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Feral pigs in north-western Australia: basic biology, bait consumption, and the efficacy of 1080 baits

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Abstract. Bait consumption, and the efficacy of 1080-treated grain, were determined for feral pigs (*Sus scrofa*) during the dry season in the Fitzroy River region of north-western Australia. There were an estimated 250 pigs on the study site (15 000-ha paddock with beef cattle) before poison-baiting, and group size and the basic biology of these pigs were similar to that found elsewhere in Australia. All animals at the study site were naive to the test baits. Fermented wheat with added blood and bone was an attractant for feral pigs but added fish oil was not. Wheat and malted barley were the 'preferred' baits. Lupins and pig pellets were consumed in lesser amounts, suggesting that they are less/not acceptable to some feral pigs. Consequently, the efficacy of 1080-treated wheat and malted barley was determined (n = 3 sites per treatment). Three independent measures of pig activity/abundance were used. The daily sighting index before and after poison-baiting suggested that pig numbers were decreased by at least 81–100% (mean 89%) regardless of which bait was used. The take of both 1080-bait and non-toxic fermented wheat added to each station generally ceased within 1–3 days, and little take occurred during the post-poisoning follow-up. Pig tracks decreased to zero within 1–3 days of poisoning on the two sites where track plots were established. However, due to the arrival of 'immigrant' pigs ~6 days after poisoning on two sites, and the need to close down a third site before poison-baiting could be completed, we believe the absolute efficacy was greater than the 89% overall reduction. Even though they had access to bait, there was no bait-take by non-target species, either native (toxic and non-toxic bait) or domestic (non-toxic bait). The 61 pig carcases found after poisoning were within 20–610 m of active bait stations (mean 232 m), and most were found in clustered groups. These findings are discussed with respect to the development of management strategies for reducing the impacts of feral pigs, and in terms of their potential implications for developing wildlife disease (exotic and endemic) contingency plans.

Introduction

Feral pigs (*Sus scrofa*) can have a devastating impact on the environment, and may also cause losses to agricultural production (Choquenot *et al*. 1996). Although the ecology and control of feral pigs is reasonably understood in much of eastern Australia, there is little information on these aspects for north-western Australia. The distribution of feral pigs in this region is disjunct, and mainly restricted to the major rivers and associated channel country, particularly in the Fitzroy River region (i.e. west Kimberley: Long 1988; Choquenot *et al*. 1996). Gaining a better understanding of the ecology and control of feral pigs in such regions is important for several reasons: (1) the development of practical control strategies, (2) understanding the potential role of feral pigs in endemic and exotic wildlife disease, (3) assessing the merits of 1080-baiting in reducing pig numbers during a disease contingency, and (4) assisting with the development of realistic management strategies for reducing the impact of feral pigs on the environment and agricultural production. Although pigs and cattle can consume the same pastures (Martin and Wheeler 2000), the main impacts of feral pigs in the Fitzroy River region are largely environmental. However, from an agricultural perspective, pig-impacts include the fouling of waterways, erosion of river banks, and the spread of noxious weeds (e.g. Noogoora burr, *Xanthium occidentale*: Martin and Wheeler 2000). There is also a need to develop reliable control procedures for feral pigs in this region in the event of an exotic disease emergency.

In this paper, we provide information on the basic biology of feral pigs during the dry season in the Fitzroy River region of north-western Australia, report on the consumption of four grain-based baits by these pigs, and provide an assessment of the efficacy of 1080-treated grain against feral pigs in the Fitzroy River region. We discuss these findings with respect to the development of management strategies for reducing the impacts of feral pigs, and also consider their potential implications for developing wildlife disease (exotic and endemic) contingency plans.

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Materials and methods

Study area

The study, which was undertaken from a remote ‘bush-camp’, was located on Gogo Station (18°18′S, 125°35′E), which is ~30 km south of Fitzroy Crossing (Fig. 1). Climate is tropical, with a defined wet (December–April) and dry (May–November) season. Long-term mean annual rainfall for Fitzroy Crossing is 541 mm. However, 743 mm of rain occurred at Fitzroy Crossing in the wet of 2004 (December 2003 to April 2004). Between 45 and 50 mm of rain fell in May and June 2004 (long-term mean annual rainfall, 11 and 8 mm), with the last significant rainfall (45 mm) occurring on 4 June 2004. There was no rainfall during July, or during the 4-week study period (26 July – 20 August 2004). The minimum and maximum temperatures at Fitzroy Crossing during our study were 7.1–16.0°C (mean 12.8°C) and 29.3–34.3°C (mean 32.6°C), respectively.

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 with billabongs, grassland savannas (e.g. ribbon grass (*Chrysopogon* spp.), blue grass (*Dichanthium* spp.)) and grassy woodlands (e.g. bauhinia (*Lysiphyllum cunninghamii*), coolabah (*Eucalyptus coolabah*, *E. microtheca*)). These areas are traversed by minor channels or meandering anastomosing channels with gradients of 1 in 2000 to 1 in 4000 (Anon. 1964). There were numerous creek systems and permanent (i.e. billabongs) and semi-permanent (dry up in some years) waterholes throughout the study site (Fig. 1).

Beef cattle (Brahman and Brahman/Shorthorn cross) are the major enterprise on Gogo Station. The 15 000-ha study paddock abutted the Fitzroy River, and contained ~600 cattle (cows, calves, yearlings and ~30 bulls). The station has an active wild-dog control program, and ground-baiting is conducted using ~3000 1080 meat baits twice a year. No wild dogs, or their tracks, were seen in the study paddock. There was very little previous persecution of the feral pigs aside from very occasional *ad hoc* shooting of solitary individuals. All shooting was curtailed for the duration of our trials. Feral pigs, cattle and native animals were all naive with respect to the experimental baits used (i.e. had no known past exposure).

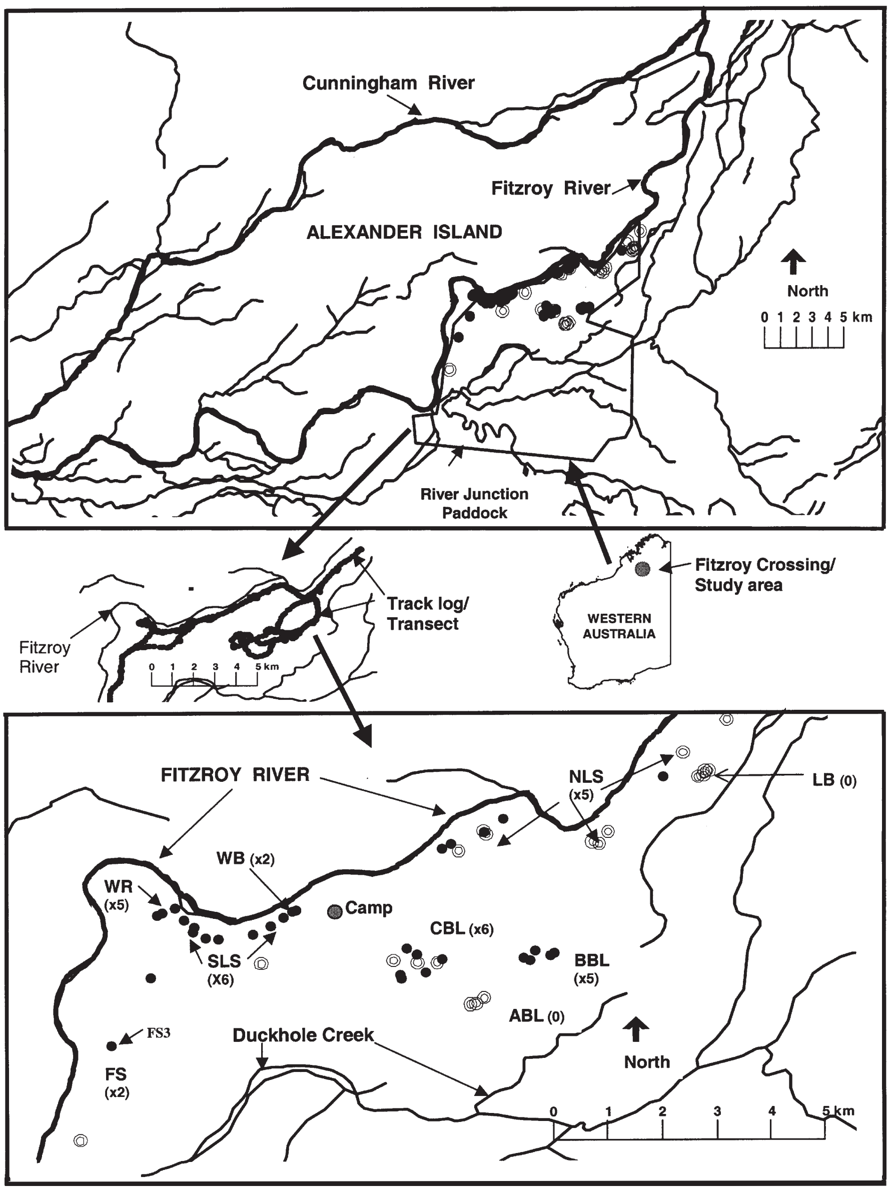

Fig. 1. The location of the trial sites in River Junction Paddock, Gogo Station, in the Fitzroy River region of Western Australia. The rivers and main drainage systems surrounding Alexander Island and the study sites are shown. The track log equates to the main tracks created/used throughout the study, and represent the pig-sighting ‘transects’. Those bait stations used for looksee baiting only (open circles) and those carried through to use as permanent bait stations (closed circles) are also shown. The number of permanent bait stations developed at each site are shown in parentheses.

