CENTRE FOR INVASIVE SPECIES SOLUTIONS

MANAGEMENT OF WILD DOGS AND DEER IN PERI-URBAN LANDSCAPES: STRATEGIES FOR SAFE COMMUNITIES

FINAL REPORT FOR PROJECT P01-L-003

AUTHORS

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We are a not-for-profit, member-based organisation formed to address the impact of invasive plants and animals across Australia.

We acknowledge the Traditional Custodians of the lands on which we meet and work and pay our respects to Elders — past, present and emerging.

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FINAL PROJECT REPORT FOR P01-L-003

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INTRODUCTION

MANAGING PESTS IN PERI-URBAN AREAS

Peri-urban areas are rapidly growing landscapes in many countries worldwide, including Australia. In these areas, where urban areas transition into bush or farmland, traditional pest management methods are largely unsuitable or need refining. There is also an increasing awareness of the impacts of pest animals in these unique landscapes; and the need to better manage natural resources, animal and plant production, and risks to human and animal health.

Managing pest animals in the rapidly expanding peri-urban regions of eastern Australia requires tools and strategies markedly different to management in the rural landscape. The two priority pests for many peri-urban councils are wild dogs and deer. Wild dogs are widespread but are becoming increasingly visible in peri-urban areas, raising public awareness and concern. Their impacts range from killing livestock, injuring pets, harassing and injuring humans, being vectors of livestock and zoonotic disease, to preying on threatened wildlife. Peri-urban local governments have identified the need for better tools and strategies for control of wild dogs, red foxes and deer. Managers have had some initial successes in controlling wild dogs, but these approaches should be refined, expanded and tailored to other areas.

Broad-scale poison baiting is rarely an option for peri-urban wild dog control because of the relatively small population size and large number of properties, which make it difficult to comply with regulations for using poisons. Peri-urban wild dog management is also contentious and difficult to implement across a large spatial scale, given the presence of a variety of stakeholders with wide-ranging and often conflicting ideologies. Additionally, public sentiment and reaction to the traditional toxin ('1080' or sodium fluoroacetate) can stifle or even halt its use within local government areas. This problem may be somewhat alleviated with recent availability of the para-amino propiophenone (PAPP) toxin that has an antidote, but it requires field assessment before widespread acceptance and best application are known. PAPP is a toxin with improved animal welfare outcomes when compared to 1080 for killing wild dogs. After recent findings on the relatively low probability of bait uptake by wild dogs (following their encounter or discovery) during field studies, similar assessments are required using control tools – including canid pest ejectors – in peri-urban environments. Comparisons with the default technique, foothold trapping, should also be done.

Wild dog control efforts are typically hampered by inadequate removals in the managed area, and immigration from uncontrolled areas. Nevertheless, selected key areas with persistent wild dog impacts may be suitable targets for localised eradication or, at least, significant population suppression. The feasibility of this approach needs to be examined, but requires collecting additional data on wild dog interactions with control tools for proper assessment.

Peri-urban local governments have also identified the need for better tools and strategies for control of deer. For deer, suppression of source populations may be more feasible because of typically fragmented distribution and modest rates of increase. The difficulty has been removing sufficient numbers of animals. Control tools are limited to shooting, trapping and fencing, but the efficacy of these methods in peri-urban settings is unknown. Methods for monitoring peri-urban deer have been developed overseas, but need to be evaluated in eastern Australia in order to guide and assess management actions.

COMMUNITY LED-PLANNING

Behavioural science and engagement approaches for communities are required to successfully identify, implement and monitor the success of strategies to manage pest animals in the peri-urban landscape. In this project, planning workshops were conducted to gauge community attitudes to wild dogs and deer; and guide the type, level and involvement in interventions required to reach 'acceptable levels of pest impact'. Monitoring, evaluation and reporting of such plans were completed during the intervention phase to determine the success of the management intervention. This would fit with more traditional assessments of control strategies and will focus on monitoring impacts (e.g. incident records) and activity (e.g. sightings, activity) as metrics of success. This project component is addressed in a separate technical report (Low-Choy 2022).

OUR PROJECT'S AIM: ALTERNATIVE STRATEGIES

The aim of the project was to provide pest managers, through collaboration and community-led actions, with alternative strategies for managing wild dogs and deer in peri-urban areas of eastern Australia.

This involved:

- refining and assessing management techniques by drawing on: (a) an improved understanding of wild dog ecology from the completed Invasive Animals Cooperative Research Centre peri-urban wild dog project (Gentle et al. 2017a), (b) removal and monitoring data on deer collected by pest managers (NSW Local Land Services (LLS) and Qld local governments), and (c) an improved understanding of community attitudes to peri-urban deer and wild dog management
- developing, implementing and monitoring community engagement strategies for wild dogs and deer issues to facilitate the effective implementation of management strategies
- testing the application of tools for wild dogs (PAPP, ejectors, traps) that have been identified as feasible and generally acceptable to the community
- evaluating the costs and benefits of techniques and strategies for different situations, and developing decision-support tools for local governments and other pest managers
- improving the knowledge of and capacity for monitoring impacts/sightings/pest activity to provide pest managers with the ongoing ability to target and monitor their control activities.

These aims were addressed in sub-projects delivered through collaboration between the Queensland Department of Agriculture and Fisheries, Griffith University, NSW Department of Primary Industries and others. Here we report on the synthesis of the findings of each of these studies, except for the Griffith University community-led planning component, which is addressed in a separate technical report.

* The authors request that referencing these findings should be done for each publication arising from this project, rather than this synthesis report. Please contact the authors for more details via matthew.gentle@daf.qld.gov.au.

METHODS

MANAGING WILD DOGS

DESKTOP MODELLING OF THE SUCCESS OF CANID PEST EJECTOR FACTORS

Devices are placed into the landscape to count, catch, kill or otherwise manage wild species. Canid pest ejectors (CPEs) are a recently introduced novel control tool available for managing foxes and wild dogs in Australia. As a result, there is little information available to inform best practice use, especially in peri-urban environments. This project used GPS-collar data of 11 peri-urban wild dogs (from McNeil et al. 2016) to compare encounters with modelled CPE devices at varying densities within their home range (spacings of every 200 m, 500 m or intersections only). Device locations were modelled into the environment using mapping software ArcGIS. We subsequently used survival analyses to determine the effect of the different deployment techniques and spacing on wild dog encounters with CPEs. We also accounted for sex and seasonal factors in the modelled interactions. To compare the three deployment strategies and to help understand how wild dogs might encounter CPEs in their environment, we tested the time taken to first CPE encounter per dog, the percentage of CPEs visited and percentage of days that a dog encountered a CPE (Harriott et al. 2021).

MONITORING WILD DOG INTERACTION AND BEHAVIOURS AT CPES

To determine target-specificity and improve our ability to target wild dogs for management, CPEs need to be monitored in the environment to improve our understanding of wild dog and non-target species behaviour at the devices. For this project component we deployed 1080 or PAPP CPEs on five separate peri-urban properties within the Sunshine Coast region at the highest permitted density (determined by toxin regulations and council risk assessment). Camera traps were used to monitor wild dog presence on properties, and additional camera traps were placed directly on CPEs to record interactions with the control tool. Wild dogs were individually identified by two independent researchers, using both the footage from monitoring and CPE camera traps. Non-target species encounters and interactions with CPEs were recorded.

COMPARING EFFICACY OF TRAPS VERSUS CPES

Historically, trapping has been heavily relied upon for wild dog management in peri-urban environments. For this project, we compared the effectiveness of foothold traps and CPEs. At two sites we deployed CPEs and engaged a professional contractor to simultaneously conduct trapping. All CPEs and traps were individually monitored with a camera trap to determine visitation, and traps were checked daily. Both sites were also monitored with additional site camera traps to determine the presence of wild dogs. Wild dogs were individually identified from images captured at both the monitoring and control device cameras. To supplement this data, we also deployed CPEs on sites where local government conducted trapping, and both traps and CPEs were monitored with camera traps.

