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Bait consumption by, and 1080-based control of, feral pigs in the Mediterranean climatic region of south-western Australia

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Abstract. The consumption of five non-toxic, grain-based baits, and the effectiveness of the preferred baits when treated with 1080 in reducing pig numbers, were determined for feral pigs (*Sus scrofa*) in several areas in the Mediterranean agricultural region of Western Australia. Fermented wheat with added blood and bone proved an effective attractant for feral pigs, and for determining areas of pig activity. Wheat and malted barley were the preferred baits, there was a variable response to lupins, and commercial pig pellets were consumed least. Malted barley, barley, and wheat treated with 1080 gave good reductions in pig numbers at the localised scale. Where pigs would eat lupins, 1080-treated lupins were usually effective in reducing pig abundance. In some instances, further evidence of feral pig activity was not seen on several sites for several months after poison-baiting occurred. The addition of a small amount of unpoisoned grain to mask the presence of 1080 did not increase the take of treated bait ($P < 0.05$). Although finding poisoned pigs was difficult owing to the terrain and the presence of bush remnants, the poisoned pigs found ($n = 90$) were often within 200 m of active bait stations. 1080-poisoned pigs included both adult (≥25 kg) and non-adult pigs of both sexes. Body mass of these pigs ranged from 4 to 90 kg. In all, 42% of poisoned adults found ($n = 50$) were 50 kg or more. There was minimal evidence of bait take by non-target species, and, where this occurred, it generally involved the consumption of the fermented wheat attractant by kangaroos (*Macropus* spp.) and foxes (*Vulpes vulpes*). Six foxes were known to have been poisoned with 1080-treated grain (4 with malted barley, 2 with wheat). Excluding foxes, no other non-target animals, including native species, were found dead during the intensive searches for poisoned pigs.

Introduction

Feral pigs (*Sus scrofa*) are significant agricultural and environmental pests, particularly in Australia, where they occur over ~40% of the continent (Long 1988; Hone 1990; Choquenot *et al*. 1996; McLeod 2004). The impacts of feral pigs in agricultural regions of Australia include the fouling of waterways, soil erosion, lamb predation, pasture damage, and the suspected spread of noxious weeds (Choquenot *et al*. 1996; Setter *et al*. 2002; Twigg *et. al.* 2005*a*). Feral pigs have also been identified as important reservoirs or maintenance hosts of several endemic (e.g. leptospirosis – *Leptospira* spp.) and exotic wildlife diseases. Exotic diseases with the potential to involve feral pigs include swine fever, foot and mouth disease, and rinderpest (Flynn 1980; Pech and Hone 1988; Saunders and Bryant 1988; Choquenot *et al*. 1996; Ausvetplan 2004). The cost of feral pigs to Australian agriculture has been estimated at over $100 million annually (Choquenot *et al*. 1996; McLeod 2004). Control options employed to reduce such impacts include poison-baiting, trapping, and ground and aerial shooting. Although each technique has advantages and disadvantages (see Saunders and Bryant 1988; Saunders *et al*. 1993; Choquenot *et al*. 1996; Mitchell 1998; Twigg *et al.* 2005*a*, 2006), poison-baiting is probably the most often used control technique. Baiting programs are commonly undertaken with 1080 (sodium fluoroacetate). Yellow phosphorus is also registered for pig control, and warfarin has been used under experimental permit, in some Australian states (Saunders *et al*. 1990; Choquenot *et al*. 1996).

In mid-2003, we commenced a project to examine the suitability of the current baiting techniques for controlling feral pigs across a range of habitats in western Australia. The overall baiting strategy was developed and assessed to provide a means for reducing pig numbers during an exotic disease emergency, and for routine operational control of feral pigs in Australia. This assessment included cafeteria trials to determine the most suitable baits and bait attractants, and the determination of the 1080-efficacy of the preferred bait(s) and/or baiting method. The initial trials were conducted in the tropical Kimberley region of Western Australia (WA) where 1080-treated wheat or malted barley were highly efficacious against feral pigs (~90% reduction in numbers), and resulted in reasonably long-term reductions in pig abundance (Twigg *et al.* 2005*a*, 2006). Tissue residue levels in 1080-poisoned pigs, the rate of degradation of pig carcases, and the distance that poisoned pigs succumbed from active bait stations have also been determined for feral pigs in Western Australia (Twigg *et al.* 2005*b*). However, the suitability of the baiting procedures developed in a tropical region needed to be assessed in other climates/habitats before they could be universally recommended for controlling feral pigs across Australia (or elsewhere).

Most problems with feral pigs in southern Australia occur within a range of habitats with a Mediterranean climate (Choquenot *et al*. 1996). Agricultural practices/enterprises, and the associated vegetation structures and habitats, also vary con-

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siderably between the tropical north (e.g. northern pastoral (rangeland) zone of the Kimberley) and the southern Mediterranean zone of Australia (used for sheep, cattle, cereal and pulse crop production). Consequently, the suitability of our baits and baiting procedures (Twigg *et al.* 2005*a*, 2006) were assessed in several different areas within the Mediterranean agricultural region of Western Australia. Here, we report the outcomes of these assessments, and suggest how our findings could be best incorporated into management strategies for feral pigs, including operational control programs and exotic disease contingencies.

Materials and methods

Study areas

The trials were undertaken at various locations throughout the Mediterranean agricultural region of Western Australia (see Table 1 for regions and specific sites). The wettest 6-month period in this Mediterranean system generally occurs in May–October, and break of season (opening rains) usually occurs in late autumn (April/May). Major agricultural enterprises include cereal growing, merino wool production, beef cattle, pulse crops, and tree-farms (*Eucalyptus* spp.). Many of the sites used had neighbouring native bush remnants and/or national parks and reserves. This vegetation was often dense mallee heath, which made finding poisoned pig carcases difficult. Western grey kangaroos (*Macropus fuliginosus*) and, to a lesser extent, euros (*Macropus robustus*) were present at some sites.

Trial conduct

The distribution and abundance of feral pigs in the agricultural region of Western Australia were generally more restricted/ lower than expected and, despite considerable effort, on some occasions this restricted our ability to truly replicate the different pig-habitats (sites). That is, site selection was more a function of the presence of feral pigs, rather than truly representing the range of habitats that occurred in this region. The location of all bait stations, tracks, and both dead and live pigs, were recorded using detailed mud maps (in 2003) or a handheld Garmin® GPS 12XL Personal Navigator (global positioning system; Garmin Corporation, Olathe, KS, USA, after 2003). Where possible, the determination of the suitability of the various baits for feral pig control involved a 5-stage process: (1) looksee, (2) habituation, (3) choice, (4) effectiveness of preferred bait, and (5) follow-up monitoring (see also Twigg *et al*. 2005*a*). Choice experiments were not always run at all sites owing to the urgent need for some landholders to reduce feral pig impact (e.g. crop damage reduction). Further, for logistical reasons, and because some landholders needed to restock the 'research' paddocks, detailed follow-up monitoring could not be conducted at all sites. Paddocks with sheep had to be destocked because sheep could not be preferentially excluded from the bait stations with temporary fencing. The associated procedures are briefly described below, with detailed methodology and bait station design given in Twigg *et al*. (2005*a*). Five types of bait were used: wheat, malted barley, lupins, plain barley and commercial pig pellets (~18% protein; Supa Finisher Pellets, Wesfeeds, Perth, Australia). Because of its ready acceptance by feral pigs (Choquenot *et al*. 1996), wheat was the standard bait against which the other baits were compared.

Bait stations and bait-take

Areas of pig activity were determined by looksee-baiting using one or two 1-m^2 raked-earth plots, each with a ~500-g pile of fermented wheat with added blood and bone (~90 g). A 5–10-m 'light' trail of fermented wheat was usually spread out from at least one side of the looksee raked plots to increase potential encounters by feral pigs (Twigg *et al*. 2005*a*).

Formal bait stations were established only at those looksee plots where pigs fed relatively consistently. These bait stations comprised two 1-m^2 raked-earth plots 5 m apart (Twigg *et al*. 2005*a*), with generally at least 100–200 m between each station. Once the formal bait stations were established, and the pigs were feeding freely, all residual looksee fermented wheat was removed and the 24–48-h habituation period commenced. During the habituation period, a ~500-g pile of each test bait (i.e. 2 × 500 g per raked plot) together with the fermented wheat (~150 g) with blood and bone (~90 g) attractant was placed on each raked plot. The matched-choice experiment immediately followed the habituation period. After removing all residual bait, a 1-kg pile of a given test bait was placed on one of the two raked plots (i.e. 1 kg Bait A on Plot 1 and 1 kg Bait B on Plot 2). A small amount of fermented wheat (~150 g) with blood and bone (~90 g) was again added to the corner of both raked-plots as an attractant (Twigg *et al*. 2005*a*). The choice experiments ran for at least 3–4 consecutive days (Twigg *et al*. 2005*a*).

After completing the choice experiments, residual grain was removed and the pigs were habituated to the preferred bait for one night. Following this, any remaining bait was removed, and two 1-kg piles of 1080-treated bait were placed on each raked plot at each bait station to assess the effectiveness of the preferred bait (i.e. 2 × 1 × 2 kg per station). 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. The use of 4 piles per station was designed to decrease the potential for single or dominant pigs consuming all the poison bait at a station. 1080-treatment of grain was as per the current label directions for 1080 Black® (Bait Production Unit, Department of Agriculture and Food, Forrestfield, WA, Australia) and 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)). Because some landholders believed that the addition of a small amount of unpoisoned grain on top of the poison bait improved the efficacy of 1080-grain, a small amount (~100 g) of plain grain was added to the top of one of the 1-kg piles of poison bait at random on each raked plot during some baiting trials in 2003–04.

In four instances, because the associated landholders needed immediate respite from the damage caused by feral pigs, 1080-baiting was undertaken without conducting prior bait-choice trials. Areas of pig activity were determined using the fermented wheat and blood and bone looksee procedure outlined above. Fermented wheat and blood and bone, together with the bait to be used for poison-baiting, were then used as prefeed until the pigs were feeding consistently at the designated bait stations. Once consistent prefeeding occurred over 2–3 days, all residual bait was removed, and poison-baiting took place as above.

