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Journal

Proceedings of the Vertebrate Pest Conference, 21(21)

ISSN

0507-6773

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Publication Date

2004

Ecology, Genetics and Socio-Biology: Practical Tools in the Design of Target-Specific Feral Pig Baits and Baiting Procedures

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ABSTRACT: Feral pigs occupy 40% of Australia along with numerous other countries. They cost Australian agriculture greater than AUD$100 M annually through stock predation and crop, pasture, and infrastructure damage. Broad-scale, integrated poisoning campaigns, predominantly using Compound 1080, are the most practical and cost-effective control method in Australia. However, the lack of a target-specific toxicant and bait for feral pigs means that baiting campaigns can place non-target species at risk. Confounding this is the wide distribution and diet of feral pigs in Australia, which means that no current single bait is effective for all feral pigs. A potential solution to this problem is to use the known ecology, genetics, and socio-biology of feral pigs in different habitats to design bait(s) with increased target specificity, then combine this with habitat-specific operating procedures inferred from ecological and genetic studies to reduce non-target exposure. This process is currently underway in Australia. Habitat-independent characteristics of feral pigs that can be used to develop target-specific baits are their large size and strong jaws, their keen sense of smell, their poor vision, their omnivorous diet, and their nocturnal and fossorial nature. Producing large, tough, odorous, dyed (to deter birds), meat and vegetable (to deter obligatory carnivores or herbivores) baits that are laid at night and buried where possible will make feral pig baits more target specific and reduce non-target exposure. Current pen and field trials of bait prototypes in a range of habitats are confirming this. Appropriate baiting regimes for feral pigs in different habitats, as determined through ecology and genetics and subsequent field trials, are presently being determined and transformed into standard operating procedures to lessen non-target exposure. The planned incorporation of more target-specific toxins or 'Achilles Heel' approaches in the future should further increase the target specificity and humaneness of broad-scale feral pig control. This protocol can potentially improve target-specificity of baits and baiting procedures for other pest animals.

KEY WORDS: 1080, bait, feral pig, genetics, pig control, socio-biology, *Sus scrofa*

Proc. 21st Vertebr. Pest Conf. (R. M. Timm and W. P. Gorenzel, Eds.)
Published at Univ. of Calif., Davis. 2004. Pp. 317-322.

INTRODUCTION

Australia's feral pig (*Sus scrofa*) population is estimated at 3.5 to 23.5 million (Hone 1990) with the species inhabiting near 40% of mainland Australia (Choquenot et al. 1996). Feral pigs occupy a wide range of habitats from semi-arid rangelands to sub-alpine forests and rainforest. The species is a significant pest to Australian agriculture, public health, and ecosystem integrity. Direct costs to agriculture are through lamb predation; damage to grain, sugarcane, fruit and vegetable crops; competition with livestock for pasture and pasture damage; being a disease vector of endemic and potentially exotic diseases; and infrastructure damage of water sources and fences. Environmental damage caused by feral pigs is through habitat degradation via their rooting and wallowing behaviours, transmission of soil-borne diseases and weeds, predation of and competition with native animals, and fouling water sources (Choquenot et al. 1996).

Control of feral pigs is generally time-consuming and ad-hoc. Broad-scale and integrated baiting campaigns are the most cost-effective method for reducing feral pig populations across large areas (Choquenot et al. 1996). For this purpose, sodium fluoroacetate (Compound 1080) in grain, meat, or vegetables is used in approximately 75% of baiting campaigns, and CSSP (4% yellow phosphorus dissolved in carbon disulphide in molasses) is used on carcases in 25% of campaigns throughout New South Wales and Queensland. Current problems for land managers with feral pig baiting are: the labour-intensive requirement to prepare grain (fermented in Queensland), vegetable, or diced meat baits (sodium fluoroacetate) or find carcasses (CSSP); the reliance of graziers on government land protection officers to provide 1080 in remote areas; the difficulty in delivering sufficient toxin to pigs and the potential suite of non-target species that may be at risk, given the very large doses of toxins that are involved; limitations imposed on pig control techniques (through environmental protection legislation); and the present review of 1080 and CSSP by the Australian Pesticides and Veterinary Medicine Authority (APVMA), with the outcomes of these reviews being uncertain. This paper discusses current research into a commercial feral pig bait that is aiming to address such problems and provide land managers with an effective, consistent, safe, and reliable product with which to undertake feral pig control.