THE LONGEVITY OF PAPP AND 1080 CAPSULES IN CPES

Toxins injected into bait material degrades under field conditions, which ensures minimal long-term hazard and risk to non-target species from residues following a baiting campaign. While the degradation of baits is generally well studied, there is limited data available on the degradation of toxins in plastic capsules used in CPEs. Additionally, there have been anecdotal reports of 1080 leakage and obvious ‘clumping’ of PAPP powder inside the capsules that requires investigation. Capsules deployed in the field during control campaigns that were never activated may be re-used to optimise toxin usage (and reduce waste), but this requires assessment.

This study aimed to assess the degradation of 1080 and PAPP capsules under storage and field conditions in peri-urban north-eastern Australia. Four capsule treatments (1080 field, 1080 storage, PAPP field, PAPP storage) were regularly sampled over a 12-month period at a peri-urban south-east Queensland site (Nambour) and tested for toxin content/concentration as measures of degradation.

PAPP and 1080 content assays were completed in a National Association or Testing Authorities (NATA)-accredited laboratory. For economy, only three capsules from each treatment were assayed each sampling period.

MODELLING CONTROL SCENARIOS

This sub-project aimed to assess the feasibility of achieving localised eradication of wild dogs at a peri-urban management site by using spatially explicit, individual-based simulation modelling. We selected a case-study area in peri-urban south-eastern Queensland that has natural barriers to restrict wild dog movement (i.e. bordered by a river and major highway). The study site ('Nambour pocket') is situated within the Sunshine Coast local government area in south-eastern Queensland. This site contains a high proportion of suitable areas for deploying conventional wild dog control tools, and is bounded by major roads and waterways that offer some resistance to re-immigration.

This modelling approach provides an efficient means for comparing and examining the likely success (or failure) of various wild dog control scenarios on the wild dog population in the case-study area. The approach follows Pacioni et al. (2018) (and following studies) that successfully used it to assess wild dog control strategies in Western Australia.

BEST PRACTICE GUIDE

The project findings have been incorporated into the draft guide *Best practice management of wild dogs in peri-urban environments*. This guide provides a strategic framework for the best practice management of peri-urban wild dogs. This guide presents key lessons, useful approaches and actions to help effectively manage the impacts of wild dogs in peri-urban areas for the benefit of individual landholders and community members. Importantly, it uses key findings from the current and previous CISS project work.

ADDITIONAL STUDIES

CASE STUDY: ACTIVITY OF WILD DOGS AND IMPACTS FOLLOWING AN INTEGRATED MANAGEMENT PROGRAM

The area of Hunchy, on the Sunshine Coast hinterland of south-east Queensland, has a long history of suffering from the impacts of wild dogs, particularly livestock attacks. Like many other areas in coastal Queensland, this area has experienced increased urbanization – evident from a general decrease in property sizes – which limits where individual landholders can safely apply traditional wild dog control options like baiting or shooting.

An evaluation was completed by Everitt (2021) to determine whether a long-term predator management program in Hunchy reduced local and landscape-scale wild dog activity and impacts. Four properties (sized 11 to 65 ha) participated in a coordinated pest-management program with the Sunshine Coast Council. Between 2018 and 2021, wild dogs and foxes were regularly removed via trapping, CPEs and opportunistic shooting. All four properties were monitored continuously with motion-sensing cameras to determine wild dog activity over this period. In addition to control efforts in the Hunchy area, trapping and CPEs were also used for wild dog and fox management in the wider area (Flaxton, Mapleton, Montville, West Woombye, Palmwoods and Landers Shoot) when required.

As a measure of wild dog activity, camera data was used to calculate the seasonal and annual passive activity index (PAI) in the Hunchy area between 2018 and 2021. As a measure of wild dog impact, researchers collated community requests for assistance with wild dog control from the Hunchy and wider area (as above), beginning two years before implementing the control program.

PATHOGEN PREVALENCE IN UN-OWNED URBAN CAT POPULATIONS

Peri-urban wild dogs are known to carry a variety of pathogens many with significant risk to public health (Harriott 2018). Given these results, Brisbane City Council requested assistance from the wild dog project research team to assist them in completing a similar study investigating the pathogens that feral cats carry. While the deleterious impacts of cats preying on wildlife are relatively well known, un-owned cats may act as reservoirs of pathogens with significant risk to public and companion-animal health. This is particularly of concern in urban and peri-urban regions where there is potential for interactions between un-owned cats, people and pets. This information is important to inform management policies for domestic and un-owned cat management, and provide evidence to support extension products. Given this was outside the key goals of the current project, the research team subsequently coordinated and co-supervised an honours-level project at The University of Queensland (School of Veterinary Science). This project, by Tamar Michaelian, aimed to establish the baseline prevalence data for priority pathogens in an urban population of un-owned cats (Michaelian 2021). To achieve this, 100 un-owned cat cadavers were collected from the Brisbane City Council region. Blood and additional organ or tissue samples were collected post-mortem. Diagnostic methods for pathogen detection included rapid enzyme-linked-immunosorbent assay (ELISA), lavage, faecal flotation and real-time polymerase chain reaction (PCR).

PEST-ANIMAL PRIORITISATION IN QUEENSLAND

Prioritising invasive animals and their impacts is critical for management efforts to be cost-effective. This project developed a statewide pest-animal prioritisation list for Queensland. Pest-management plans from 66 (of 71) local government areas (LGAs) across the state were collated to develop a list of pest species present in each LGA. LGAs were then grouped into easily identifiable regions (10 Regional Organisation of Councils, or ROC regions) and vertebrate pest species lists were collated for each region. Regional workshops were held with representatives from local and state governments, or landcare/natural resource management groups. Here the stakeholders assigned a single ranking of *no*, *low*, *medium* or *high* priority according to the potential or perceived impacts of the pest, as well as the availability of effective control tools. Rankings were used to develop impact scores, resulting in a priority list of vertebrate pest animal species at the state level. To explore similarities or differences in species occurrence between ROC regions, a method called non-metric multidimensional scaling was used. We also collated research and management needs for each species. Results from this study have been published in Harriott et al. (accepted).

MANAGING DEER

We collaborated with South East LLS and Wollongong City Council to access management and monitoring data collected during the Illawarra Wild Deer Management Program (IWDMP). Since 2011, this program had aimed to reduce the impacts of rusa deer (*Cervus timorensis*) on the community, infrastructure and economy of the Wollongong LGA.

We first assessed the animal-welfare outcomes of vehicle-based night shooting of peri-urban rusa deer by professional contractors in eastern Australia. Shooters targeted the heads of deer using.223-calibre Remington® rifles and 55 grain bullets. Independent veterinarians conducted ante-mortem (i.e. from the shooting vehicle) and post-mortem (i.e. inspecting the carcass) observations. The ante-mortem data were used to estimate the proportion of deer seen that were shot at, killed, wounded or escaped. We assessed the influence of variables predicted to affect shooting outcomes. The numbers and locations of bullet wounds were recorded post-mortem.

We increased the frequency and the extent of the deer monitoring based on faecal pellet counts to an annual survey of 108 transects. We then collated the shooting data recorded by the contract shooters during the management operations to assess the cost-effectiveness of ground-based shooting in peri-urban areas. For each site visit, the contract shooters recorded the date, number of deer seen and the number of deer killed. Between 2011 and 2018, Wollongong City Council recorded all complaints from the community regarding deer (date and location). This database was used as a secondary assessment of the effectiveness of the management program in decreasing the impact of deer on the community.