Table 1. Description of the 2003–06 experimental sites used in the Mediterranean agricultural region of Western Australia

Date[A]	Region	Site	Nearest locality[B]	Agricultural enterprise	Habitat	Bush remnant / water	Estimated no. of pigs[C]	Trials run[D]	Follow-up date
1 Oct 2003	Boddington	Culford Farm	North Bannister (32°35′, 116°27′)	Tree farm	Blue gum, Jarrah/Marri forest, abandoned pasture	Forest, dams, creeks	~17^{+}	C, Wht *v.* Mbar C, Wht *v.* Lup E, Lupins F	 21 Oct 2003 4 Nov 2003
16 Feb 2005	Boddington	Floral Park	Boddington (32°48′, 116°28′)	Tree farm	Blue gum, Jarrah/Marri forest	Forest, dams, creeks	~12^{+} (?)	E-pf, MBar	n.a.
19 Jan 2004 15 Feb 2004 24 Feb 2004	Northampton / Geraldton	Yarder Creek	Port Gregory (28°11′, 114°14′)	Merino sheep, beef cattle, cereals	Farmland with bush remnants and Yarder Creek	Mallee heath, dams, troughs, creeks, soaks	~20+	C, Wht *v.* Lup C, Sur *v.* Bur Wht E, Bur Wht F	 3–5 Mar 2004
18 Feb 2004	Northampton / Geraldton	Eastough	Hutt River (28°04′, 114°29′)	Merino sheep, cereals	Farmland with bush remnants	Mallee, banksia heath, dams, troughs	~20	C, Wht *v.* MBar	n.a.
18 Jun 2004	Greenough / Geraldton	Desmond	Ellendale Pool (28°51′, 114°58′)	Merino sheep, cereals	Farmland with bush remnants, reserve	Mallee heath, troughs, dams	~40^{+} (2–3? mobs)	C, Wht *v.* Lup E, Wht F	 ~18 Jul 2004 22 Feb 2005
21 Feb 2005	Greenough / Geraldton	Blayney	Ellendale Pool (28°51′, 114°58′)	Merino sheep, cereals	Farmland with bush remnants, road reserve	Mallee heath, troughs, dams	~15–20	C, Wht *v.* Mbar E, Mbar F	 2 Mar 2005
26 Jul 2005	Greenough / Geraldton	Broad	Mingenew (29°12′, 115°26′)	Merino sheep, cereals, beef cattle, pulse crops	Farmland with bush remnants	Banksia heath, troughs, dams	~40	E-pf, Lup	22 Aug 2005
24 May 2006	Greenough / Geraldton	Rowe	Mingenew (29°12′, 115°26′)	Merino sheep, cereals, pulse crops	Farmland with bush remnants	Banksia heath, troughs, dams	~15–20	C, MBar *v.* Bar E, Bar	
30 Jul 2005	Greenough / Geraldton	Gillam	Dongara (29°15′, 114°56′)	Merino sheep, cereals, pulse crops	Farmland with bush remnants	Banksia woodland, dams	~20–40	E-pf, Lup	~8 Aug 2005
24 Sep 2005	East Nabawa / Geraldton	Kupsch	Nabawa (28°30′, 114°48′)	Merino sheep, cereals, pulse crops	Farmland with bush remnants	Banksia heath, troughs, dams	~40 (2–4 mobs)	C, Wht *v.* Lup E, Wht F	 13 Oct 2005
25 Mar 2006	East Nabawa / Geraldton	Wicka Site 1	Nabawa (28°30′, 114°48′)	Merino sheep, cereals, pulse crops	Farmland with bush remnants	Banksia heath, troughs	~20–30 (3^{+} mobs?)	C, MBar *v.* Pell E, MBar	10 Apr 2006
19 May 2006	East Nabawa / Geraldton	Wicka Site 2	Nabawa (28°30′, 114°48′)	Merino sheep, cereals, pulse crops	Farmland with bush remnants	Banksia heath, troughs	~20	C, Wht *v.* Pell E, Wht	~6 Jun 2006
19 May 2006	East Nabawa / Geraldton	Wicka Site 3	Nabawa (28°30′, 114°48′)	Merino sheep, cereals, pulse crops	Farmland with bush remnants	Banksia heath, troughs	~20–30	C, Sur *v.* Bur Wht E, Bur Wht	~6 Jun 2006
2 Apr 2006	Geraldton / Bringo	Clune	Geraldton (28°47′, 114°37′)	Merino sheep, cereals	Farmland with bush remnants	Open woodland, troughs, soak	40^{+}	E-pf, Bar	10 Apr 2006

[A] Start date for choice or effectiveness of 1080 bait trials.

[B] Some landholders did not wish precise coordinates to be given.

[C] Seen/estimated by us or landholder. Activity, tracks and the remote sensing cameras were used to help with abundance estimates.

[D] As appropriate, looksee baiting, habituation and prefeeding preceded all trials (see Materials and methods). C, choice; E, effectiveness of 1080 bait; F, follow-up; E-pf, effectiveness only but preceded by prefeed. Wht, wheat; MBar, malted barley; Bar, barley; Lup, lupins; Pell, pellets.

In two instances, the effect of burying bait on its take by feral pigs was determined using wheat bait. Bait was buried in a shallow depression (5–10 cm) with a light covering (1–2 cm) of soil on top of the grain to form a small ‘hump’. These humps were located in the centre of the 1-m^2 raked-earth plots. A small handful (<50 g) of unpoisoned grain was placed near one corner of the hump as an attractant. These assessments included both non-toxic (choice) and toxic (effectiveness) wheat.

Bait stations were monitored each morning when bait-take was visually estimated for all stations using 10% increments and 1-kg reference samples contained in plastic bags. When bait was taken, all piles were replenished back to the original amount. Animals (e.g. pigs, birds, rabbits, foxes, macropods) visiting the bait stations and/or taking bait were identified by their tracks, or other evidence, that were present on or near the raked plots (Twigg *et al*. 2005*a*).

Where possible, follow-up monitoring was undertaken after poison-baiting was complete (2–5 days after poisoning) by removing any residual 1080-bait and replacing it with ~500 g of fermented wheat with blood and bone (~90 g) (note: blood and bone was not used in 2003) for a further 2–5 days. Signs of recent pig activity at the bait stations, and in the immediate study area, were also recorded as part of follow-up monitoring. In several instances, the level of pig activity was recorded on some sites for several months after 1080-baiting was complete (e.g. Culford Farm, Desmond, Kupsch). This provided a further check of any activity/presence of feral pigs well after poison-baiting took place.

Track plots

Even though feral pigs were frequently recorded in the same area over consecutive days, the route by which they travelled to these areas varied between days. Therefore, it was not always possible to establish track plots that could provide a reliable measure of changes in pig activity. Where used, raked track plots (~2 m^2) were located on active feral pig pads or across vehicle-access tracks, and were at least 5–10 m from an active bait station. No bait material was provided on these plots. Track plots were monitored daily before (2–11 days) and after (3–6 days) poison-baiting was undertaken. Plots were raked clean after each monitoring/recording session (Twigg *et al*. 2005*a*).

From early 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 carcase searches.

Pig carcases and measurements

Considerable effort (1–3 person h per day per site, post-baiting) was put into finding poisoned pigs (see Twigg *et al*. 2005*a*, 2006). This included both foot and vehicle-based searches (Twigg *et al*. 2005*a*). However, the relatively large distances some pigs were believed to have travelled to feed at the bait stations, and the impenetrable terrain/vegetation where most pigs seemed to die, meant that our ability to find poisoned pig carcases was often low. Carcase searches were most concentrated on the first three days after poison-baiting, but observation continued routinely during the ongoing conduct of the trials at each site. Where possible, bodyweight was estimated for all dead pigs found, and 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) from mid-2004. 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 weighing <5 kg (Twigg *et al*. 2005*a*).

Early bait trials in south-western Western Australia (1986–87)

Under the supervision of the Vertebrate Pest Research Section, District Officers of the Agriculture Protection Board, Western Australia undertook several bait-consumption trials for feral pigs in the mid 1980s in the Donnybrook (33°35′S, 115°50′E) and Nannup (33°59′S, 115°46′E) regions of south-western Western Australia. These trials contribute additional information on the acceptability of the baits used (oats, wheat and commercial pig pellets) to feral pigs in this Mediterranean region and so are included here.

Consumption of baits by feral pigs was investigated in a variety of Mediterranean habitats including native forest, agricultural lands, and the forest–agricultural land interface. These trials generally involved a three-way choice between oats, wheat and commercial pig pellets, although bait attractants (e.g. molasses) were added occasionally. Such comparisons were not included in our analyses. Over the two-year period at Donnybrook, 24 independent sites were used/available, and there were 186 separate observations across these sites (thus $n = 186$ bait nights × 3 bait types = 558 observations). Similarly, at Nannup, there were 13 sites with 86 separate observations across the sites ($n = 86$ bait nights × 3 bait types = 258 observations) over the same period.

Depending upon feral pig activity, and the level of bait taken, 7, 14 or 21 kg of each bait type were offered simultaneously at each bait station. There was ~1–2 m between each pile of grain, and each bait station was generally several kilometres from any other. Bait was placed on bare ground. Depending upon pig activity, bait was on offer in both regions for 2–50 days at each site. Take was visually estimated as a proportion of the original amount on offer and, after each monitoring period, depending upon the amount taken, each station was then either: (1) made up to the original amount, or (2) if significant take occurred, the amount of bait was increased to the next highest amount (i.e. 7, 14 or 21 kg) for all three bait types. Data for those nights where significant rainfall was recorded were excluded from our analyses because (1) there was some uncertainty regarding the quality of the bait following rain, and (2) due to the difficulty in reading tracks and other evidence after rain it was not always certain that pigs had been responsible for all the bait take recorded. Further, we also excluded those nights where the amount of grain on offer differed between the three bait types (on the rare occasion where this occurred). The data from those monitoring periods where no bait of any type was consumed, and/or where there was no obvious visitation by feral pigs, between assessment periods, were also excluded from the analyses. Although it led to the exclusion of some of the available data, this conservative approach ensured that we included only those observations where feral pigs had a true choice between the baits on offer (i.e. equal opportunity to consume any bait).