The mid-dry season (August) was chosen for the trials because: (1) food and water resources become restricted at this time, often concentrating pigs around waterholes and billabongs (baiting programs are best conducted at such times, as feral pig numbers in the tropics are often limited by their food supply: Caley 1993), (2) populations are relatively 'stable' as the breeding season is nearing completion, and (3) reliable ground access is possible only during the dry. Several species of parrots, doves and pigeons were seen during our study, but substantial numbers of the water-birds often associated with wetlands (e.g. waders or magpie geese (*Anseranas semipalmata*)) were not present. Agile wallabies (*Macropus agilis*) were often seen but red kangaroos (*Macropus rufus*) were less common during the study period.

As there were a limited number of station tracks in the area, we needed to establish our own tracks to traverse much of the study site (Fig. 1). The location of all bait stations, tracks, and both dead and live pigs, were accurately recorded using a hand-held Garmin GPS 12 XL Personal Navigator (global positioning system; Garmin Co.). GPS data were manipulated and stored using MapSource (ver. 5.4, Garmin Corporation, 2003) and/or Ozi-Explorer (ver. 3.95, D&L Software Pty Ltd, www.oziexplorer.com), and a laptop computer. The same tracks were routinely travelled with the aid of the Garmin GPS track-log feature.

Site selection and site layout

Ultimately, six areas (sites) (Fig. 1) with good activity/numbers of feral pigs were identified after the assessment of potential areas using the fermented wheat with blood-and-bone attractant survey technique ('looksee baiting', see below). The four sites close to the Fitzroy River were: NLS, northern section of the main entry track; SLS/WB, southern section of the river track; WR, adjacent to the western portion of the river; and FS, far southern portion of the site towards Christmas Creek. The two semi-permanent waterhole sites, which were 2–4 km from the river, were: BBL, 'Black' billabong (~14 ha) and CBL, 'Cow' billabong (~11 ha). Two other waterholes were investigated but were found to have only limited pig activity: ABL, A'look Billabong (~2 ha) and LB, Long billabong (~6 ha). The estimated area includes the 'mud' and water level (i.e. to the 'high'-water mark). Other areas investigated/monitored throughout the study paddock, that were not used due to insufficient or inconsistent take of the fermented wheat, are also shown in Fig. 1. The main criteria for selection of sites were the presence of reasonably consistent pig activity at a number of localities, and the ability to construct several bait stations in a given habitat. On the basis of pig sightings, the final sites used were relatively independent at the time of the study, but whether these pigs had overlapping home ranges at other times of the year was unknown. Pigs in this area are likely to be acting as a metapopulation over the longer term.

Bait stations and bait-take

Once their final location was determined, all bait stations comprised two 1-m^2 raked-earth plots 5 m apart (Fig. 2). In some instances, due to the cracking soils around waterholes, it was necessary to transport river sand onto the raked plots to enable reliable identification of tracks. Bait stations were temporarily fenced to exclude cattle in most instances where it was considered that cattle would have had potential access to poison bait. These fences were constructed with steel posts, and plain and barbed wire. The bottom wire was ~65 cm from the ground, which prevented access by cattle while not restricting the access by feral pigs. One or two wires, with at least one barbed, were spaced above the bottom wire. The fences were sufficient distance from the raked plots to ensure that stock could not access the bait. They were erected before conducting the bait-choice trials (see below). Once established, the same bait stations were used for all stages of bait assessment on each site (see below).

Bait-take was visually estimated for all trials/stations using 10% increments and 1- or 2-kg reference samples for each bait type, which were contained in resealable plastic bags. When required, the reference bags were 'moulded' into the shape of the remaining bait to assist with determining bait-take. Once fully active, 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 weight/amount). Treatments/comparisons were randomly allocated to sites such that the number of replicates was similar for each comparison.

Animals (e.g. pigs, cattle, birds, macropods) visiting the bait stations and/or taking bait were identified by their tracks, and any other spoor, present on the raked plots. The plots were scored each morning and reraked each afternoon, as described above. It generally took several hours to monitor all bait stations each day (see below) using two 4WDs, which each travelled ~80 km per day.

Bait consumption

Determination of the consumption, and suitability, of the various baits for feral pig control involved a 5-stage process: (1) looksee baiting, (2) habituation, (3) choice, (4) efficacy of preferred bait, and (5) follow-up monitoring.

Looksee baiting was undertaken with ~500-g piles of fermented wheat to establish the locality and feeding behaviour of the feral pigs. Initially, we had some difficulty in predicting where feral pigs were routinely feeding. Fermented wheat was prepared by soaking wheat in equal parts of water for at least 24 h. This technique is known to be effective in attracting pigs in several habitats throughout Australia

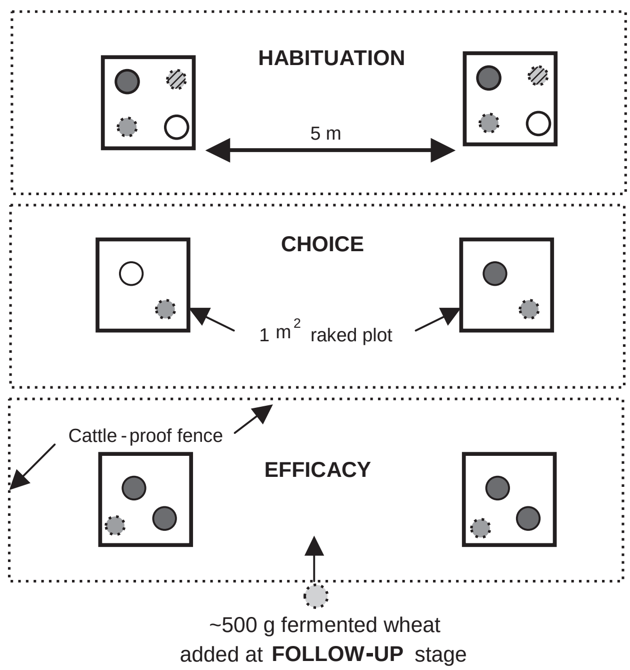

Fig. 2. Bait station design for the various stages of assessing suitable baits for controlling feral pigs in the Fitzroy River region, Western Australia. The large circles represent the different bait types and the smaller circles show either fermented wheat and/or blood and bone attractant. The looksee investigation period used similar raked plots with ~500 g fermented wheat plus attractants. A 5–10-m 'light' trail of fermented wheat was usually added out from one side of the looksee raked plots.

(Saunders *et al*. 1993). Our ultimate procedure included the use of a small amount of blood and bone (~90 g; Five Star 100% Organic with 6.0% nitrogen and low phosphorous (0.8–1.5%)) as an added attractant for pigs. Fish oil (~12 mL, Mako-Strike Combination Oil – fish oil and fish attractants) was also trialled as an attractant but this proved unsuccessful (see below). A 5–10-m 'light' trail of fermented wheat was usually spread out from one side of the 1-m^2 looksee raked plots to increase the potential encounters of feral pigs with these plots. The looksee procedure was used to establish where the individual bait stations should be located.

The suitability of blood and bone and fish oil as pig-attractants, when added to fermented wheat, was examined during the development of the looksee procedure. For blood and bone, 2 SLS raked-plots, 5 BBL raked-plots (two consecutive nights), and 8 CBL raked-plots, were used (i.e. n = 11 with and 9 without added attractant). Fish oil additive was tested over the same period using 10 NLS and 8 SLS/WB raked-plots (i.e. n = 9 with and 9 without added attractant). The appropriate attractant was added to the top of a 0.5-kg pile of fermented wheat (see above) on each odd-numbered raked-plot. The even-numbered plots had fermented wheat only. The amount of fermented wheat consumed by the feral pigs was then recorded the next morning. Except for the BBL raked-plots, the effectiveness of each attractant was formally assessed over one night's take by feral pigs.

Once the bait stations had been established at the desired locations, feral pigs were habituated to the test baits and attractants before undertaking any subsequent bait-choice trials. Depending upon pig-behaviour, this usually took place over a 24-h period although, occasionally, two days were needed. Approximately 500 g of the two bait types to be compared (e.g. wheat and lupins), and ~400 g of fermented wheat and ~90 g of blood and bone were located separately in different corners of each of the two 1-m^2 raked plots for each bait station (Fig. 2). This approach meant that all pigs had potential exposure to the test products, which thus helped to account for any prior learned food preferences (e.g. during the looksee investigation).

The choice experiments were conducted immediately after habituation and tested the acceptability of matched sets of the various bait types presented to feral pigs at the previously established bait stations. The baits tested were: wheat, malted barley, lupins and commercial pig pellets (~18% protein). Wheat was used as the standard bait against which the other baits were compared. Except for malted barley, all baits were commercially available in the Fitzroy Crossing region (i.e. in the north of Western Australia (WA)). All residual bait from earlier investigation was removed from the raked plots and a 1-kg pile of the test bait was added to one raked plot in the matched set. A small pile of fermented wheat (~200 g) and blood and bone (~90 g, placed on top of the fermented wheat) were added as attractants (Fig. 2). On a few occasions where a relatively large number of pigs were feeding at an individual station, 2-kg piles of the test baits only were used. The number of pairs (sets) used varied according to pig feeding behaviour/activity; however, except for two occasions, there were generally at least four pairs (bait stations). Only one 'reliable' bait station could be established for the FS site, and two stations were used at WB.