We used a reduced representation approach (Diversity Array Technology Pty Ltd, Canberra) to sequence the DNA of 174 rusa deer culled during the management program. To investigate for genetic structure or similarities among subgroups that were separated by natural and human landscape features, we conducted principal component analysis and admixture proportion inference. The latter determines the number of genetic groups found in the total population, and shows for each individual the proportion of ancestry that can be assigned to each of these genetic groups.

In Queensland, we accessed management and/or monitoring data from with Brisbane City Council, Moreton Bay Regional Council, Sunshine Coast Council, SEQ Water and Livingstone Shire Council to determine effectiveness of their control programs. In Brisbane, we monitored deer abundance using yearly faecal-pellet counts based on the IWDMP. At North Pine Dam we used a camera grid to determine deer abundance. We also trialled a thermal drone with automatic post-processing for deer monitoring.

RESULTS AND DISCUSSION

MANAGING WILD DOGS

DESKTOP MODELLING OF THE SUCCESS OF CANID PEST EJECTOR FACTORS

CPE survivability (or the probability of encounter) was significantly different between seasons for individual wild dogs, and between male and females. CPEs placed within female home-ranges found to have significantly less survivorship than those in male home-ranges. Ejectors spaced at closer intervals (200 m) had a greater percentage of days with wild dog encounters. Placing CPEs at road or track intersections provided the highest probability of wild dog encounter, with the average ejector at this location 1.5 times more likely to be encountered than those at the alternative spacings (200 m and 500 m). Our results show that achieving the most appropriate ejector placement depends on whether managers want maximum interactions or maximum efficiency, which are important considerations in the short- or long-term deployment of ejectors for managing wild dogs. These findings assist us to develop guidelines for the optimal and efficient placement of ejectors to ensure their safe and effective use in peri-urban environments. They also have additional relevance for other applications of device placement to survey or manage mobile species in peri-urban areas. These results were published (Harriott et al. 2021) and was recognised by the editors of *Applied Animal Behaviour Science* as one of their highlight papers for 2021.

MONITORING WILD DOG INTERACTION AND BEHAVIOURS AT CPES

The field data shows that CPEs can be deployed safely and effectively in peri-urban environments. There were a total of 14,303 trap nights in the 12-month period, with 165 CPE activations – 65 of those CPEs contained PAPP and the remaining 97 contained 1080. A high number of CPE activations (n = 63) were caused by Australian bush turkeys (*Alectura lathami*); however, encounter and interaction rates for turkeys were also higher than for any other species (Table 1). We individually identified 82 wild dogs across five sites. Of the wild dogs that could be identified, most (77%) encountered a CPE. Of those that encountered a CPE, most (71%) interacted with them but only 18% went on to activate the device. Overall, 10% of wild dogs detected on the properties activated a CPE. The desktop CPE data suggested higher encounter rates (> 90%); however, the sample size in the field trial was larger than that modelled. Regardless, this suggests that there is little benefit from increasing the currently used 20 CPE per 100 ha maximum. However, there is clear scope to increase the interaction and activation rates of wild dogs following encounters with CPEs.

Table 1. Number of CPE encounters, interactions, and activations per species, with common behaviours detected at CPE interactions

Species	Common CPE behaviours	*n* CPE encounter	*n* CPE interaction	*n* CPE activation
Bandicoot	Sniff, scratch, nibble	197	45	2
Cattle	Sniff, lick, kick	3,049	524	28
Crow	Peck, remove bait head	214	94	4
Currawong	Peck	2	2	1
Dog	Sniff, lick, bite, scratch, urinate	452	153	14
Fox	Sniff, lick, bite, urinate, timid	395	130	11
Hare	Sniff	539	17	0
Human	–	n/a	n/a	6
Lace monitor	Sniff, scratch, bite	280	88	3
Magpie	Peck	489	112	1
Macropod	Sniff	1,113	240	0
Pig	Sniff, bite	29	17	1
Possum	Sniff, nibble	457	54	1
Brush turkey	Peck, remove bait head	3,353	1,277	63
Unknown	–	n/a	n/a	30
Total		10,569	2,753	165

It took, on average, 5.6 days for a CPE to be activated by any species. Activations by wild dogs usually happened within the first five days after the lure was refreshed (average 4.75, range 0–15). However, turkeys were also quick to activate them within an average of 3.9 days (range 0–20). Approximately 20% (range 7–34%) of CPEs were activated in any three-week period. This varied across sites: Property B had the highest average percent of activations per sampling period (27%) and property E had the lowest average (10%).

All lures used in the trial were food-based, so there is scope to test an array of other lure types to see whether this control method can be improved. Reassuringly, the data suggests that CPEs are relatively target-specific to canids, with lower rates of interaction and activation by non-target species (~25.4% interactions, ~1.4% activations). Lure type is likely to be paramount here, and non-target interest and activations could be further reduced with careful lure choice. Nevertheless, for non-target species, the risk of ingestion or a lethal dose is very low, given the species' relative tolerance to 1080, body size, design of the CPEs and the activation behaviour.

In summary, these results suggest that, while encounter rates are high, there are potentially large gains to be had in the effectiveness and efficiency of control by increasing the interaction and activation rate by wild dogs. Lure improvements may help, but this is unlikely to be the only solution. We are examining the data further to determine whether an extreme dislike or aversion to anything new or unfamiliar (neophobia) or learned aversions are responsible. Collectively, the data suggests that CPEs in peri-urban areas are a useful and target-specific tool to target some, but not all, wild dogs. Again, this demonstrates that relying on a single control tool is insufficient for 'total' wild dog control, and the use of multiple control tools will be required to target individuals (and subpopulations of multiple individuals). This will likely be supported by our ongoing wild dog modelling component to enable broader comparisons of applying control than what is possible through field experiments. Comparisons with trapping encounter (and capture) rates should provide useful guidelines on the relative efficiency of these control tools to assist end-users.

The testing of wild dog PAPP CPE capsules (before registration and commercial availability) provided confidence to local governments in their ability to use PAPP as a substitute to 1080 capsules once the product became commercially available. The benefits perceived by local governments, including the likely improved acceptability by the public for use of PAPP because of improved animal welfare outcomes compared to 1080, has also promoted the ongoing future use of PAPP. Some local governments are discussing the possibility of switching to PAPP-only CPEs to target wild dogs in the future, given the recognised benefits.

COMPARING EFFICACY OF TRAPS VERSUS CPES

The field data to compare traps and CPEs shows that wild dogs encountered CPEs at all six of the trial sites (100%) but only encountered traps at four sites (80%). Foxes encountered CPEs and traps at all sites. There were a total of 36 device activations (11 CPE, 25 trap). The number of encounters, interactions and activations for wild dogs, foxes and other species can be found in Table 2. *Other species* includes all non-target species that were detected on the camera traps.

Forty-nine per cent of wild dogs that encountered a CPE interacted with the device compared to only 25% interaction with traps. However, of those wild dogs that interacted with devices, traps were more likely to be effective – 50% resulted in capture compared to only 12.5% activation for CPEs. Interestingly, a higher percentage of traps (60%) were activated by non-target species compared to CPEs (45%). But the overall percentage of traps or CPEs activated by wild dogs was the same regardless of the control device (28% and 27% respectively).

The presence of wild dogs and foxes on the two targeted sites was relatively low during the two treatment periods. Despite best attempts to monitor camera traps to predict wild dog presence, their detection on cameras during the trial period was infrequent. Rainfall events also occurred during the two trapping periods, which possibly interfered with trapping success. Data analyses for this section of the project is ongoing, and further investigations into a cost-benefit analysis comparing the two control techniques is being conducted. This manuscript is in preparation and expected to be published in scientific literature.