Data analysis

Ultimately, the experimental design/conduct was largely dictated by the abundance, 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 between some sites, which resulted in an unbalanced design. Therefore, it was not possible to realistically analyse all sites concurrently (e.g. factorial ANOVA). Consequently, the comparison of the amounts of bait consumed was analysed independently for each site using a paired *t*-test (Zar 1984). Wheat was the standard bait against which the other baits were compared, and the data were arcsin-transformed before analysis. All probabilities are for two-tailed tests.

Bait take from the bait stations used in our trials was determined as a percentage of the amount of bait available on each raked plot at each station (expressed either as daily means or grand means over all days, with standard deviation (s.d.) for each treatment). However, these assessments excluded any station that was not visited by feral pigs during each experimental period. Once a station was visited by pigs, it was then included in all subsequent assessments regardless of whether it was revisited by pigs, and whether any bait was taken. Thus, in all figures, internal numbers refer to the number of active bait stations included in each assessment, and this generally represents the cumulative total except on the odd occasion where a particular bait station had to be discontinued over a trial period. The amount of bait (kg) consumed by feral pigs for each period is also given in parentheses for each trial.

For reasons similar to those given above, a single-factor ANOVA (Zar 1984) was used to compare the 1986–87 bait-consumption data from the two study areas in the south-west of WA.

Results

Boddington region (Culford Farm)

Our trial protocols were first tested at Culford Farm in mid 2003. Although only a small number of pigs were present (Table 1), they readily consumed the non-toxic baits, wheat, malted barley and lupins (Fig. 1). However, even though the consumption of all baits was quite high (>80% of bait offered: Fig. 1), these pigs consumed significantly greater amounts of malted barley (grand means of bait consumed 94% (s.d. = 8%)) and lupin bait (98% (12%)) than wheat (82% (s.d. = 13%) and

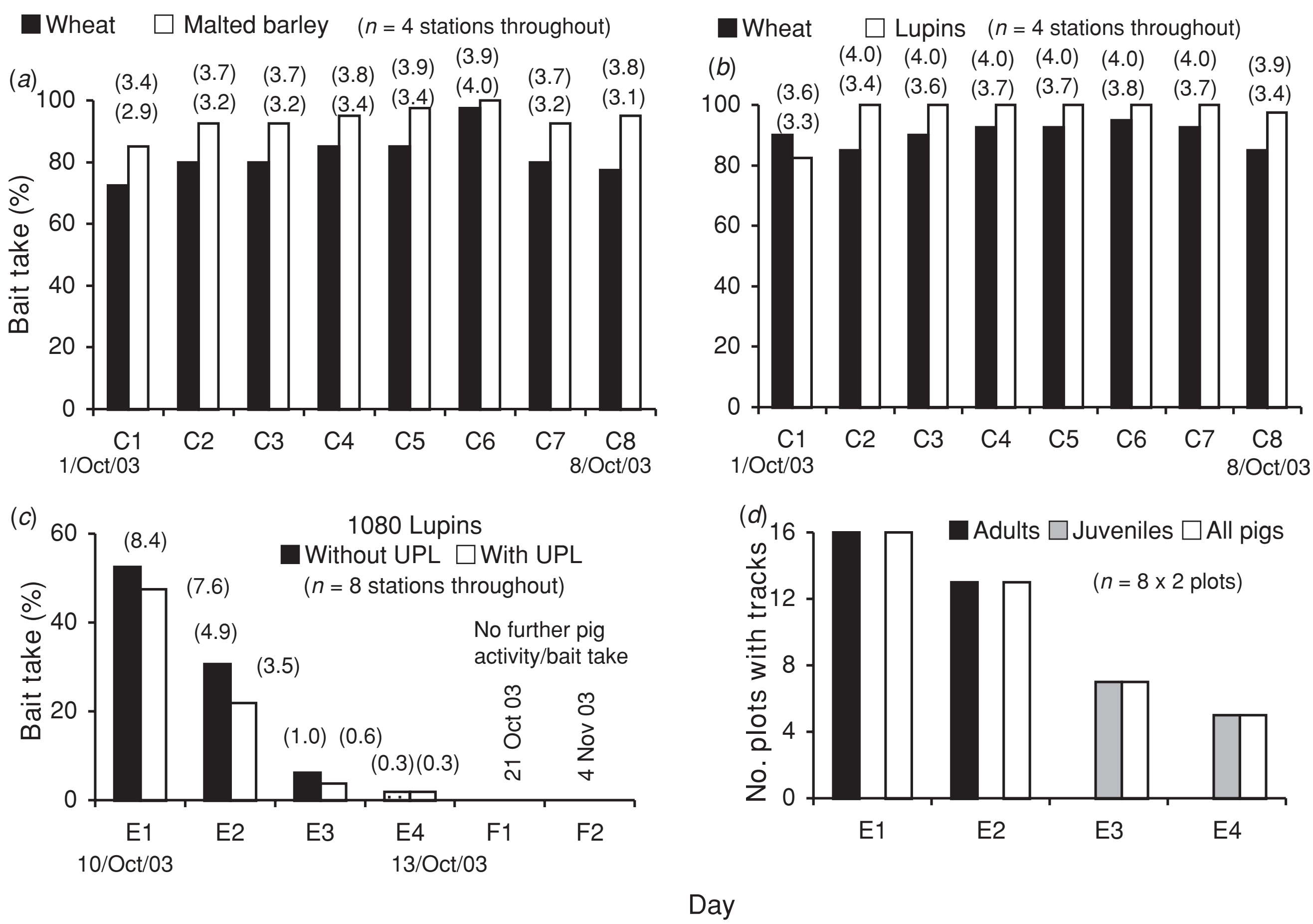


Fig. 1. The consumption of (*a*) wheat and malted barley, and (*b*) wheat and lupins by feral pigs at Culford Farm in the Mediterranean agricultural region of south-western Australia. (*c*) The effectiveness of 1080-treated lupins, with and without a small amount (~100 g) of unpoisoned lupins (UPL) on top, and (*d*) visitation rates by adult and non-adult pigs to the 8 bait stations during 1080-baiting, are also shown. Numbers in parentheses are the amount of bait (kg) consumed by feral pigs for each period. C1–C8, Days 1–8 of the choice trials; E1–E4, Days 1–4 of the effectiveness trials; F1–F2, Days 1–2 of follow-up monitoring.

90% (8%)). The corresponding paired *t*-tests were: $t = -8.532$, d.f. = 31, $P < 0.001$, and $t = -3.186$, d.f. = 31, $P = 0.003$. The trends in bait take remained the same over the eight days of the choice trials (Fig. 1); consequently, most of the other choice trials were generally run for 3–4 consecutive days only.

On the basis of the above findings, and because we suspected that the two different areas used at this site were not truly independent with respect to pig visits, the whole Culford Farm site was baited with 1080-treated lupins using all eight available bait stations (Fig. 1*c*). All bait take and feral pig activity ceased 4 days after 1080-baiting (13 October 2003) (Fig. 1), and no further feral pigs or pig activity were seen at the site until at least January 2004 (last formal inspection). Two track plots (no bait material) within the baited area were included at this site. Before 1080-baiting, the number of 'hits' by feral pigs and western grey kangaroos were 0.44 (s.d. = 0.32) and 0.25 (0.27) plots with tracks per day ($n = 8$). Small pig tracks were present on one plot after the first night's baiting, but no further pig tracks were seen after this time, including the follow-up monitoring over 8 days after poison-baiting ceased. In contrast, the number of plots with kangaroo tracks increased over the same period (during 1080-baiting, 0.50 (s.d. = 0.38) plots with tracks, $n = 4$ days). One of the two plots had kangaroo tracks during the follow-up monitoring. The above findings suggest that our baiting program had removed all pigs within the immediate area, and that it had no discernable detrimental effect on non-target species (e.g. western grey kangaroos).

The addition of unpoisoned lupins on top of one of each pair of the 1-kg piles of 1080-lupins on the raked plots did not increase the take of poison bait by these feral pigs (Fig. 1*c*): Day 1, $t = 1.257$, d.f. = 15, $P = 0.228$; grand mean consumption, without 53% (s.d. = 21%) of bait offered, with 48% (21%)). Although the data were limited, juvenile pigs were not recorded on the baited raked plots until after most adult pigs had succumbed (Fig. 1*d*).

Northampton region

Feral pigs in this region (Yarder Creek) showed a distinct preference for wheat over lupin bait (Fig. 2) ($t = 2.336$, d.f. = 22, $P = 0.029$; grand means, wheat 93% (s.d. = 10%) of bait offered, lupins 76% (34%)). Further, during a 3-day habituation period over 12–14 February 2004 for additional trials at the same site, these pigs consumed very little lupin bait, such that the trial had to be switched to surface versus lightly buried wheat. Bait consumption (500 g of each bait type per station) during the habituation period was: fermented wheat 99% (s.d. = 3%) and lupins 27% (47%) ($n = 6$ stations × 2 nights) and fermented wheat 100% (s.d. = 0%) and wheat 94% (10%) ($n = 7$ stations × 1 night). During the resulting choice trial with surface and lightly buried (covered) wheat, these feral pigs consumed more of the surface wheat than the lightly buried wheat (Fig. 2), probably because the latter may have been less visible/easy to find. The paired *t*-test was: $t = 3.859$, d.f. = 26, $P < 0.001$ (grand means, surface wheat 97% (s.d. = 6%) of bait offered, buried wheat 69% (40%)).