Recent advances in molecular biological approaches have had an enormous impact on our understanding of population dynamics; however, molecular ecological data have not been widely used in pest animal species management. As a combination of genetic, behavioural, and demographic data are becoming more widely used in such studies, they will have important benefits in understanding feral pig ecology, which is often difficult and costly to elucidate using classical field-based methods such as mark and recapture or telemetry studies. Data obtained using such approaches will give estimates of what individuals do in the population in general, but far more important is to understand the behaviour of the 'non-conforming individuals' (those individuals that do not behave like the population as a whole). Such data are therefore relevant to both management practices, in terms of standard operating procedures that target the population as a whole rather than the population in general, and for exotic disease outbreak preparedness.

The integrated approach to feral pig control described in this paper– one involving ecology, genetics, socio-biology, ethology, morphology, physiology, and importantly, industry– has the aim of re-examining the efficacy, target-specificity, and humanness of feral pig control in Australia. This paper reports on work in progress towards achieving this aim.

METHODS

Ecology

Feral pig ecology in Australia has been well studied, with Choquenot et al. (1996) providing an excellent overview of the findings, along with more recent publications (i.e., Hone 2002). This research was used as the basis for ecological information required for the current study, along with additional information gathered during field exercises discussed below.

Genetics and Socio-Biology

A large-scale molecular ecology study was undertaken in February 2003 on 33 pastoral properties comprising a total area of 4,430 km^2 near the town of Cunnamulla (Noorama area), in Queensland, Australia (S 28° 29', E 146° 16'; Figure 1). The study was recently repeated in February 2004 in the same area; however, genetic analysis is yet to be conducted. The local feral pig population was free-ranging and previously subjected to at least two years of integrated aerial baiting with 1080 meat baits.

Feral pigs were shot from a Robinson Beta II helicopter by a skilled aerial marksman (Department of Primary Industries, Queensland), and their Global Positioning System (GPS) locations recorded. Ground crews located and sampled shot pigs within 2 hrs of death. The weight, sex, age, and reproductive condition were recorded for each pig. A 1-cm^3 piece of liver (in 100% ethanol) was collected from each animal for genetic analysis. Feral pigs were considered to be sexually mature once they had reached 25 kg (Choquenot et al. 1996).

Complete genotypes were generated for 122 feral pigs (55 adults, 67 juveniles) using 13 polymorphic microsatellite loci that have been shown to be highly informative for *S. scrofa* (Lowden et al. 2002). Genetic analysis was carried out at Murdoch University, Western Australia, under the guidance of P. B. S. Spencer. Where possible, maternity, paternity, and relatedness of all feral

