Association, Australia, Northern Territory Branch (SSAA, NT) over a two-week period in September, 2004 on two neighbouring Stations after our 2004 baiting program (Jubilee Station abuts the Cunningham River, thus it has little influence on Gogo immigration rates; Old Cherrabun Station abuts the Fitzroy River south of Gogo Station and thus may provide a source of immigrant pigs). (4) Besides the aforementioned shooting, there has been little persecution (i.e. shooting) of the pigs on Gogo and Old Cherrabun Stations, which is likely to have resulted in pigs from these populations being forced to leave previously established home ranges (see Caley 1997). The age (i.e. >45 kg) of some poisoned pigs found in 2005 suggests that some were adult in 2004; hence, low-level immigration had occurred after, or a few pigs were not poisoned during, the August 2004 trials. For example, there were one brindled sow with seven suckers, one relatively large boar (>70 kg), and two adult sows remaining on the study area after the 2004 baiting trials, which could not be removed owing to time constraints (Twigg *et al*. 2005). If the 28 pigs born on site during the 2005 breeding season, and the 11 resident pigs known to be alive after the 2004 baiting are discounted, then ~17 pigs may have immigrated into the area after the 2004 baiting. Regardless of the reasons, our results indicate that the recovery of baited pig populations in northern Australia can be relatively slow provided that a large area is targeted, and a high level of efficacy is achieved (>85% knockdown). In contrast, in semi-arid western New South Wales, the number of feral pigs 12 months after a 1080-baiting program had virtually doubled from the immediate postbaiting levels to almost attain prebaiting numbers within 12 months (Hone and Pedersen 1980). However, in this instance, meat baits were placed around available water points, and the overall reduction in pig numbers was only 58% (meat-bait efficacy is recognised to be less than that of grain bait: Twigg *et al*. 2005). Most of this population recovery was attributed to a birth pulse rather than to immigration (Hone and Pedersen 1980).

The reduction of the range of the pigs on Gogo Station to areas along the Fitzroy River during the 2005 dry season is not unexpected as riparian ecosystems are an important habitat for feral pigs in northern Australia (Caley 1997). However, the presence of adequate water at some waterholes, but the lack of obvious pig-shelter, suggests that the availability of adequate shelter is an equally important determinant of the localised distribution and abundance of feral pigs in northern Australia. Adequate shelter is required to enable pigs to escape the effects of temperature extremes (Choquenot *et al*. 1996; Caley 1997; Dexter 1999). Even though environmental conditions were relatively poor, and plant biomass was generally low during the 2005 trials, low numbers of seed of three plant weeds (*Xanthium occidentale*, *Pennisetum basedowi* and *Achyranthes aspera*; 4–27 seeds per pelt) were seen on the hides of some poisoned pigs on Gogo Station (4 of 38 pigs; L. Twigg, unpublished data). This suggests that feral pigs may play some role in the spread of weeds, and further investigation of this aspect of feral pig ecology may be worthwhile.

The demography of pigs on Gogo Station in 2005, including group sizes, was generally similar to that observed during the 2004 study, although there were some exceptions. There was a 'switch' in the frequency of coat colour from ginger/brown (53% in 2005 versus 88% in 2004) to brindled (50% versus 14%). Whether this reflects any significant change in paternity or the gene pool was not determined. Adult boars were not only solitary, but were also found with adult sows and family groups in 2005. This may reflect a relaxation of territoriality associated with reduced resources during this dry season. Further, although samples sizes were small, the pregnancy/lactation rate appeared lower (55% versus 88% of adult females) and the number of resorbing embryos higher in 2005, again suggesting that resources were limited at this time. Half of the recorded pigs in 2005 were non-adult individuals (41% juveniles, 9% subadults of 56 pigs: Table 4) that had almost certainly been bred on site since the 2004 baiting program (i.e. during the 2005 breeding season). This provides further support that the immigration rate following the 2004 baiting was probably low, and that most pigs on site in 2004 had been destroyed. The mean estimated weight of poisoned adult pigs found in 2005 was 61 ± 15 (s.d.) kg (mean, maximum for males (n = 5), 62 and 95 kg; for females (n = 12), 61 and 75 kg) and 61 ± 22 kg in 2004 (mean, maximum for males (n = 7), 79 and 120+ kg; for females (n = 14), 53 and 80 kg), suggesting that our baiting programs were effective in removing large pigs (Twigg *et al*. 2005).

The baiting program conducted in 2005 mirrored the likely techniques that would be used for operational pig control in northern Western Australia. That is, no choice experiments were conducted in 2005, and the standard practice of prefeeding immediately followed by 1080-baiting took place once the pigs were feeding consistently. Under these conditions we were able to achieve a >90% knockdown of resident pigs within 5–9 days. This is similar to the level of efficacy achieved in the 2004 dry season (~90%: Twigg *et al*. 2005). Most poisoned pigs were also recovered in clustered groups close to the active bait stations (within 150 m in 2005, and 230 m in 2004), and over relatively small areas (0.003–0.684 ha: Table 4, Twigg *et al*. 2005). These findings provide further support for the use of 1080-baiting during routine operational programs, and during an exotic disease contingency (Twigg *et al*. 2005). However, as stated previously (Twigg *et al*. 2005), some other method, such as shooting, may be required to remove those adult boars that may travel relatively large distances (Choquenot *et al*. 1996; Spencer and Hampton 2005; Spencer *et al*. 2005), particularly during an exotic disease emergency. Given that a few cattle also showed a minor interest in the fermented wheat, we again reinforce the recommendation that domestic livestock should be excluded from the toxic bait. There have been no other non-target issues with our baiting procedures, including the lack of bait take by birds (Twigg *et al*. 2005).

The time required to get the pigs to feed consistently on the fermented wheat prefeed, and then to undertake the poison-baiting took 6–10 days in 2004 and 5–9 days during the 2005 trials. This is well within the 21-day knockdown period suggested for the containment of several exotic diseases of major concern (Pech and Hone 1988). The pig densities of ~1.7 pigs km^{-2} in River Junction paddock before the 2005 baiting were also less than the 2 pigs km^{-2} that has been suggested for disease containment. Postpoisoning density estimates in 2005 were 0.05– 0.67 pigs km^{-2}, again within the levels suggested for the containment of relevant wildlife diseases (Pech and Hone 1988; Pech and McIlroy 1990; Caley 1993; Dexter 2003). This provides further support for the use of 1080-baiting as a disease-containment tool should a disease emergency involving feral pig populations occur in the rangelands of northern Australia.

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