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Authors

Bengsen, Andrew J.
Leung, Luke K.-P.
Lapidge, Steven J.
[et al.](#)

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Developing Target-Specific Baiting Methods for Feral Pigs in an Omnivore-Rich Community

Andrew J. Bengsen

The University of Queensland, Invasive Animals Cooperative Research Centre, and CSIRO Sustainable Ecosystems, CSIRO Davies Laboratory, Queensland, Australia

Luke K.-P. Leung

The University of Queensland, Queensland, Australia

Steven J. Lapidge

Invasive Animals Cooperative Research Centre, South Australia, Australia

Iain J. Gordon

CSIRO Sustainable Ecosystems, CSIRO Davies Laboratory, Queensland, Australia

ABSTRACT: The risk of non-target species being harmed by pest management activities can be a major impediment to animal control being implemented. This problem is particularly acute in complex faunal communities, where the pest occurs with functionally-similar species. Here, we present a framework for developing target-specific pest management tools for complex communities that helps managers reduce the risk of non-target species impacts. We applied the framework to the problem of poison baiting for feral pig control in the tropical rainforests of north-eastern Australia, and identified several potential methods to reduce adverse baiting impacts on non-target species. We evaluated the target-specificity of different baits and bait presentation methods using camera traps and sandplots to monitor animal-bait interactions in the field. As predicted using the framework, making baits available only at night prevented bait take by diurnal species, and bait burial substantially reduced bait consumption by non-fossorial species. The illumination of bait sites also reduced the foraging intensity of small non-target mammals, without inhibiting bait take by feral pigs. Two putative auditory repellents for small mammals were ineffective. Temporal variation in bait take by pigs and other species was unpredictable, and we were unable to exploit seasonally-variable factors to further enhance target-specificity. The use of a starch-rich vegetable bait, rather than an omnivore bait, prevented bait take by dingoes and improved bait take by feral pigs. The use of a light plastic container to cover this bait prevented bait take by small omnivores when an uncovered free-feed was also provided. This latter baiting method renders nocturnal distribution, bait burial, and site illumination unnecessary, and provides a simple, target-specific baiting protocol that will allow effective feral pig control in the region for the first time. Our field results demonstrate the usefulness of the framework in our study site. The framework is similarly suitable for developing target-specific methods for delivering other chemical or biological agents to wildlife or pest populations, or for developing other pest control tools such as traps. The framework awaits further evaluation in other complex faunal communities.

KEY WORDS: Australia, baiting, feral animals, feral swine, non-target species, poisons, *Sus scrofa*, Wet Tropics World Heritage Area

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INTRODUCTION

The range of pest control tools available for any given pest management problem is generally limited by a variety of technical, environmental, social, economic and logistical constraints (Norton 1988). Consequently, the tools that may be best able to achieve desired management outcomes are not always available, and resource managers must sometimes rely on less-effective means for pest control. One common constraint is the potential for pest control tools to harm non-target species. This can be particularly problematic in complex faunal communities, that is, communities in which the pest is difficult to isolate from one or more non-target species (Bengsen et al. 2008).

Most efforts to develop target-specific pest control tools have sought to exploit morphological, behavioural, sensory, or physiological differences between pest and non-target species, in order to reduce adverse non-target impacts without inhibiting the efficacy of control. The identification of exploitable differences has generally

been undertaken in an *ad hoc* manner, or with the guidance of broad conceptual frameworks that were not designed to deal with pervasive interspecific similarities that characterise complex faunal communities (e.g., O'Brien 1986, Marks 2001). Exploitable interspecific differences are generally difficult to identify in complex communities, and pest management developers may overlook useful differences that exist beyond their own experience. A more systematic approach to the problem would help to identify these differences, and facilitate the more effective and efficient development of pest management tools.