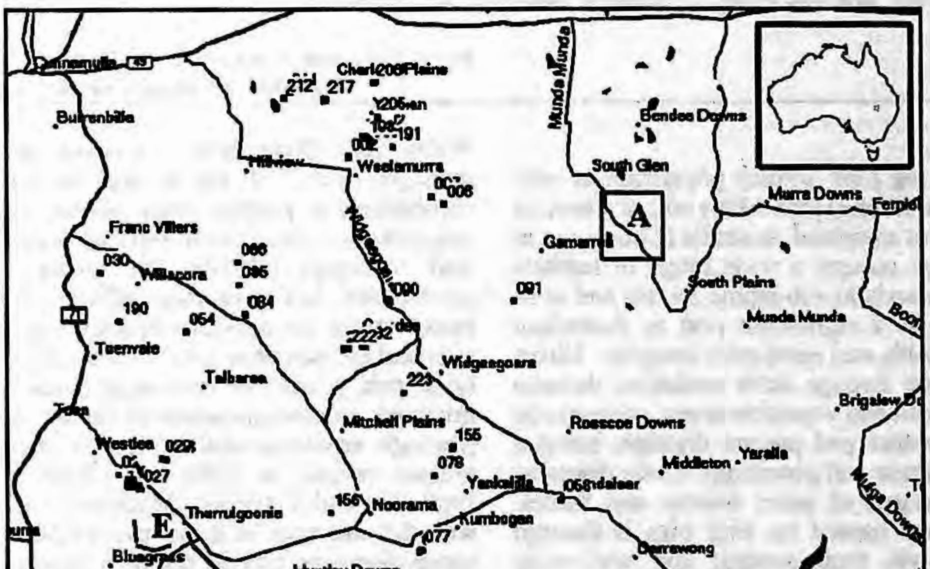

Figure 1. Location of Noorama area used for molecular ecology studies and feral pig bait trials in Australia. Numbers indicate GPS locations of shot feral pigs. Letters and boxes indicate sites of bait testing. Site A was baited around waters, site B on a grid pattern, site C a combination of grid and waters, site D contained triple-biomarked control baits and site E, the only site where feral pigs were not culled, was the location of target and non-target species bait transect trials.

pigs shot and in-utero foetuses were assessed genetically.

Socio-biology of feral pigs in the Noorama area was inferred from a combination of geographic (location where shot and with whom), demographic (age, mass), and genetic (parentage, relatedness) data. The detailed method and results generated are currently the subject of submitted journal articles and as such only management implications from the results will be discussed herein.

Bait Development

O'Brien (1986) proposed a framework for the design of a target-specific feral pig bait, based on socio-ecological differences between feral pigs and other species inhabiting the same range as feral pigs that may be exposed to baits during pig control exercises. O'Brien (1986) recommended that a feral pig-specific bait should be large, tough, odorous, dyed (to deter birds), meat and vegetable based (to deter obligatory carnivores or herbivores), laid at night, and buried where possible to minimise non-target species exposure while detracting little from the bait's effectiveness for feral pigs. This research culminated in the design and initial testing of a grain sachet pig bait before the project finished. This was used as the starting point for the current project. However, rather than a grain sachet bait, a 250-g grain-based sausage bait with odorous attractants has been developed, based on the fact that feral pigs are opportunistic omnivores with preferences for green vegetation, animal material, and fruit, as well as grain (Giles 1980).

Seven bait prototypes containing different substrates and attractants were developed by Animal Control Technologies Pty. Ltd. and trialled against two controls on captive feral pigs at the Robert Wicks Pest Animal Research Centre in Queensland to ascertain bait acceptability and preferences. Controls were fresh meat and whole wheat, as these are the two most commonly used bait substrates for pig control exercises. Four adult boars, 4 adult sows (all >25 kg), 3 sub-adults (10 - 25 kg) of each sex, and two piglets (<10 kg) of each sex were individually housed in pens (5 × 2 m). Pigs were placed in enclosed hutches at the end of each pen (1 × 2 m) whilst two baits were positioned at the far end of each pen. Hutches were then opened and the time was recorded until each bait was chosen (as indicated by most or all of the bait being consumed). Baits were randomised by type and position until all animals had been trialled with all baits. Individual pigs were fed their normal diet throughout the trials so that bait choice was not influenced by starvation. The three most promising prototype baits from pen trials and the two controls were subsequently repeat tested in paddock trials (100 m^2) whereby pigs had access to native vegetation and habitat. The five baits were placed in an equidistant arc from the point of entry, and 1-16 pigs were released into the paddock and allowed to forage for 30 minutes to test the effect of individual (boar) and mob (generally sows and their progeny) feeding behaviour. The order and time in which each bait was found and consumed was recorded. Each trial group ($n = 5$) was trialled five times with bait-type position changing each time to ensure location was not a determining factor in bait choice. Results were analysed using ANOVA on SYSTAT 10 software.