Despite the above outcome, the effectiveness of buried 1080-wheat was tested at this site. Lightly buried 1080-wheat seemed to be effective in removing all localised pigs at Yarder Creek at this time, as no further pigs or pig activity were seen up to 13 days after poison-baiting (Fig. 2). This outcome was also supported by the changes in pig-tracks on the two track plots established at this site. Before 1080-baiting, the number of 'hits' by feral pigs and kangaroos were 0.45 (s.d. = 0.35) and 0.05 (0.15) plots with tracks per day ($n = 11$). No pig tracks were seen on the track plots during the 4-day 1080 baiting period, but kangaroo tracks increased over this period (0.25 (s.d. = 0.29) plots with tracks). The track plots were not run during the follow-up monitoring. However, a small number of pigs were known to have re-established at this site within 1–2 months of the 1080-baiting, probably because we were able to bait only a relatively small section of this extensive creek system that covered several properties, and which had considerable native vegetation (e.g. *Melaleuca* spp.) shelter present.

Pigs at West Binnu (Eastough–Northampton region) showed a mixed response to malted barley (Fig. 2*d*), although the site used had extensive areas of native vegetation remnants that offered several different areas of shelter for feral pigs. Most of this site also comprised poorly harvested lupin stubble. These factors combined to make it difficult to consistently predict pig feeding behaviour, hence only a relatively small proportion of the 10 bait stations used were visited by feral pigs on a given night. With this caution, these pigs appeared to favour wheat over malted barley (grand means, wheat 88% (s.d. = 18%) of bait offered, malted barley 58% (48%); $t = 2.550$, d.f. = 12, $P = 0.025$), although the consumption of malted barley may have increased further with time as the consumption of both baits was similar by Day 6 (Fig. 2*d*).

Greenough region

Initially, lupins were a less acceptable food to feral pigs at the Desmond site; however, by Day 3, similar amounts of unpoisoned wheat and lupins were consumed by these pigs and the difference in the overall consumption of these baits was marginally not significant (Fig. 3*a*): $t = 1.946$, d.f. = 26, $P = 0.063$; grand means, wheat 98% (s.d. = 10%) of bait offered, lupins 87% (32%)). 1080-wheat proved highly effective in removing resident pigs although there were two distinct pulses in pig activity at the bait stations (Fig. 3*a*). This probably resulted from several mobs (2–3?) being active at the site (Table 1). Non-toxic wheat was used on Day E3 (Day 3 of the effectiveness trials, see also Twigg *et al.* 2005*a*) because it was thought that pig activity had ceased. However, subsequent take of this bait indicated further pig activity, and poison-baiting continued for another 3 days, after which no further activity was recorded. In addition to the 19 poisoned pigs found (Table 2), dead pigs were also reported on a neighbouring property on the opposite side of the Greenough River (2–3 km away) during the baiting program. This site was monitored for evidence of pigs (tracks, rooting) for several months after the 1080-baiting. No evidence of feral pigs was recorded either by us or the landowner up to 22 February 2005 (~8 months post-baiting), but a small number of tracks of juvenile pigs were observed on site after this time. The addition of a small amount of unpoisoned wheat on top of some piles of 1080-wheat did not improve the take of this bait (Fig. 3*a*): $t = 1.453$, d.f. = 19, $P = 0.163$).

Both wheat and malted barley were acceptable baits to feral pigs elsewhere in the Greenough region (Blayney's – Fig. 3*b*): $t = 0.214$, d.f. = 8, $P = 0.836$; grand means, wheat 66%

(s.d. = 33%) of bait offered, malted barley 68% (34%)). 1080-malted barley was effective in reducing pig activity, although we were unable to fully complete this baiting due to overnight rain after 3 nights. Although the number of pigs at this site was relatively low (Table 1), follow-up inspection and farmer feedback 5 days after baiting ceased suggested that few feral pigs remained at the site at this time (i.e. no new activity was detected).

Barley and malted barley were also consumed in identical amounts when tested at Rowe's in the Greenough region (Fig. 3*c*); $P = 1.0$; grand means, malted barley 83% (s.d. = 41%) of bait offered, barley 83% (41%)). 1080-barley was effective in reducing pig activity, although baiting had to be curtailed after 3 nights due to overnight rain (Fig. 3*c*). Three track plots were included at this site. Before 1080-baiting, the proportion of plots with feral pig tracks was 0.78 (s.d. = 0.19) per day ($n = 3$ days × 3 plots) compared with 0.33 (0.29) and 0.33 (0.58) on Days 1–2 ($n = 2$ days × 3 plots) and Days 3–8 ($n = 1$ day × 3 plots) after 1080-baiting, respectively. The 'hit' on Days 3–8 was caused by a single visit by a large pig to one plot. Kangaroos were not recorded on the track plots during any of the trial period.

East Nabawa region

Despite the presence of a green, ripening lupin crop, and the presence of this plant material with immature pods in the stomachs of poisoned pigs, feral pigs at the Kupsch site consumed very little lupin bait over the 3-day choice trial (Fig. 4): $t = 10.086$, d.f. = 29, $P < 0.001$; grand means, wheat 88% (s.d. = 25%) of bait offered, lupins 7% (9%)). Since these pigs were causing considerable damage to lupin crops, and because they readily accepted wheat-bait, 1080-baiting with poisoned wheat was conducted immediately after the choice trial. Several relatively discrete mobs of pigs (~10 individuals per mob, 2–4? mobs) were using this area, which resulted in several pulses in

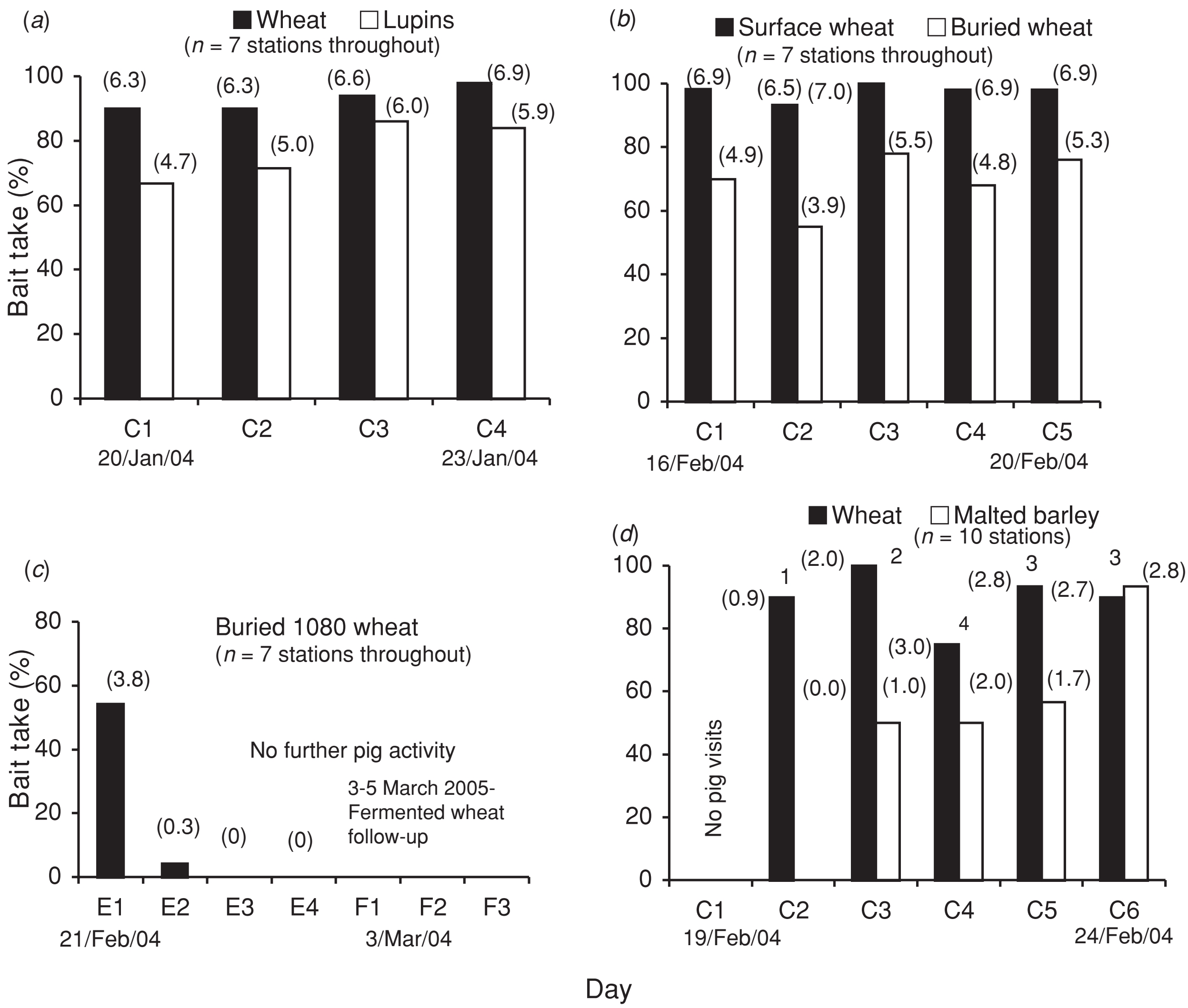
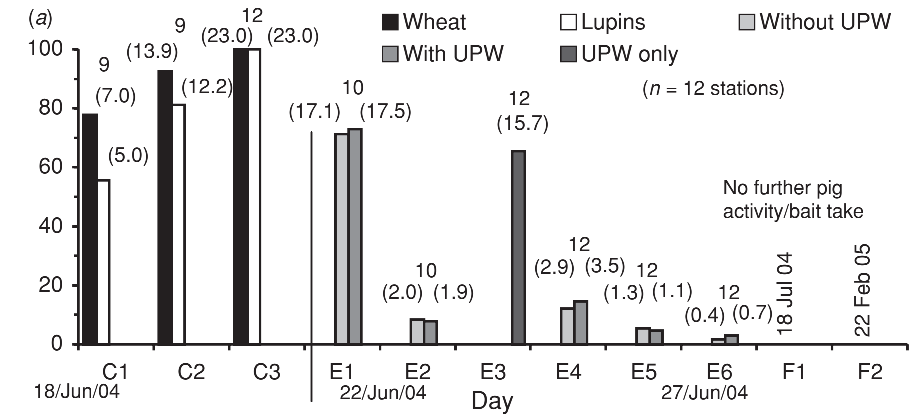


Fig. 2. The mean consumption of a variety of baits by feral pigs in the Northampton region of Mediterranean Western Australia: (*a–c*) the Yarder Creek area where wheat and lupins, and surface versus buried wheat were compared, and the effectiveness of buried 1080-wheat was determined; (*d*) wheat versus malted barley choice trials only were undertaken at the West Binnu (Eastough) site. Internal numbers refer to the number of active bait stations included in each assessment. Numbers in parentheses are the amount of bait (kg) consumed by feral pigs for each period. Abbreviations as for Fig. 1.

pig activity/feeding at the bait stations (Fig. 4). Trends in pig activity were characterised by a recurring pattern that consisted of a period of bait take/visitation followed by a night with no pig visits. Although we believe most of these pigs were ultimately poisoned (limited activity/spoor), a small number of fresh pig tracks were observed on site once the trials stopped. That is, the eradication of these pigs was not complete by the end of the 13-day formal poisoning period (1080 bait remained *in situ* after this period at the landholder's request). However, there was little evidence of feral pig activity when the site was reinspected some 5 months later (March 2006).