Once the preferred bait was established for each site, its efficacy with 1080 was determined. All residual bait from previous trials was removed and two 1-kg piles of 1080-treated bait was placed on each raked plot within each bait station (Fig. 2). The use of four piles per station (i.e. 2 raked plots × 2 piles per plot) was designed to help prevent single or dominant pigs from consuming all the poison bait at a particular station. Again, to maintain design-continuity, and to ensure that we attracted the maximum number of pigs, the fermented wheat with blood and bone was used as an attractant, as described above. Due to the outcomes of the choice trials, the efficacy of only two baits, wheat and malted barley, was tested. Efficacy was determined over 5–12 days after poisoning (see below). 1080-treatment of grain was as per the current label directions for 1080 Black and feral pig control in WA; namely, 100 mL of a 40 mg mL^{-1} aqueous 1080 solution was thoroughly mixed with 6 kg of bait (or 667 mg kg^{-1} bait) (Note: this is likely to change to 7 kg per 100 mL or 571 mg kg^{-1} in the near future.)

'Follow-up' monitoring of bait-take was also undertaken for four of the six poisoned sites towards the end of the 'efficacy period' (FS and WR sites could not be monitored due to time constraints). With the 1080-treated grain in place, ~500 g of fermented wheat was placed between the two raked plots (Fig. 2) as a further check for any activity/presence of pigs after poison-baiting. The piles of 1080-treated grain, the attractants, and the central pile of fermented wheat were checked, and refreshed daily when needed (usually only required the addition of fresh fermented wheat). The central pile of fermented wheat was only added once we were sure that the take of poisoned grain was complete. That is, follow-up monitoring was conducted 3–6 days after poisoning, and took place for 2–5 days thereafter.

Abundance estimate

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 (e.g. bait station). These records included the time of day, group size and, where possible, the sex, age and coat colour of pigs. The same or very similar routes were travelled each day with the assistance of the Garmin GPS track-log feature. Excluding the post-poisoning period, these records were used to determine the number of pig sightings each day before and after 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. The post-poisoning period was excluded from the abundance estimates for each site as poison-baiting (i.e. decrease in pig numbers) may have influenced pig behaviour.

Efficacy was estimated using the number of pig-sightings for each day before and after poison-baiting. These values were calculated using the total number of sightings divided by the number of days for each relevant period. There were 9–12 days (average, 10) for the before-baiting period, and 5–9 days (average, 7) for the after-baiting period. These variable periods resulted from the need to allow a 'staggered' entry of the different sites into the trials due to the associated logistics, and the finite amount of time available (4 weeks). The percentage decrease was calculated as the change in the before and after sightings per day expressed as a percentage of the before values.

Track plots were also established on the SLS/WB and WR sites to further monitor pig abundance/activity. Respectively, these comprised four and two 1-m^2 raked-earth plots that were located on active track-pads of feral pigs. The plots were ~5–10 m from an active bait station, but no bait material was provided with the track plots. Track plots were monitored twice daily before (4–5 days) and after (5–7 days) poison-baiting was undertaken. Plots were raked clean after each morning and afternoon monitoring/recording session. Although the pigs on the other sites were consistently seen at similar locations each day, the routes by which they travelled to these areas were not consistent and no track pads were evident. This precluded the establishment of track plots on these sites. Furthermore, the terrain and vegetation structure precluded the use of spotlight counts, and, as we also did not wish to possibly interfere with the behaviour of pigs, spotlight counts were not a viable option for monitoring pig abundance.

Pig carcases and measurements

Carcase 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 1 person-hour (±16 min, s.e.m.; excludes autopsy time) per day for each site on these days. However, observation continued routinely during the ongoing conduct of the trials at each site. The activity of birds of prey was often a reliable indicator of pig carcases. The GPS location was recorded for all dead pigs found.

The degradation of carcases, and the collection of tissue samples for 1080 analysis, were also part of our overall study (Twigg *et al*. in press). Consequently, dead pigs needed to be found and processed as quickly as possible with the minimum of disturbance. For these reasons, and because of the associated logistics in accurately determining bodyweight at remote field locations, this parameter and head–body length (HBL) were estimated only. After calibration with known weights, bodyweight was estimated by the same person for all dead pigs found. A minimum estimate of HBL was determined by calculating the curved distance over the back from the tip of the nose to the base of the tail (Saunders 1988; Choquenot and Saunders 1993) using reference photographs of individual pigs that contained the same scale-measure of known length. These calculations utilised the ratio of the HBL to the length of the known scale in the photograph, and the actual length (27 cm) of the scale-measure. All HBLs were determined by the same person. These derived values will be slightly less accurate than those measured directly (Choquenot and Saunders 1993); however, our measures were adequate for assigning pigs to broad age classes (see Saunders 1988; Choquenot and Saunders 1993; Choquenot *et al*. 1996; Saunders and McLeod 1999). Our age classes were: juveniles, 1–15 kg; subadults, 16–24 kg; and adults, >24 kg. ‘Suckers’ are a subclass of juveniles and refer to young pigs <5 kg.

Statistics

The final experimental design used was largely dictated by the feeding behaviour and activity of the feral pigs. The time taken to habituate pigs to bait, the number of bait stations visited by pigs, and the number of days that pigs were exposed to bait, varied slightly between some sites, which resulted in an unbalanced design. Therefore, it was not possible to analyse all sites concurrently (e.g. factorial ANOVA). Consequently, the bait comparison at each site was analysed independently using a paired *t*-test (Zar 1984). These analyses excluded those stations that were not visited by feral pigs for a given monitoring period (i.e. at least one raked plot in each pair had to be visited by pigs (but not necessarily consuming bait) for each monitoring period). A single-factor ANOVA was used to analyse the distance that poisoned pigs were found from bait stations.

Results

Demography

There were 442 sightings of feral pigs during the 4-week study. Of these, 275 were determined as different individuals according to our abundance criteria. However, because our abundance-estimation method relied upon accurate identification of all pigs, it is possible that we may have included a few pigs more than once. We believe, therefore, that an estimate of ~250 resident pigs is a more conservative estimate of the number of pigs on the study area before poison-baiting. These pigs were more concentrated/abundant close to the waterholes, billabongs and the Fitzroy River. Using a minimum polygon of the area occupied by all bait stations (~3300 ha or 33 km^2), and the estimated abundance of feral pigs (250), then the estimated density of pigs in the immediate area of our study sites was ~7.6 pigs km^{-2}. However, if an edge effect (see Saunders and Kay 1991) of 5 km, excluding the northern boundary abutting the Fitzroy River, is included, then this density would reduce to ~3 pigs km^{-2}. Ginger/brown was the most common coat colour, accounting for over 80% of the 61 recovered pigs; 14% were brindled, and ~3% were black and white. No completely black pigs were seen or recovered during the trials.

Adult males were usually seen as solitary individuals (72% of 32 records) or, less frequently, in pairs (Fig. 3). In contrast, adult females were rarely solitary as they were usually associated with family groups (88% of 25 records). The most common size of these family groups was 1–2 sows with 5–12 juveniles, although family groups of up to 20–30 pigs were occasionally seen, particularly at the FS site. These larger groups comprised at least 4–5 adult sows and numerous other pigs ranging from suckers to large juveniles. No adult males were identified with these groups. When not with adults, juvenile pigs were usually seen in groups of 4–10 individuals (Fig. 3).

An estimate of the viable litter size can be obtained from the sighting records for the family groups comprising 1–2 sows and their associates (the rough terrain meant that it was not always possible to get a precise count of all individuals when groups contained >2 sows). On this basis, 118 young were identified from 26 relevant sows, giving an estimated viable litter size of 4.5 individuals per sow. This was similar to the observed viable litter size of our autopsied pigs, and also to the range in litter size for feral pigs elsewhere in Australia (4.6–8.2: Choquenot *et al*. 1996).

Of the 14 adult sows (>24 kg) recovered after poisoning, 12 (i.e. 86%) were in breeding condition or had recently

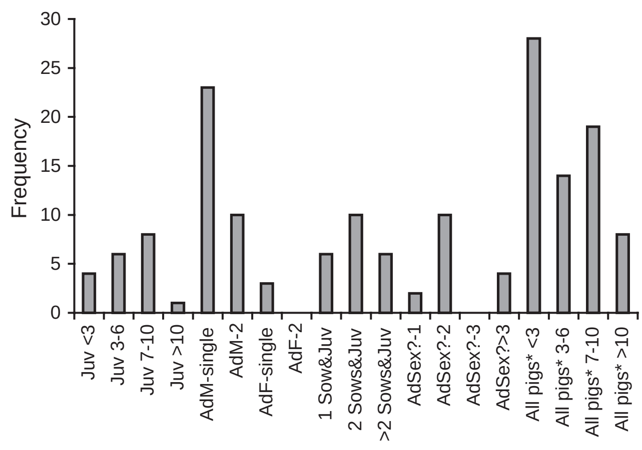

Fig. 3. Group size of all feral pigs sighted during the dry season (August 2004) on Gogo Station in the Fitzroy River region of Western Australia. Each sighting was treated as unique irrespective of whether the pigs had been seen previously during the 4-week study. Juv, juvenile pigs only with group sizes of <3, 3–6, 7–10 or >10. AdM, adult males occurring either solitaryily or in pairs. AdF, adult females, excludes those females associated with family groups. Breeding sows with juveniles ‘at foot’/associated with family groups are also shown. AdSex? refers to adult pigs whose sex was unknown; these group sizes are 1, 2, 3 and >3. *The frequency of group sizes for all pigs with solitary adult males excluded.

weaned a litter. The two non-breeding sows weighed ~25 kg, suggesting that some females at Gogo Station may not breed until they are heavier than 25 kg. Two sows were pregnant: one had four near-full-term embryos and three resorbing embryos, the other had seven very small ('peanut') embryos in the early stages of development, and, on the basis of the condition of the teats, this may have been her second litter. Four sows had just weaned a litter and six were lactating. Those sows that had obviously bred weighed 45–80 kg. Given that the gestation period for feral pigs is ~113 days (Choquenot *et al*. 1996), and that many juveniles were at least 1–2 months old, the sows probably mated during April and May (i.e. towards the end of the wet season).