Table 2. Number of encounters, interactions, and activations of control tools by peri-urban wild dogs, foxes and other species

	Wild dogs	Foxes	Other	Total
Encounters				
CPEs	49	56	578	683
Traps	55	44	455	554
Total	104	100	1,033	1,237
Investigations				
CPEs	24	24	147	195
Traps	14	15	171	200
Total	38	39	318	395
Activations				
CPEs	3	3	5	11
Traps	7	3	15	25
Total	10	6	20	36

THE LONGEVITY OF PAPP AND 1080 CAPSULES IN CPES

The degradation trial (initiated in April 2021) to assess the impact of environmental exposure on 1080 and PAPP capsule degradation has yielded interesting results. We have assayed samples from 12-month sampling periods following initial deployment (in April 2021). The dose (mg) for 1080 and PAPP capsules at deployment were 6.23 mg (SD = 0.17) and 988.7 mg (SD = 6.1) respectively, pleasingly consistent with their respective nominal dose at manufacture of 6 mg (1080) and 1,000 mg (PAPP). There was little evidence of degradation or leakage of PAPP following 12 months of deployment (Figure 1), with field and stored capsules (pooled) sampled at 52 weeks containing an average of 985.43 mg (SD = 10.42, n = 6). For 1080, there also appears to be minimal degradation in capsules following deployment over 52 weeks in the store (mean = 5.68 mg, SD = 0.35) and field treatments (mean = 5.65 mg, SD = 0.53). Importantly, the capsules from both toxins and treatments still far exceed the lethal dose (LD50)[1] required for a 16 kg wild dog (Figure 1), estimated at 416 mg of PAPP (Gentle et al. 2017b) and 0.96 mg of 1080 (McLeod and Saunders 2013). In view of limited evidence of degradation over 12 months, the remaining sampling periods were adjusted to allow sampling until April 2023 (i.e. to encompass 24 months).

These data are informative and provide confidence to end users and for sound guidelines on the longevity and safety of deploying CPE capsules. Ongoing degradation testing of capsules provides reassurance that PAPP and 1080 capsules remain viable for extended (12-month) periods – thus capsules can be re-used if they were not activated. It also provides supporting data for guidelines to direct withholding periods for domestic dogs, where capsules or CPEs are lost or cannot be retrieved after a CPE program is complete.

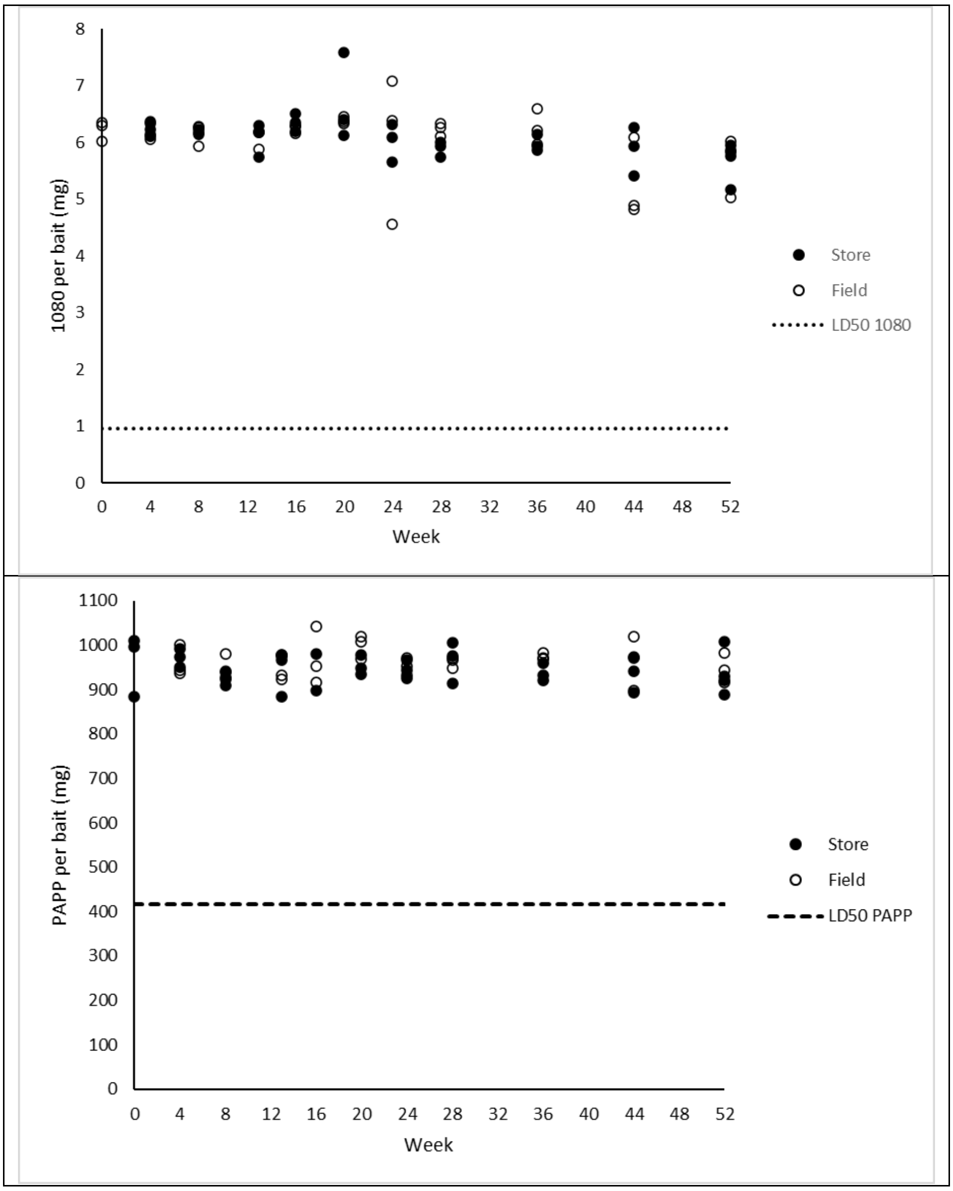

Figure 1. The toxin content (mg) for individual 1080 (top) and PAPP (bottom) baits up to 52 weeks since deployment for field and store treatments at Maroochy Research Station, south-east Queensland. The approximate LD50 for a 16 kg wild dog for 1080 (0.96 mg; dotted line) and PAPP (416 mg; dashed line) are also shown.

[1] An estimate of the amount of poison that, under control conditions, will be a lethal dose to 50% of a large number of test animals of a particular species

MODELLING CONTROL SCENARIOS

The Arthur Rylah Institute (Victoria) has been contracted to complete the modelling for this component. This approach, based the on Pacioni et al. (2018) modelling of control scenarios in Western Australian wild dog populations, has to be modified to suit peri-urban eastern Australia's wild dog population parameters, control and scale. Hence, this component could only be initiated late in the project cycle following the availability of data collected during field trials. The Institute will apply a series of plausible control scenarios for a simulated wild dog population to the south-east Queensland study area (Figures 2 and 3) over a 30-year simulation period, then analyse and interpret the results, and provide a report and copy of all data to Biosecurity Queensland. The work is expected to be completed in late 2022. The Institute will also work with Biosecurity Queensland researchers to prepare a draft scientific manuscript of the modelling outcomes.