Here, we demonstrate a framework to guide the development of target-specific pest control tools for complex faunal communities. The framework provides methods for organising information about the similarities of large numbers of species, and for identifying exploitable differences between the pest species and those non-target species to which it is most similar. We evaluate the utility of the framework by using it to guide

the development target-specific baiting methods for feral pigs (*Sus scrofa*) in the tropical rainforests of northern Australia's Wet Tropics World Heritage Area (WTWHA or 'Area'), and then experimentally evaluating the outcomes in the field.

The rainforests of the WTWHA include the most complex vegetation types on the Australian continent, and they provide habitat for some of the continent's richest faunal communities. Feral pigs are considered the most serious vertebrate pest in the Area because of their environmental impacts and the difficulty of their control (Harrison and Congdon 2002). Within the WTWHA, pigs inhibit rainforest regeneration (Mitchell et al. 2007), alter successional processes (Hopkins and Graham 1985), spread noxious weeds (Setter et al. 2002), and are recognised as a threatening process to 12 of the Area's rare or threatened species (Braysher 2005). However, pig control programs have largely been limited to expensive and labour-intensive trapping programs, which have been unable to achieve sustained reductions in pig density or damage beyond the scale of individual properties (Wet Tropics Management Authority 2004). The development of effective and target-specific control tools for feral pig populations has consistently been identified as a high research priority (e.g., Stork and Stanley 1999, Poon et al. 2007).

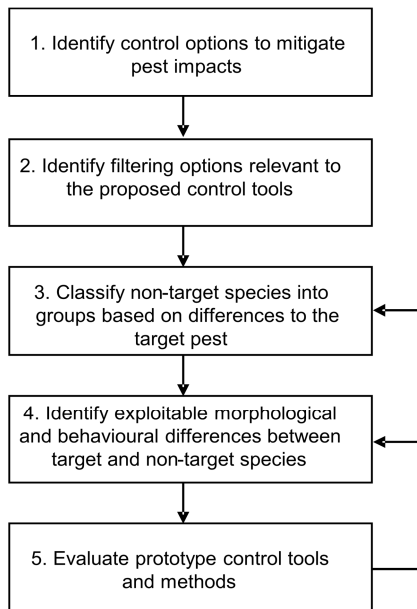


Figure 1. A 5-step methodological framework for developing target-specific pest control tools for complex faunal communities (adapted from Bengsen et al. 2008).

METHODS

The methodological framework can be summarised as a 5-step process (Figure 1). Applying the first step of the framework to the problem of feral pigs in the WTWHA, we identified the range of tools that were able to achieve effective reduction of feral pig population densities in the region. Effective sustained control of feral pig populations requires severe population reductions over short time-scales to inhibit rapid population recovery to pre-control levels (Giles 2001). Currently, this is only likely to be achievable in the rainforests of the WTWHA using

poison baiting, in combination with other methods such as trapping in areas close to human habitation. We therefore focussed our efforts on developing target-specific methods for poison baiting.

Using the second step of the framework, we identified 4 opportunities to prevent non-target species from interacting with poison baits in a harmful manner. In order for an animal to be harmed by any control tool, it must first encounter the tool, and then choose to engage with it, and finally, be able to access it in a harmful manner. Animals can therefore be prevented from consuming toxins, or other agents in baits, by preventing them from: 1) encountering baits, 2) selecting baits as food, 3) physically accessing bait, and 4) physically accessing the toxin or other agent within the bait (Bengsen et al. 2008). These 4 filtering opportunities all correspond with the selection and access of foraging habitat or food.