Bait consumption

During the looksee investigations, the addition of a small amount of fish oil (~12 mL) on top of the fermented wheat pile did not improve bait consumption or visitation rates by feral pigs to these stations (NLS, WB, SLS). The mean consumption of fermented wheat for the odd-numbered stations ($n = 9$), with fish oil added, was 51.1% (s.d. = 49.1%) compared with 54.4% (s.d. = 51.7%) for the even-numbered stations ($n = 9$), with fermented wheat only ($t = -0.140$, d.f. = 16, two-tailed $P = 0.890$). However, the addition of blood and bone (~90 g) did improve visitation/bait consumption by feral pigs (BBL, CBL, SLS sites). The mean consumption of fermented wheat for the odd-numbered stations ($n = 11$), with blood and bone added, was 65.5% (s.d. = 37.2%) compared with 14.4% (s.d. = 27.9%) for the stations with fermented wheat only ($n = 9$) ($t = 3.397$, d.f. = 18, two-tailed $P = 0.003$). Interestingly, the pigs often did not consume all of the blood and bone offered (Fig. 4). The consumption of blood and bone by feral pigs during the habituation period for all sites (the period where the consumption of blood and bone and fermented wheat was most accurately monitored) ranged from 0% to 100% whereas 100% of the fermented wheat was generally consumed at this time (37% *v.* 83% of cases, $n = 41$) (Fig. 4). Mean consumptions for the habituation periods were 65.4% (s.d. = 37.1%) and 92.2% (s.d. = 23.2%) for blood and bone, and fermented wheat, respectively. However, as blood and bone clearly attracted feral pigs, it was routinely added to each raked plot (i.e. all stations) after, and during, the remaining looksee investigations (i.e. during the habituation, choice, efficacy and follow-up stages).

The consumption of the various baits by feral pigs during the habituation, choice, efficacy and follow-up monitoring periods is shown in Figs 5–7. Although there was some variation during the choice trials, wheat and malted barley were the most acceptable baits, with lupins and pig pellets being consumed in lesser amounts. A summary of the choice trials follows.

Wheat v. *pellets.* The pigs feeding at the WB stations consumed all bait on offer (all $P > 0.05$) (Fig. 5). However, the pigs on the NLS site consumed significantly ($t = 2.281$, d.f. = 15, $P = 0.038$) more wheat than pellets (means 90% *v.* 58%, $n = 16$) (Fig. 5). Conclusion: pellets are likely to be less/not acceptable to some feral pigs.

Wheat v. *malted barley.* Although the means were relatively high (means 60% *v.* 75%, $n = 20$), significantly less wheat was consumed than malted barley on the SLS site ($t = -3.203$, d.f. = 19, $P < 0.005$) (Fig. 5). In contrast, the consumption of wheat and malted barley (means 95% *v.* 96%, $n = 24$) did not differ on the BBL semi-permanent waterhole site ($t = -0.700$, d.f. = 23, $P = 0.491$) (Fig. 6). Again, the pigs feeding at the WB bait stations showed no preferences for any bait tested (all $P > 0.05$) (Fig. 5). The pigs most often observed at these two stations were generally a mob of ~10 juvenile pigs (~8–15 kg). Malted barley was also an acceptable bait for those pigs feeding at the FS site (Fig. 7). Conclusion: with adequate prefeeding, wheat and malted barley were acceptable baits to these feral pigs.

Wheat v. *lupins.* There was a mixed response by feral pigs to lupin bait. The consumption of wheat and lupins (means 99% *v.* 94%, $n = 16$) (Fig. 6) by feral pigs did not differ ($t = 1.187$, d.f. = 15, $P = 0.254$) on the CBL semi-permanent waterhole site. In contrast, those pigs feeding at the WR bait stations showed little interest in the lupin bait (means 60% *v.* 4%, $n = 19$; $t = 5.782$, d.f. = 18, $P < 0.001$) (Fig. 5). However, on the basis of the observed tracks, we believe the pigs feeding at the WR stations were likely to have been a few isolated adult boars. Pigs at the WB site readily consumed both wheat and lupins (Fig. 5). Conclusion: lupins are likely to be less/not acceptable to some feral pigs.

Other observations. (1) WB site. There was no habituation period between when these stations were switched from a wheat *v.* pellet comparison to a comparison between malted barley and lupins, and yet the pigs at this site readily consumed all of these baits on the first night, and thereafter (Fig. 5). (2) On the basis of tracks and other spoor, the pigs present on the WR site were large solitary adult pigs

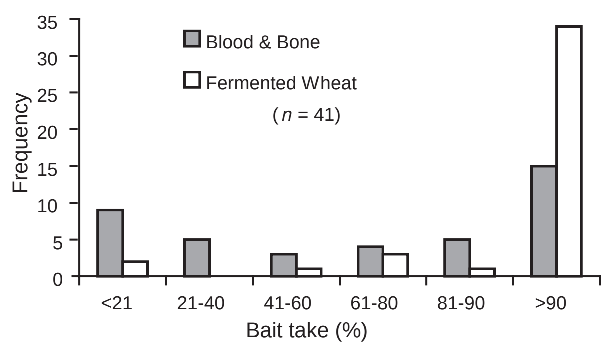

Fig. 4. The consumption of the blood and bone (~90 g), and fermented wheat (~400 g), 'attractants' during the habituation period for each site on Gogo Station, WA. The attractants were added along with wheat (~500 g) and the other test bait (~500 g) on each raked plot within each bait station.