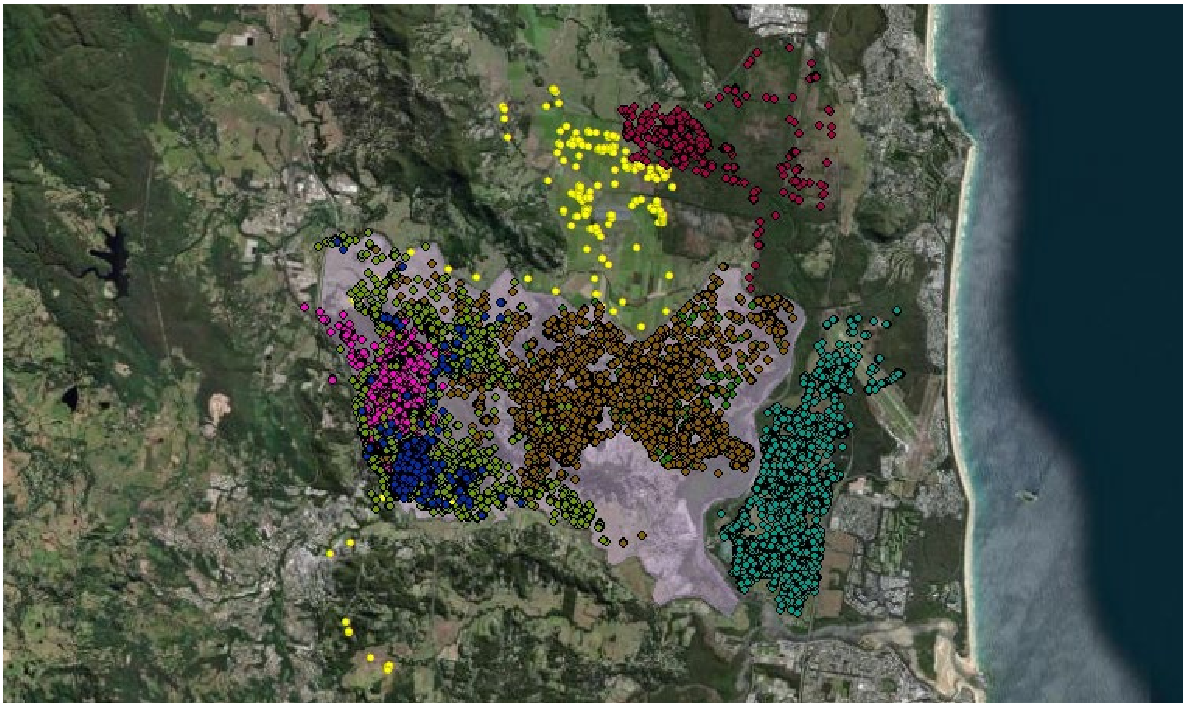

Figure 2. The study area (shaded light pink) for the peri-urban wild dog modelling of control scenarios. Each different coloured dot represents the GPS-tracked movements of individual wild dogs. This data supports the study area selection to suggest that the boundaries (rivers to the north, east and south plus a major highway to the east) may act as barriers (not complete) to wild dog immigration into the study area.

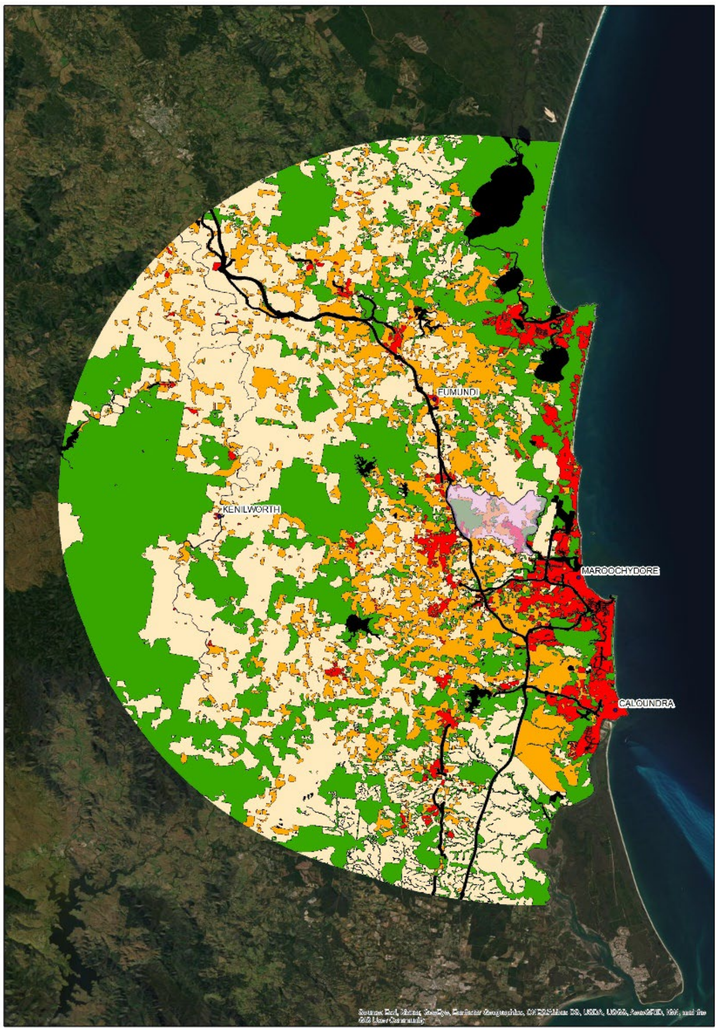

Figure 3. Land use classifications in the study area (shaded light pink) and surrounding 40 km buffer area. Each colour represents a separate land use type and has been mapped to represent habitat suitability (for resources) to support the modelled wild dog population. A buffer area is required to model the population of wild dogs adjacent to the study area, and account for (any) partial immigration into the study area following implementation of control scenarios.

BEST PRACTICE GUIDE

The guide has been copyedited and is in preparation with CISS (Harriott et al. submitted).

ADDITIONAL STUDIES

CASE STUDY: ACTIVITY OF WILD DOGS AND IMPACTS FOLLOWING AN INTEGRATED MANAGEMENT PROGRAM

On the four properties at Hunchy, wild dog activity (PAI) decreased significantly ($P = 0.04$) over the four-year period between 2018 and 2021 (Figure 4A). Similarly, community requests for assistance (complaints) to local government from the Hunchy area and surrounding suburbs showed an overall decline between 2016 and 2020 (Figure 4B), with a statistically significant difference between 2016 and 2020 ($P < 0.001$). Additionally, the PAI of small macropods, small birds and reptiles increased between 2018 and 2021, suggesting a potential benefit to monitored native species (Everitt 2021).

This evaluation indicates the benefits of coordinating wild dog control activities in peri-urban landscapes, but researchers could not formally compare results because non-treatment sites were not monitored. Nevertheless, the declines in wild dog activity and in community requests for assistance are supportive of this coordinated management approach. This evaluation also highlights the strength of monitoring the outcomes of control programs to inform management approaches. For more details, see Everitt (2021).

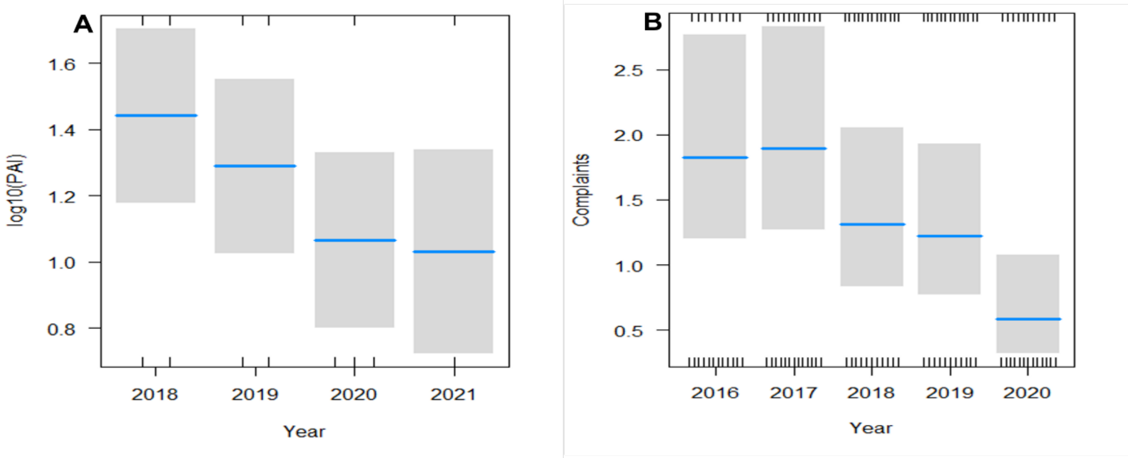

Figure 4. Box plots displaying (A) the decline in wild dog activity (PAI) between 2018 and 2021, and (B) the decreasing overall trend in community requests between 2016 and 2020.