The two most promising feral pig bait prototypes were recently (February 2004) field tested against fresh meat baits (all non-toxic) using aerial deployment one week prior to an aerial feral pig cull (for molecular ecology purposes) in the Noorama rangelands, the site of ongoing demographic and molecular ecology studies. Similar to Fleming et al. (2000), four study sites were used, each approximately 100 km^2 in size (Figure 1). Three sites received the same overall baiting intensity (30 baits km^2 or 10 baits km^2 of each type; Figure 1 A, B, and C) but a different baiting regime (water source baiting at site A, grid baiting at site B, and a combination of both at site C on Figure 1). Each bait type ($n = 3$) containing either tetracycline (TC), rhodamine B (RB), or iophenoxic acid (IA) biomarker, with biomarker-bait combinations different at each of the three sites to avoid biomarker bias. A fourth site (site D on Figure 1) was baited with 300 prototype baits containing all three biomarkers to independently assess biomarker bias. Samples (lower jaw for TC and RB fluorescence analysis, and blood for IA analysis) from shot pigs were collected, along with demographic and genetic samples, to determine bait consumption. Feral pigs shot that were far removed from where baits had been deployed acted as controls. Target and non-target uptake was assessed using ground baiting at a fifth site (site E on Figure 1) through camouflaged remote infra-red photography and sand plot monitoring. Two 10-km property tracks were baited on alternative sides every 200 m with the two prototype baits. Cameras and sand plots were checked daily for five days to assess bait take and the species responsible. Baits removed were replaced daily.

Further target and non-target testing of feral pig bait prototypes is currently planned for Namadgi National Park, Australian Capital Territory (see McIlroy et al. 1989, Hone 2002), state forests in southern Queensland (see Lapidge et al. 2003), and Cape York, Queensland (see Mitchell 1998) to compare the efficacy and target-specificity of commercial pig bait prototypes to currently-used baiting practices.

Results from the pen and field trials will be compiled, analysed, and prepared as a formal registration package to the Australian Pesticide and Veterinary Medicine Authority by Animal Control Technologies Pty. Ltd. As part of the registration process, standard operating procedures will be written for pig bait(s) developed based on prior ecological and current genetic studies.

RESULTS

Demographics

Aerial shooting of feral pigs in 2003 occurred for 26 hrs (flying time) over 4 days, during which time 174 pigs were shot. A total area of 4,430 km^2 was inspected, equivalent to a cull density of 1 pig per 25 km^2. On average, a pig was shot every 9 minutes at a cost of AUS$76 per head. The sex ratio of collected pigs was near unity (52M:66F), with males weighing 30 ± 24 kg (mean ± standard deviation) and females 25 ± 15 kg, although numerous near-100-kg boars were shot. Pigs were 10 ± 7 months of age with the oldest being no greater than 3 years, according to aging equations formulated for semi-arid zone feral pigs (Choquenot and

Saunders 1993). Colour variation was 43% black, 35% brown, 9% black and white, and 13% variations in between. Despite the worst drought in 100 years occurring in the area, pigs were in excellent condition, with most sows pregnant or suckling young. This was likely due to the abundance of sheep carrion, hand feed (cotton seed, sugar cane, and molasses) and water in bore drains, and little competition from other carnivores.

The 2004 feral pig cull consisted of 32 flying hours over 4 days, during which 187 pigs were shot. On average, a pig was shot every 10 minutes at a cost of AUS$69 per head. The sex ratio of collected pigs was slightly female biased (68M:99F), with males weighing 24 ± 19 kg, females 23 ± 15 kg, and the average age being 9 ± 8 months.

Genetics and Socio-Biology

Results from the 2003 feral pig molecular ecology studies undertaken in the Noorama area have confirmed that the species exists as highly dynamic units; has mobs comprised of matriarchal assemblages (highly related individuals, particularly females); tolerates multiple paternity; demonstrates surrogacy of young not born within the mob; and that large boars sire few young within the population. Furthermore, genetic data have shown that dispersing/traversing pigs move distances in the order of 100+ km within days to breed, as indicated through foetus/piglet conception dates in different mobs, and that interchange of individuals between feral pig mobs is high (0.3 individuals/month). This has resulted in feral pigs exhibiting no genetic structuring over this large area, with animals living next to each other similarly related to those several hundred kilometres away S. Lapidge, unpubl. data). These findings suggest that the Noorama feral pig population is much more social and in much greater contact than thought. These findings are currently being re-tested with genetic samples obtained in the recent 2004 Noorama feral pig cull.