Applying the third step of the framework, we constructed a matrix in which the presence or absence of 15 traits relating to the selection of foraging habitat or food was assigned to each of 240 resident animal species. We used this information to build a dichotomous classification which sorted all species into 5 functional groups based on dissimilarities to the feral pig in these traits. The classification indicated that 97.5% of non-target species should not select or be able to access bait that consisted of a combination of meat and vegetable products and was buried and presented at night (Bengsen et al. 2008). We tested this prediction by exposing non-toxic variants of a commercially-manufactured feral pig bait (PIGOUT[®], Animal Control Technologies Australia, Somerton, Victoria) to feral pigs and non-target species in the rainforests and neighbouring agricultural lands of the WTWHA. We presented vegetable-only, and vegetable and meat baits, buried or on the ground surface at 18 sites. We used a crossover experimental design in which each treatment was presented once at each site for 5 consecutive days. We monitored animal-bait interactions using passive infrared-triggered cameras (Moultrie Game Spy 100, EBSCO Industries/Moultrie Feeders, Alabaster, AL, USA), and compared bait encounter and bait consumption rates for different groups of non-target species among bait treatments, using generalised linear mixed models.

Using the fourth step of the framework, we conducted methodical interspecific comparisons to identify potentially exploitable differences between feral pigs and the small number of fossorial omnivores that we could not separate from pigs using the classification process. This group of species comprised small fossorial omnivores such as native rats (*Rattus* spp.) and bandicoots (*Isodon macrourus*), as well as the larger-bodied dingo (*Canis lupus dingo*). Previous trials of similar baits in different locations indicated that few baits were taken by dingoes (Cowled et al. 2006) or coyotes (*Canis latrans*) (Campbell et al. 2006, Campbell and Long 2007), so we concentrated the detailed comparison on small omnivorous mammals. We compared morphological and behavioural characteristics of small mammals and feral pigs that related to bait encounter, selection, and access (Bengsen et al. 2008).

Methodical interspecific comparisons led us to predict that bait take by small omnivores would be lowest during periods when alternative food was most available, or when animal activity levels were lowest. At the same time, bait take by pigs was predicted to be greatest when pigs were most abundant or when they were experiencing the greatest nutritional stress. We tested these predictions by exposing manufactured baits for 5 days at 6 rainforest sites during 9 bi-monthly sampling periods. We used cameras to monitor animal-bait interactions, and an array of litter traps to estimate the availability of fruits and seeds to omnivores at each site and sampling period. We indexed small mammal abundance as the number of individuals captured at a 20-trap \times 3-day trapping grid, and indexed pig abundance using 30 camera traps deployed for 14 days at each sampling period (Bengsen 2010). We indexed the physiological condition of pigs using kidney and femur marrow fat indices (Hanks et al. 1976) taken from at least 9 pigs captured in each period. We used information-theoretic model selection procedures to identify important descriptors of the numbers of non-target species that interacted with baits, and to describe the relationship between antecedent rainfall and pig condition.

From further detailed comparisons of small omnivorous mammals and feral pigs, we predicted that small mammals could be selectively deterred from foraging at bait sites by augmenting the sites with cues that signalled a high predation risk for small mammals, without inhibiting bait take by pigs. We tested the effects of site illumination and the broadcast of pig and dingo vocalisations on the foraging behaviour of small mammals, using giving-up-densities (GUDs) (Brown 1988), at depletable patches of sunflower kernels mixed with sand. We then tested whether illumination or pig vocalisations selectively deterred small mammals from feeding on commercially-manufactured baits by deploying baits at 60 sites in the forest and monitoring animal-bait interactions using cameras. We also tested whether illumination selectively deterred small mammals from feeding on a corn-based bait preparation at a further 60 sites. Comparisons among treatments for each of the 3 feed types were conducted using generalised linear mixed models.

Finally, based on the results of the preceding experiments, we conducted a second round of detailed interspecific comparisons to identify methods to prevent dingoes from taking baits, and to enhance bait take by feral pigs. We predicted that dingoes would not consume an unprocessed starch-rich bait, and that small omnivores would not be able to access such a bait, if it were presented beneath a simple cover that could easily be removed by pigs. We tested the first hypothesis by presenting a bait preparation comprising soaked corn and copra meal alongside manufactured baits at 65 sites for 8 consecutive days, and monitoring animal-bait interactions using cameras and sandplots. Both bait types were covered by a lightweight plastic box to prevent access by small omnivores. We tested the second hypothesis by presenting covered and uncovered corn bait together at 45 sites for 3 consecutive days, again monitoring animal-bait interactions using cameras and sandplots. Comparisons

among treatments were conducted using generalised linear mixed models.