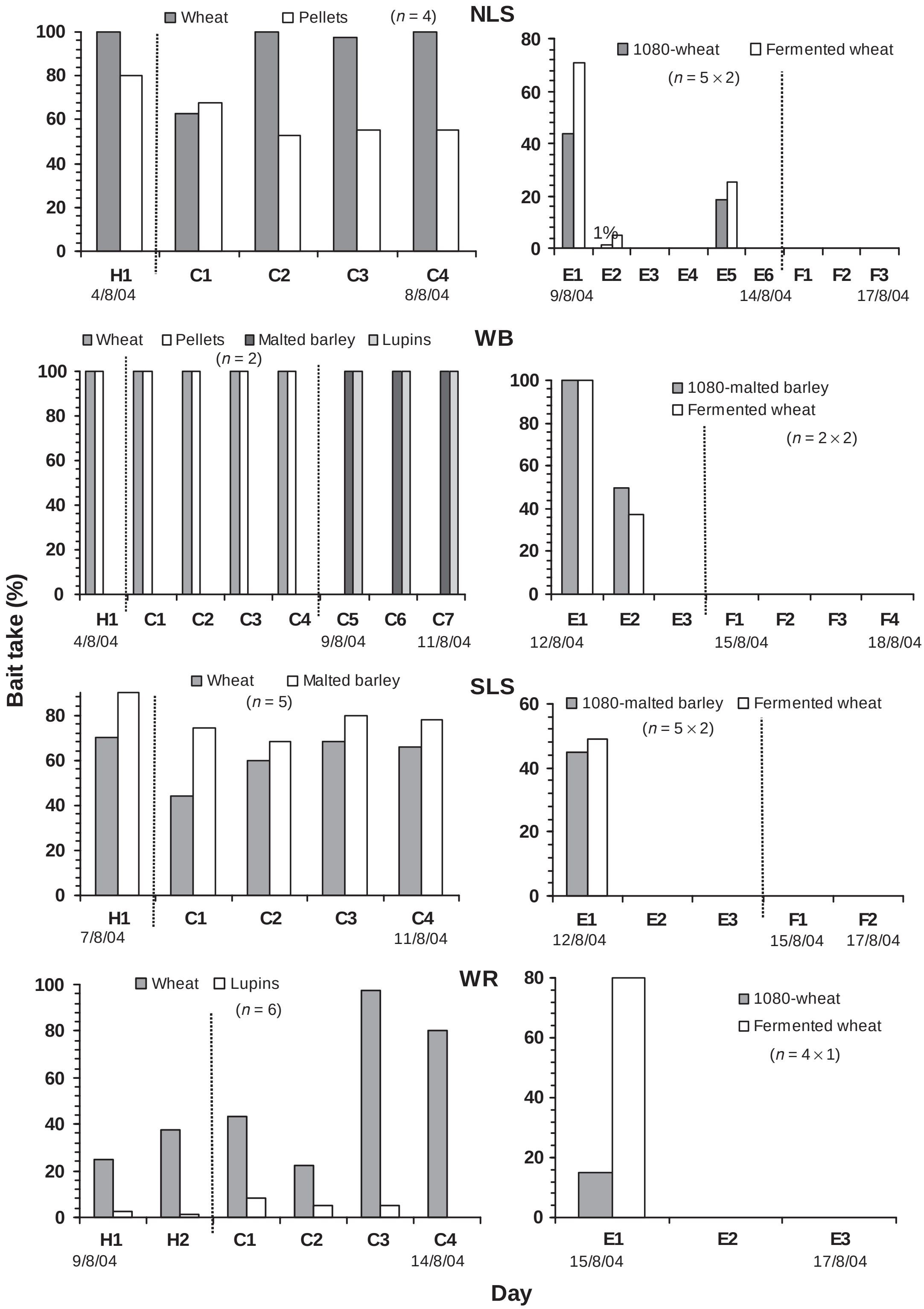

Fig. 5. The consumption of various baits by feral pigs from raked-earth plots adjacent to the Fitzroy River on Gogo Station, WA. Bait stations comprised two 1-m^2 raked plots 5 m apart. H, habituation period for relevant baits; C, choice experiment; E, efficacy period with 1080-treated bait; F, follow-up period with 1080-bait and an extra pile of fermented wheat (~500 g) between the raked plots. Fermented wheat (~200 g) with a small amount (~90 g) of blood and bone on top was added to all raked plots. Most bait was offered as 1-kg piles, but occasionally 2-kg piles were used (e.g. WB site). 1080-bait was added as 2 × 1-kg piles on each raked plot.

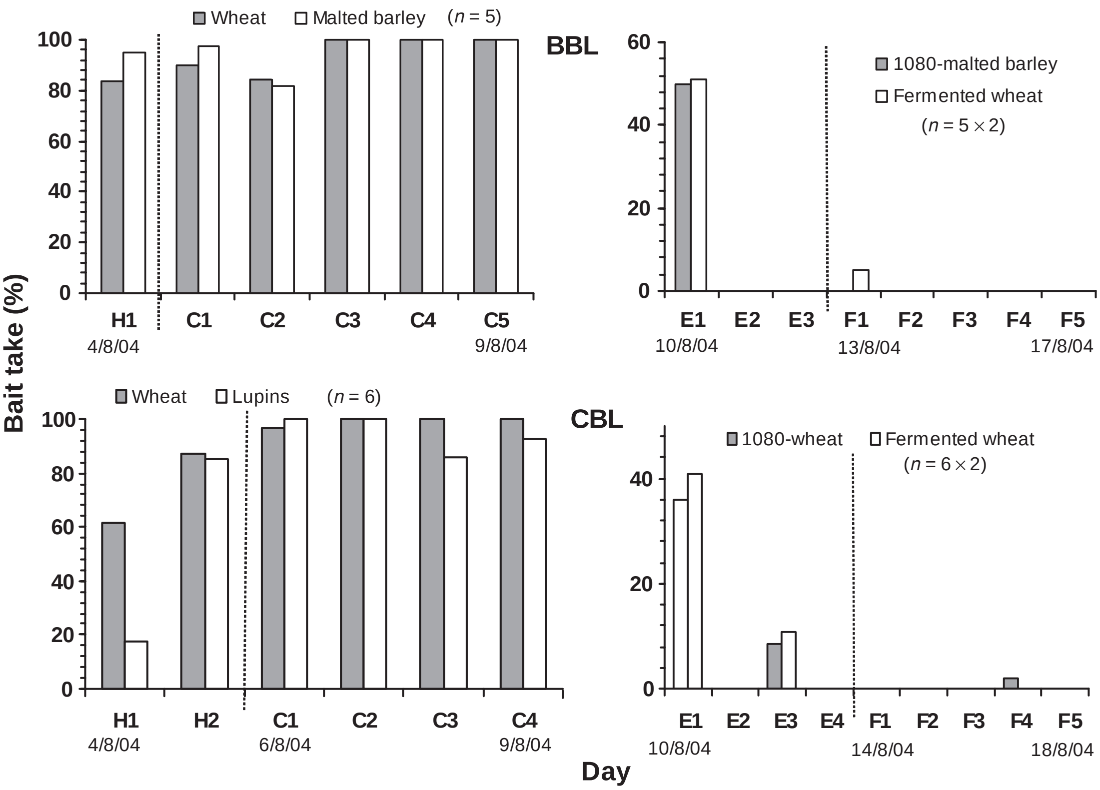

Fig. 6. The consumption of various baits by feral pigs from rake-earth plots located near semi-permanent waterholes on Gogo Station, WA. Abbreviations and protocols as per Fig. 5.

(probably boars), whereas the pigs, and their spoor, seen at the WB/SLS stations were mainly groups of juvenile and smaller adult pigs. The WB and SLS sites were combined during the efficacy trials because once we relocated and 'ran' some SLS choice bait stations closer to the river it became less certain that pigs on these two sites were truly independent. (3) FS site. The pigs on this site were not habituated to malted barley before conducting the efficacy trial (Fig. 7), but malted barley proved to be an effective bait once we had the pigs feeding on the fermented wheat (however, it took ~6 days to get consistent prefeeding). (4) Non-target species. There were no occasions where identifiable amounts of bait were taken by non-target species, including cattle and native species. This was despite cattle having ready access to non-toxic bait, and native animals to both toxic and non-toxic bait. Some native birds (e.g. magpie-larks (*Grallina cyanoleuca*)) scattered the bait on occasion but there was little evidence that any bait was actually consumed.

Efficacy

1080-treated malted barley and wheat were highly efficacious against feral pigs on Gogo Station (Table 1), with most bait-take (Figs 5–7) and associated pig deaths occurring within two days of poison-baiting. Pig sightings were reduced by 80–100% after poisoning with an overall reduction of 89%. However, the reductions that occurred on two sites (CBL, BBL) may have been confounded by the appearance of immigrant pigs 6–7 days after poison-baiting was thought to be complete (i.e. 8–9 days after poison was laid). One sow with seven suckers arrived on the CBL site 6 days after bait-take ceased (Fig. 6). This group, which had not been seen previously, was probably transient as they entered

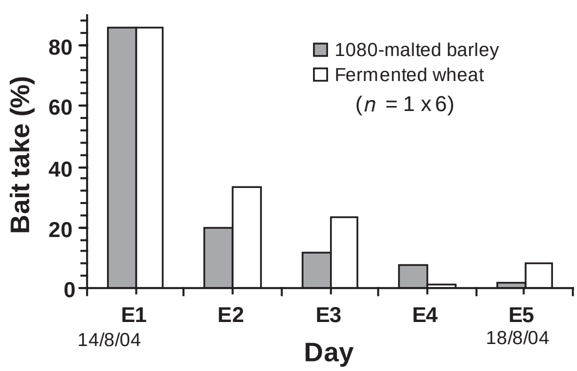

Fig. 7. The consumption of 1080-treated malted barley by feral pigs from raked-earth plots during the efficacy trial on the FS site near the Fitzroy River on Gogo Station, WA. These pigs had no previous exposure to malted barley but had been prefed with fermented wheat with blood and bone attractant. Abbreviations and protocols as per Fig. 5.

from the north, and were last seen leaving via the southern end two days later. These 8 pigs were included in two days of the 'after counts'. Similarly, an adult boar was seen over the last two days of the 'after counts' on BBL. This boar was last seen leaving the BBL site and travelling towards another unbaited waterhole (ABL) some distance away. Despite ensuring that fresh poisoned and unpoisoned bait were present over the associated period, no further bait was taken from the CBL and BBL sites (Fig. 6) by these 'immigrant' pigs.

The lower, though still acceptable (82% decrease), efficacy observed on the FS site was not unexpected. This site was the last to be established as we initially had some difficulty in predicting where these pigs travelled to feed. Although there were high numbers of pigs present, ultimately, we could only get these pigs to feed consistently at one bait station (FS 3). We also had to close this station before bait-take had ceased (Fig. 7) due to the 4-week time constraint. Two adult pigs were seen near FS 3 on the day poison-baiting had to cease, and these were included in the post-baiting sightings. Thus, efficacy at this site may well have increased had we been able to continue baiting until all known pigs had been destroyed.

The consumption of 1080-treated grain during the efficacy trials is shown in Figs 5–7. 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 (~200 g and ~90 g, respectively, per raked plot). There was little bait-take during the follow-up periods, which generally commenced 3–4 days after poisoned bait was laid. Poisoned bait was still present during these periods (i.e. poisoned bait was generally in place for 8–9 days). As noted previously, we were unable to complete the 1080-baiting on the FS site. However, bait-take (Fig. 7) and pig sightings (Table 1) had decreased considerably on this site within 5 days.

Table 1. The efficacy of 1080-treated grain against feral pigs on Gogo Station in the Fitzroy River region, WA

Although pig tracks were recorded, and bait-take (1080-wheat) occurred, on the WR site, no pigs were seen or recovered on this site

Site	Bait type	MNKA[A]	Sightings per day[B] Before	After	Decrease (%)
NLS	Wheat	47	5.2	0.1	97.2
SLS/WB	Malted barley	33	5.5	0	100.0
FS	Malted barley	75	9.0	1.6	82.2
BBL	Malted barley	51	7.7	0.1	98.1
CBL	Wheat	69	13.1	2.6	80.5
All sites[C]		275	8.1	0.9	89.0

[A]Estimated from all pig sightings but excluding any obvious 'replicate' sightings over the trial period. Probably a slight overestimate as we believe there were ~250 pigs present.