The consumption of malted barley, and wheat versus pellets, and that of surface versus buried wheat were also compared in the East Nabawa region (Wicka Sites 1–3: Fig. 5). Both malted barley (t = 5.170, d.f. = 15, $P < 0.001$; grand means, malted barley 89% (s.d. = 27%), pellets 40% (31%)) and wheat (t = 4.37, d.f. = 9, P = 0.002; grand means, wheat 100% (0%), pellets 58% (31%)) were preferred over pellets. Both these grains were also effective in removing resident pigs, although the outcome with malted barley at Site 1 was more variable (Fig. 5). This probably resulted from the presence of several mobs (3+?), and because it took several days before all pigs had



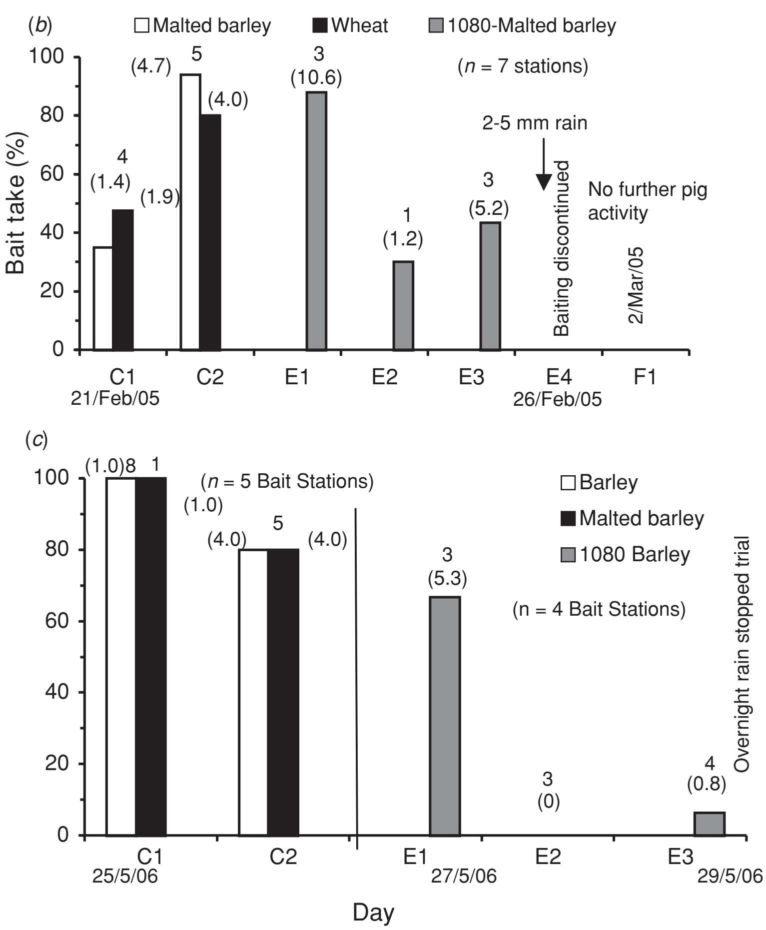


Fig. 3. The mean consumption of a variety of baits by feral pigs in the Greenough region of Mediterranean Western Australia. (*a*) Wheat versus lupins, and the effectiveness of 1080-wheat at the Desmond site. Note that Day E3 was 1 kg unpoisoned wheat only per raked plot because we believed all pigs had been removed by this time. Poison-baiting recommenced for Day E4. (*b*) Malted barley versus wheat, and the effectiveness of 1080 malted barley at the Blayney site. (*c*) Malted barley versus plain barley, and the effectiveness of 1080 barley at the Rowe site. Internal numbers and parentheses as for Fig. 2. Overnight rain curtailed baiting at two sites (*b* and *c*). Abbreviations as for Fig. 1.

Table 2. The demographics, and distance from active bait stations, of poisoned feral pigs found after baiting with 1080-treated grain in the Mediterranean agricultural region of Western Australia

Date	Site	Bait	*n*	Males/ females (unknown)	Adults/ non-adults[A]	Weight (kg) Adults Mean	Min.	Max.	Non-adults Mean	Min.	Max.	Distance (m) Adults Mean	Min.	Max.	Non-adults Mean	Min.	Max.
October 2003	Culford	Lupins	4	3/1	4/0	47.5	35	65				115.0	30	180			
October 2003	Yarder Creek	Buried wheat	2	1/1	1/1	70			20			50			40		
June 2004	Desmond	Wheat	19	10/8 (1)	12/7	50.0	30	90	16.4	15	20	119.0	16	258	92.1	23	202
February 2005	Blayney	Malted barley	1	1/0	1/0	25.0						1040					
July 2005	Broad	Lupins	1	Unknown	1/0	~65						175					
September 2005	Kupsch	Wheat	6	4/2	0/6				15.7	10	22				153.3	100	250
March 2006	Wicka Site 1	Malted barley	6	1/3 (2)	2/4	65.0	65	65	19.0	10	23	222.0	220	224	177[B] 3501[C]	 177[C]	 4897[C]
March 2006	Clune	Barley	37	12/25	24/13	42.4	25	85	12.7	8	20	147.9	32	300	97.9	60	158
May 2006	Wicka Site 2	Wheat	10	6/4	3/7	45.0	30	55	4.6	4	6	120.3	103	139	109.3	106	114
May 2006	Rowe	Barley	4	1/3	2/2	42.5	30	55	5.0	5	5	100.8	77	125	29.4	27	32
	All sites		88/90[D]	39/47 (4)	50/40	46.3	25	90	12.8	4	23	154.3	16	1040	105.2[B] 460.7[C]	23[B] 23[C]	250[B] 4897[C]

[A]Adult pigs, ≥25 kg; non-adults, <25 kg.
[B,C]Without [(B)] and with [(C)] the extreme distance travelled by three non-adult pigs before they succumbed (4858, 4070, 4897 m).
[D]Demographic/distance measurements were available for 88 of 90 pigs.

fed at the 1080-bait stations. Three track plots were established at Site 2, but we were unable to establish meaningful track plots at Site 1. At Site 2, the proportion of plots with pig visits before 1080-baiting was 0.89 (s.d. = 0.19, $n = 3$ days × 3 plots) and this reduced to 0.50 (0.50, $n = 2$ days × 3 plots) by Days 1–2 after baiting, and 0.06 (s.d. = 0.10, $n = 6$ days × 3 plots) by Days 3–8 after baiting. This provides additional evidence that 1080-grain was effective in removing localised resident pigs. Kangaroos were not recorded on the track plots at any stage.

Feral pigs at the Wicka Site 3 consumed more surface wheat than lightly buried (covered) wheat, but this preference did not persist by Day C5 (Day 5 of the choice trials, see Twigg *et al.* 2005*a*) (Fig. 5*c*), suggesting that these feral pigs ultimately recognised buried grain as food. The paired *t*-test was: $t = 3.138$, d.f. = 15, $P = 0.007$ (grand means, surface wheat 86% (s.d. = 34%) of bait offered, buried wheat 49% (50%)). Despite the above preference, the effectiveness of buried 1080-wheat was tested at Site 3. Lightly buried 1080-wheat was effective and seemed to remove all localised pigs (Fig. 5*c*). One-track plot (no bait material) was included at Site 3, and before 1080-baiting feral pigs tracks were recorded on both of the days monitored (>5 tracks per plot). No pig tracks were recorded after the take of 1080-wheat had ceased ($n = 2$ days).