RESULTS

In the absence of tailored baiting methods, surface-laid PIGOUT® baits were readily consumed by 7 non-target species: dingoes or wild dogs (*Canis lupus dingo*, *C. familiaris* and hybrids), northern brown bandicoots (*Isodon macrourus*), native rats (*Rattus fuscipes* or *R. leucopus*), fawn-footed melomys (*Melomys cervinipes*), white-tailed rats (*Uromys caudimaculatus*), water rats (*Hydromys chrysogaster*), and yellow-spotted monitors (*Varanus panoptes*). Most of these species are omnivores. Only the yellow-spotted monitor can be considered an exclusively diurnal forager.

The first experiment confirmed that burial and nocturnal distribution substantially reduced bait take by non-target species. No exclusively diurnal species encountered baits by night, and shallow burial reduced the number of non-fossorial omnivores that consumed baits by 72% ($t_{250} = 3.910$, $P = 0.001$). Burial also reduced bait take by non-target fossorial omnivores by 70% ($t_{250} = 4.598$, $P \leq 0.001$); this was largely due to fewer fossorial omnivores encountering baits ($t_{250} = 2.840$, $P = 0.005$) (Figure 2). The simultaneous inclusion of meat and vegetable products into baits did not reduce bait take by dietary specialists, because these species did not consume baits of any type. Feral pigs only encountered baits at 4 sites and consumed baits at 1. Pigs consumed all baits at this site, regardless of treatment. Unexpectedly, dingoes also removed all bait types at several sites. Cotton spool lines inserted into some baits revealed that baits were frequently cached or taken to den sites, rather than immediately eaten.

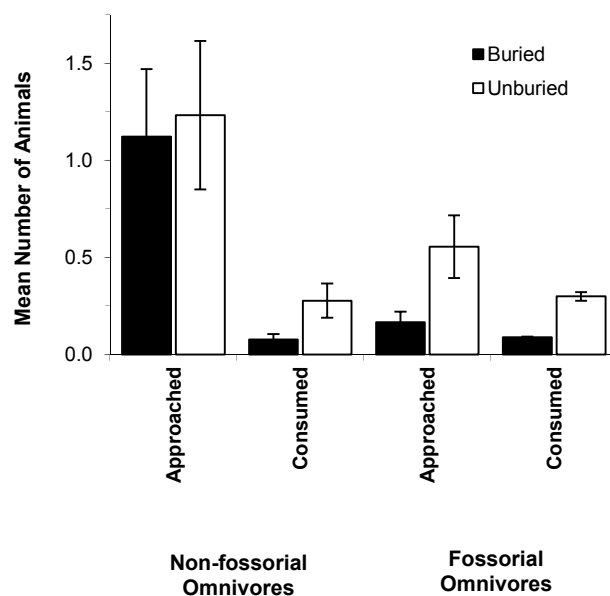


Figure 2. Mean numbers of non-fossorial and fossorial omnivores that approached and consumed buried and surface-laid baits site⁻¹ day⁻¹, excluding feral pigs. Error bars represent one standard error.

The seasonal experiment was, by itself, largely inconclusive. Information-theoretic model selection procedures indicated that feral pig kidney and femur marrow fat indices of physiological condition deteriorated with decreasing antecedent rainfall, measured over the preceding 2 months. However, bait encounter and consumption by feral pigs was too low to determine the extent to which seasonal variation in physiological condition or abundance might contribute to bait take. The number of small mammals that encountered baits at each site and period was best described as a linear correlation with the number of individuals trapped there. However, the number of small mammals that actually consumed baits was not related to abundance or the availability of alternative foods in the form of fruits and seeds.