[B]Based on all pig sightings, including any repeats between days, for each site. There were 442 sightings of pigs during the trial period.

[C]Excludes the WR site.

We are confident that the decrease in both feral pig numbers and in the amount of bait consumed over time were the result of the 1080-baiting. Over 60 dead pigs were recovered (see below), and all had bait in their stomachs. Further, due to the need to stagger the commencement of the trials through time, some of the choice experiments were run concurrently with the efficacy trials on other sites. There was no change in the overall level of bait-take during the periods that non-toxic bait was in place, but there was a marked decrease in bait-take once 1080-bait was introduced (e.g. compare the overlapping dates for choice trials on WR, SLS, WB with the efficacy periods of NLS, BBL, CBL: Figs 5–6. That is, these choice periods were acting as untreated sites for the latter sites during their treatment with 1080-grain). No non-target species were recorded as having consumed 1080-bait.

Further support that 1080-treated grain was highly efficacious against feral pigs on Gogo Station was seen from the results obtained for the two sites (SLS/WB, WR) where we were able to establish track plots to reliably monitor changes in pig activity/abundance. After poison-baiting, the proportion of monitoring periods with recorded pig tracks on both sites decreased to zero, usually within 2 days (Table 2). There was no recorded pig activity after Day 3, and this corresponded with the cessation of bait-take at these sites (Fig. 5). In contrast, the ongoing presence of macropod tracks (mostly agile wallabies) provides further support that these species were unaffected by the poison-baiting.

Recovery of carcases

Sixty-one pig carcases were recovered after poisoning with 1080-treated grain: 18 and 22 juvenile males and females, and 7 and 14 adult males and females. The frequency distributions of the estimated bodyweights and HBLs for these pigs are given in Fig. 8. The relationship between the estimated head–body lengths and bodyweights were well correlated (Fig. 9), further supporting the field observation that the recovered pigs were generally in good condition. However, two lactating sows were showing obvious signs of the physiological demands of lactation.

Although distances were variable, on average, feral pig carcases were found within 230 m (range 20–610 m) from the nearest bait station from which poison-bait was consumed (Table 3). However, compared to those sites adjacent to the river (NLS, SLS, FS; means 207–506 m), these distances were much smaller on the two semi-permanent waterhole sites (BBL, CBL; means 54–140 m). Except for solitary adult males, dead pigs were usually found in groups. These groups comprised 2–13 individuals, and were generally tightly clustered (Table 4). The distance between assigned group members was 3–260 m, but most mean distances were less than 55 m. The area over which the groups were found was small, and ranged from 0.003 to 0.684 ha (Table 4). There were age-specific, but not sex-specific, differences between the distances travelled by juvenile and adult pigs

Table 2. 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, WA
Track plots were 1-m^2 raked-earth and were located on an active pad ~5–10 m from a bait station; they were not provided with any bait material

	Proportion of monitoring periods with tracks					
	Before		Days 1–2		Days 3–7	
SLS/WB[A]						
Pigs	0.73	(0.24)	0.13	(0.14)	0.00	(0.00)
Macropods[B]	0.11	(0.14)	0.31	(0.24)	0.16	(0.12)
WR[C]						
Pigs	0.17	(0.08)	0.00	(0.00)	0.00	(0.00)
Macropods[B]	0.50	(0.24)	0.50	(0.35)	0.00	(0.00)

[A]Four track plots, monitored twice daily for 4 days before nearby baiting with 1080-malted barley.
[B]Mostly agile wallabies.
[C]Two track plots, monitored twice daily for 5 days before nearby baiting with 1080-wheat.

before they succumbed (Table 5). That is, distances for juvenile male and female pigs (ANOVA: $F = 4.10$, d.f. = 1,38, $P = 0.153$), and for adult male and female pigs (ANOVA: $F = 4.38$, d.f. = 1,19, $P = 0.127$), respectively, were similar. However, juvenile pigs were found significantly closer to the bait stations than were adult pigs (ANOVA: $F = 3.156$, d.f. = 2,88, $P = 0.009$) (Table 5).

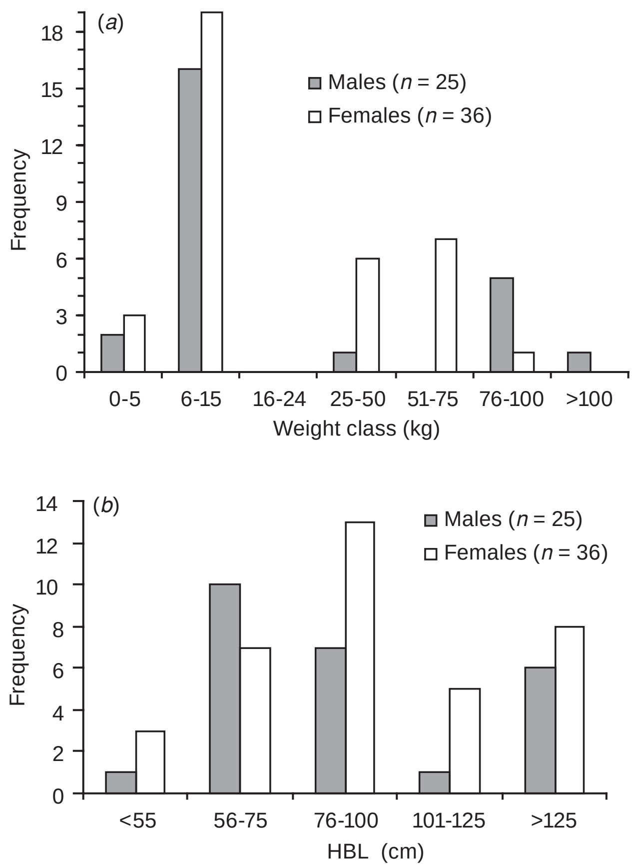

Fig. 8. Frequency distributions of estimated (*a*) bodyweight (kg) and (*b*) head–body length (HBL, cm) of the feral pigs recovered after 1080-baiting on Gogo Station, WA.

The stomachs of all recovered pigs contained bait material (usually considerable quantities) and, in all but one instance, they also contained large amounts of other food in such quantities that it was not possible to realistically estimate the amount of bait ingested. These other foods included grasses (most abundant), other herbage, fruiting bodies, (especially introduced wild passionfruit (*Passiflora foetida*)) and bulbs. One stomach (SDP 13) contained only watery fluid and some grain bait, suggesting that this pig may have vomited. Despite considerable search-time, no vomitus was found on any site, although it may have been smelt on one occasion (near SDP 13). This, and the presence of copious quantities of food in the stomachs of autopsied pigs, suggests that very few poisoned pigs had vomited.

Similarly, there was no evidence of any tetanic muscle contractions in poisoned pigs. The final position of most pigs 'at death' simply involved collapsing onto their side with no evidence of prior 'kicking'. In several instances, poisoned pigs appeared to simply collapse while walking as they were still in an 'upright position'.

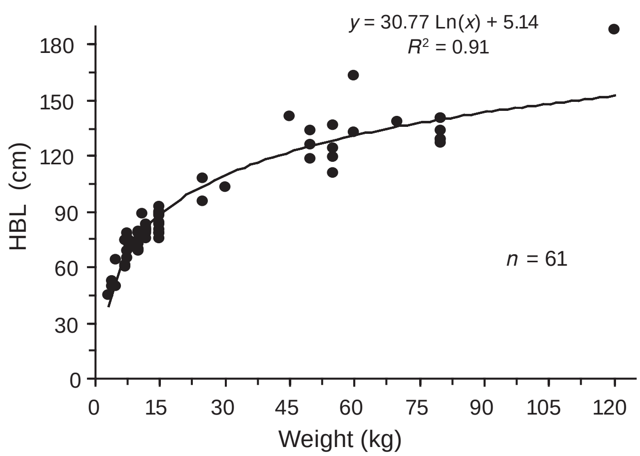

Fig. 9. The relationship between the estimated weights and head–body lengths (HBL) of the feral pigs recovered after 1080-baiting on Gogo Station, WA.

Table 3. The distances that feral pig carcases were found from the nearest bait station from which bait was taken

BBL and CBL were semi-permanent waterholes, the remaining sites were adjacent to the Fitzroy River. Although pig tracks were recorded on the WR site, no pigs were seen or recovered on this site

Site	Distance from station (m)				*n*
	Minimum	Maximum	Mean	s.d.	
NLS	101	430	309	124	8
SLS/WB[A]	46	430	207	111	13
FS	357	610	506	92	13
BBL	110	164	140	18	11
CBL	20	120	54	29	16
All sites	20	610	232	178	61

[A]A mean of the distance from three stations was used as we were unable to clearly determine at which of these station(s) the pigs had fed.

Discussion

Although it was clearly an approximation, our density estimate of 3–8 pigs km^{-2} in the immediate study area used on Gogo Station was comparable to that recorded for feral pigs in wetlands and in other similar habitat in Australia (Hone 1990; Choquenot *et al*. 1996; Anon. 2002). The basic demographics of feral pigs on Gogo Station was also similar to that reported elsewhere in Australia (Hone and Pedersen 1980; Caley 1993; Choquenot *et al*. 1996). Mob sizes were generally ~12 or less, although, occasionally, mobs of ~30 pigs were seen. Adult boars were mostly solitary. Estimated litter size was 4.5 viable young per sow. Although a few sows showed signs of the physiological cost associated with successfully raising young, all pigs were in good body condition. However, the feeding patterns/behaviour of feral pigs was more predictable around the semi-permanent water holes than was often the case at some of the river sites. This was probably related to the requirement for pigs to have at least some daily access to water (Choquenot *et al*. 1996). Water and shelter along the river could be obtained from many locations compared to their more restricted availability at the billabongs and semi-permanent waterholes. Feral pigs in our study were also frequently seen grazing together with cattle, and both species were often present simultaneously at the water's edge. This has implications for wildlife disease management (see below).