PATHOGEN PREVALENCE IN UN-OWNED URBAN CAT POPULATIONS

One hundred un-owned cats were contributed for examinations, but not all samples could be collected for the various tests. Pathogens were found in 79% (*CI* = 71–87) of sampled cats (Table 3). Sixty-two percent (*CI* = 52–72) of cats showed evidence of co-carriage of two or more pathogenic organisms. The overall prevalence found for pathogens and parasites investigated were (Michaelian et al. submitted; Michaelian 2021):

- toxoplasmosis (*Toxoplasma gondii*): seven per cent (*CI* = 2–12)
- Q Fever (*Coxiella burnetii*): zero per cent (*CI* = 0–0)
- feline immunodeficiency virus (FIV): 12% (*CI* = 6–18)
- feline leukaemia virus (FeLV): zero per cent (*CI* = 0–0)
- gastrointestinal helminth parasites: 76.8% (*CI* = 68–85).

Table 3. The prevalence of gastrointestinal parasites detected by intestinal lavage or faecal float in un-owned cats from the Brisbane City Council region

Pathogen	**Sample size (*n*)**	**Prevalence %**	**Prevalence 95% *CI***
Ancylostoma tubaeforme	92	10.9	4–17
Cystoisospora rivolta	92	37.4	27–47
Dipylidium caninum	92	17.4	9–25
Spirometra erinacei	92	19.6	11–28
Cystoisospora felis	91	22.0	13–31
Toxocara cati	91	19.8	11–28
Toxoplasma-like oocysts	91	26.4	17–36

This study presents contemporary prevalence data for these pathogens that has not previously been available for un-owned cats of south-east Queensland. High rates of gastrointestinal parasitism (Table 3) observed throughout the study population should prompt concerns of a general increase in pathogenic prevalence, especially in comparison to that of owned domestic cats, as per previously published literature. Signs of fighting is an important risk factor for increased likelihood of infection.

This study demonstrates that un-owned cats in the Brisbane City Council region carry pathogens of human and companion-animal concern. This knowledge is essential baseline data to inform both un-owned and owned cat management, and contributes to informing cat management strategies and efforts throughout urban regions. We recommend continued and expanded investigations, considering prevalence and risk factors of pathogens important to human and companion-animal health, for the south-east Queensland area and beyond.

These results were presented in a honours thesis (awarded First Class) and have subsequently been drafted for publication (Michaelian et al. submitted; Michaelian 2021).

PEST-ANIMAL PRIORITISATION

Fifty-three species were listed by local government in their pest-management plans, but only 25 were classified during the stakeholders' elicitation workshops into *low*, *medium* or *high* rankings at the regional level (Table 4). The top 10, as well as the overall majority (76%) of species prioritised at the regional level, were mammals. Wild dogs were the only species listed as a priority pest animal across all 10 ROC regions and all 66 LGAs surveyed; as such, they were ranked the highest priority pest animal in Queensland. Feral pigs and feral cats were also listed highly by all ROC regions, with only a few LGAs leaving them as an unranked priority. Cane toads (*Rhinella marina*) were the highest ranked non-mammalian species. Mozambique tilapia (*Oreochromis mossambicus*) were the highest ranked freshwater pest species and (Indian) myna (*Acridotheres tristis* or *Sturnus tristis*) were the highest ranked of the avian species. Non-metric multidimensional scaling ordination of ROC regions in Queensland indicates that there is large variation in the occurrence of pest-animal species across the state. Variations in similarity appear to reflect geographical and environmental variations which roughly reflect five geographical regions across the state. These consist of a northern coastal zone; a broad southern region excluding south-east Queensland which stands grouped alone; Far North Queensland which is also grouped as a single region and finally the combination of north-west Queensland and the Torres Strait islands.

At the stakeholder workshops, specific research and management priorities included only 15 of the 25 listed invasive species that were considered significant at the regional level. The research and management needs for prioritised invasive animal species fell into three main themes: (1) more effective control methods; (2) baseline ecological data, most commonly specific to their region or unique environment; and (3) increased and ongoing landowner and public education surrounding pest animals and their management.

The prioritised list of invasive vertebrate pests of Queensland provides a baseline of pest species distribution and impact, which can be monitored over time to assess whether climate change, new species incursions or other changes (e.g. habitat disturbance) influence the presence, distribution and impacts of invasive species. These results can be used to guide how managers can prioritise resources, management or research efforts to address the impacts of established invasive animals in Queensland, as well as identify opportunities for collaboration to improve these outcomes. This should assist with policy and decision-making for pest animal management now and into the future.

Table 4. Impact scores of the 25 species identified by ROC regions as priority pest-animal species in Queensland. ROC regions or LGAs that list a species have recognised them as a priority in their region. This does not necessarily equate to confirming the presence of that species in their region.

No.	Common name	Recognised as established in Qld	No. of ROC regions listing invasive animal	No. of LGAs listing invasive animal	Per capita-invasive animal impact (E)	Mean invasiveness score (A*R)	Mean impact score (A*R*E)	Ranked impact score
1	Wild dog	Yes	10	66	50.283	10.000	502.833	1.0000
2	Feral pig	Yes	10	62	43.981	9.399	413.366	0.8220
3	Feral cat	Yes	10	62	31.032	9.345	290.004	0.5766
4	European rabbit	Yes	9	52	26.462	7.165	189.595	0.3768
5	European red fox	Yes	9	48	17.222	6.707	115.512	0.2295
6	Chital deer	Yes	8	25	24.675	3.655	90.197	0.1791
7	Fallow deer	Yes	8	17	27.424	1.271	34.843	0.0690
8	Rusa deer	Yes	5	16	23.568	1.275	30.044	0.0594
9	Feral goat	Yes	8	34	7.875	3.420	26.932	0.0532
10	Red deer	Yes	5	17	19.271	1.271	24.484	0.0484
11	Cane toad	Yes	7	22	7.102	2.387	16.954	0.0334
12	Mozambique tilapia	Yes	5	10	15.950	1.033	16.471	0.0324
13	Feral horse	Yes	6	20	8.590	1.392	11.957	0.0234
14	Indian myna	Yes	5	17	5.916	1.895	11.213	0.0220
15	Red-eared slider turtle	Yes (localised)	3	7	35.714	0.159	5.682	0.0110
16	European carp	Yes	2	13	12.615	0.413	5.205	0.0100
17	House mouse	Yes	5	8	2.800	0.575	1.611	0.0029
18	Ferret	No	4	4	14.500	0.077	1.113	0.0019
19	Gambusia/mosquitofish	Yes	2	4	7.500	0.121	0.909	0.0015
20	European hare	Yes	2	7	2.000	0.390	0.780	0.0012
21	Asian black-spined toad	No	1	1	64.000	0.009	0.582	0.0008
22	Hog deer	No	2	3	10.667	0.051	0.540	0.0007
23	Sambar deer	No	2	3	10.667	0.051	0.540	0.0007
24	Peafowl	Yes	1	3	3.000	0.103	0.309	0.0003
25	Feral water buffalo	Yes	2	4	2.500	0.068	0.170	0.0000

MANAGING DEER

From 269 deer seen in 21 nights of ground-based shooting in 2018 and 2019, 48% were shot at and 85% of those shot at were killed by either one (87%), two (10%) or three (three per cent) shots. The frequency of non-fatal wounding (i.e. escaping wounded) was 3.5% for those shot at and hit, and the median time to insensibility for the deer that were shot multiple times was 289 s. There was variation among shooters in their ability to hit a deer, and also to do so with a killing shot. The number of bullet wounds per deer ranged from one to three (mean = 1.1), with 83% of shots striking the brain and 17% striking the anterior skull, neck or jaw.