Routine baiting trials

Because some landholders needed immediate respite from pig-damage, and to test our procedures under standard operational conditions, 1080-baiting was undertaken at some sites

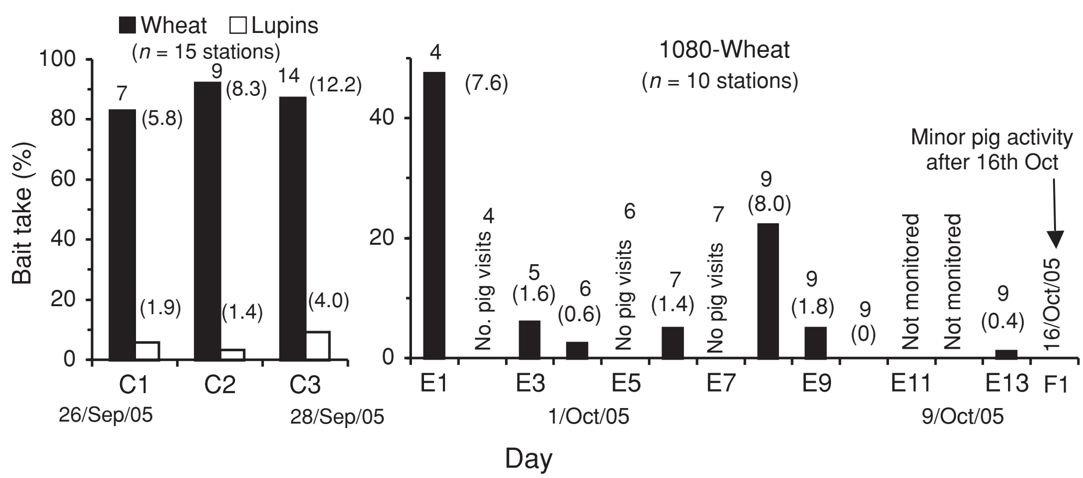


Fig. 4. The mean consumption of unpoisoned wheat and lupins, and 1080-treated wheat, by feral pigs in the East Nabawa (Kupsch site) region of Mediterranean Western Australia. Internal numbers and parentheses as for Fig. 2. Abbreviations as for Fig. 1.

according to the directions-for-use in Western Australia (see Materials and methods). Prefeeding took place for 1–7 days. Plain barley treated with 1080 proved highly effective in reducing pig numbers at the Clune site (Geraldton region) with over 37 pigs being killed in one night using two bait stations and ~18 kg of 1080 bait (Fig. 6). Very little pig activity occurred after this time, and the landholder reported no further pig activity 3 weeks after poison-baiting took place. In two other of these tests, 1080 on malted barley or lupins gave good localised control of feral pigs (Fig. 7). However, at a fourth site, and where prefeeding was conducted for only 1 night, 1080-lupins were less effective in reducing pig numbers (activity) (Fig. 7*c*). This outcome is interesting because the feral pigs at the two sites baited with 1080-lupins were dam-

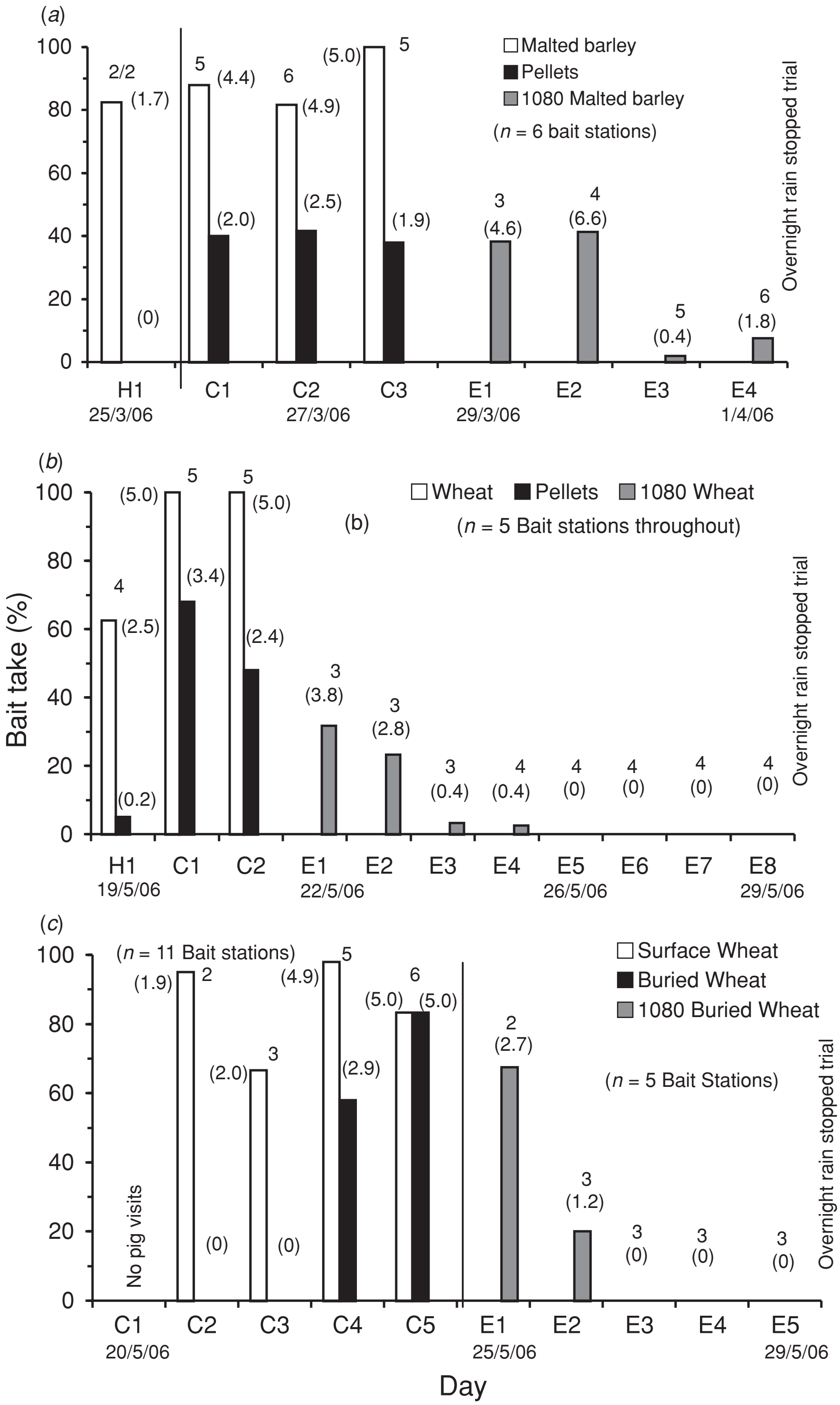


Fig. 5. The mean consumption of a variety of baits by feral pigs at the three independent sites on Wicka Farm near East Nabawa in the Mediterranean agricultural region of Western Australia. (*a*) Site 1, March 2006, malted barley versus pellets. (*b*) Site 2, May 2006, wheat versus pellets. (*c*) Site 3, May 2006, surface versus buried wheat. Internal numbers and parentheses as for Fig. 2. Abbreviations as for Fig. 1; H1, Day 1 of the habituation period.

aging pulse crops, including lupins. It also reinforces our finding of the variability in response to lupins by some feral pigs (Fig. 4).

Recovery of carcases

Ninety pig carcases were found after the baiting trials with 1080-treated grain in the Mediterranean region of WA. These pigs included male (45%) and female (55%), and adult (56%) and non-adult pigs (44%). The estimated weights of the poisoned pigs found ranged from 4 to 90 kg, with several pigs in the 40–70-kg range (Table 2). Of the adult pigs, 21 (42%, or 23% of all pigs found) were 50 kg or heavier, and only 32% of adults were 30 kg or less. The relationship between HBL (cm) and bodyweight (kg) was: HBL = 29.83ln(x) + 3.94 (R^2 = 0.94, n = 64) (also see Twigg *et al*. 2005*a*, fig. 9). The stomachs of all dead pigs found contained bait material (usually considerable quantities) and, in most instances, the stomachs also contained large quantities of other food, which made any assessment of the amount of bait ingested unrealistic.

Although distances were variable, on average, feral pig carcases were found within 200 m (range 16–1040 m) from the nearest bait station from which poison-bait was consumed (Table 2). This excludes three 20–23-kg subadult pigs that were found over 4 km from the closest bait stations (Table 2). The remote-sensing camera photographs indicated that these pigs formed part of a subadult group comprising ~12 similar-sized individuals. Excluding the three 'outliers', the mean distance travelled by adults (154 ± 146 (s.d.) m) and non-adults (105 ± 53 m) before they succumbed was marginally non-significant (ANOVA: F = 3.61, d.f. = 1,83, P = 0.061) (Table 2). Other feral pigs were also believed to travel some distance to feed at some bait stations. These observations, together with the remote-sensing camera photographs, indicated that not all poisoned pigs were found. Despite this, many pigs did succumb quite close to the active bait stations (Table 2).

Vomiting and poisoned pigs

The only major incident of vomiting following the use of 1080-baits occurred in 6 young pigs (10–22 kg) at the Kupsch site in 2005. These pigs had eaten most of the 1080-wheat bait from two adjacent bait stations (equals 2 × ~4 kg of 1080 wheat, enough to kill over 25 medium-sized adult pigs). Several small piles of vomitus (~10–30 g) were found in the bush area where the poisoned pigs were found, and also close to two of the carcases. The vomitus content ranged from ~100% wheat (poison bait material) to 50% wheat plus 50% green immature lupin crop. All dead pigs still had considerable food in their stomachs. No other incidents of vomiting were recorded during the conduct of the Kupsch trials.

Excluding the 2005 incident at Kupsch's, there were only two other minor instances where vomitus was found. Two small piles (~10, ~35 g) were recorded during 2003 Yarder Creek trials, and similar amounts were found during the 2006 Wicka Site 2 trials. Interestingly, all three vomiting incidents involved 1080-wheat bait.

Non-target species

Although kangaroos, some birds, foxes and rabbits (*Oryctolagus cuniculus*) were recorded near the raked-earth plots, there were few occasions where identifiable amounts of bait were taken by these species. Kangaroos, foxes and rabbits occasionally consumed the fermented wheat and malted barley. Where this occurred, 10–100% of the fermented wheat (usually 100 g), and ~10% of the malted barley (1 kg on offer), was consumed. Six foxes were poisoned by the 1080-treated grain (malted barley: Greenough (n = 2) and East Nabawa (n = 2); wheat: East Nabawa (n = 2)). The foxes were found within 50–100 m of an active bait station with bait in their stomachs. Some native birds (e.g. magpie-larks, *Grallina cyanoleuca*; Australian ravens, *Corvus coronoides*; common bronze-wing pigeons, *Phaps chalcoptera*) scattered the bait on occasion but there was little evidence that any bait was actually consumed at these times. Some parrot species very occasionally dehusked small amounts of grain. Despite considerable search time for the carcases of poisoned pigs, and aside from the six foxes, no other non-target species, including native species, were found poisoned during the trials.