After establishing feeding by feral pigs at the bait stations, wheat and malted barley were very acceptable foods to feral pigs on Gogo Station, but lupins and pig pellets were consumed in lesser amounts. We recommend, therefore, that the former grains should be the first choice for baiting programs for feral pigs in north-western Australia. This is particularly so given the rapid and considerable knock-down of pig numbers we achieved when these grains were treated with 1080. However, we do have some caveats. (1) Adequate prefeeding is essential in achieving such a result, and there needs to be a good, consistent take of prefeed before poisoning. (2) A small amount of fermented wheat with blood and bone on top could be used as an added attractant for pigs (but it is necessary to prevent ruminants from gaining access to blood and bone). (3) Poison-baiting needs to continue until all known pigs have been killed (i.e. at least 4–7 days). (4) Follow-up monitoring with fermented wheat and blood and bone attractant should be used to ensure that the maximum number of (all) pigs have been killed. (5) Follow-up shooting could be used to kill any pigs remaining *after* a poisoning program is complete. Control programs would be best directed at the areas surrounding the semi-permanent and permanent waterways in the first instance. That is, control efforts should initially focus on when and where the target species is most abundant/concentrated, and this is likely to occur with feral pigs in north-western Australia during the mid- to late-dry season.

The level of efficacy obtained at Gogo Station with 1080-grain (at least an 89% reduction in numbers) was greater than

Table 4. The distance between group members, and the minimum area from which each group of carcases were recovered after baiting with 1080-grain

Although pig tracks were recorded, no pigs were seen or recovered on the WR site. Area, the area over which the carcases were recovered for each group, was estimated from the minimum polygon using the carcase GPS locations (s.d. is shown in parentheses)

Site	Group No.[A]	No. of pigs	Distance between group members (m)				*n*[B]	Area (ha)
			Minimum	Maximum	Mean	s.d.		
NLS	1	5	3.6	73.8	50.8	19.5	10	0.238
SLS	1	13	4.4	260.0	112.4	71.2	78	0.684
FS	1	7	2.7	77.6	32.7	20.1	21	0.040
	2	6	4.8	144.0	73.3	51.5	15	0.159
BBL	1	3	2.7	30.2	20.4	15.4	3	0.003
	2	5	3.8	35.6	22.6	11.5	10	0.027
	3	2	–	–	8.6	–	1	–
CBL	1	9	7.7	103.0	42.8	24.7	36	0.223
	2	6	6.5	100.0	47.6	28.1	15	0.175
All groups combined		56	2.7	260.0	72.0	61.6	189	0.194 (0.218)

[A]Excludes solitary pigs.

[B]Includes all combinations for all group members.

that often reported for feral pigs achieved by a variety of control techniques. For example, aerial distribution of non-toxic biomarked meat baits resulted in only a 63% bait uptake, and ground-shooting and trapping over a 6-day period resulted in only an 18% and 16% reduction in pig numbers in northern Queensland, respectively (Mitchell 1998). Pig numbers were reduced by between 53% (ground survey) and 61% (aerial survey) following aerial deployment of 1080 meat baits in far north Queensland (Atherton Tableland). This reduction was improved to 75–80% with follow-up shooting (Anon 2002). Toxic meat baits for feral pigs usually contain 72 mg 1080 per bait, and there is no prefeeding period with their use (Choquenot *et al*. 1996; VPC 2002). Aerial shooting in the Macquarie Marshes, New South Wales (NSW), during an exotic disease simulation exercise, resulted in a 75% reduction of resident pigs (Saunders and Bryant 1988). In temperate climates, the uptake of non-toxic, biomarked, aerially distributed, meat baits by feral pigs in western NSW was 31–72% (Mitchell and Fleming 1998). Similarly, an average population reduction of only 58% was recorded with 1080-treated meat in north-western NSW, with pig numbers actually increasing at one site (Hone and Pedersen 1980). 1080-treated pellets reduced pig numbers in southern NSW by 73% (Hone 1983). The efficacy of grain treated with warfarin against feral pigs is also variable, and can range from 65% (Choquenot *et al.* 1990) to >90% (McIlroy *et al*. 1989; Saunders *et al*. 1990). However, the most successful baiting programs against feral pigs generally depended upon a good and consistent prefeeding period (also see Bryant and Hone 1984; Choquenot *et al*. 1996). We believe this was an important factor in achieving our result. Further, our main research objective was identifying those materials and protocols that were effective in reducing pig numbers, and not the total removal of pigs from the 15 000-ha River Junction paddock. Population reductions of >70% to >90% are considered necessary for effective control of feral pigs for operational and exotic disease purposes, respectively (Hone and Robards 1980; Pech and Hone 1988; Mitchell 1998).

It could be argued that our pigs were naïve to both non-toxic grain and the 1080-treated grain bait, and this may have contributed to the success of our baiting program. Although the former is true, we believe this made our initial task of establishing bait stations more difficult as it often took several days, and the addition of the blood and bone attractant, to entice our pigs to consistently feed at the bait stations. Once this occurred, however, we achieved consistent take of non-toxic bait, and a high level of efficacy with 1080-grain bait. The relatively rapid rate at which bait consumption increased once bait was found to be acceptable has also been reported for feral pigs in NSW (Saunders *et al*. 1993). Such an increase was most likely due to a combination of an increase in the number of pigs finding bait and to, at least some of, these individuals also consuming larger quantities of bait. It is possible, but unlikely, that feral pigs on Gogo Station had had some prior exposure to 1080 through the 1080-meat baiting program routinely undertaken to control wild dogs. However, possibly the greatest unanswered question arising from our trials, is whether our success can be repeated in other areas, and at other times of the year, in northern Australia. We believe this should be possible at similar times of the year, but efficacy could vary between the different seasons in northern Australia. Such a finding has been suggested for feral pigs in north-eastern Australia; however, the greatest uptake of non-toxic biomarked meat baits occurred during the wet, and not the dry, season (81% *v.* 49% of pigs were marked from meat baits, although this may have been influenced by the set grid used to lay baits where pigs are more concentrated at available waters in the dry: Mitchell and Fleming 1998). Although blood and bone has also proved an effective attractant for feral pigs in northern Queensland (J. Mitchell, personal communication), its effect as an added attractant for feral pigs needs to be tested in other land systems.

The long-term effectiveness of any control program will depend upon several factors. These include: the level of efficacy achieved, the reproductive and dispersal/immigration rates of remaining individuals, the home ranges and bait distribution, and the size of the area over which the control program has been implemented. In tropical environments such as those in much of northern Australia, food resources often become more limited as the dry season proceeds and feral pigs may concentrate around available waters (Caley 1993; Mitchell 1998; Mitchell and Fleming 1998; this study). The home range of feral pigs is also thought to be mainly driven by food supply and the presence of suitable refuge sites for day-time shelter (Saunders and Kay 1991). It is therefore not unexpected that a species such as the feral pig is regulated mainly by extrinsic factors such as resource limitation, disease, and predation (Caughley and Krebs 1983; Caley 1993). For these reasons, pigs are likely to become more susceptible to baiting programs during the dry season as their food choices become limited. Feral pigs are also likely to cover larger areas in search of suitable food at this time. Such aspects of pig behaviour are likely to have, at least

Table 5. The distance, by age and sex, that feral pig carcases were found from the nearest bait station from which bait was taken

Although pig tracks were recorded, no pigs were seen or recovered on the WR site

Age class	Distance from station (m)				*n*
	Minimum	Maximum	Mean	s.d.	
Juvenile males	24	402	156	115	18
Juvenile females	20	584	223	162	22
All juveniles	20	584	193	145	40
Adult males	50	610	205	184	7
Adult females	49	584	357	214	14
All adults	49	610	306	213	21

partially, influenced the high level of bait-take and efficacy we achieved. We believe, therefore, that provided the area baited/controlled is sufficiently large, and the level of efficacy is high, then a reduction in pig numbers during the dry season is likely to result in a relatively long-term reduction in pig abundance. This would be particularly so if an additional follow-up control technique, such as shooting, is employed to remove any remaining pigs. However, in smaller areas, control may well need to be implemented on an annual basis to maintain a sustained reduction in pig numbers. This is consistent with the findings in many other areas of Australia (Hone and Pedersen 1980; Choquenot *et al*. 1996). The required frequency and effectiveness of control programs may become less clear where feral pigs have ready access to grain crops (e.g. sorghum, maize), which would provide a nutritious additional food (Caley 1993).