The animal-welfare outcomes of professional ground-based shooting in peri-urban areas were comparable to those reported from other professional ground-based shooting programs for ungulates, but were poorer than those reported for professional ground-based shooting of peri-urban kangaroos. One way to improve the animal-welfare outcomes of ground-based shooting of peri-urban deer is by improving shooter training. Assessing shooter performance should be a routine part of ground-based shooting programs.

Between May 2011 and April 2022, six contractor teams conducted 845 nights of ground shooting, with an average of 5.3 sites visited per night. The contract shooters removed on average 427.4 deer per year (standard error, *SE* = 58.5, range = 125–728); a total of 4,701 deer were shot during the management program. The number of deer shot per night was stable until 2016 and then steadily increased. The highest efficiency for ground-based shooting was during the rut season between June and September. Across all years, the mean cost to remove one deer was $458 – varying annually between $392 in 2021 to $493 in 2016, and monthly between $373 in August and $561 in February. The relative abundance of deer decreased steadily over time, but the annual number of complaints from the community changed little during 2011–2015 and increased from 2015 to 2018. Community complaints were not correlated with deer relative abundance but peaked annually during the rut season.

Professional ground-based shooting can reduce peri-urban deer relative abundance with low frequencies (less than four per cent) of adverse animal-welfare outcomes. Ground-based shooting of rusa deer in peri-urban landscape was most effective during the rut season between June and September. This period also coincided with the highest frequency of complaints from the community. Focusing shooting effort during the rut season could therefore increase the cost-effectiveness of the management program.

The genetic structure of the Illawarra rusa deer population is consistent with rusa deer spreading south from their introduction site in Royal National Park (in south Sydney). The population is not panmictic (i.e. not all individuals are potential partners). Genetic diversity was highest in the north, near the original introduction site of rusa deer. A railway line demarcated restricted gene flow. Surprisingly, the Illawarra escarpment – a prominent landscape feature – did not restrict gene flow. There was no evidence of sex-biased dispersal. Seven individuals were identified as genetic outliers. The genetic structure of the population identified three potential management units on which to prioritise ground-shooting operations. Rusa deer can be expected to continue invading southwards in the Illawarra region, but landscape features associated with urbanisation might reduce dispersal.

We found that in a subtropical and peri-urban environment in south-east Queensland, four rusa deer with GPS collars ranged over areas of < 400 ha annually, with core areas of ~100 ha over a period of 10–17 months. Home ranges varied little in size and location from season to season. The relatively small home ranges and seasonal stability in the subtropical peri-urban rusa deer suggest these deer can be effectively managed at the local level.

From thermal drone footage analysis we found that, when comparing automated versus manual detection, rusa deer are difficult to detect using automated detection. Not only is it harder to gather training data because deer are often in small groups, but the animals are often so close together that multiple animals may be detected as one heat signature. Despite having slightly lower detection rates, automated detection is cheaper and faster than manual detection of deer in video footage taken by the drone (remotely piloted aircraft system, RPAS).

Collectively, the project provided local land managers with a suitable monitoring tool (faecal pellet counts) for peri-urban deer populations. The method, replicated in Brisbane and in the Illawarra region, revealed trends in deer relative abundance at small and large scales that were consistent with control effort. A reliable monitoring protocol is an essential component of a cost-effective management strategy.

RECOMMENDATIONS

Through our findings and experience from this project, we identify key recommendations for future research and/or management practices to improve wild dog and deer management in Australia.

WILD DOGS

CPE PLACEMENT AND USE

- **Validate the modelled optimal and efficient placement of CPEs** (by Harriott et al. 2021) by analysing empirical data from field studies of control campaigns. This would help to account for other factors not considered in Harriot et al.'s modelling study that can affect the probability of dogs visiting or activating devices following an encounter.
- Given most wild dogs can readily locate CPEs when deployed at the maximum rate, there is no advantage in increasing the density of CPEs to increase the efficacy of control programs. However, there are potentially large gains in effectiveness and efficiency of wild dog control with CPEs if we can **increase the interaction and activation rate by wild dogs**. Improving lures and better understanding wild dog–behaviours that could influence CPE interaction following an encounter by wild dogs will certainly assist this. However, relying on a single control tool is insufficient for 'total' wild dog control (100% of population removed). Pest managers using multiple control tools is required, and needs to be encouraged, to target all individuals.
- After our study of CPE capsule degradation, this should **provide guidelines for the effective re-use of 1080 and PAPP capsules to the manufacturer** so they can include it on the product label or product-use documentation. This will provide evidence-based guidance for users to potentially re-use capsules after a CPE campaign, reducing waste. This will also provide guidelines for withholding periods for domestic dogs if capsules or CPEs are lost or cannot be retrieved after a CPE program.

WILD DOG MONITORING

- **Promote widespread monitoring of wild dog activity and impacts** to gauge the effectiveness of management interventions. Monitoring is important to inform and adapt management practices, particularly if local authorities allocate competing resources to pest management.

PEST PRIORITISATION (QUEENSLAND)

- Wild dogs were recently considered the highest priority vertebrate pest across Queensland, highlighting their enduring, substantial impacts that require ongoing management. These **results should be used to help prioritise resources, management and research efforts in Queensland**; and, further, identify opportunities for collaboration to improve these outcomes. Ideally, this study should be repeated in the future to re-assess and monitor changes to the prioritisation given to invasive species over time.
- Despite this prioritisation study being limited to Queensland, the **methods could be adapted for other jurisdictions to develop similar priority lists**. Other states and territories of Australia (and elsewhere) have locally and broadly distributed invasive species, and this approach may have useful application in these jurisdictions to inform decision-making for invasive species research and management.

DEER

DEER MONITORING AND GROUND-BASED SHOOTING

- Assess the cost-effectiveness of ground-based shooting for other deer species present in peri-urban areas in Australia.
- Assess the cost-effectiveness of ground-based shooting for peri-urban deer management at different spatial scales.
- Promote the use of robust monitoring for all peri-urban deer management programs so that their cost-effectiveness can be assessed.
- Complete a CISS glovebox guide for emerging management and control technologies (such as DNA, thermal-vision equipment and drones) that are applicable to multiple vertebrate pest species, not just deer.

ALTERNATIVE CONTROL METHODS

- Determine the cost-effectiveness of trap designs for different deer species.
- Determine the effectiveness of non-lethal methods to mitigate deer impacts (e.g. fences, virtual fences, sound deterrent, habitat alteration).

OUR COLLABORATIONS, COMMUNICATION, OUTPUTS AND PUBLICATIONS

COLLABORATIONS

The Illawarra deer project was explicitly designed as a collaboration between public agencies and private landholders. The deer-management program was a collaboration between NSW Department of Primary Industries, Queensland Department of Agriculture and Fisheries, South East LLS, Wollongong City Council, WaterNSW, NSW Parks and Wildlife Service, and the many landholders who provided access to their properties.