The third experiment showed that the augmentation of baiting sites with cues signalling a heightened predation risk for small mammals provided mixed results. Small mammals consistently reduced their foraging activity at illuminated GUD stations ($z = 6.33$, $n = 227$, $P < 0.001$), manufactured bait sites ($z = -2.61$, $n = 32$, $P = 0.009$), and corn bait sites ($z = -5.90$, $n = 42$, $P < 0.001$). However, neither pig nor dingo vocalisations had an impact on foraging activity on any substrate, relative to untreated control sites. Illumination did not inhibit the consumption of corn bait by pigs (Figure 3), but consumption of manufactured baits by pigs was too low for comparison among treatments.

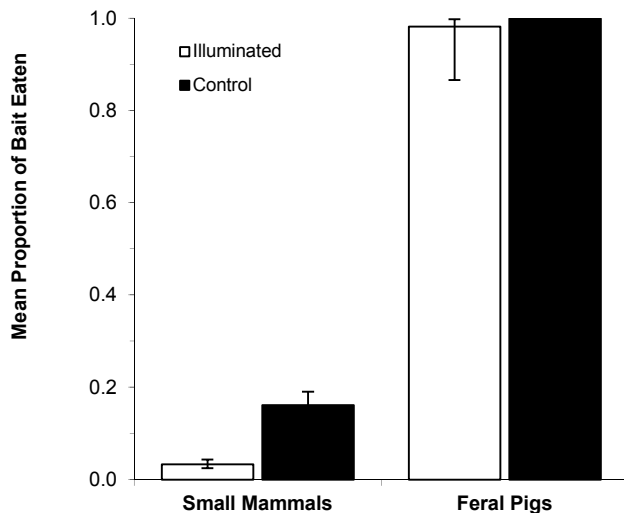


Figure 3. Mean proportion of illuminated and control corn baits consumed by small non-target mammals and feral pigs. Error bars represent one standard error.

The final experiment showed that the use of a corn and copra meal bait preparation effectively prevented bait removal by dingoes, and greatly enhanced bait-encounter and consumption by feral pigs. One dingo consumed up to 0.5 L of corn bait in one of 95 dingo-corn encounters, but dingoes removed manufactured baits on 46% of the 78 occasions that they encountered them. Feral pigs were 1.54 times more likely to eat corn bait than manufactured baits ($t_{84} = 1.966$, $P = 0.03$), and consumed corn bait on 94% of the 105 occasions on which they encountered it

(Figure 4). Pigs occasionally left small amounts of corn bait (<0.7 L) uncovered and uneaten after they had consumed all bait available at several other bait stations that night. The use of a lightweight plastic box to cover corn bait completely prevented non-target species from consuming bait when an uncovered free-feed was also provided, but small mammals burrowed under boxes to access corn or manufactured baits on 14% of 391 occasions when no free-feed was available.

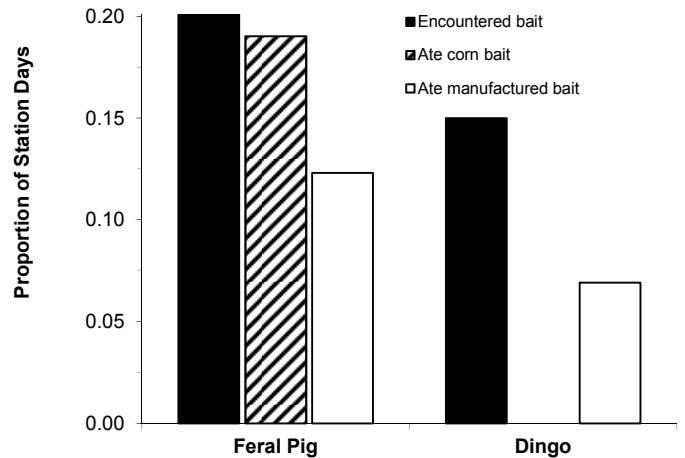


Figure 4. Proportion of station days at which feral pigs and dingoes approached bait stations and consumed corn or manufactured baits. Both bait types were simultaneously available at 65 bait stations for 8 days.