Although vomiting does not affect the overall toxicity of 1080 to feral pigs (mortality is similar in pigs where vomiting does and does not occur: McIlroy 1983; O'Brien 1988), it has been argued that this aspect of using 1080 for feral pig control may represent a potential hazard to non-target species (McIlroy 1983; O'Brien 1988; O'Brien and Lukins 1988). However, the recorded incidence of vomiting is largely based upon the outcomes of captive pen trials where test pigs were largely maintained on a limited diet (mainly grain). We found no evidence that vomiting occurred during our field trials in north-western Australia where these feral pigs had obviously fed on a wide range of foods, including our 1080 grain bait. Similarly, during trials in the agricultural regions of WA, we have found very limited evidence that vomiting by feral pigs occurs with 1080-baiting (Twigg *et al.* in press). Only relatively small amounts of vomitus were observed in the field. We suggest, therefore, that some natural foods may contain some anti-emetic properties, and that the frequency of vomiting resulting from 1080 ingestion by feral pigs based only on captive trials is likely to overestimate this phenomenon. Although there are few published reports of vomiting by feral pigs during control programs, we suspect that this phenomenon has rarely been specifically monitored. This needs to change during future control/research programs.

Recently, there have been concerns that single-dose 1080-meat baits may not be killing all large pigs, and this is thought to be possibly related to the 'bioavailability' of the 1080 within the meat bait (M. Gentle and J. McIlroy, personal communication). This potential problem does not seem to occur with 1080-grain baits. In our studies, we are regularly removing large adults with 1080-grain. For example, pigs with estimated weights of over 90 kg were killed on Gogo Station (Fig. 8), and similar-sized pigs have been killed during our trials in the agricultural regions of WA (L. Twigg, unpublished). A potential difference in the 1080 loading and subsequent bioavailability of 1080 between some bait matrixes may partially explain the lower efficacy with meat baits, or this outcome may simply be due to the failure of all pigs to find sufficient toxic meat bait where a prefeed period is not used, or it may result from some other, yet to be identified, cause. The reduced efficacy seen with aerially laid 1080-meat baits may be partially offset by this technique enabling relatively large and/or inaccessible areas to be covered. However, there is cause for concern if the reduced efficacy is the result of sublethal dosing, rather than pigs not finding the baits. Grain-baits suitable for aerial distribution are yet to be developed.

Although several granivorous bird species (e.g. parrots, pigeons), some macropods, and cattle were present on our study area, we have no records of any non-target take of toxic or non-toxic bait. Nevertheless, we would still recommend that the bait stations be stock-proofed before adding the toxic bait. Once the pigs are reliably taking the prefeed, if required, any take of the added toxic bait by birds could be reduced by lightly covering the bait with soil, or covering the bait with a few small branches. Such procedures do not reduce the take by feral pigs (L. Twigg, unpublished data).

Feral pigs have been identified as important reservoirs or maintenance hosts of several potential exotic diseases, including swine fever, foot and mouth disease, and rinderpest (Flynn 1980; Pech and Hone 1988; Saunders and Bryant 1988; Choquenot *et al*. 1996; Ausvetplan 2004). From this perspective, our findings suggest that baiting with 1080-treated grain would provide a useful mechanism for reducing the abundance of a potential problem species such as feral pigs, especially for many areas in northern Australia. Provided that dead pigs are found relatively quickly, it would also provide a means for monitoring disease status by sampling poisoned individuals (although shooting may be a more convenient method for this). The poisoned pigs found during our 1080-based efficacy trials had generally travelled relatively short distances from the relevant active bait stations before they succumbed. Further, many dead pigs were also found in relatively tight clusters/groups, again with minimal distance between individuals (Tables 3–5). If such an outcome can be reproduced in other areas, and/or at other times of the year, then this would have considerable advantages during a wildlife disease contingency where a rapid and confined knockdown would be required. Feral pigs could be rapidly killed, and those individuals found could be monitored for disease status. Although adding to the cost, the use of helicopters is likely to have increased our effectiveness in finding dead pigs. In contrast, and depending upon the control objectives, the appearance of a small number of 'immigrant' pigs ~6 days after poisoning suggests that monitoring and poison-baiting would need to continue for at least 7–10 days, or until no new pigs are seen, to ensure that the maximum number of pigs were destroyed. Similarly, follow-up shooting, either from the ground or using helicopters, may be required to remove any remaining pigs during a disease contingency. We believe that a combination of 1080-baiting with follow-up shooting would have enabled us to remove most pigs from the 15000-ha River Junction paddock, at least during the dry season. Thus, if the efficacy obtained during our trials (>90% reduction for resident pigs) could be repeated in other areas, then pig numbers may well be driven below the threshold required to support any undesirable disease (e.g. Pech and Hone 1988). However, as with any control program at a landscape scale, sufficient resources would need to be available to implement such a program over a sufficiently large area so that any disease could be contained. Buffer zones would need to be established, and the presence and abundance of any undesirable species or disease monitored. Control boundaries also need to reflect natural boundaries (e.g. individual waterholes, swamps) as much as possible (also see Saunders and Bryant 1988).

Our field observations that feral pigs and cattle freely intermingled, both during grazing and at waterholes, has potential implications for wildlife diseases. Such interaction is likely to be important to disease contingency plans; for example, both cattle and feral pigs can be reservoirs or hosts for foot and mouth disease (exotic) and leptospirosis (*Leptospira* spp., endemic) in Australia.

On average, we required ~12 days to complete our research trials on each site. This generally included a period where the pigs were offered a choice between grains. However, in reality, such a step is unlikely to be needed during operational baiting programs. For example, the pigs on our FS site readily consumed 1080-barley after being prefed only with fermented wheat (see Fig. 7). The Department of Agriculture, Western Australia, recommends that free-feeding continue until bait-take levels out, which generally occurs within ~4 days. This is similar to the 6-day period recommended in NSW (Saunders *et al*. 1993). We believe, therefore, that determination of the location and construction of bait stations, achieving good prefeeding rates, undertaking the knockdown with 1080 wheat or malted barley, and the follow-up monitoring could all be achieved within 6–10 days with the input of one full-time person (may need an extra person to help to construct the stations, however). The use of aerial survey (i.e. helicopters) to help establish where control sites need to be located may also be necessary and/or assist with any control exercise. The 6–10 days required for successful baiting compares favourably with the estimates of 8–9 days required to reduce pig numbers by >90% with helicopter shooting in NSW (Saunders and Bryant 1988). The 6–10 days required for effective 1080-baiting meets the requirements of many wildlife disease-containment strategies (Pech and Hone 1988). For example, feral pigs may need to be eradicated within 21 days of an outbreak of foot and mouth disease (Hone and Bryant 1981), or at least reduced to densities of ~0.03 to <2 pigs km^{-2} (Pech and Hone 1988; Pech and McIlroy 1990; Caley 1993; Dexter 2003), for disease containment. Our observed after-poisoning pig densities were 0.13–0.33 pigs km^{-2}.

The implementation of such a strategy with 1080-grain in northern Australia, including the initial material and maintenance costs, and based upon servicing 10 bait stations for 12 days with a single person, was estimated to cost ~$2,230 or $223 per station (A$, Derby 2004 prices including 10% GST). Per station, this comprised: materials, and labour for construction and removal of bait stations, $83.11; all wheat and 1080 toxin, $32.87; and vehicle and labour costs in maintaining the stations, $107.04. This assumes that no new vehicle purchases are required, but vehicle costing includes fuel, repairs, insurance, licensing and general maintenance based on a medium-sized 4WD ($0.40 per kilometre for 100 km per day). Labour was costed using the minimum station hand/ACTU rate of $12.30 per hour. These costs would only change marginally if different grains were used, but they could be discounted considerably where the servicing of bait stations could be included in routine station management (e.g. part of a 'mill' run). However, labour charges may increase in other areas of the State. The above costing would generally be well within the realms of conservation agencies, landholders, community interest groups and government agencies alike. Using a similar costing for the 31 active bait stations we ran, this would equate to $6913 or $113 per recovered dead pig ($n = 61$), or ~$27–$34 per pig if it is assumed that we destroyed at least 200+ pigs (a reasonable assumption based on the level of efficacy achieved).

Finally, we are not implying that 1080-treated grains are the only viable method for controlling feral pigs in northern Australia. Clearly, the most effective option is likely to involve a combination of techniques. Aerial or ground shooting, trapping, and the use of other bait materials and toxins, may well prove effective in these control programs. Even when a combination of control techniques is used, a small residual population of feral pigs is likely to remain (Saunders and Bryant 1988). Whether such pigs are problematic will depend upon the stated goals of a given control exercise (e.g. exotic disease eradication below a given threshold level versus routine control operations). Furthermore, there will be 'trade-offs' with the chosen method(s). For example, aerial shooting is restricted to more open habitats, it will be relatively expensive, and it may not remove sufficient pigs. Ground shooting may remove pigs of a particular age class (e.g. solitary boars), which may or may not be acceptable for any disease contingency. Shooting may change the behaviour of, or disperse, some feral pigs (Saunders and Bryant 1988). Trapping often does not always remove the older, more experienced pigs (Saunders *et al*. 1993; Choquenot *et al*. 1996; Mitchell 1998). Successful poison-baiting with grain relies upon obtaining good take of non-toxic prefeed and, hence, can be time consuming in some situations. Nevertheless, poison-baiting may well destroy pigs that are not susceptible to other forms of control (e.g. shooting, trapping; also see

Saunders and Bryant 1988). Consequently, provided the directions for use are followed, the use of 1080-treated grain is a cheap, safe, easy to use, and relatively humane control technique. One current draw-back with this approach is, however, the restriction that only suitably trained personnel are 'licenced' to mix the 1080-bait. This difficulty could be overcome by having an 'off-the shelf' grain product.

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