Early bait trials in south-western Western Australia (1986–87)

Feral pigs in the Donnybrook region showed a significant (P = 0.002) preference for the non-toxic oat-bait during the three-way choice trials (Table 3) in this Mediterranean region.

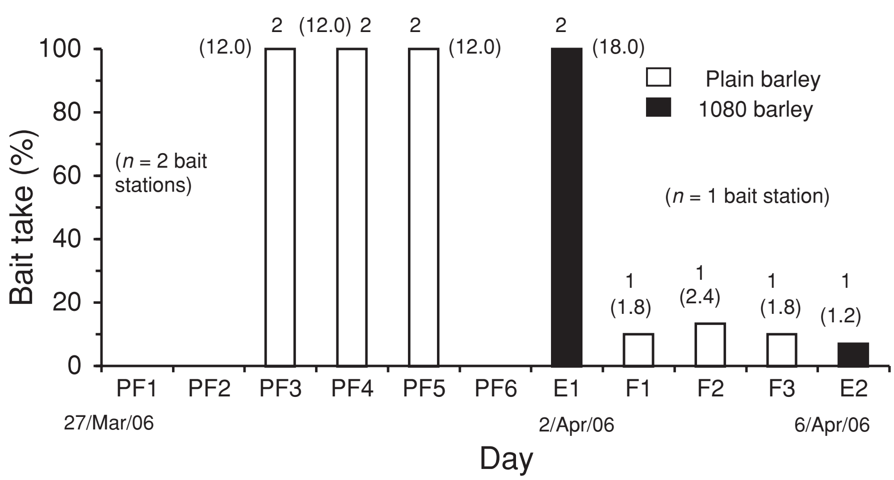


Fig. 6. Consumption of unpoisoned (prefeed, PF), and 1080-treated barley by feral pigs at the Clune site in the Geraldton region of Mediterranean agricultural Western Australia. Internal numbers and parentheses as for Fig. 2. Abbreviations as for Fig. 1; PF1–PF6, Days 1–6 of prefeeding.

Tukey *post hoc* HSD tests indicated that oats were consumed in greater amounts than pellets (P = 0.001), but the consumption of oats and wheat (P = 0.096), and wheat and pellets (P = 0.314) was similar. Further, two-way choice trials, using the same methodology, at other localities near Donnybrook also showed that these pigs consumed non-toxic oats and wheat in similar amounts (mean and s.d.: oats, 65% (s.d. 27%) and wheat 60% (27%) of bait on offer; ANOVA, F = 0.23, d.f. = 1,38, P = 0.64). The consumption rates of non-toxic pellets, oats, and wheat by feral pigs during the 3-way choice trials in the Nannup region were similar to those recorded at Donnybrook. Average bait consumption was 67%, 78%, and 72% of bait on offer for pellets, oats and wheat respectively (P = 0.089) (Table 3).

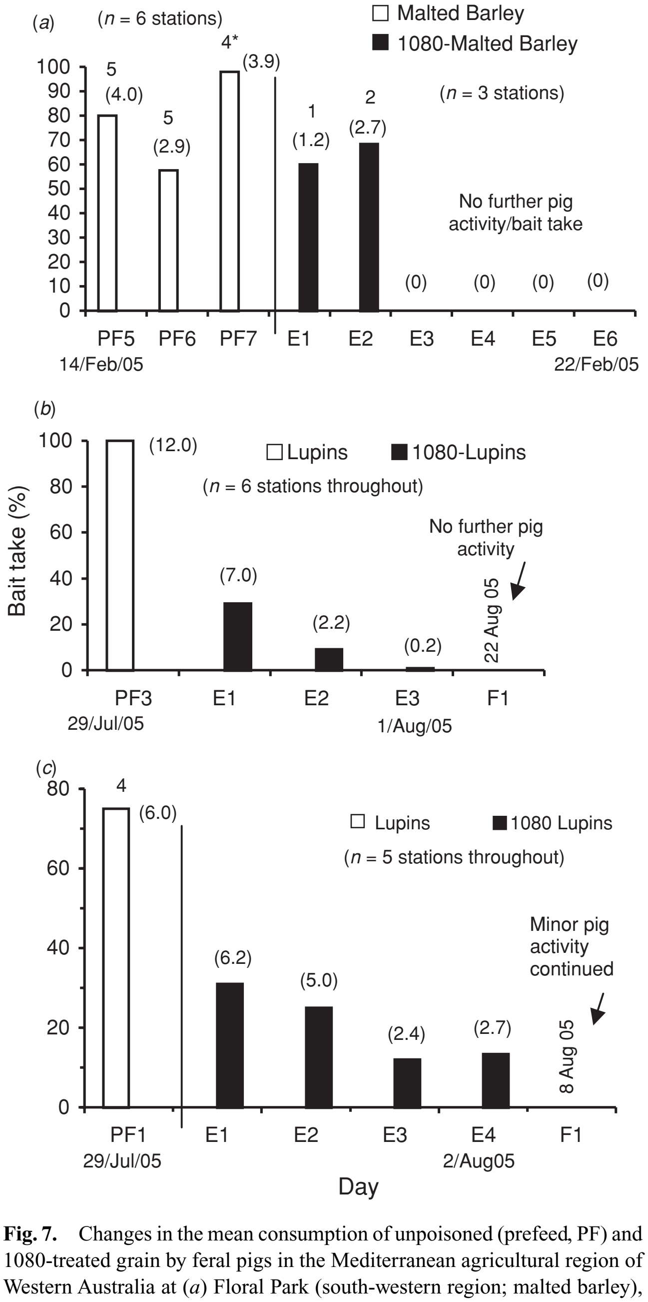


Fig. 7. Changes in the mean consumption of unpoisoned (prefeed, PF) and 1080-treated grain by feral pigs in the Mediterranean agricultural region of Western Australia at (*a*) Floral Park (south-western region; malted barley), and (*b*) Broad and (*c*) Gillam (mid-western region; lupins). 1080-baiting (4 kg per station) was preceded by a prefeeding period (PF) with the relevant non-toxic bait material, and fermented wheat (~200 g per station) and blood and bone (~50 g) as attractants. Internal numbers and parentheses as for Fig. 2, but one bait station was discontinued during the prefeed period at Floral Park (*). Abbreviations as for Figs 1 and 6.

Discussion

The field observations when establishing the trials in the Mediterranean agricultural region of Western Australia indicated that the abundance, and possibly the distribution, of feral pigs in this region were not as great as previously suggested. Considerable effort was made to find suitable research sites over the life of the project (~3 years). Of the 66 formal farm/landholder visits/contacts in this region, only 14 (21%) were found to be suitable. Most sites were rejected mainly on the basis of low or no pig activity/numbers, and occasionally because of the potential for unauthorised interference with the trial sites, or the associated landholders did not wish poisons to be used. Feral pig activity was most evident in this Mediterranean agricultural region in autumn and early winter, probably because water and food resources become less abundant at these times and pigs need to travel further in search of food. Further, feral pigs in this region were not always associated with those areas traditionally accepted as prime pig habitat (e.g. creeks, swamps, riparian habitat). There were several instances where they were also associated with breakaways that were a considerable distance from the areas of 'traditional' pig refuge habitat. These breakaways were generally relatively elevated, and their use probably helped to maximise the cooling effect of sea-breezes, particularly during the summer months. Feral pigs appeared to leave these shelters in the late afternoon, travel to their watering points (usually at creeks, dams, troughs, swamps) and then travel to their feeding areas, which were often considerable distances from both the shelter and watering sites. Such behaviour requires confirmation by a telemetry/GIS-based study, but, if confirmed, this behaviour/habitat use by feral pigs would need to be allowed for in both routine control strategies and wildlife disease contingencies.

The main objective of our study was to determine the best baits, and baiting methods, for controlling feral pigs in a Mediterranean climate/habitat with mixed agricultural enterprises. However, for the above reasons, the areas baited were usually restricted to a single property during each trial, and we often had difficulty in estimating the total numbers of feral pigs present. This, together with the distances some pigs seemed to travel to feed, meant that we were not able to determine efficacy in the traditional sense where changes in abundance before and after baiting are used (i.e. efficacy could not be determined at the regional/landscape scale). Nevertheless, as supported by our follow-up monitoring, we were generally able to achieve good medium-term reductions in pig numbers/activity at the local scale with most selected baits. Provided pig control could be coordinated across several properties, a difficult task given the differing values and attitudes towards the pest status of feral pigs, our techniques could be successfully employed at the broader landscape level. 1080-treated malted barley or wheat were certainly successful in reducing pig numbers by ~90% over a relatively large area (~15 000 ha) in the Kimberley (Twigg *et* *al*. 2005*a*, 2006), and the use of grain baits has also been successful in reducing pig numbers in regional New South Wales and the Australian Capital Territory (McIlroy *et al*. 1989; Saunders *et al*. 1990; Choquenot *et al*. 1996).

The poor and varied acceptance of commercial pig pellets and lupins, respectively, and the ready acceptance of fermented wheat, wheat, and malted barley as food items by feral pigs in the Mediterranean agricultural region is consistent with that found for feral pigs in the tropical Kimberley region of WA (Twigg *et al*. 2005*a*, 2006). This suggests that the latter are likely to be universally acceptable baits. Moreover, at an identical dose (4.34 mg 1080 kg^{-1}), 1080-treated pellets resulted in lower mortality (28%) in captive feral pigs than did 1080-wheat (60%; $n = 40 \times 2$) (O'Brien *et al*. 1988), further emphasising that commercial pig pellets are unlikely to prove efficacious against most feral pigs. We can offer no suggestions as to why the acceptability of lupins was so variable, particularly as, in some instances, resident pigs were known to be feeding on maturing lupin crops when baiting took place. Our fermented wheat (with blood and bone) looksee procedure seems ideal for attracting feral pigs, and for determining areas of pig activity. This technique would be suitable for use during poison-baiting or trapping programs alike (also see Saunders 1988). Oats and plain barley also seem to be acceptable foods (bait) to feral pigs (Table 3, Fig. 6). However, the addition of a small amount of non-toxic grain to mask the presence of 1080 did not improve the consumption of toxic bait, and we recommend against using this practice as it provides no apparent benefit.