DISCUSSION

Previous considerations of poison baiting for feral pig management in the WTWHA have concluded that poison baiting is unlikely to be broadly useful because of low bait encounter rates by feral pigs, or high bait take by non-target species (Pavlov et al. 1992, Mitchell 1993). The results of this study have demonstrated the value of a methodical and proactive approach to overcoming both of these problems.

The classification of all resident non-target species into functional groups according to their dissimilarities to the feral pig provided an efficient and objective method of organising information about a large number of species, and generating hypotheses about potential bait design features. Predictions about bait presentation and design features that were derived from the classification were supported by experimental evaluation. The unexpected ability of species that were classified as non-fossorial omnivores to occasionally access buried baits was due to the excavation and subsequent abandonment of some buried baits by fossorial species, as well as the misclassification of the white-tailed rat (*Uromys caudimaculatus*) as non-fossorial. The removal of baits by dingoes was also unexpected, given results of previous studies using similar baits (Campbell et al. 2006, Cowled et al. 2006, Campbell and Long 2007), but was predicted by the classification process.

The use of methodical interspecific comparisons between feral pigs and the small number of species that

were most similar to the pig, in terms of diet and foraging habitat selection, provided a useful method of identifying exploitable differences between functionally-similar species. By dissecting the process of an animal-bait interaction into its basic components of encounter, selection, and access, and then relating these components to behavioural and morphological traits of pigs and other omnivores, we were able to generate useful hypotheses about bait design features. Consistent with our predictions, the illumination of baiting sites reduced bait take by small omnivorous mammals, and the covering of baits with lightweight boxes completely prevented bait take by these species when a small alternative feed was provided. Neither of these design features inhibited bait take by pigs. The failure of predator vocalisations to deter small mammals from consuming baits might be attributed to several factors, but was most likely caused by a failure to recognise the vocalisations as indicators of enhanced predation risk (Bengsen et al. 2010). The use of an unprocessed starch-rich bait preparation instead of a processed bait designed to appeal to omnivores effectively eliminated bait take by dingoes, and greatly enhanced bait consumption by feral pigs. Contrary to our predictions, the absence of predictable seasonal variation in bait take by small mammals indicates that variability in the activity levels of these species, and the availability of alternative foods in the form of fruits and seeds were relatively unimportant in determining the number of animals that progressed from encountering baits to consuming them.

MANAGEMENT IMPLICATIONS

The results of these experiments show that poison baiting for feral pig population management in the WTWHA can be conducted in a manner that does not pose a substantial threat to populations of non-target species. Toxic bait delivered in a corn and copra meal bait preparation, presented beneath a lightweight plastic cover, should be inaccessible to small non-target omnivores and unattractive to dingoes. A small amount of non-toxic decoy bait should be presented at each site to prevent small mammals from burrowing under boxes to access toxic bait. The total amount of toxic bait presented at each site should be divided into relatively small portions and placed under separate boxes throughout the baiting site, to minimise the risk of pigs becoming satiated and abandoning baits that they have uncovered. An important qualification to this point is that enough bait stations must be made available within the baiting site to ensure that all pigs feeding there are able to ingest a lethal dose. This requires active monitoring of bait take during free-feeding. Provision of insufficient bait can be expected to result in sub-lethal dosing, which can cause pigs to develop persistent bait aversions particularly with the toxin 1080 (O'Brien et al. 1986), and greatly inhibit the efficacy of current and future baiting programs. The effects of any toxic baiting program on non-target species, feral pigs, and the damage caused by pigs should be experimentally evaluated before being widely adopted in the region.

More generally, this study has demonstrated the value of following a methodical and proactive approach to the design of target-specific pest control tools for complex

faunal communities. The framework presented here provides a useful example of such an approach. Moreover, as noted by O'Brien (1986), the proactive incorporation of target-specific design features into pest control tools can enhance the efficacy of pest control operations because control tools are designed to closely match the characteristics of the target pest.

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