Bait Development

Seven feral pig bait prototypes containing different substrates and attractants were trialled against two control baits (fresh meat and wheat) in January 2004. Initial pen trials with 18 individually-housed feral pigs showed that the time for each bait type to be chosen significantly differed between baits ($F_{8,112} = 2.07$, $P = 0.035$; Figure 2), with prototypes 3 and 5 recording the lowest overall times until consumption. Furthermore, both baits performed as good, if not better, than the two controls (wheat and meat) that are currently used as poison substrates in feral pig control exercises.

Analysis of demographic trends showed no significant sex differences in bait choice times between boars and sows ($F_{1,218} = 2.3$, $P > 0.05$). However, significant differences ($F_{2,217} = 14.0$, $P < 0.001$) occurred between different aged pigs, with adults rapidly consuming baits whilst sub-adults and piglets took longer to open and consume baits. The position at which each bait was placed had no bearing on the result ($F_{1,218} = 0.009$, $P = 0.93$), indicating feral pigs were making a conscious choice rather than going for the closest (by a few centimetres) bait. Feral pigs had generally made their first bait choice within 10 minutes of being released from the hutch (Figure 3); however, the consumption of the non-preferred bait generally took longer, if at all.

Baits 3, 5, and 7 were selected from pen trials to be re-tested in more field-realistic paddock trials because they had the lowest times until consumption and the smallest deviations from the mean. Results did not significantly differ between the five bait types tested ($F_{4,68} = 0.117$, $P = 0.98$; Figure 4), indicating that prototype baits performed as well as currently used feral pig bait substrates. Bait placement was randomised every trial and consequently did not significantly affect bait choice ($F_{4,75} = 0.682$, $P = 0.607$). Interestingly, the mean time to locate and consume all baits in the 100-m^2 paddock significantly decreased throughout the trials ($F_{4,68} = 8.29$, $P < 0.001$; Figure 5), indicating feral pigs quickly remembered and retained information about the bait preferences when in familiar surroundings. This finding instills the virtues of pre-feeding pigs with non-toxic baits prior to toxic baiting, in order to ensure rapid bait uptake and a synchronised knockdown in the population.

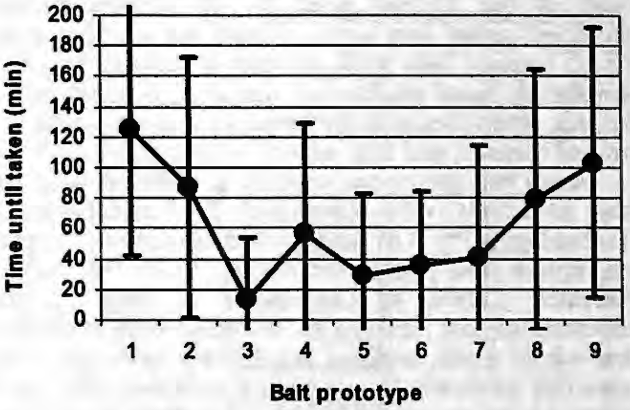

Figure 2. Results of first bait preferences by feral pigs in pen tests of seven prototype (1-5, 7, and 8) and two control (6 and 9) baits. Findings indicate bait prototypes 3 and 5 out-performed the control baits and had the least variation across feral pig demographic cohorts.

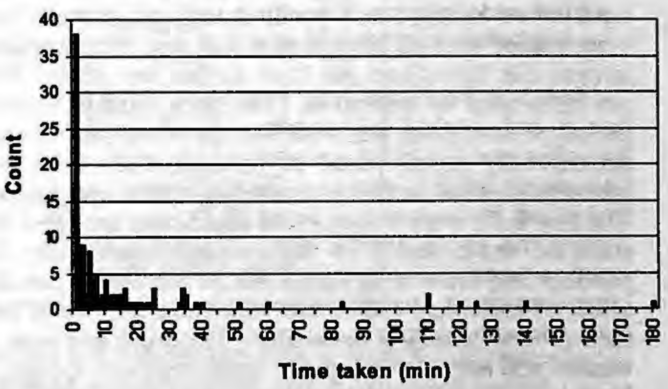

Figure 3. Time until feral pigs had made their first bait preferences in pen trials. This generally occurred within the first 10 minutes of each trial.