In the Mediterranean agricultural region of WA, the body mass of adult pigs found after baiting with 1080-treated grain ranged from 25 to 90 kg, with 42% of these individuals being 50 kg or heavier. Thus, as found for other grain-based control programs that utilise prefeeding (McIlroy *et al*. 1989; Saunders *et al*. 1990; Choquenot *et al*. 1990, 1996; Twigg *et al*. 2005*a*), our baiting techniques were successful in removing large pigs. Such an outcome may not always be the case with 1080 meat-based control programs, where there is some concern regarding the bioavailability of 1080 in meat (M. Gentle, J. McIlroy, personal communication; Twigg *et al*. 2005*a*), and the ability of pigs to readily find baits where prefeeding is not undertaken (Hone and Pedersen 1980; Mitchell 1998; Mitchell and Fleming 1998; Twigg *et al*. 2005*a*).

As found in the tropical rangelands of northern Western Australia (Twigg *et al*. 2005*a*, 2006), 1080-poisoned pigs in the Mediterranean region of WA were often found close to active bait stations (mean, <200 m). These distances are also similar to those travelled by 1080-poisoned feral pigs in western New South Wales, although pigs were occasionally found up to 1 km from active bait stations (O'Brien and Lukins 1988). In the Mediterranean agricultural region of WA, some pigs also appeared to travel relatively large distances (>10 km) to feed at the bait stations. This, together with the difficult terrain that needed to be searched, and as supported by the remote-sensing camera photographs (which identified the number of pigs feeding at a bait station) meant that not all poisoned pigs could be found. The Western Australian Mediterranean agricultural region provides a mosaic habitat including domesticated pastures, crops, rivers and creeks, abundant remnants of dense native vegetation, reserves, and a range of agricultural and horticultural enterprises. For reasons that are not clear, and irrespective of habitat type, feral pigs in this region were more prevalent in some areas than others. There was no obvious indication of the driving forces for this although differential hunting/control pressure is likely to be involved in some instances. Some areas also seemed to be used as 'pig highways', with several mobs frequenting the same relatively small area(s). Such findings have implications for operational control, and for any exotic disease contingency involving feral pigs, and investigation of the spatial behaviour of feral pigs in this environment would be worthwhile.

Although western grey kangaroos and granivorous birds were present at most sites, there were few instances of toxic bait take by any native non-target species, and where this occurred it was in quite small amounts. In contrast to pig tracks, the frequency of kangaroo tracks on the established track plots also remained unchanged or actually increased during the 1080-baiting period. However, on occasions, some kangaroos (likely western greys) did consume fermented wheat but ate little of the other baits present at this time. Some birds also occasionally scattered the bait, but there was little evidence that they actually consumed significant amounts of bait. In contrast, several species of birds were observed to feed on non-toxic wheat placed at bait stations in the forested environment of the Namadgi National Park, Australian Capital Territory (McIlroy *et al*. 1993). At least six

Table 3. The mean consumption of pellets, oats and wheat by feral pigs during non-toxic bait choice trials undertaken during 1986–87 in the Mediterranean agricultural region of south-western Western Australia

Bait was placed on bare ground in piles of either 7, 14 or 21 kg, with ~2 m between piles

	Donnybrook	Nannup
No. of sites (observations)[A]	24 (558)	13 (258)
Mean no. of times monitored (range)[B]	7 (2–16)	7 (2–12)
Proportion consumed		
Pellets (mean ± s.d.)	0.59 ± 0.38	0.67 ± 0.37
Oats (mean ± s.d.)	0.74 ± 0.29	0.78 ± 0.33
Wheat (mean ± s.d.)	0.65 ± 0.34	0.72 ± 0.35
ANOVA	$F = 6.23$, d.f. = 2,555, $P = 0.002$	$F = 2.44$, d.f. = 2,255, $P = 0.089$

[A]$n = 186$ bait nights × 3 bait types at Donnybrook, and $n = 86$ bait nights × 3 bait types at Nannup.

[B]The number of times that individual sites were monitored during the study. This does not necessarily correspond to consecutive nights, as bait take was not always monitored after one night's feed.

foxes were also poisoned with 1080-treated grain during our trials (4 with malted barley, 2 with wheat).

We had only one major incident where 1080-poisoned pigs were known to have vomited, and this involved 6 young pigs in the 10–22-kg range. These pigs had consumed most of the bait from two bait stations, and we believe this vomiting episode was linked to excessive feeding which resulted in toxin overload. There were only two other minor incidents of vomiting recorded during the remainder of our trials in the WA agricultural region, and vomiting was not recorded during our 1080-baiting trials in the Kimberley (Twigg *et al*. 2005*a*, 2006). It is interesting that all three vomiting events involved wheat bait and relatively young pigs. 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), but it may represent a potential hazard to non-target species in some situations (McIlroy 1983; O'Brien 1988; O'Brien and Lukins 1988). However, our findings suggest that extrapolation of the frequency of vomiting as seen during captive-pen trials to the field is likely to overestimate the frequency of the field-occurrence of this phenomenon. Given the generally low occurrence of vomiting by 1080-poisoned pigs in the wild, it is also possible that some natural foods may have anti-emetic properties (Twigg *et al*. 2005*a*).

Although lightly buried bait was consumed in lower amounts by feral pigs than surface-placed bait, buried bait seemed to be efficacious. However, the increased effect of microbial action on buried grain bait would need to be determined before this practice could become standard operational procedure. Such degradation could ultimately result in the ingestion of sublethal amounts of bait. Several soil bacteria are capable of rapidly degrading 1080, and buried meat baits used for wild dog and fox control are known to have reduced longevity (Saunders *et al*. 2000; Twigg *et al*. 2000; Twigg and Socha 2001). The effectiveness of buried pig bait would also need to be tested in other regions before it became standard practice. Given our concerns regarding bait longevity, we suggest that buried bait should be used only as a last resort where there are potential concerns regarding non-target species that cannot be rectified by other means.

Feral pigs were regularly seen to intermingle with cattle during our previous trials in the tropical rangelands of northern Australia (Twigg *et al*. 2005*a*). Similarly, feral pigs in the Mediterranean agricultural region of WA were also seen intermingling with domestic livestock, and/or drinking from the same water supply (dams, windmills, soaks). This has implications for wildlife disease management, including exotic disease contingencies. Given the relatively quick knockdown generally obtained with our baits and baiting procedures (also see Twigg *et al*. 2005*a*, 2006), and although we do have some caveats (see below), these baiting procedures could be equally applied to both routine operational control programs, and during an exotic disease emergency involving feral pigs. The 5–10 days required to reduce pig abundance is within the range believed to be required for disease containment (e.g. foot and mouth disease: Hone and Bryant 1981; Pech and Hone 1988). However, given the difficultly we often had in finding poisoned pigs in the agricultural region, we suggest that some other means (e.g. shooting, use of tracker dogs, sentinel pigs) may also be needed to enable adequate disease surveillance. Poisoned pigs were considerably easier to find in the Kimberley region (Twigg *et al*. 2005*a*, 2006).

On the basis of our trials in Western Australia, we believe that wheat and malted barley, plain barley, and possibly oats would be the best baits for grain-based control programs for feral pigs (Twigg *et al*. 2005*a*, 2006). This includes both poison-baiting and trapping programs. With poison-baiting, the 1080-residues in the tissue of poisoned-pigs are low and represent minimal or little risk to native non-target scavengers (Twigg *et al*. 2005*b*). Because of their relatively large size and hard testa, lupins may also provide an alternative bait in places where there are potential concerns regarding non-target species, provided they are an acceptable food to feral pigs. Unfortunately, both in the northern rangelands and the agricultural region of Western Australia, lupins were not universally accepted as food, so adequate take of prefeed would need to occur before poison-baiting could be undertaken. Commercial pig pellets were generally consumed only in relatively low amounts and we do not recommend their use. The potential risk to non-target species from our recommended baits and baiting procedures is likely to be low and easily manageable. Additional precautions, such as covering bait with small twigs, lightly burying bait, or using lupin bait if possible, could also further reduce any potential risk if required. Covering bait with forest litter or soil does not reduce its take by feral pigs (McIlroy *et al*. 1993; Twigg *et al*. 2005*a*).

The estimated cost of our baiting strategy in the northern tropical region was ~\$225 per station or ~\$27–34 per poisoned pig (see Twigg *et al*. 2005*a*), and this would be expected to increase only marginally in the agricultural region. We do, however, have the following caveats (Twigg *et al*. 2005*a*): (1) key areas of pig activity need to be identified; (2) raked-earth plots should be used to enable determination of those species taking bait; (3) adequate prefeeding is essential to obtain good efficacy; (4) a small amount of fermented wheat with blood and bone should be used as attractants; (5) follow-up monitoring should be undertaken to assess when poison-baiting should cease; (6) domestic livestock need to be excluded from bait stations/baited paddocks; (7) other control options (e.g. shooting) may need to be employed to ensure that all pigs have been destroyed; (8) as malted barley is no longer fertile it can be used in areas of high conservation value where there are concerns regarding germination and establishment of the other grain baits; and (9) where possible, control programs need to be implemented at the landscape scale (can be difficult in some agricultural regions). We are not suggesting that poison-baiting with grain is the only method for controlling feral pigs but, rather, that it can provide a valuable control option in most circumstances provided directions for use are followed, and a commonsense approach is used to minimise any potential for detrimental impacts upon non-target species. Well conducted, coordinated feral pig control programs provide potential benefits to agricultural production, disease containment, and the environment (Mitchell 1998; Choquenot *et al*. 1996; Twigg *et al*. 2005*a*, 2006). In the first instance, control programs would be best directed at preferred pig habitats during times when food and/or water resources become limited (e.g. autumn in the Mediterranean agricultural regions, mid/end of dry season in tropics).

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