In Queensland, collaborative deer research led by the Queensland Department of Agriculture and Fisheries was undertaken with Brisbane City Council, Moreton Bay Regional Council, Sunshine Coast Council, SEQ Water, Livingstone Shire Council, Queensland University of Technology, and The University of Queensland. The collaborations created synergies about monitoring deer to determine effectiveness of control. Deer were monitored in new locations, and a thermal drone was also assessed for how it could be used for deer monitoring.

The wild dog component was a collaboration between Queensland Department of Agriculture and Fisheries, Sunshine Coast Council, The University of Queensland, Southern Downs Regional Council, Brisbane City Council and the Arthur Rylah Institute. Many private landholders and public land agencies provided access to property.

COMMUNICATION

There were two main target audiences for communicating about managing peri-urban deer and dogs: the scientific community and public agencies/local land managers. Each group was receptive to specific media and had different expectations for the communication content. We therefore diversified our communication strategy to successfully transfer the knowledge gained through this project to each audience group.

This project delivered eight scientific peer-reviewed scientific publications (plus two accepted, three submitted and two in preparation). We have worked on additional publications as collaboration with other CISS deer projects (P01-L-001 and P-L-002). You can find a numbered publication list at end of this section.

Our findings were incorporated into student projects at the University of Wollongong (deer) and The University of Queensland (wild dogs, and additional study on feral cat pathogens):

- Sebben O (2020) *Habitat suitability and movement modelling for an increasing population of wild deer in Wollongong, NSW* [honours thesis], University of Wollongong.
- Everitt R (2021) *Evaluation of a long- term integrated management program on the activity of peri-urban wild dogs in Hunchy, Sunshine Coast* [masters thesis], The University of Queensland.
- Michaelian TA (2021) *Prevalence of pathogens important to human and companion animal health, in un-owned cats of south-east Queensland* [honours thesis], The University of Queensland.

CONFERENCE PRESENTATIONS

During the course of the project, we presented our results at conferences:

- Annual conferences of the Australasian Wildlife Management Society (about our deer research). These conferences were generally attended by about 150 scientists and practitioners from Australia and New Zealand.
- Australasian Vertebrate Pest Conference 2021 (deer, wild dogs, cat pathogens and pest-animal prioritisation).
- Pest Animal and Weed Symposium 2019 (Queensland) (deer, wild dogs).

MASTERCLASSES, WORKSHOPS AND MEETINGS

For public agencies, the key was to translate the scientific knowledge into practical and applied advice and general guidelines.

- Deer masterclasses were two-day training opportunities for public agencies' staff involved in deer management. The courses typically consisted of technical presentations from experts on deer monitoring and control techniques, complemented by *in situ* group projects. We organised six deer master classes: four in NSW (during 2019, 2021 and 2022) and two in Queensland (in 2022). We also presented (virtually) at a masterclass in South Australia (in 2021).
- NSW Vertebrate Pest Management Course is a one-week training course organised by NSW DPI annually. We presented deer research to biosecurity officers from NSW LLS and NPWS.
- In Queensland, a deer management workshop was held for local government and other associated land management agencies and natural resource management groups.
- We created a guide for land managers and pest managers: *Best-practice management of wild dogs in peri-urban environments*.

We also presented our findings during targeted meetings such as:

- IWDMP stakeholder meeting
- IWDMP Steering Committee meeting
- Hunter Regional Pest Animal Committee Meeting
- Australian Alps National Parks' Ungulates Management Workshop
- Regional Deer Coordinators Meeting, Victoria
- NSW LLS Statewide Advisory Group
- NSW Game and Pest Management Advisory Board Meeting
- South-east Queensland Pest Animal Management (SEQPAM) group

Results are also being incorporated in a glovebox guide for deer management: Forsyth, D. M., Comte, S., Bengsen, A. J., Hampton, J. O., and Pople, A. R. (In preparation). *Glovebox Guide for Managing Wild Deer*. This will be provided to CISS for publication on the PestSmart website.

Media that resulted from this study also include: 'Wild dog threat in rural areas – population density and logistical challenges', 'Researchers developing strategy to manage wild dogs' and 'Talking wild dogs', a radio segment interview with Rod Corfe at 2WEB.

Project staff Dr Harriott and Dr Gentle were also the source for a CISS-sponsored podcast *Towards a feral future*, hosted by Prue Adams, ‘8. Not just a rural problem – why we need tailored management plans for peri-urban areas?’, that was introduced:

> *Many people think invasive species and, in particular, feral animals are only a problem in rural areas, but in this episode we’ll chat with two pest animal researchers from Biosecurity Queensland – Dr Matt Gentle and Dr Lana Harriott – who are looking at ways of effectively managing feral animals in urban landscapes, where approaches such as broadscale baiting, shooting and largescale fencing programs just simply cannot be rolled out.*
> *We may hear of more impacts from feral predators and other species in rural areas, but you may be surprised to know there are many ferals lurking likely in your own urban backyard or fence line, and stakeholders are calling for ways to manage them that are safe, effective and timely.*

PUBLICATIONS

1. Amos M, Cathcart A, Kimber M (2019) ‘Counting deer not tourists on the Sunshine Coast’, in Sydes, T (ed) *Proceedings of the 1st Queensland Pest Animal and Weed Symposium*.
2. Amos M, Pople T, Brennan M, Sheil D, Kimber M and Cathcart A (2022) ‘Home ranges of rusa deer (*Cervus timorensis*) in a subtropical peri-urban environment in South East Queensland’, *Australian Mammalogy*, doi:10.1071/AM21052.
3. Comte S, Bengsen AJ, Cunningham CX, Dawson M, Pople AR and Forsyth DM (in preparation) ‘Cost-effectiveness of professional ground-based shooting to manage peri-urban rusa deer in Australia’.*
4. Gentle M, Allen BL, Oakey J, Speed J, Harriott L, Loader J, Robbins A, de Villiers D and Hanger J (2019) ‘Genetic sampling identifies canid predators of koalas (*Phascolarctos cinereus*) in peri-urban areas’, *Landscape and Urban Planning,* 190:103591, doi:10.1016/j.landurbplan.2019.103591.
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7. Harriott L, Amos M, Brennan M, Elsworth P, Gentle M, Kennedy M, Pople T, Scanlan J, Speed J and Osunkoya O (in press) ‘State-wide prioritisation of vertebrate pest animals in Queensland, Australia’, *Ecological Management & Restoration*.
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11. Harriott L, Speed J, Kelly C, Michaelian T and Gentle M (in preparation) 'The application of canid pest ejectors in peri-urban environments'.*

12. Harriott L, Wood C, Gentle M, Traub R, Soares Magalhães R, Perkins N, Tozer S and Cobbold R (2019d) 'Occurrence of bacterial pathogens and antimicrobial resistance in peri-urban wild dogs', in Sydes T (ed) *Proceedings of the 1st Queensland Pest Animal and Weed Symposium*.

13. Harriott LC (2018) *Prevalence, risk factors, and geographical distribution of zoonotic pathogens carried by peri-urban wild dogs* [PhD thesis], University of Queensland.

14. Hill E, Murphy N, Li-Williams S, Davies C, Forsyth DM, Comte S, Rollins LA, Hogan F, Wedrowicz F, Sherwin WB, Crittle T, Thomas E, Woodford L and Pacioni C (submitted) 'Hybridisation rates, population structure, and dispersal of sambar deer (*Cervus unicolor*) and rusa deer (*Cervus timorensis*) in south-eastern Australia', *Wildlife Research.*

15. Kelman M, Harriott L, Carrai M, Kwan E, Ward MP and Barrs VR (2020) 'Phylogenetic and geospatial evidence of canine parvovirus transmission between wild dogs and domestic dogs at the urban fringe in Australia', *Viruses,* 12:663, doi:10.3390/v12060663.

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