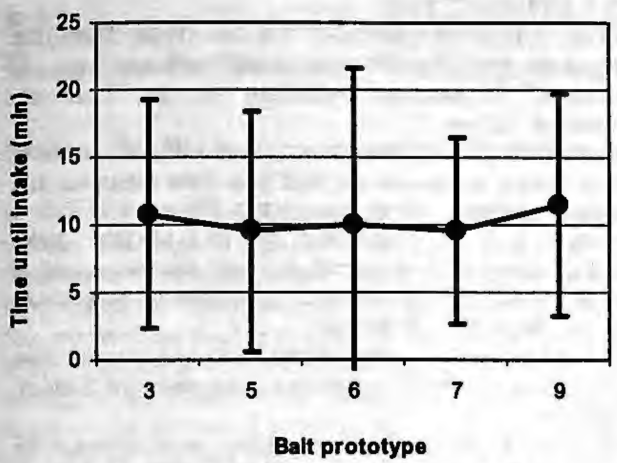

Figure 4. **Time taken by feral pigs to locate and consume the three most promising prototype feral pig baits (3, 5, and 7 as determined from pen trials) and two controls (6 and 9) in paddock trials. No significant difference occurred between baits (although prototypes 5 and 7 performed marginally better), indicating commercial bait packages are as attractive and palatable as currently used feral pig baits (bait 6 was wheat and bait 9 was fresh meat).**

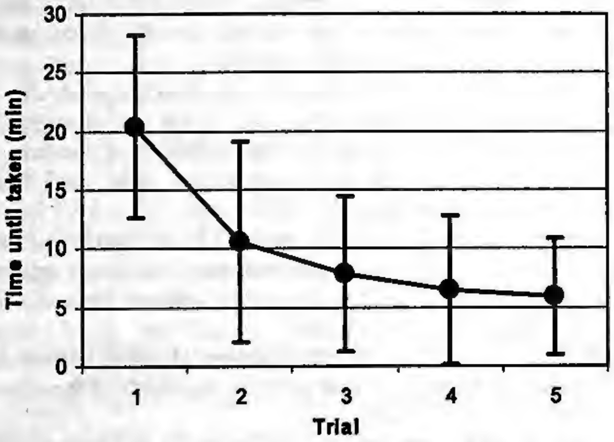

Figure 5. **Mean time to locate and consume all baits ($n = 5$) significantly decreased ($F = 8.29$, $P < 0.001$) during feral pig bait paddock trials. Findings instill the virtues of pre-feeding before commencing feral pig baiting exercises.**

Based on the results from paddock trials, bait 3 and a bait 5 and 7 combination were chosen to test in the Noorama area field trial against similarly sized fresh meat (kangaroo) baits in February 2004 (Figure 1). Results from field trials were still being analysed at the time of writing this paper. Importantly though, remote infra-red cameras positioned above feral pig baits indicated that no other animals in the area were interested or could open baits, including domestic sheep, kangaroos, emus, lizards, raptors, and scavenging birds.

DISCUSSION

Feral pig molecular ecology studies in the Noorama area occurred after two years of intensive aerial baiting. The low-density feral pig population, estimated to be approximately 0.1/km^2 from aerial surveys conducted at the commencement of the study, was found to be particularly young and light, with a mean age of 9 months and weight of 26 kg. These findings indicate broad-scale, integrated aerial baiting operations were effective in reducing and suppressing feral pig numbers in the >5,000-km^2 baiting area. The technique is recommended for other large interconnected areas inhabited by feral pigs, particularly if used in combination with feral pig baits that offer increased target specificity.

Demographic results collected from the two aerial feral pig culls undertaken 12 months apart were relatively consistent, except in terms of the average boar weight. The 20% lower mean weight recorded in the second cull was caused by no large boars (>90 kg) being shot. This was possibly due to many of the older boars being culled in the first shoot, and continual selective pressure on immigrating boars from commercial harvesting operations. As large boars generally caused the greatest agricultural damage (Choquenot et al. 1996), their reduction should significantly reduce feral pig impacts, such as lamb predation and rooting, in the Noorama area.

Whilst still in its infancy, feral pig molecular ecology studies occurring around Australia (see Hampton 2003) are assisting researchers in defining the most appropriate methods and scales of managing feral pigs. While fairly new to the field of pest animal management, this technique can provide rapid and accurate assessments of the level of integration (relatedness) and size of a pest animal problem. As the same technique can be undertaken non-destructively using scats, it can help reduce initial costs in pest animal population assessment. For example, due to the high level of feral pig genetic integration in the Noorama area, feral pig control exercises must be directed over as wide an area as possible to avoid rapid re-establishment of preferred habitats by dispersing pigs. In contrast, Western Australian genetic studies revealed a high level of population structuring, with six discrete populations associated with local water catchments existing as little as 25 km apart (Hampton 2003). These results indicate a local approach is necessary to best target pigs and not expose non-targets species. Such information should form the basis of localised standard operating procedures that best address feral pig impact reduction while minimising potential non-target species exposure during control operations.

No known commercially available feral pig bait package exists in Australia or overseas, despite feral pigs being a widespread problem in Australia, New Zealand, and parts of the Americas. Current toxic control operations thus rely on field-manufactured baits, which can be labour-intensive, non-consistent, and reliant on the involvement of government personnel (supply of 1080) or other control measures. The current project is addressing this situation by developing highly palatable target-specific (thus far), quality-controlled, and cost-effective broad-acre tools for feral pig control. If commercial baits are adopted widely by land managers for integrated control of feral pig populations, baits have the potential to reduce the labour investment in feral pig control campaigns, increase target-specificity, help reduce the impact of feral pigs on Australian agriculture and the environment, and potentially assist in control of an exotic disease outbreak.

Early indications from the current study are that feral pig baits being developed are proving to be as attractive and palatable to feral pigs as currently used baits, but with greater consistency and target specificity. Toxic trials of bait prototypes will commence shortly to examine the efficacy of prototype baits against currently used baiting practices in three (of many) different habitats around Australia (sub-alpine mountains, plantation forest, and tropical savannah). Should trials be successful it is hoped that baits will be registered within two years. Baits will initially contain 1080 (currently used in 75% of pig baiting exercises in Australia) in a species-targeted delivery system based on bite-force differentials. Pertinent to assessing the potential benefit of this research project will be the outcome of the current government reviews of 1080 and CSSP. Should either toxin be withdrawn or limited in use to commercially-made, quality-assured products, any baits developed under the current proposal will likely provide a significantly greater benefit to the land managers. In the unlikely event that 1080 is withdrawn, field-proven bait packages will still provide a basis for the incorporation of alternative feral pig toxins, vaccines, viruses, or 'Achilles Heel' approaches.

CONCLUSION

In summary, feral pig molecular ecology studies can be used to determine regional socio-behaviour of feral pigs, such as breeding systems, dispersal, actual mob sizes, and overall range. This information can then be used to determine appropriate baiting areas and regimes for feral pigs in different habitats, and transformed into standard operating procedures to increase baiting efficacy and minimise non-target exposure. Combining this approach with the current development of target-specific feral pig baits will provide land managers with suitable tools to manage the impact of feral pigs in Australia.

ACKNOLEDGEMENTS

The authors thank collaborators at Animal Control Technologies, Murdoch University Western Australia, and the Queensland Department of Natural Resources and Mines. This research has been generously supported by Meat and Livestock Australia Ltd and the Federal Governments' Natural Heritage Trust through grants received from the National Feral Animal Control Program (Bureau of Rural Science) and Wildlife and Exotic Disease Preparedness Program (Department of Agriculture, Fisheries and Forestry). Research has been undertaken with appropriate Queensland Animal Ethics Committee approvals.

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